BUTTERWORTH
HEINEMANN
ELSEVIER

11830 Westline Industrial Drive
St. Louis, Missouri 63146

SPORTS VISION: VISION CARE FOR THE ENHANCEMENT OF SPORTS PERFORMANCE ISBN: 978-0-7506-7577-2
Copyright © 2007 by Butterworth-Heinemann, an imprint of Elsevier Inc.

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Permission is hereby granted to reproduce the *appendices* in this publication in complete pages, with the copyright notice, for instructional use and not for resale.

Permissions may be sought directly from Elsevier's Health Sciences Rights Department in Philadelphia, PA, USA: phone: (+1) 215 239 3804, fax: (+1) 215 239 3805, e-mail: healthpermissions@elsevier.com. You may also complete your request on-line via the Elsevier homepage (http://www.elsevier.com), by selecting 'Customer Support' and then 'Obtaining Permissions'.

Notice

Neither the Publisher nor the Author assume any responsibility for any loss or injury and/or damage to persons or property arising out of or related to any use of the material contained in this book. It is the responsibility of the treating practitioner, relying on independent expertise and knowledge of the patient, to determine the best treatment and method of application for the patient.

The Publisher

ISBN: 978-0-7506-7577-2

Publishing Director: Linda Duncan
Senior Editor: Kathryn Falk
Senior Developmental Editor: Christie M. Hart
Publishing Services Manager: Julie Eddy
Project Manager: Andrea Campbell/Laura Kudowitz
Design Direction: Maggie Reid

Working together to grow
libraries in developing countries
www.elsevier.com | www.bookaid.org | www.sabre.org
ELSEVIER BOOK AID International Sabre Foundation

Printed in China

Last digit is the print number: 9 8 7 6 5 4 3 2 1

Contributors

Jason Brumitt, MSPT, SCS, ATC, CSCS, OD
Laboratory Instructor
School of Physical Therapy
Pacific University
Forest Grove, Oregon

Peter Shaw-McMinn, OD
Assistant Professor
Southern California College of Optometry
Fullerton, California

To my wife, Dina, and children, Alexander and Maya,
for their enduring love and support,
and to students and practitioners
of sports vision for their inspiration

Preface

The role of visual performance in sports has received considerable attention over the years. With the increasing participation rates in sports and recreational activities, interest in vision care services for athletes has intensified among eye care practitioners and sports personnel. Sports vision can be defined as vision care and consultation designed to protect, correct, and enhance vision to make sports and athletic competition safe, enjoyable, and more successful. It encompasses a broad scope of professional skills, including the prevention and management of sports-related eye injuries, the determination and delivery of appropriate refractive correction, the determination of appropriate protective eyewear, the understanding of filters and their potential application in sports, assessment and remediation of functional vision inefficiencies, assessment of sports-specific vision skills, vision training to enhance visual performance, and consultation with athletes and other sports personnel. Vision is the guiding sense for most sports performance, and sports vision is one of many disciplines that can contribute to the achievement of peak performance.

In searching for the role sports vision may play for athletes, previous surveys have suggested that there remains an unmet need in vision care services, with an increasing interest in the sports vision field. As athletes continue to reach new heights, many efforts have been made to enhance performance by optimizing skills in every area pertinent to a given sport. The surveys have shown both an interest by team personnel and optometrists to include vision screenings, proper ocular health care, refractive evaluation and correction, and remedial and/or enhancement vision training to optimize visual performance. However, the available literature in this area is scattered and varies tremendously in quality.

Personally, I have been involved in both the provision of sports vision services in a variety of clinical settings, and the teaching of sports vision to optometry students and practitioners. This combination of experiences obligated me to not only develop the requisite clinical skills, but also to develop an understanding of the relevant professional and research literature. For teaching purposes, I have found that the published texts on sports vision are either very limited in scope, out of date, or out of print. This text reviews the main elements of the vision care services provided to athletes by eye care practitioners, all of which begin with an analysis of the visual demands that are critical to success in sports. I have attempted to build a foundation from vision science research to guide the application of clinical care, an evidence-based approach. I am indebted to the many practitioners and researchers who have shared their ideas and insights on the burgeoning area of sports vision, for the concepts and procedures discussed in this text are the culmination of those collective contributions. Although there are many areas where numerous questions remain unanswered, the combination of careful task analysis, review of related research findings, and logical deduction can guide the practitioner in determining appropriate vision care.

There are several items on the accompanying CD that can help the practitioner to incorporate sports vision services in a variety of clinical settings. Although this text is

primarily addressed to eye care practitioners, other sports personnel may find useful information for assisting athletes with visual performance needs.

The pursuit of sport and recreational activities is a multibillion-dollar-a-year industry that has seen tremendous growth in the past 30 years. As I like to point out to students and practitioners, almost every patient is a sports vision patient. The ability to understand their needs and provide specialty services to meet these individual needs is a fundamental attribute of every successful practice.

Graham B. Erickson, OD, FAAO, FCOVD

Acknowledgments

I gratefully acknowledge the following individuals for their contributions to the development of this publication: Drs. Bradley Coffey, Alan Reichow, Karl Citek, Stephen Beckerman, Steven Hitzeman, Alan Berman, Lorne Yudcovich, and Dina Erickson. I thank Pacific University for the encouragement and support on this project, and the Vision team at Nike for their conceptual and pragmatic assistance. My students and research assistants have my enduring appreciation for the role each of them plays in my professional growth. I thank Christie Hart and Laura Kudowitz of Elsevier for their assistance and flexibility in development and production.

1

Introduction to Sports Vision

CHAPTER OUTLINE

Overview of Terminology
Historical Perspective
Overview of a Clinical Model of Sports Vision
The Future of Sports Vision

Have you ever wished you could improve your batting average, lower your golf score, or just play your favorite sport better? Most people who participate in sporting activities love to win or at least improve their performance. Athletes at all levels of competition spend a substantial amount of money on sports, including equipment and clothing. Yet many performances that fail are not caused by poor equipment or clothing, or even the wrong physical movement, but by the movement being performed at the incorrect time or in the incorrect place.

A significant percentage of the general population in developed nations participate at some level in sporting activities. The National Sporting Goods Association produces yearly estimates of participation by sport and gender for the United States (available at www.nsga.org). The eye care practitioner must recognize that sports participation crosses all lines of age, gender, race, and socioeconomic status; every patient is potentially a sports vision patient. In addition, a significant percentage of the population may not actively participate in sports but are avid spectators.

Considerable debate has taken place concerning the role of vision in sports. Vision is the signal that directs the muscles of the body to respond. The legendary football coach Blanton Collier is credited for developing the concept that "the eyes lead the body."[1] Vision provides the athlete with information regarding *where* and *when* to perform. Superior size, strength, speed, and agility cannot completely make up for inefficient processing of visual information. For example, if the eyes do not tell a batter where the ball is, he or she is not going to hit it no matter how perfect the swing. Even for the discriminating spectator, excellent visual function allows improved opportunity to enjoy watching sports. Little debate exists that vision is a critical factor in sports performance; however, conflicting evidence shows that successful athletes possess superior visual function that allows them to see and perform better than novices in sports.

The athletic community should be educated about the aspects of vision that potentially affect sports performance. To clearly communicate these aspects, the following visual elements should be discussed:

- *Sight:* The clarity of the image on the retina and ocular health
- *Motor/sensory:* Fixation stability and eye movements, accommodation, vergence, and fusion; visually guided motor performance
- *Information processing:* Quick and accurate visual processing, interpretation, and decision making

Understanding the relevance of these aspects to performance provides an avenue for effective communication of specific vision care recommendations. A better-informed sports community benefits by improved access to services that potentially make sports and athletic competition safe, enjoyable, and more successful.

OVERVIEW OF TERMINOLOGY

The term *sports vision* has been used to describe many vision care services provided to athletes. The mission of the American Optometric Association Sports Vision Section is to advance the quality and delivery of optometric sports vision care through education, injury prevention, and enhancement of the visual performance of athletes. Practitioners working in this area usually are involved with one or more of the following professional activities[2]:

- Prevention and management of sports eye injuries
- Assessment and remediation of functional vision inefficiencies that may negatively impact competitive consistency
- Specialized contact lens services with emphasis on environmental factors in sports, position of gaze factors, emergency care, and attainment of maximal visual acuity
- Performance-based ophthalmic eyewear services that address visual and environmental demands
- Assessment of specific sports-related visual abilities
- Enhancement training of specific visual abilities considered to be essential for competitive consistency for a specific sport activity
- Consultation with athletes, coaches, trainers, and teams regarding visual factors and strategies related to consistent peak athletic performance

Many in the global community are dedicated to the pursuit of athletic excellence. A critical but often neglected aspect of peak human performance is vision. The information presented in this text should help stimulate the inclusion of these specialized services in the care of athletes, no matter what level of sports participation.

In North America, the term sports vision has been associated with vision therapy designed for the enhancement of sports performance. The areas of sports vision defined above clearly demonstrate that many of these services are basic primary vision care services that are modified to address specific task demands. All eye care practitioners should consider visual performance factors when providing vision care services to athletic patients.

HISTORICAL PERSPECTIVE

The use of special eyewear for sports is perhaps the oldest application of vision factors to performance. Daland described the early use of stenopeic slit masks by Eskimos for hunting,[3] and many other special-purpose optical appliances have been described in the literature.[4] Optical protection from solar radiation and glare have been used to some degree for centuries. The use of optical refractive compensation for sports has not been as frequently used, most likely for a combination of practical and aesthetic reasons. The available eyewear was not typically appropriate for use in sports; contact lens technology did not emerge as a reasonable option for most athletes until the later half of the twentieth century; and refractive surgery options did not become advantageous until the late 1990s. Today the benefits of significant advances in technology and designs for the correction and protection of vision are enjoyed by athletes (see Chapter 6).

The evaluation of vision skills in athletes has also been an area of intense interest. The earliest literature citation found is an account of the sensory and motor gifts of the legendary baseball player Babe Ruth in 1921.[5] This report was followed later by an article discussing the role of vision in baseball.[6] These early articles produced suggestions for procedures to assess performance potential in baseball on the basis of vision skill analysis. Interestingly, debate in the literature exists concerning the actual vision profile of the great Babe Ruth. Despite the early report that Ruth had eyesight that was 12% faster than the average person,[5] a 1991 article reported that an ophthalmologic examination revealed amblyopia ex anopsia in his left eye.[7] The potential role of depth perception in batting is challenged by these discrepancies in Ruth's visual status; either he performed so well because he had superior vision skills, or he was successful despite having degraded stereopsis as a result of a congenital amblyopia. Although no definitive resolution can be made from these contradictory reports, some have speculated that the unilateral vision loss was likely the result of a complication of his nasopharyngeal carcinoma rather than an undetected congenital condition.[8] The exact role of vision in sports performance is still hotly debated, and many vision evaluation procedures have been suggested over the years in an attempt to discover the nature of this aspect of sports performance.

Because vision skills are generally recognized as a critical element to most sports performance, significant interest has been expressed in improving sports performance by using training procedures to enhance vision. Many of the visual attributes that have been identified as important in sport are amenable to training. The relevant questions are whether sport-specific visual abilities can indeed be trained and whether any improvements in visual skills transfer to improved sports performance by the athlete. Although the literature has few reports supporting sports vision training, and these reports often have significant flaws, enhancement of visual skill performance can be logically predicted to provide the athlete with a potential advantage when preparing for competition.

The increasing interest in sports and the role of vision in sports has produced the impetus for the formation of organizations to facilitate professional communications. The United States was the first to form an entity through the establishment of the Sports Vision Section of the American Optometric Association (AOA) in 1978. Like many similar organizations, the AOA Sports Vision Section affords practitioners a venue for continuing education, updates through an e-newsletter, a referral network through a member directory, and access to professional materials such as the *Sports Vision Guidebooks* and the *Sports Vision Bibliography*. The section has also been active in interprofessional relations with other organizations, such as the U.S. Olympic Committee, Special Olympics, Amateur Athletic Union (AAU) Junior Olympics, American College of Sports Medicine, National Athletic Trainers' Association, and the National Collegiate Athletic Association. The section provides practitioners and students opportunities to participate in sports vision activities, such as the sports vision screening program at the annual AAU Junior Olympic Games. Ultimately the AOA Sports Vision Section offers practitioners an opportunity to collaborate and advance the profession.

Organizations dedicated to sports vision have also been created outside the United States. The Canadian Association of Optometrists formed a Sports Vision Section in 1987, the European Academy of Sports Vision was formed in Italy in 1989, Optometrists Association Australia established its Sports Vision Section in 1992, and the Sports Vision Association was formed in the United Kingdom in 1993.[4] These organizations perform similar functions to

the AOA Sports Vision Section in their respective regions and have helped facilitate the growth of sports vision globally.

In 1979 Pacific University College of Optometry began providing an elective course on sports and recreational vision in the optometry curriculum. All schools and colleges of optometry in North America now offer some degree of education in sports vision as part of the curriculum. The AOA Sports Vision Section has been supplementing this education with an education program called Sports Vision University. Sports Vision University provides optometry students the opportunity to receive a comprehensive overview of the many aspects of sports vision in one course delivered by two recognized experts in sports vision (one academic practitioner and one private practitioner). The course covers the topics of correcting and protecting athletes, managing sports eye injuries, evaluating visual performance skills in athletes, enhancing visual performance skills in athletes, and marketing and building a sports vision practice. Every 4 years the program will be delivered at each of the schools and colleges of optometry in North America.

OVERVIEW OF A CLINICAL MODEL OF SPORTS VISION

Vision care for athletes should begin with the identification of visual factors that potentially contribute to peak human performance so that these specific functions can be isolated and measured if possible. The visual demands critical to success in sports can vary tremendously. Chapter 2 details an approach to the task analysis process, a process essential to providing appropriate vision care for athletes in any sport or position. Because sports performance generally requires the athlete to process visual information and execute an appropriate motor response, the practitioner should also understand how visual information is processed to understand the exact nature of the processes occurring in skilled motor performance. A model of information processing in skilled motor performance is presented in Chapter 3 to provide a useful approach for understanding the relevant aspects of sports performance.

Once the practitioner has identified the vision factors essential to performance of the visual tasks critical for success in a sport, an evaluation should be created to measure the quality of those skills in the most appropriate, accurate, and repeatable manner. The visual skills that correlate with successful sports performance have not been definitively identified yet, so the practitioner must rely on the available literature and professional judgment to determine the most appropriate evaluation for each athlete. Chapter 4 provides an evidence-based description of each potential vision assessment area and the relative value of each assessment area in an evaluation. Chapter 5 presents recommendations for performing team vision screenings and the unique challenges associated with providing vision care to a team. The results of a screening or evaluation should be summarized for the patient, and a performance profile is recommended in Chapter 5 to highlight areas of strength or weakness and communicate vision recommendations.

A fundamental role of the vision care practitioner is to provide expert consultation services to athletes regarding vision correction and the potential uses and benefits of ophthalmic products. Each athlete has specific variables that will affect ophthalmic recommendations. The gender, age, level of participation, combination of sports activities, and previous history of product use influence the choice of available options. Some athletes seek a single product to meet all visual performance needs, and others seek the optimal products for a variety of highly specific uses. The eye care practitioner should advise athletic patients about the

advantages and disadvantages of spectacles, protective eyewear, sun eyewear, contact lenses, and refractive surgery. Chapter 6 discusses the issues involved in the available modalities for vision correction, eye protection, and vision enhancement. The practitioner should help the athlete make informed decisions about the best options for his or her individual needs.

Participation in sports carries a risk of sustaining an eye injury. The vision care practitioner can perform a crucial role in the prevention of sports-related eye injuries, immediate first aid management if an eye injury occurs, referral of the athlete to an appropriate specialist if necessary, and follow-up care for the athlete who has sustained an eye injury. Chapter 7 provides an overview of assessment and management of sports-related ocular trauma from the perspective of both the athletic trainer and the eye care professional. The chapter concludes with recommendations for effective co-management of ocular injuries in athletes.

As previously mentioned, significant interest exists in determining whether sports performance can be improved by using training procedures to enhance vision. The athlete with identified visual deficiencies is logically expected to achieve improvement in affected aspects of sports performance if those deficient skills are improved to average performance levels. The athlete who possesses average, or even above-average, vision skills presents a more compelling and controversial challenge. Can the vision skills of this athlete be enhanced above the current level, and would this skill enhancement result in demonstrable improvements in sports task performance? A recent review of the literature concluded that most normal visual functions can be improved by specific training paradigms, although thousands of trials may be required to demonstrate enhancement.[9] Several studies have reported positive effects of vision training programs on sports-specific tasks,[10-13] and some have not found improvement in performance.[14-16] Each sports vision practitioner develops an approach to visual performance enhancement that best suits his or her mode of practice; however, useful guidelines should be observed. Chapter 8 provides a sample of visual performance enhancement procedures that have been used by sports vision practitioners, with a rationale and framework for developing effective training programs.

The final chapter deals with the unique issues pertaining to the development of sports vision services in professional practice. Challenges of internal and external marketing are discussed, and methods for growing this area of practice are highlighted.

THE FUTURE OF SPORTS VISION

During the past 30 years a general increase in the use and provision of sports vision services by optometrists has been observed.[17] Eye care practitioners are a common component in the health care service team in professional sports and many collegiate athletic departments in North America. The range of vision care services includes vision screening programs, vision correction with contact lenses, eye protection consultation, eye injury management, and visual performance enhancement training programs. These services are either provided on-site at the athletic facility or in the practitioner's practice. Great interest in sports vision services exists within the sporting community, and the consensus is that this need is not being adequately met by eye care practitioners.[17]

The eye care professions have considerable room for growth in the delivery of sports vision services. Many high-level athletes have never received a comprehensive vision examination and are largely unaware of the potential impact of sports vision services on athletic performance. Indeed, the rate of use of protective eyewear in sports demonstrates the limited impact that

public education programs have had in the athletic community. Significant growth potential clearly exists in all of the areas of sports vision care listed at the beginning of this chapter.

Continued professional growth requires that the profession address some of the concerns and issues that may prevent fulfillment of the potential inherent in this area. Specifically, clinical evaluation procedures need to be ergonomically appropriate, produce repeatable and reliable results, discriminate performance levels, be readily available and not cost prohibitive, and be practical for implementation in most clinical practice facilities. If such evaluation procedures are produced, these procedures must have sound scientific validity demonstrated by controlled studies. If this can be achieved, sports vision skill assessment may become a common aspect of patient care.

Similarly, visual performance enhancement procedures need a degree of validation to engender broader acceptance. Some of the same desirable characteristics described for evaluation procedures pertain to training procedures as well. Training programs should attempt to demonstrate vision skill improvement with relevant laboratory and clinical research. The improvement of vision skill performance should also be correlated to a concurrent improvement in sports performance, if possible. However, isolating one area of intervention as being solely responsible for changes in performance is incredibly difficult. This is true for any area of sports training, including strength training, conditioning, speed and agility training, nutritional regimens, and sports psychology. If the improvement of obviously critical vision skills is evident from well-controlled research, the transfer to sports performance offers a logical correlation that perhaps would be more readily accepted than anecdotal reports.

Sports vision specialists have tremendous potential to provide consultation services. The vision factors that influence perception are generally not calculated in the development of sports products. The sports vision specialist is in a unique position to facilitate product innovation in a potentially unique direction. The sports vision specialist can provide scientifically supported advice in such areas as the selection of product colors, the optical properties of performance eyewear, the engineering of performance tints, and the desirable properties of contact lenses for athletes. These potential opportunities could yield fulfilling professional experiences for the practitioner.

The authors hope that, in some small way, this text will help increase the provision of sports vision services to athletic patients and stimulate interest in elevating the professional development of sports vision. Eye care practitioners have the potential to contribute to the performance of their athletic patients; ultimately, sports vision care can contribute to elevating human potential.

REFERENCES

1. Collier B: The eyes lead the body, *Optom Management 15:*73, 1979.
2. Coffey B, Reichow AW: Optometric evaluation of the elite athlete, *Prob Optometry 2:*32, 1990.
3. Daland J: Eskimo snow blindness and goggles, *Optom J Review Optom 39:*1334, 1917.
4. Loran DFC: An overview of sport and vision. In Loran DFC, MacEwen CJ, editors: *Sports vision,* Oxford, 1995, Butterworth-Heinemann.
5. Fullerton HS: Why Babe Ruth is the greatest home run hitter: *Popular Science Monthly* tests in the laboratory his brain, eye, ear and muscle—and gets his secret, *Popular Science Monthly 99:*19, 1921.
6. Abel O: Eyes and baseball, *Western Opt World 12:*401, 1924.
7. Blodi FC: Some famous persons with visual problems as shown on postage stamps, *Doc Ophthalmol 77:*295, 1991.

8. Voisin A, Elliott DB, Regan D: Babe Ruth: with vision like that, how could he hit the ball? *Optom Vis Sci 74:*144, 1997.
9. Ciuffreda KJ, Wang B: Vision training and sports. In Hung GK, Pallis JM, editors: *Biomedical engineering principles in sports,* New York, 2004, Kluwer Academic, pp 407-433.
10. West KL, Bressan ES: The effect of a general versus specific visual skills training program on accuracy in judging length-of-ball in cricket, *Int J Sport Vis 3:*41, 1996.
11. Quevedo-i-Junyent L, Sole-i-Forto J: Visual training program applied to precision shooting, *Ophthalmol Physiol Opt 15:*519, 1995.
12. McLeod B: Effects of eyerobics visual skills training on selected performance measures of female varsity soccer players, *Percept Mot Skills 72:*863, 1991.
13. Kofsky M: Sports vision visual training and experimental program with Australian Institute of Sport Basketball players, *Austr J Optom 6:*15, 1988.
14. Abernethy B, Wood JM: Do generalized visual training programmes for sport really work? An experimental investigation, *J Sports Sci 19:*203, 2001.
15. Quevedo L, Sole J, Palmi J, et al: Experimental study of visual training effects in shooting initiation, *Clin Exp Optom 82:*23, 1999.
16. Wood JM, Abernethy B: An assessment of the efficacy of sports vision training programs, *Optom Vis Sci 74:*646, 1997.
17. Zieman B, Reichow A, Coffey B: Optometric trends in sports vision: knowledge, utilization, and practitioner role expansion potential, *J Am Optom Assoc 64:*490, 1993.

2

Visual Task Analysis in Sports

CHAPTER OUTLINE

General Visual Characteristics of the Sport or Activity
- Static versus Nonstatic
- Sustaining Demands
- Nondynamic versus Dynamic
- Contrast Levels
- Target Size
- Boundaries
- Visual Space Ranges
- Figure/Ground Color, Texture, Shade
- Visual Time
- Distance versus Near
- Directional Localization
- Depth Discrimination and Spatial Localization
- Gaze Angles
- Body Position and Balance
- Stress (Cognitive and Cardiovascular)
- Visual Attention Demands (Central versus Peripheral versus Split Attention)

Environmental Analysis in Sports and Recreation

Visual Task Analysis Examples
- Dynamic Reactive Sports
- Nondynamic Precision Sports

Vision care for athletes should begin with the identification of visual factors that potentially contribute to peak human performance so that these specific functions can be isolated and measured, if possible. The visual demands critical to success in sports can vary tremendously. For example, a dynamic and reactive sport such as basketball has very different visual demands from the static precision requirements of target shooting. This chapter provides an approach to this task analysis process, which is essential to providing appropriate vision care for athletes in any sport or position.

A practitioner's depth of knowledge concerning a sport activity provides the foundation for delivering the highest quality vision care for the athlete. Personal participation in the sport activity by the practitioner offers the most intimate insights into the visual task demands encountered by the athlete. However, many crucial insights into the visual task demands of a sport activity can be acquired by extensive interaction with the athlete or other experts (e.g., coach, athletic trainer) in the sport. These insights can be further supplemented by observation of the sport activity, which may offer the opportunity for a personal experience. For example, the first time the author worked with a skeet shooter, extensive interaction with the athlete was necessary because the author had no personal experience with this sport. This interaction was followed up with a visit to the shooting range for observation of the activity and personal experience to gain further insights into the visual task demands of skeet shooting.

Many other avenues are available for information concerning the demands of a specific sport activity. The American Optometric Association (AOA) Sports Vision Section offers a collection of detailed insights into the many visual factors involved in a variety of sports in the form of guidebooks.[1] These guidebooks were compiled with input from experienced optometric practitioners and are available on the AOA Web site (www.aoa.org) with membership in the Sports Vision Section, or printed copies may be purchased from the AOA. Information concerning less-common recreational activities can easily be found by searching on the Internet or consulting the many sports periodicals and books available. Consultation with a practitioner who has extensive experience with athletes in the sport activity can provide additional valuable insights for the task analysis process.

GENERAL VISUAL CHARACTERISTICS OF THE SPORT OR ACTIVITY

Visual characteristics comprise the visual task demands of any sport activity. A series of task subcategories is presented and can be used to develop a profile of the salient features involved in a sport.

Static versus Nonstatic

Static task demands are those in which the visual information is stationary, allowing for a steady image to be processed. Sport activities with static task demands include archery, target-shooting sports, golf, free-throw shooting in basketball, and free penalty shots on goal in soccer and hockey. The sports tasks allow the athlete to fine tune the motor response based on stable visual information.

Nonstatic task demands are those in which the visual information is in motion, necessitating the constant processing of changes in the visual information. Many sport activities have nonstatic demands (Box 2-1). For example, the running back in football does not typically have much time to study the defensive movements of the opponent before choosing a path to run.

Sustaining Demands

The duration of the competition determines how long the athlete must sustain visual performance. In one study, the majority of sports were determined to be completed within 2 hours.[2] Therefore many sports require sustained performance longer than 1 hour (Box 2-2). In a sport activity such as mountaineering, the ability to sustain a high level of

BOX 2-1 SPORTS WITH NONSTATIC VISUAL DEMANDS

Baseball	Sailing
Basketball	Skating
Boxing	Skeet and trap shooting
Cycling	Skiing
Football	Soccer
Hockey	Softball
Martial arts	Surfing
Motor racing	Water polo
Racquet sports	Volleyball

BOX 2-2 SPORTS WITH SUSTAINED PERFORMANCE DEMANDS (MORE THAN 1 HOUR DURATION) AND SPORTS WITH INTENSE DEMANDS FOR BRIEF PERIODS

SUSTAINED PERFORMANCE	SHORT DURATION
Baseball and softball	Archery
Basketball	Baseball and softball batting
Boxing	Drag racing
Cycling	Gymnastics
Football	Speed and figure skating
Golf	Skiing (alpine and jumping)
Hockey	Shooting sports
Martial arts	Track and field events
Motor racing	
Mountaineering	
Racquet sports	
Sailing	
Skating	
Skeet and trap shooting	
Nordic skiing	
Soccer	
Water polo	
Volleyball	

visual information processing over many hours with little rest is not just an asset; it is also life protecting.

The duration of each individual event in some other sports is short, even though performance levels must be sustained for the length of the competition. These types of sports typically have significant rest intervals during the course of the competition, such as the examples listed in Box 2-2. The demand on visual information processing is generally intense during the event, such as in alpine skiing, but the athlete is allowed a generous amount of time between events to rest.

Nondynamic versus Dynamic

Dynamic is used in this text to describe the athlete during a sport activity. In many sports, the athlete must perform while in motion (Box 2-3). The hockey player must continue to process the action in a game despite being challenged to maintain balance while in motion with constantly interrupted views of the action.

In nondynamic sports activities, the athlete is relatively stationary when performing. Nondynamic sports include the examples listed in Box 2-3. Even though movement occurs in golf during the swing at the ball, the athlete is allowed to analyze the visual information used to guide each stroke while remaining relatively motionless.

Contrast Levels

The judgment of subtle contrast differences is a common visual task in sports (Box 2-4). Contrast levels can be affected by changing illumination levels produced by weather, artificial illumination, shadows, glare, playing surface conditions, and backgrounds. In addition, the

BOX 2-3 DYNAMIC SPORTS IN WHICH THE ATHLETE MUST PERFORM WHILE IN MOTION AND NONDYNAMIC SPORTS IN WHICH THE ATHLETE IS RELATIVELY STATIONARY

DYNAMIC SPORTS	NONDYNAMIC SPORTS
Baseball and softball	Archery
Basketball	Golf
Boxing	Motor racing
Football	Shooting sports
Gymnastics	
Hockey	
Martial arts	
Motor racing	
Mountaineering	
Racquet sports	
Skiing	
Skating	
Soccer	
Surfing	
Track and field events	
Water polo	
Volleyball	

relative contrast of the object is reduced any time the object is in motion, so fast action sports tend be more demanding on contrast sensitivity. For example, a classic black-and-white patterned soccer ball has high contrast when stationary but significantly reduced contrast when kicked with a large amount of spin. Because the spin of the ball provides vital clues concerning its flight trajectory, the ability to discriminate the contrast of the ball pattern is potentially beneficial to the athlete. The selection of filters or refractive correction modality may also be affected by the contrast sensitivity demands of a sport (see Chapter 6). For example, the downhill skier must select the filter that provides the optimal transmission characteristics to enhance relevant contrast information for the current light conditions.

The judgment of subtle contrast differences does not offer an advantage in some sports, such as archery, target shooting sports, and some track and field events.

BOX 2-4 SPORTS WITH CONTRAST JUDGMENT DEMANDS

Baseball	Mountaineering	Soccer
Basketball	Racquet sports	Softball
Cycling	Sailing	Surfing
Football	Skating	Water polo
Golf	Skeet and trap shooting	Volleyball
Hockey	Skiing	
Motor racing		

Target Size

Significant differences may exist in the size of the visual information that must be discriminated in different sport activities. For example, the visual discrimination task for a hockey puck is much more demanding than for a basketball. For each sport activity, the interaction between the size of the visual target or object and the viewing distances encountered in the sport should be evaluated to determine the visual discrimination demands. Significant interaction may also exist between visual discrimination level and contrast sensitivity demands. Again with the soccer example, the size of the soccer ball is relatively large, but the judgment of ball spin requires an enhanced level of visual discrimination than the ball size would suggest.

Boundaries

Boundaries for the competition area are established in many sports. In some sports, such as table tennis and billiards, the boundaries are relatively small and can easily be seen during competition. In other sports, such as soccer and football, the competitive boundaries are too large to be seen entirely at all times during competition. The extent of the boundaries establishes the peripheral vision demands for the athlete and may also affect selection of refractive correction modality.

Visual Space Ranges

The athlete must attempt to control a range of physical space in many sports by constantly processing the visual information in that physical space. The physical space can be relatively confined, as in wrestling, or it may be much larger, as in sailing competitions. This factor also relates to the peripheral vision demands for the athlete.

Figure/Ground Color, Texture, Shade

An analysis of the figure/ground characteristics encountered in a sport can assist in the selection of filters to enhance performance. For example, a skeet or trap shooter must quickly locate an orange-colored target against the background of the ground (brown dirt, green grass, brown grass, etc.), any foliage (trees, shrubbery, etc.), and the sky (blue sky, partly cloudy sky, heavily overcast sky, etc.). The selection of the optimal filter for the current light levels and backgrounds is an essential aspect of competitive skeet or trap shooting. Filter selection may offer significant benefits in many sports by sharpening contrast and enhancing critical visual information. Filters also offer a potential benefit by muting distracting visual "noise" from the background. Filter selection is discussed in detail in Chapter 6.

Visual Time

Many sport situations have an established time course of action in which visual processing characteristics can be analyzed. The time course of a Major League Baseball pitch is one situation that has been scrutinized by researchers from a variety of backgrounds.[3,4] Depending on the speed of the pitch, the Major League batter has approximately 400 ms between the release of the pitch and the time the ball arrives at the plate. Because the swing takes approximately 150 ms to complete, the batter has approximately 250 ms to process the visual information from the pitch and decide on the appropriate response. These time characteristics are discussed in greater detail in Chapter 3. However, many other sport situations have time characteristics that unfold in a relatively predictable manner. The serve in many racquet sports and volleyball, the pitch in cricket, penalty shots on goal in soccer and hockey, the judgment of hurdles in track, the judgment of the approach in the high jump and pole vault in field

events, the judgment of maneuvers in gymnastics and diving, and the flight of clay pigeons in skeet or trap shooting all have a range of time characteristics that define the visual processing demands for successful performance.

In other sport situations, the time course of the action can be less predictable (e.g., skiing, cycling, boxing, kayaking, motor sports, wrestling), thereby elevating the role of reactive visual information processing skills for success. Some sports have essentially no reactive component to the motor response (e.g., archery, target-shooting sports, golf, billiards). These sports require development of the ability to modulate attention appropriately for success.

Distance versus Near

The viewing distance from which most of the visual information is received can be analyzed to determine the vision demands for the athlete. In billiards, for example, the distances that must be clearly focused are fairly predictable. In other sports, such as hockey, the viewing distances many vary considerably during the course of competition. Most sports have aspects that require clear vision for distances beyond 3 m (Box 2-5). However, other sports have aspects of the activity that involve near and intermediate distance focus.

Directional Localization

In some sports the accuracy of directional localization is often critical to success. Directional localization is the ability to determine the exact direction of visual information (e.g., a target, object, opponent, teammate, terrain). For example, the ability to putt in golf requires the athlete to discriminate precisely the subtleties of the terrain for the shot to determine the

BOX 2-5 SPORTS WITH VISION DEMANDS AT DISTANCES FARTHER THAN 3 M AND THOSE THAT INVOLVE VISUAL DETAILS AT INTERMEDIATE AND NEAR DISTANCES

FAR DISTANCE DEMANDS	NEAR DISTANCE DEMANDS
Archery	Billiards
Baseball and softball	Boxing
Basketball	Cycling
Cycling	Martial arts
Football	Motor sports
Golf	Shooting sports
Hockey	Wrestling
Motor racing	
Mountaineering	
Racquet sports	
Sailing	
Skating	
Shooting sports	
Skiing	
Soccer	
Surfing	
Track and field events	
Water polo	
Volleyball	

BOX 2-6 SPORTS WITH SIGNIFICANT DIRECTIONAL LOCALIZATION DEMANDS

Archery	Gymnastics	Soccer
Baseball	Hockey	Softball
Basketball	Kayaking	Surfing
Billiards	Martial arts	Track and field events
Bowling	Motor racing	Water polo
Boxing	Racquet sports	Wrestling
Cycling	Sailing	Volleyball
Diving	Shooting sports	
Football	Skating	
Golf	Skiing	

best path for the putt. This skill requires the athlete, in part, to determine correctly the direction that the shot needs to take to account for the slope of the terrain and distance of the putt. Farnsworth[5] discusses this aspect of golf in detail. Directional localization ability is a crucial feature, to varying degrees, in sports such as the examples listed in Box 2-6.

Depth Discrimination and Spatial Localization

The other aspect of localization involves judgment of distance, either to other competitors, to a target, or of the trajectory that the target is taking. As in the previous example with directional localization, the golfer must judge the direction that a putt needs to take and also determine the stroke response that will cause the ball to traverse the specific distance to the hole. Therefore, as with directional localization, the ability to judge spatial localization accurately is found to varying degrees in almost all sports.

Gaze Angles

Many sports require that the athlete process visual information coming from nonprimary positions of gaze. In volleyball, for example, most of the action takes place above the athletes' heads, requiring an upgaze eye position to view the action. Therefore, for each sport or position, an appraisal of relevant gaze positions directs the vision evaluation, particularly concerning ocular alignment assessment. Sports such as hockey and skiing require a significant amount of judgments with the eyes in downgaze position. In other sports, such as billiards, cycling, swimming, and volleyball, much of the visual information requires an upgaze eye position. Some sports also require a significant number of judgments while the eyes are in a lateral gaze position, such as baseball or softball batting and golf. Many other sport activities can involve all positions of gaze at any time, such as baseball, softball, basketball, football, racquet sports, soccer, and wrestling.

Body Position and Balance

Precise body position and maintenance of balance can be critical features of sport performance and are often critically considered in sport biomechanics. In a sport such as luge, meticulous attention is devoted to developing optimal body positioning and adjustments. Development of this skill area can produce the difference needed for success in this sport, in which milliseconds matter. Training and enhancement of body position and balance maintenance are essential elements for most sports, and examples of sports in which it is not relevant (e.g., auto racing) are rare.

Stress (Cognitive and Cardiovascular)

A universal aspect of sports is the influence of stress on performance. Most of the stress encountered in sports is cognitive in nature, in which the athlete must control the locus of attention despite a significant amount of potential distractions and pressures inherent in the sports environment. The competitive diver must ignore irrelevant visual and auditory information, as well as the knowledge of his or her previous performances relative to the other competitors. This is typically the territory of the sports psychologist, whose goal is to assist the athlete in controlling attentional focus for optimal sports performance. Many sports also add the factor of cardiovascular stress to cognitive stress during competition. The Olympic biathlete must control breathing and heart rate to shoot accurately while competing in a cross-country skiing race, an example of both cognitive and cardiovascular stress features that must be controlled for optimal performance. This universal feature to sports performance has lead many practitioners to evaluate visual performance skills under stress-inducing conditions.

Visual Attention Demands (Central versus Peripheral versus Split Attention)

The visual attention demands for an athlete can be primarily central (e.g., target shooting), peripheral (e.g., seeing the release of the clay pigeons in skeet shooting), or split between central and peripheral processing (e.g., the striker in soccer seeing the goal and goalkeeper while simultaneously monitoring the movements of teammates and opponents). Peripheral vision can be argued to be relevant in almost every sport because it is a critical element of balance maintenance. Therefore, even in predominantly central processing sports such as target shooting, archery, and baseball and softball batting, peripheral processing is a performance factor. However, in these types of sports situations the attentional focus is predominantly central, and processing of extraneous peripheral information can degrade performance. Most of the sports discussed in this chapter compel the athlete to balance attention between central and peripheral visual information for optimal performance, although aspects of performance may be predominantly central or peripheral in nature.

ENVIRONMENTAL ANALYSIS IN SPORTS AND RECREATION

Participation in sports can occur in many different environmental conditions. These conditions can have detrimental effects on visibility or produce ocular hazards. The presence of ocular hazards should be evaluated, and issues of appropriate ocular, face, or head protection should be thoroughly addressed. The choice of the best protective eyewear should consider the mechanical forces or foreign body potentials encountered in a sport; the optimal design for visibility is discussed in detail in Chapter 6.

Sports take place under many types of natural and artificial lighting. Variations in lighting can affect performance when critical visual information is tainted by the altered lighting. Studies have demonstrated that when visibility starts to diminish because of reducing light levels, reaction times also begin to slow in relation to the decreasing light level.[6-11] The effects of glare on visual performance is a particular burden in some sports and should be exhaustively addressed. Although little can be changed about natural lighting conditions outdoors, the use of specific filters and filter densities can be explored to determine maximal benefits for the athlete. This aspect of task analysis is discussed in detail in Chapter 6.

The use of eyewear or contact lenses can be adversely affected by many factors encountered in sports. Eyewear can create visibility problems in conditions of precipitation and mud and

are particularly prone to troubles with sweat, dust, and lens fogging. Many of these problems can be alleviated by contact lenses; however, contact lens wear can be complicated by temperature, altitude, wind, and humidity. These issues are addressed in detail in Chapter 6.

VISUAL TASK ANALYSIS EXAMPLES

Many methods exist for evaluating the visual tasks critical for successful sports performance. Many of the visual factors have been briefly discussed, and sports can be organized into categories with similar visual task demands. An example of this approach is described below. However, meticulous scrutiny of the factors specific to a particular sport activity often yields more profitable information concerning the visual aspects that elevate the potential for peak sports performance.

Dynamic Reactive Sports

Many sports have dynamic visual features that need to be rapidly processed by the athlete to determine the best motor response. These sports often require the athlete to balance attention between central and peripheral information for optimal performance, especially in team and racing sports. Sports that are dynamic and reactive in nature, and generally require the athlete to balance central and peripheral visual attention, include those listed in Box 2-7.

In many dynamic sports, judgment of ball spin is a critical element to determining a successful response, such as tennis, soccer, and volleyball. The judgment of ball spin relies on visual resolution ability, dynamic visual acuity, contrast sensitivity, and oculomotor function to provide the best visual information for processing; therefore these visual skills should be evaluated in athletes participating in these sports. In racing sports such as cycling, kayaking, motor (car, motorcycle) racing, skiing, and swimming, central visual information is often critical for determining the most advantageous path or timing of responses, and contrast levels frequently change significantly during competition. Racing sports, however, also entail a significant peripheral vision demand to monitor competitors during the race. These types of dynamic reactive sports can be distinguished for other types of team sports in which central visual information is often less important than peripheral information. Team sports such as basketball, football (certain positions), hockey, and water polo are examples in which peripheral information for some aspects is often more vital than central details. Performance in combative sports such as boxing, fencing, martial arts, and wrestling rely on responsiveness

BOX 2-7 DYNAMIC REACTIVE SPORTS

- Baseball
- Basketball
- Boxing
- Cycling
- Diving
- Fencing
- Football
- Gymnastics
- Hockey
- Kayaking
- Martial arts
- Motor racing
- Racquet sports
- Skating
- Skeet and trap shooting
- Skiing
- Soccer
- Softball
- Surfing
- Swimming
- Track and field events
- Volleyball
- Water polo
- Wrestling

to peripheral visual information more than resolution thresholds for central vision. Therefore assessment of peripheral awareness and reaction factors is more important than visual acuity measurements.

The judgment of depth is a crucial factor in all the dynamic reactive sports listed, necessitating an assessment of the pertinent visual factors that contribute to accurate depth perception. In addition, an assessment of speed of recognition is valuable in all these sports because athletes are required to process visual information rapidly to determine the best motor response. Depending on the type of motor responses typically made in competition, visual reaction times to eye-hand, eye-foot, and/or eye-body testing paradigms are indicated for all dynamic reactive sports. In addition, visual coincidence anticipation can provide valuable information in the evaluation of athletes competing in baseball, softball, football (receivers), hockey, racquet sports, skeet and trap shooting, soccer, and volleyball.

EXAMPLE: SPORTS VISION EVALUATION FOR BASEBALL

Case History: Include the supplementary questions listed in Chapter 4
Static Visual Acuity: Landolt rings at 6 m, OD, OS, OU
Dynamic Visual Acuity: Protocols?
Contrast Sensitivity Function: Vistech or Vector Vision tests
Refractive Status
Ocular Alignment: Cover test in primary gaze and the eight secondary gaze positions
Depth Perception: Howard-Dolman stereopsis at 6 m (threshold and speed)
Accommodative Facility: Haynes Near-Far Facility Test
Oculomotor Skills
Speed of Recognition
Visual Motor Reaction Time (Eye-Hand and Eye-Foot): Wayne Saccadic Fixator
Eye-Hand Coordination: Wayne Saccadic Fixator
Visual Coincidence Anticipation: Wayne Speedtrack or Bassin Anticipation Timer

Nondynamic Precision Sports

Nondynamic precision sports are characterized by significant demands placed on central vision to assist in determining exact directional and spatial localization. Sports such as archery, billiards, bowling, golf, and target shooting involve targets that are stationary; therefore no demand is made to react to changing visual information. Although critical demands are placed on processing of central visual information, balancing that central information with peripheral visual information is a fundamental aspect of performance in all these sports.

The sports vision evaluation for athletes competing in nondynamic precision sports typically emphasizes static visual acuity and refractive status, pertinent elements contributing to accurate depth perception, accommodative function, field dependence or independence, and visualization and imagery.

EXAMPLE: SPORTS VISION EVALUATION FOR GOLF

Case History: Include the supplementary questions listed in Chapter 4
Static Visual Acuity: Landolt rings at 6 m, OD, OS, OU

Contrast Sensitivity Function: Vistech or Vector Vision tests
Refractive Status
Ocular Alignment: Cover test in primary gaze and in putting stance with head tilt; fixation disparity at 6 m in primary gaze and in putting stance with head tilt
Depth Perception: Howard-Dolman stereopsis at 6 m (threshold)
Accommodative Facility: Haynes Near-Far Facility Test
Oculomotor Skills
Field Dependence or Independence: Rod and Frame Test
Visualization/Imagery (Test?)

REFERENCES

1. The AOA Sports Vision Section Guidebook Committee: *Sports vision guidebook: volumes I-V*, St Louis, 1984-2000, American Optometric Association.
2. Obstfeld H, Pope R, Efron N, et al: Sports vision correction. In Loran DFC, MacEwen CJ, editors: *Sports vision,* Oxford, 1995, Butterworth-Heinemann, p 131.
3. Bahill AT, Karnavas WJ: The perception of baseball's rising fastball and breaking curveball, *J Exp Psychol Hum Percept Perf 19:*3, 1993.
4. Adair RK: *The physics of baseball*, New York, 2002, Perennial, pp 29-46.
5. Farnsworth CL: *See it and sink it: mastering putting through peak visual performance,* New York, 1997, HarperCollins.
6. Appler DV, Quimby CA: The effect of ambient room illumination upon Wayne Saccadic Fixator performance, *J Am Optom Assoc 55:*818, 1984.
7. Campbell FW, Rothwell SE, Perry MJ: Bad light stops play, *Ophthalmol Physiol Optics* 7:165, 1987.
8. Perry MJ, Campbell FW, Rothwell SE: A physiological phenomenon and its implications for lighting design, *Lighting Res Technology 19:*1, 1987.
9. Rothwell SE, Campbell FW: The physiological basis for the sensation of gloom: quantitative and qualitative aspects, *Ophthalmol Physiol Optics 7:*161, 1987.
10. Beckerman SA, Zost MG: Effect of lighting levels on performance on the Wayne Computerized Saccadic Fixator and Wayne Peripheral Awareness Trainer, *J Behav Optom 5:*155, 1994.
11. Beckerman S, Fornes AM: Effects of changes in lighting level on performance with the AcuVision 1000, *J Am Optom Assoc 68:*243, 1997.

3

Visual Information Processing in Sports

CHAPTER OUTLINE

Information Processing Model for Sports Performance
Perceptual Mechanism
- Visual Resolution
- Depth Judgment
- Eye Movements
- Peripheral Vision

Decision Mechanism
Effector Mechanism
- Complex Interactions Mediating Effector Mechanism Responses

Application of the Information Processing Model to Batting in Baseball
- Perceptual Mechanism
- Decision Mechanism
- Effector Mechanism

Vision Care and Visual Information Processing

Discussion, speculation, and research concerning the role of vision and visual information processing in sports have a long history. There is little debate that vision is a critical factor in sports performance or that visual information is the dominant sensory system when performing practically any perceptual motor task such as those encountered in sports.[1-5] The visual physiological attributes of athletes have been extensively studied and compared with those of nonathletes, novices, and other athletes of varying skill levels. Some believe that the literature supports the opinion that athletes possess superior visual systems that allow them to see and process critical visual information better than their peers.[5-9] Others contend that the literature does not support the opinion that their visual system physiology is superior, but that elite athletes are able to use available visual information more efficiently and effectively than novices.[10-13] The results of research attempting to address these contentions has been equivocal, thereby allowing both sides of the debate to claim support for their assertions.

Many factors influence sport performance: biomechanical factors, strength and conditioning factors, visual factors, and cognitive factors, to name a few. Experts in any of the relevant fields would be expected to find support for the importance of factors in their area of expertise because they evaluate aspects of performance from the perspective of their expertise. Definitive answers to global questions are rarely ascertained by isolating factors without consideration of the complete process. To suggest that superior visual skills are of little consequence compared with the cognitive processing of the visual information overlooks the role that visual information plays in cognition. This argument would content that it is not the golfer's ability to see the details of the green that is critical when attempting a putt,

but rather the ability of the golfer to interpret that visual information in order to select the appropriate direction and distance for the putt. This is certainly a cogent argument when comparing a novice with an expert golfer with similar visual abilities; the two may see the same information, but the experience of the expert allows interpretation of the contours of the green and judgment of the distance to the hole better than the novice. However, when comparing golfers with similar skills and experience, the golfer with poor contrast sensitivity will be at a disadvantage in reading the contours of the green when compared with the golfer with excellent contrast sensitivity. This visual disadvantage is present notwithstanding any perceptual adaptations that have developed in the golfer with poor contrast sensitivity in order to succeed; the golfer has deficient ability to use contrast information to judge the contours of the green. No matter how well developed the cognitive processing of visual information becomes, poor visual information creates an impediment to peak performance. Peak sports performance cannot be expected without both adequate visual information and the cognitive abilities to use the visual information. Superior capacity in either vision abilities or cognitive proficiency would logically offer an advantage to the athlete over a peer with less-developed skills.

INFORMATION PROCESSING MODEL FOR SPORTS PERFORMANCE

Sports performance generally requires the athlete to process visual information and execute an appropriate motor response. Many elaborate information processing models have been developed to understand the exact nature of the processes occurring in skilled motor performance. A traditional information processing model of skilled motor performance first proposed by Welford,[14] and later modified by others,[4,11,14-18] is presented here because it provides a useful approach for understanding the relevant aspects of sports performance.

The information processing model in Figure 3-1 proposes that skilled motor performance is the result of three central processing mechanisms: the perceptual mechanism,

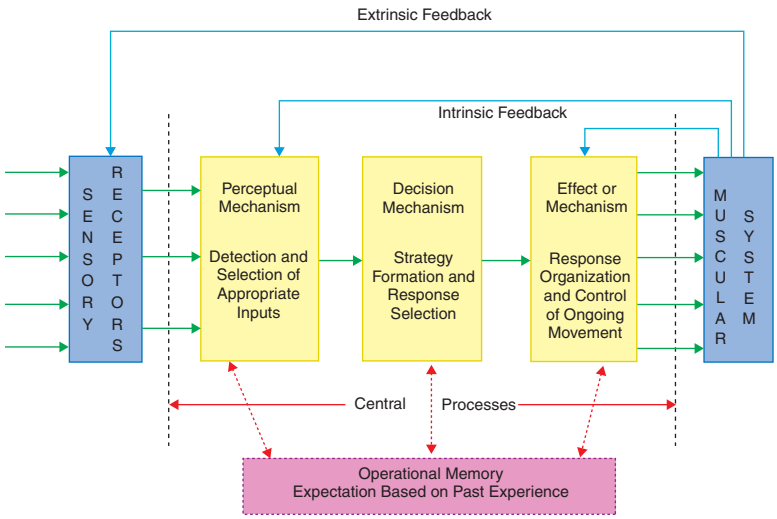


Figure 3-1. An information processing model of skilled performance. (Modified from Welford AT: The measurement of sensory-motor performance: survey and reappraisal of twelve years progress, *Ergonomics* 3:189, 1960.)

the decision mechanism, and the effector mechanism. These three mechanisms are proposed to operate sequentially; however, significant consideration is given to the effects of both intrinsic and extrinsic feedback, as well as the contributions of experiential memory.

The perceptual mechanism receives an incredible amount of information from a wide variety of sensory receptors (e.g., vision, vestibular, tactile, and auditory receptors). Sensory channel capacity limits the amount of information that can be thoroughly processed, requiring that the current input information that has immediate relevance for executing the required task be selected for processing. This also requires that irrelevant sensory information be filtered out by similar neurologic mechanisms. The athlete's experience and ability to control attention are suggested to guide this selection and filtering process.[14,19] The perceptual mechanism is then responsible for organizing and interpreting the processed information in an approach that facilitates optimal performance.

The sensory information that has been processed is conveyed to a decision mechanism. The purpose of the decision mechanism is to determine the appropriate motor response strategies for the sensory information, which may also include the repression of a motor response in some sport situations. The athlete's sport knowledge and past experience obviously exert substantial influence on the effectiveness of decision processing.

The motor response selected by the decision mechanism is transmitted to the effector mechanism. The neural commands necessary to produce the desired response at the correct time are organized and sent to the appropriate brain centers for execution of the action. The motor response is both initiated and controlled by the effector mechanism. Both internal and external information is continually processed by the perceptual and decision mechanisms, allowing both control and adjustment of the motor response to occur when sufficient time exists to alter the response.

This model is both simple and practical for understanding the processes occurring when an athlete must react and respond to sensory information in a sport situation. Comparisons have been made between this model and the functioning of a computer; the computer receives information input, processes that information in the manner that it was programmed, and produces the planned output result. Although this analogy of computer hardware and software has been challenged, and other factors are not clearly revealed by this model, it remains a useful global method for understanding the processes involved in sports performance. The computer analogy also clarifies the importance of both superior hardware and software for achieving peak human performance.

PERCEPTUAL MECHANISM

In the information processing model presented, the perceptual mechanism stage of processing is the most directly related to the realm of the vision care provider. It is the basic role of the vision care provider to ensure that the sensory receptors for visual information are functioning adequately. A comprehensive vision evaluation should evaluate the patency of the basic functions of the visual apparatus and identify any deficits that may limit performance potential. A secondary level of vision care is the evaluation of visual performance skills that relate to sports performance, yet the development of visual performance evaluation procedures that appropriately measure relevant vision skills that are directly related to sports tasks has been challenging. Recommendations for procedures to assess visual performance abilities in athletes are discussed in Chapter 4. Four general areas of visual information processing in the perceptual

stage have been defined, each of which is richly supported by intrinsic and extrinsic feedback and experience: visual resolution, depth judgment, eye movements, and peripheral vision.

Visual Resolution

The first aspect of the information processing model is sensory reception of the information. The ability to resolve subtle details can be a factor in perceptual processing if the details contain relevant visual information. Static visual acuity (SVA) has been found to be better in athletes than nonathletes in some studies,[20-23] whereas some have found no difference.[24] The variance in results is most likely a consequence of the visual acuity testing methods used and the differences in the visual task demands of the variety of sports assessed. The ability to resolve detail when movement between the observer and the test object is induced, referred to as dynamic visual acuity (DVA), has arguably more relevance in sports than static measurements. Most of the research has attempted to determine the relation between DVA and visual task performance; however, studies have compared athletes and nonathletes.[25-29] Despite significant differences in methods for measuring DVA, all but one study found better DVA in athletes.[28] A significant amount of human and stimulus variables can affect DVA, including the resolving power of the retina, peripheral awareness, oculomotor abilities, target luminance, angular velocity, the time exposure of the target, and psychologic functions that affect interpretation of visual information. In addition to DVA, measurement of contrast sensitivity function (CSF) has been recommended in athletes because athletes often must perform visual discrimination tasks with suboptimal lighting because of environmental variability. The common conclusions from investigations comparing CSF in athletes indicate elevated CSF for athletes.[22,23,27,30-37] Therefore the consensus of studies evaluating the resolution capacities of athletes indicates that, although athletes can still perform with suboptimal visual acuities, superior visual resolution capabilities are expected.

The resolution of visual details also requires the athlete to be proficient at adjusting focus for a variety of distances. Studies that have evaluated accommodative facility in athletes compared with nonathletes have had mixed results, primarily because of the method of testing used. The use of lenses to manipulate accommodative demand does not simulate the visual task demands encountered in sports, and studies using this method have found no difference in athlete performance.[24,38] The use of resolution threshold demand targets at two different distances with fixation being rapidly alternated between the two charts may better represent the accommodative task demands of sport.[22,39]

Depth Judgment

Discrimination of distance information and judgments of spatial localization are commonly encountered in sports. The results of research comparing performance on tests of static stereopsis with a variety of testing procedures in athletic populations have had mixed results; some have found better stereopsis[20,23,31,39-44] and others have found no difference.[24,38,45,46] The lack of athlete differences in many studies has been suggested to be the result of the static nature of the testing and that testing of dynamic stereopsis may discriminate sports-related visual abilities better.[47-55] Better ocular alignment can contribute to better depth perception; however, early findings of lower amounts of heterophoria in athletes[20,41] have not been confirmed in recent studies.[24,37] Various evaluation methods for assessing vergence function have been conducted with athletes, and all but one study[37] found better performance in athletes than in nonathletes.[22,24,38,56] Although vergence responses are a type of eye movement used

for tracking the trajectory of something moving toward or away from the observer, in addition to a compensating system for ocular misalignment, it is considered in this text because of the direct impact of vergence information on depth localization. Again, the consensus of studies evaluating the binocular abilities of athletes indicates that, although athletes can still make distance judgments by using the abundance of monocular cues to depth that are often present, superior binocular depth perception and robust vergence function are expected.

Eye Movements

Oculomotor function is another aspect of the perceptual mechanism in information processing and can include evaluation of pursuit eye movements, saccadic eye movements, and steadiness of fixation. The ability to initiate a pursuit eye movement to maintain fixation of a rapidly moving object can be a critical aspect for allowing visual processing of crucial information in sports. The ability to initiate an accurate saccadic eye movement to shift fixation from one location to another is also an essential aspect of many sports tasks. Athletes have not demonstrated shorter latencies for the initiation of pursuit or saccadic eye movements[37,46,57]; although if a target trajectory is predictable, shorter latency periods can be learned for these eye movements.[58-62] The quality of pursuit and saccadic eye movements in athletes, however, has been found to be better than in nonathletes.[24,53,63] In precision sports such as target shooting, skilled athletes demonstrate better ability to maintain steady fixation despite distractions—a vital aspect of successful performance.[64] The use of fixations and eye movements to search for critical information efficiently and effectively may be a more sensitive discriminator of expert skill than the traditional measurements of eye movements performed by vision care providers.

The visual search patterns of experts compared with novices during specific sports demands have been the focus of many studies. The study paradigms typically used attempt to discriminate differences in the number of fixations to determine the amount of information assessed by the observer and differences in the duration of fixations to determine the amount of time expended to collect the visual information from each specific fixation. Most studies have found that experts have a lower number of fixations for longer durations than do novices during the viewing of specific sport situations, especially when the subjects are required to move while gaze behaviors are recorded.[65-86] Research that has investigated more open-field viewing conditions, or conditions that use photographic or video displays and do not require physical movement by the subjects, has found the opposite—that experts have a greater number of fixations on more peripheral aspects of the action.[87-92] Regardless of the visual search pattern, the accuracy of object localization and motor response depend on the type and accuracy of the eye movements used.[73,93] A universal finding in all studies of visual search patterns is that the fixations are typically clustered on features that provide a significant amount of information about the task being viewed. In addition, novices are much less skilled at determining these informational locations and distributing their fixations in a manner most efficient for processing the information within the time constraints of the action. Visual search strategies have been found to vary among individuals at all expertise levels, which can affect results and conclusions in the studies, as can the method for determining expert and novice or near-expert status. The distribution of attention to central and peripheral visual information is also not measured by these systems; therefore determining the exact nature of the visual information being processed during a fixation is difficult. The optimal visual search pattern for specific sports tasks has yet to be determined, if such

an optimal pattern exists, because of an inability to demonstrate objectively the features containing the premium information and the most advantageous temporal distribution of fixations for attending to those premium features.

The process of visual search patterns during critical sport situations appears to represent continual cycles of the information processing model presented, in which visual fixation information is processed by the perceptual mechanism, the decision mechanism determines the next appropriate eye movement response (based on experience), and the effector mechanism organizes and controls the signals delivered to the extraocular muscles. A considerable amount of perceptual, motor, and cognitive feedback is present in this process, leading to speculations about the relative value of each portion of the process. As previously mentioned, the evidence suggests that all aspects of information processing must be operating optimally to potentiate peak performance.

Peripheral Vision

Processing of information from the peripheral visual fields is a universally beneficial element to successful sports performance, whether the task is to monitor teammates and opponents or maintain steady balance. Results indicate that athletes have a larger extent of horizontal and vertical visual fields than nonathletes[41-43,94-99] and that athletes have better form recognition at more peripheral locations.[24,37,95,96] The restriction of peripheral vision has also been found to increase the latency and accuracy of head movements during eye movement localization tasks,[100] as well as significantly degrading balance ability.[101] Therefore peripheral sensitivity also appears to be enhanced in athletes.

The evidence concerning visual resolution, depth judgment, eye movements, and peripheral vision supports the role of excellent visual information as a vital element for the function of the perceptual mechanism in the model of information processing for skilled performance. The evidence also converges on the general conclusion that athletes should, and typically do, possess superior visual skills. The results do, however, clearly illuminate the need for visual evaluation procedures sensitive to the visual task demands required in specific situations of sports, especially if these procedures are to be used to predict performance capabilities of an athlete. For example, one study that reported no difference in the visual skills of experts compared with novices used an accommodative facility test with a +1.00/−1.00 D flipper at 50 cm.[102] Not only has the use of lenses to assess accommodative facility been found to be nondiscriminatory with athletes, but the use of +1.00 and −1.00 D is such a low accommodative demand at 50 cm that virtually all subjects would perform at maximal capacity, generating a superthreshold response that would predictably result in a lack of discrimination between subject categories. Additional consequences result when considering specific visual skills in isolation without the substantial dynamics of both visual skill interaction and other forms of intrinsic and extrinsic feedback essential in the information processing model.

DECISION MECHANISM

The critical role that the decision mechanism performs in the information processing model is undeniable. The ability to rapidly select the stimulus-response choice most compatible with the sport situation provides the biomechanical elements of performance with the opportunity for success. This mechanism requires the athlete to know where crucial visual information exists, be able to direct attention to those crucial elements, select the best

information from all that is available, organize and interpret the information in the most appropriate manner based on experience and memory of similar situations and information, and select the most accurate response with consideration of an anticipated action plan.

In many sport situations this process must occur in a time interval that approaches the limits of human capacity. In some sport situations, the time factors exceed the human capacity to process the important visual information before initiating a motor response, so the motor response must be initiated with anticipation of the most likely scenario that will unfold. For example, in a penalty shot in hockey, the puck can cross the goal line within approximately 100 ms of being struck.[103] The typical simple visual reaction time is approximately 150 to 200 ms; therefore the goaltender cannot wait until the puck has been hit to predict the trajectory of the shot. The study of advance cues for anticipation of sports action has attempted to address this skill, which can mean the difference between a smooth, efficient response or an embarrassing misplay.

An athletes' ability to process visual information rapidly from a competition situation and structure that information into a useful paradigm to facilitate performance decisions is a critical ability acquired as expertise improves. Sports researchers have adopted a study design used with chess in which experts were able to recall more structured chess positions from brief exposures than nonexperts.[104-106] However, the experts did not exhibit superior recall when presented with unstructured chess positions, suggesting that the superior recall of experts was the result of task-specific experience rather than exceptional memory abilities. The same results have been found when speed of recognition has been evaluated in athletes using numerical stimuli rather than sport-specific stimuli.[24,107] These same structured versus unstructured recall differences between experts and novices have been found with athletes in various team sports, including basketball,[108,109] field hockey,[10,110] and football.[12] The organization of common sport situations into a knowledge architecture clearly is a common development with sport expertise. This knowledge architecture offers many advantages, including the ability to process larger quantities of information in a short amount of time and the possibility of priming the perceptual and effector mechanisms for subsequent information.

Superior ability to structure and recall sport-related perceptual information should improve an expert's ability to make more accurate decisions in a shorter amount of time or make those decisions earlier in the time course of the action. Study results have been mixed. Expert field hockey players demonstrated better accuracy than lower level players, but the tactical decisions were not made any faster.[110] Studies of soccer,[80,91,111] volleyball,[112] and ice hockey[113] found faster decisions with equivalent accuracy. The crux of the difference in expert performance was proposed to be the ability to use advance visual cues to anticipate the location of subsequent critical information and use that subsequent critical information to improve performance.

The common paradigm for assessing the use of advanced cues for anticipation of sport action has been the use of film occlusion. The subjects watch a brief video of a sports situation, and the footage is occluded at various intervals. This occlusion requires the subjects to predict the outcome of the interrupted action (e.g., where the tennis ball will land). This is a form of temporal occlusion that indicates how expertise affects the minimal time interval and type of information that benefits the experienced athlete.

The use of spatial occlusion has also been used, in which strategic portions of the footage are masked (e.g., the badminton opponent's racquet) to determine which features provide

the best information to the athlete. Studies involving badminton, baseball, cricket, field and ice hockey, soccer, squash, tennis, and volleyball have all demonstrated the superior ability of experts to use advance visual cues to anticipate the outcome of the sport action.[80,87,89,110,112,114-125] These studies provide ample empirical evidence that the development of sport expertise produces enhanced ability to identify and use sport-specific visual cues to anticipate action outcomes. Anticipation of forthcoming action allows the athlete to shuffle the most likely scenarios to the top of the stack of possibilities effectively, thereby reducing the time needed to match stimulus-response choices as the action progresses.

The complex visual behavior of advance cue utilization allows the skilled athlete the enviable advantage of shortening visual reaction times in sport-specific tasks and also establishes a proactive feedback mechanism in the information processing model. The accurate processing of cues in advance of sport action allows the athlete to direct attention to the correct locations and temporal aspects of critical features of the action, thereby reducing the athletes' uncertainty about the impending action. Modulation of attention has been shown to be another discriminating aspect of sports performance in athletes and is developed in a manner that is task specific. Elite shooters demonstrate narrower attentional focus with less influence from visual field distractions,[64,126] whereas volleyball players have a more expansive attentional focus.[127] The ability to modulate attention appropriately, and often split attention between multiple stimuli,[128] is another valuable aspect of the decision mechanism in the information processing model.

As expertise is developed in a sport, the complex knowledge structures acquired facilitate expanded and enhanced use of mental imagery strategies. Mental rehearsal is the act of constructing mental images of an event, and it is commonly used by elite athletes in preparation for performance.[127-131] Studies have demonstrated that mental imagery may share the same types of neural processes as visual perception, which has significant implications in sports.[132] Mental imagery of motor skill performance shares cognitive processes with physical skill performance,[133-139] and comparable brain activity in the areas of motor preparation and performance has been demonstrated.[140-143] Similar muscles and motor programs are also activated during imagery, and expertise levels influence the amount of muscular response during skill imagery.[134,136,144-148] As the use of mental rehearsal is expanded and enhanced with sport skill development, the possibility of priming the perceptual and effector mechanisms for subsequent information offers significant potential advantages if the advance visual cues are accurately located and interpreted.

The fundamental role of the decision mechanism in achieving peak sports performance is indisputable. The ability of the elite athlete to find and use critical features in sport situations quickly and convert that information rapidly into effective response strategies through anticipation and response priming characterizes the "intelligent" athlete.

EFFECTOR MECHANISM

The effector mechanism is responsible for converting information processed by the perceptual mechanisms and decision mechanisms into appropriate motor response signals. The organization and control of the motor response signals must be sufficiently accurate to allow the proper biomechanical action sequence to occur with precise timing for optimal performance. Coordination of hand reactions, foot reactions, body reactions, and balance adjustments must all be directed with efficient precision within the time constraints of the specific sport situation.

The information from the perceptual and decision mechanisms concerning the space-time behavior of critical factors in fast-action sports should contain the vital information necessary for the motor responses to occur at the proper time and location. For successful performance, the motor responses must also be sufficiently adjustable to allow modification on the basis of continuing input from the perceptual and decision mechanisms as the sport action continues.

Visual-motor reaction time refers to the amount of time that elapses between the initiation of a visual stimulus and the completion of a motor response to that stimulus. The effector mechanism is responsible for translating the processed information to the neuromuscular system, which sends the information to the muscles that need to be stimulated to make the appropriate motor response. The measure of a simple reaction time (RT) reflex represents the minimal amount of time required to process a visual stimulus presentation and perform a simple motor response to that stimulus. The assessment of simple RT may be the most direct method of evaluating the effector mechanism because the requirements of the perceptual and decision mechanisms are minimal. Several studies have found faster simple RTs in athletes (both eye-hand and eye-foot reaction times) in various sports compared with nonathletes, and it has been demonstrated to be a discriminator between expertise levels.[37,43,149-154]

A simple stimulus-response procedure that requires minimal cerebral processing will result in a faster reaction time than a complex stimulus-response procedure that requires discrimination of visual information.[155,156] Eye-hand and eye-foot coordination is a repeated complex reaction time function for an extended period in which synchronized motor responses with the hands or feet must be made in response to unpredictably changing visual stimuli. The studies designed to provide normative information for athletes using available instrumentation to evaluate eye-hand coordination have had mixed results depending on the testing paradigm.[22,24,107,157-159] Eye-body coordination is similar to eye-hand coordination, except that the athlete must make synchronized motor responses to visual stimuli by shifting balance of the whole body. Very limited information is available concerning this type of visual-motor reaction skill in athletes.[22]

The ability to maintain balance while processing complex, fast-action visual information is a task demand fundamental to many sports. The athlete is frequently required to preserve balance while the oculomotor system is engaged in pursuit, saccadic, and/or vergence eye movements. Some normative data have been provided for athletes on the basis of subjective assessment protocols,[22] and a series of investigations found that vision played an important role in dynamic balance skill acquisition in gymnastics.[160-162]

Balance maintenance may also be affected by the athlete's relative field dependence or independence, which refers to the cognitive style of processing information to discern relevant stimuli from an irrelevant stimulus background. The theory implies that field-dependent persons rely more on external cues during information processing, and field-independent persons use internal cues more.[163,164] Kane[165,166] postulated that field independence was an advantage for athletes competing in "closed skill" sports (e.g., diving, gymnastics, track and field) because they tend to rely more on internal physical components such as body orientation when executing motor responses.[167] Field dependence was considered an advantage in "open skill"[165,166] team sports (e.g., basketball, football, hockey) because athletes must make constant adjustments in performance to external factors (e.g., teammates, opponents).[167] Much is still to be discovered concerning the use of visual, vestibular,

and other sensory information to make discrete and accurate adjustments in balance during sports.

Complex Interactions Mediating Effector Mechanism Responses

The ability to predict the arrival of an object or stimulus at a designated place can be measured with a motor response and is referred to as visual coincidence anticipation. Excellent perceptual processing combined with exceptional decision processing in fast-action sports can provide a significant advantage in executing the most appropriate motor responses.[168-178] A substantial body of research addresses the many factors that influence the impressive human ability to perform the complex visual-motor tasks encountered in sports. The literature contains extensive information—from the basic physiologic and neuronal mechanisms to global models using physics computations to explain how human beings can catch or hit a ball. Covering all these factors to the degree that would do justice to the collective contributions is beyond the scope of this chapter; however, some basic information distilled from the research is presented in the context of the information processing model.

To hit or catch an approaching ball successfully, the athlete must judge the spatial information of height, rightward or leftward displacement, and distance of the ball. In addition to these three-dimensional space judgments, the temporal aspects of time to contact must be calculated with exacting precision. Several visual cues are available to assist the athlete in making these judgments, including retinal image and disparity information. Some neurons in the visual cortex are tuned to binocular retinal image disparity, providing information about the depth position of an object.[179-181] The difference in retinal locations for the ball as seen by the right eye and left eye constitutes binocular disparity, supplying the stereoscopic perception of relative distance.[182-185] In addition, evidence indicates that a system of binocularly driven cortical neurons sensitive to motion in depth are separate from the position in depth system.[181,186-196]

The perception of motion in depth is also produced by a changing retinal image size information system that operates relatively independent of the changing retinal disparity system.[190,197,198] Ample evidence shows that human beings possess cortical neurons that are selectively sensitive to changing image size and that these "looming" detectors provide a significant amount of information for judging time to contact even under monocular viewing conditions.[199,200] Additional monocular visual information about time to contact is also available from the flow pattern of visual information,[190,201-204] and this information also appears to be processed by the changing size system.[190] Regan and Beverley[205] concluded that

> The relative effectiveness of changing-disparity and changing-size as stimuli for motion-in-depth sensation varies as follows: (a) changing disparity grows relatively more effective as velocity increases (according to a power law); (b) changing disparity grows relatively more effective as inspection time increases; (c) changing disparity grows relatively more effective as the linear horizontal width of the target decreases; (d) the relative effectiveness of changing disparity and changing size shows marked intersubject variability (at least 80:1).

The precision of the motion in depth system is hypothesized to be attributable to a relative excitation mechanism in the stereomotion channels for changing size and changing disparity that acts similar to the opponent-color stage of human color discrimination. Separate stereomotion channels also seem to exist for different directions of motion: one for motion that is approaching the head and one for motion of a receding object.[192]

The retinal information concerning changing disparity and changing size is sufficiently accurate to judge time to contact with a ball; however, it does not provide exact information concerning the actual distance of the ball or its speed.[206,207] Stereoscopic depth perception from calibrations within the vergence system and from motion in depth information provides precise information about relative depth but not about the exact distance location.[208-211] Ocular vergence information is notoriously unstable when the vestibular signals must contend with a freely moving head,[212-214] and changes in vergence angle or changes in absolute disparity do not affect binocular fusion or the perception of motion in depth for images beyond a few meters when independently altered.[211] Binocular viewing offers advantages in catching or hitting a ball[215-217]; however, monocular catching ability can be trained to similar skill levels as binocular viewing.[218] Comparison of binocular and monocular performance of a table tennis hitting task revealed that only stroke consistency was affected under monocular viewing, not accuracy or movement time.[219] A frame of reference to assist the judgment of relative depth has been shown to improve catching and hitting performance,[217,220] and the vergence system demonstrates a rapid ability to recalibrate.[221-223]

Because the time to contact can be determined by the changing size and changing disparity information available to the visual system from an approaching ball, Lee[224] derived an optical quantity signified by the Greek letter tau (τ) and the τ-margin[225] to describe the calculation of time to contact on the basis of the relative rate of dilation of the ball's optical contours during approach. Many studies have confirmed the use of τ in guiding motor responses during acts requiring spatial and temporal judgments.[170,173,175,225-237] Further studies elaborating the τ-margin found that the rate of constriction of the optical gap separating the moving object from the interception point also provides sensitive information concerning time to contact.[171,177,238]

The actual performance of catching tasks has demonstrated that extensive feedback from the visual and kinesthetic systems constantly updates the time to contact judgments[239,240] and that observer movement improves the judgments.[241] Visual and kinesthetic feedback during motor task acquisition and performance has been manipulated in many studies, and removal of vision feedback typically produces decrements in performance.[242-252] Elaborate models have been constructed (and debated) to explain how baseball fielders select a path and movement speed to intercept a ball in flight[253-258] or hit a ball in flight.[206,207,259] Misjudgment of ball velocity can cause significant perceptual misjudgments concerning the trajectory and appearance of speed changes.[207,254,260]

The quality of visual input is a critical factor to sports task performance, and extensive feedback from the sensory receptors provides continuous information for performance adjustment. The value of skill repetition and performance experience cannot be underestimated in its role of providing the effector mechanism with the framework for effectively and efficiently using the information from the perceptual mechanism. The gifted athlete's ability to make the correct responses routinely and consistently generates the appearance of effortless "natural" ability, a venerated description in sports society,[261] thereby neglecting to duly recognize the contribution of years of demanding practice and experience.[262]

Collectively, the wealth of research information provides extensive insight into the mechanisms responsible for successful sports performance. The information processing model for skilled performance provides a useful structure for applying this information to specific tasks. An application of the model is presented for batting in baseball, often called "the single hardest act in all of sports."[263,264]

APPLICATION OF THE INFORMATION PROCESSING MODEL TO BATTING IN BASEBALL

The time frame from when the pitcher releases the ball to when it reaches the average point of contact with the bat must first be considered. Simplified calculations have suggested that a 90-mph fastball pitch reaches the bat approximately 400 ms after release, and a 75-mph curveball arrives in approximately 480 ms.[207] The type of pitch thrown will have significant consequences on the flight trajectory of the ball because of the properties of aerodynamics; this is discussed in the decision mechanism portion of the information processing model. The batter will have access to visual and cognitive cues to help anticipate the most likely type of pitch to expect, but time must be allocated for completing the mechanics of the swing. Although batters typically complete the swing in 150 ms, some can perform this feat faster.

For the purposes of this application, a 400-ms time frame is presented for the time course between the pitcher's release and the contact with the bat, and 150 ms is used for completion of the swing mechanics. The pitcher is at the moment of release, and the clock is ticking.

Perceptual Mechanism

The perceptual mechanism is responsible for organizing, processing, and interpreting the sensory information to facilitate the optimal response to the pitch. The successful batter uses efficient and effective visual search patterns during the pitching motion to analyze any advance cues to the pitch type,[74,88] hopefully narrowing the trajectory probabilities that need to be considered by the decision mechanism. At the moment of release, the batter initiates a saccadic eye movement to move fixation to the release point[74] or pitcher's elbow.[88] Basic physiology indicates that retinal cell information must be encoded and assembled, a process that takes approximately 25 ms. This retinal information must be conducted to the visual cortex, requiring another 20 ms. The visual cortex must process the retinal information to construct the image; because a substantial amount of memory is available, this process takes approximately 30 ms. Therefore the visual information contained in the pitch release takes approximately 75 ms to process, and the ball is now one fifth of the distance to the plate. The visual images can be continuously processed with only the 25-ms conduction delay requiring that the batter maintain pursuit eye movements.[265]

How good is the visual information being received? Previous studies have demonstrated superior visual resolution skills, contrast sensitivity, and DVA in baseball players.[20,23,26,29,31] Although enhancing the seams of the baseball has been shown to improve curveball hitting, the sport demands that the visual system use the subtle cues of a traditional ball.[266] Some measures of stereopsis have been found to be superior in baseball players,[23,52,53] as has the visual field size of female softball players.[99] The interaction effect of the dominant eye and dominant hand on batting in baseball has received considerable scrutiny. Although the findings have been somewhat contradictory, the preponderance of evidence indicates no relation between eye dominance patterns and batting performance.[267-275]

Because the use of pursuit eye movements to track a pitch all the way to contact appears to be impossible, the batter must use a complex combination of pursuit and saccadic eye movements to track the approaching ball.[57,74,276] One study of pursuit and saccadic eye movement quality found subjectively better performance in those athletes with better batting averages.[63] Anticipatory saccades are common in tracking a pitch, in which the pursuit eye movements fall far enough behind the ball that a saccade is initiated to a location where

the trajectory of the ball can be intercepted.[57,277] The mechanism of saccadic suppression prevents the batter from seeing during, and for approximately 20 ms after, the saccadic eye movement.[278,279] Therefore a faster pursuit eye movement system offers an advantage to tracking a pitch. The vestibuloocular system is used to a small degree to stabilize eye posture during head movements, and vergence eye movements do not appear to be used to track the pitch.[57]

How good is the visual system in providing the information for predicting when the ball will arrive? The retinal image information provided by changing size and changing disparity detectors for motion in depth supplies the capability of judging time to contact (τ) within 2 to 10 ms.[173,231] For objects subtending less than 1.5 degrees (a baseball farther than 10 feet away), cortical neurons are sensitive to changing size characteristics as low as 0.02 degrees.[199] This capability is well above the visual threshold at the moment of release, allowing the batter the opportunity to estimate time to contact with an accuracy of better than ±9 ms. A batter must estimate the time to contact to within 7 to 9 ms[207,265,280] to hit a 90-mph ball close to the center of percussion of the bat; other estimates, however, and estimates from cricket, suggest that accuracy may need to be even better than ± 9 ms.[206]

How good is the visual system in providing the information for predicting at what location the ball will arrive? The batter needs to judge the vertical height of the ball to within 0.75 inches and the inside-outside location of the pitch with respect to the batter's body to within 3 inches.[281] The batter can estimate the ball's vertical speed from the retinal velocity information combined with the distance to the ball. The range of speeds encountered in pitched balls is within the human capability for accurately judging time to contact within 5%.[282,283] Because the batter can only estimate pitch speed, and the visual system is incapable of providing more than just a relative estimate of distance,[208-211] judgments of ball location are susceptible to significant uncertainty. This may explain why batters are typically better at timing the arrival of the pitch than judging the location of the ball.

Decision Mechanism

Because the swing will take approximately 150 ms to initiate to the point of contact, the decision of where and when to swing must be made by 250 ms after the release. If the ball has been followed by pursuit eye movements, then a nearly continuous stream of information has been available with information critical to selecting the proper response. The batter may also have additional information concerning the idiosyncrasies of the pitcher, the current situation in the game, the status of the pitch count, and the wealth of information stored from previous experience. This additional information, combined with the pitching motion information acquired before the moment of release, provides the potential for preselecting the most likely pitch scenarios.

Many models have been proposed to explain how cognition occurs in situations such as batting in baseball,[284] but a minimum of 50 ms is needed to select the appropriate response and send it to the effector mechanism to begin the action. This means the batter has approximately 200 ms to process the visual information to make an accurate decision; more time than that is a luxury that is not available for a pitch of this speed. This time is not much longer than measurements of simple reaction time in human beings (approximately 150 ms)[285] and is much shorter than the reaction times to complex choice conditions demonstrated by Hick.[286] The batter has many issues of spatial and temporal uncertainty to resolve because of the aerodynamics produced by the seam and texture of a baseball, and these must be

resolved rather quickly. A variety of pitch types can be delivered in a manner that can lead a batter to misjudge velocity and trajectory.[206,207,258,287-289] Occlusion studies have demonstrated that the early portion of the pitch provides sufficient information for experienced batters to set accurate probabilities about different types of pitches.[284]

The skill of the pitcher can place the batter at the edge of human physiologic capacity. A fastball thrown at 95 mph will arrive approximately 25 ms faster than a 90-mph fastball and arrive at a height approximately 3 inches higher. Considering the human weakness for estimating velocity, a misjudgment of the pitch speed would affect the time to contact assessment, as well as the height location of the ball. The loss of 25 ms also needs to be subtracted from some aspect of the visual information processing model. The 25 ms will most likely be sacrificed from the decision mechanism because the perceptual mechanism is crucial for making the spatiotemporal judgments, and the time needed for the effector mechanism is relatively set.

Effector Mechanism

At 225 ms from the moment of release, the initial muscle response for a swing must occur. The first muscles to respond are the back leg muscles, and although approximately 25 ms are required to initiate the response, the movement does not commit the batter to a swing at the pitch.[265] The rest of the swing mechanics takes approximately 150 ms, but further visual processing can provide feedback for adjustments. After the first 50 ms of the swing, the bat is moving at approximately 30% of its final velocity, and the swing can be changed substantially (or checked) on the basis of continued visual information processing.[265] By 100 ms into the swing, the bat is moving at approximately 75% of its final speed and cannot be changed because of the time factors to the muscles.[265] Some can execute the swing more rapidly than the time course described, which may allow more time for visual information processing and decision making. However, studies have not found correlation between simple motor reaction time and batting skill[290] or a difference during play in cricket batting.[291]

VISION CARE AND VISUAL INFORMATION PROCESSING

Many vision performance evaluations and enhancement training programs attempt to assess and improve overall processing of visual information. Most enhancement training programs attempt to affect the perceptual mechanism by improving the requisite visual skills for successful sports performance. The fundamental goal of visual enhancement training programs is to focus the athlete to process larger quantities of information in a shorter amount of time while simultaneously priming the perceptual and effector mechanisms for subsequent information. Ultimately this improves the speed and efficiency of the decision mechanism, which is additionally enhanced by procedures that provide feedback on visual attention and encourage the development and use of mental imagery. Although many unanswered questions regarding the role of visual enhancement training and sports performance still exist, the conclusion that improved visual skills compounded with improved ability to modulate attention and use positive mental imagery should have a salutary effect on overall visual information processing is a logical one.

Chapter 4 discusses the evaluation of visual skills in athletes, and Chapter 8 discusses the development of visual enhancement training programs that use the framework of the visual information processing model described in this chapter. Many other professionals also affect

the visual information processing and motor responses of the athlete. For example, the development of biomechanically advantageous motor performance skills and an optimal mental mindset directly affect the effector and decision mechanisms and also have a salutary effect on the perceptual mechanism. The athlete can potentially reap tremendous benefits from directly addressing all aspects of sports performance.

REFERENCES

1. Colavita FV: Human sensory dominance, *Percept Psychophys 16:*409, 1974.
2. Lee DN, Lishman JR: Visual proprioceptive control of stance, *J Hum Mov Stud 1:*87, 1975.
3. Posner MI, Nissen MJ, Klein RM: Vision dominance: an information processing account of its origins and significance, *Psychol Rev 83:*157, 1976.
4. Abernethy B, Kipper V, Mackinnon LT: *The biophysical foundations of human movement,* Champaign, IL, 1997, Human Kinetics.
5. Ciuffreda KJ, Wang B: Vision training and sports. In Hung GK, Pallis JM, editors: *Biomedical engineering principles in sports*, New York, 2004, Kluwer Academic/Plenum Publishers, pp 407-433.
6. Stine CD, Arterburn MR, Stern NS: Vision and sports: a review of the literature, *J Am Optom Assoc 53:*627, 1982.
7. Hitzeman SA, Beckerman SA: What the literature says about sports vision, *Optom Clin 3:*145, 1993.
8. Gregg JR: *Vision and sports: an introduction,* Stoneham, MA, 1987, Butterworth, pp 17-32.
9. Hazel CA: The efficacy of sports vision practice and its role in clinical optometry, *Clin Exp Optom 78:*98, 1995.
10. Starkes JL, Deakin J: Perception in sport: a cognitive approach to skilled performance. In Straub WF, Williams JM, editors: *Cognitive sport psychology,* Lansing, NY, 1984, Sport Science Association, pp 115-128.
11. Abernethy B: Enhancing sports performance through clinical and experimental optometry, *Clin Exp Optom 69:*189, 1986.
12. Garland DJ, Barry JR: Sports expertise: the cognitive advantage, *Percept Mot Skills 70:*1299, 1990.
13. Abernethy B, Wann J, Parks S: Training perceptual-motor skills for sport. In Elliott B, editor: *Training in sport: applying sport science,* New York, 1998, John Wiley & Sons, pp 1-68.
14. Welford AT: The measurement of sensory-motor performance: survey and reappraisal of twelve years progress, *Ergonomics 3:*189, 1960.
15. Whiting HTA: *Acquiring ball skill: a psychological interpretation,* London, 1969, Bell.
16. Martenink RG: *Information processing in motor skills,* New York, 1976, Holt, Rhinehart and Winston.
17. Stelmach GE: Information-processing framework for understanding motor behavior. In Kelso JAS, editor: *Human motor behavior: an introduction,* Hillsdale, NJ, 1982, Lawrence Erlbaum, pp 63-91.
18. Abernethy B, Russel DG: Skill in tennis: considerations for talent identification and skill development, *Austr J Sport Sci 3:*3, 1983.
19. Pashler HE: *The psychology of attention,* Cambridge, MA, 1997, MIT Press.
20. Winograd S: The relationship of timing and vision to baseball performance, *Res Q Am Assoc Health Phys Educ 13:*481, 1942.
21. Fremion AS, DeMyer WE, Helveston EM, et al: Binocular and monocular visual function in world class tennis players, *Bin Vis 1:*147, 1986.
22. Coffey B, Reichow AW: Optometric evaluation of the elite athlete, *Probl Optom 2:*32, 1980.
23. Laby DM, Rosenbaum AL, Kirschen DG, et al: The visual function of professional baseball players, *Am J Ophthamol 122:*476, 1996.

24. Christenson GN, Winkelstein AM: Visual skills of athletes versus nonathletes: development of a sports vision testing battery, *J Am Optom Assoc 59:*666, 1988.
25. Bailey IL, Sheedy JE, Fleming DP, et al: Dynamic visual acuity: rotational measurement [abstract], *Invest Ophthalmol Vis Sci 29(suppl):*78, 1988.
26. Rouse MW, DeLand P, Christian R, et al: A comparison study of dynamic visual acuity between athletes and nonathletes, *J Am Optom Assoc 59:*946, 1988.
27. Coffey B, Reichow AW: Athletes vs nonathletes: static visual acuity, contrast sensitivity, dynamic visual acuity [abstract], *Invest Ophthalmol Vis Sci 30(suppl):*517, 1989.
28. Long G, Rourk D: Training effects on the resolution of moving targets—dynamic visual acuity, *Hum Fact 31:*443, 1989.
29. Ishigaki H, Miyao M: Differences in dynamic visual acuity between athletes and nonathletes, *Percept Mot Skills 77:*835, 1993.
30. Melcher MH, Lund DR: Sports vision and the high school student athlete, *J Am Optom Assoc* 63:466, 1992.
31. Hoffman LG, Polan G, Powell J: The relationship of contrast sensitivity functions to sports vision, *J Am Optom Assoc 55:*747, 1984.
32. Reichow AW, Coffey B: A comparison of contrast sensitivity in elite athletes vs normal population [abstract], *Am J Optom Physiol Optics 63:*82P, 1986.
33. Kluka DA, Love PA, Allen S: Contrast sensitivity functions of selected collegiate female athletes, *Sports Vis 5:*18, 1989.
34. Kluka D, Love P: Contrast sensitivity in International Special Olympics, National Invitational Volleyball Championships, and recreational volleyball players, *Palaestra J 8:*11, 1992.
35. Schneider HG, Kluka DA, Love PA: Contrast sensitivity and sighting dominance in selected professional and collegiate football players, *J Optom Vis Dev 23:*23, 1992.
36. Love PA, Kluka DA: Contrast sensitivity function in elite women and men softball players, *Int J Sports Vis 1:*25, 1993.
37. Kluka DA, Love PA, Sanet R, et al: Contrast sensitivity function profiling: by sport and sport ability level, *Int J Sports Vis 2:*5, 1995.
38. Hughes PK, Blundell NL, Walters JM: Visual and psychomotor performance of elite, intermediate and novice table tennis competitors, *Clin Exp Optom 76:*51, 1993.
39. Coffey B, Reichow AW: Athletes vs nonathletes: 6m vergence ranges, accommodative-vergence facility, and 6m speed of stereopsis [abstract], *Optom Vis Sci 67(suppl):*81, 1990.
40. Banister H, Blackburn JM: An eye factor affecting proficiency at ball games, *Br J Psychol 21:*382, 1931.
41. Montebello RA: *The role of stereoscopic vision in some aspects of baseball playing ability* [thesis], 1953, Ohio State University College of Optometry.
42. Graybiel A, Jokl E, Trapp C: Russian studies of vision in relation to physical activity and sports, *Res Q Am Assoc Health Phys Educ 26:*480, 1955.
43. Olsen EA: Relationship between psychological capacities and success in college athletics, *Res Q Am Assoc Health Phys Educ 27:*79, 1956.
44. Ridini LM: Relationship between psychological functions tests and selected sport skills of boys in junior high, *Res Q Am Assoc Health Phys Educ 39:*674, 1968.
45. Clark B, Warren N: Depth perception and interpupillary distance as factors in proficiency in ball games, *Am J Psych 47:*485, 1935.
46. Deshaies P, Pargman D: Selected visual abilities of college football players, *Percept Mot Skills 43:*904, 1976.
47. Weissman S: *Sex differences in dynamic stereoacuity,* Proceedings of the 80th Annual Convention, American Psychological Association, *7:*81, 1972.

48. Weissman S, Slonim P: Effects of knowledge of results on dynamic stereo acuity in males and females, *Percept Mot Skills 36:*964, 1973.
49. Slonim PS, Weissman S, Galzer E, et al: Effects of training on dynamic stereo acuity performance by males and females, *Percept Mot Skills 40:*359, 1975.
50. Solomon H, Zinn W: An introduction to dynamic sports vision, *Optom Monthly 74:*569, 1983.
51. Zinn WJ, Solomon H: A comparison of static and dynamic stereoacuity, *J Am Optom Assoc* 56:712, 1985.
52. Soloman H, Zinn HJ, Vacroux R: Dynamic stereoacuity: a test for hitting a baseball? *J Am Optom Assoc 59:*522, 1988.
53. Hofeldt AJ, Hoefle FB: Stereophotometric testing for Pulfrich's phenomenon in professional baseball players, *Percept Mot Skills 77:*407, 1993.
54. Laby DM, Kirschen DG: Dynamic stereoacuity: preliminary results and normative data for a test for the quantitative measurement of motion in depth, *Bin Vis Eye Muscle Surgery Q 10:*191, 1995.
55. Hofeldt AJ, Hoefle FB, Bonafede B: Baseball hitting, binocular vision, and the Pulfrich phenomenon, *Arch Ophthalmol 114:*1490, 1996.
56. Falkowitz C, Mendel H: The role of visual skills in batting averages, *Optom Weekly 68:*33, 1977.
57. Bahill AT, LaRitz T: Why can't batters keep their eyes on the ball? *Am Sci 72:*249, 1984.
58. Whittaker SG, Eaholtz G: Learning patterns of eye motion for foveal pursuit, *Invest Opthalmol Vis Sci 23:*393, 1982.
59. McHugh DE, Bahill AT: Learning to track predictable target waveforms without a time delay, *Invest Ophthalmol Vis Sci 26:*932, 1985.
60. Carnahan H, Hall C, Lee TD: Delayed visual feedback while learning to track a moving target, *Res Q Exer Sport 67:*416, 1996.
61. Adolphe RM, Vickers JN, Laplante G: The effects of training visual attention on gaze behavior and accuracy: a pilot project, *Int J Sports Vis 4:*29, 1997.
62. Elmurr P, Cornell E, Heard R: Saccadic eye movements (part 2): the effects of practice on saccadic reaction time, *Int J Sports Vis 4:*13, 1997.
63. Trachtman JN: The relationship between ocular motilities and batting average in little leaguers, *Am J Optom Arch Am Acad Optom 50:*914, 1973.
64. DiRusso F, Pitzalis S, Spinelli D: Fixation stability and saccadic latency in elite shooters, *Vis Res 43:*1837, 2003.
65. Mourand RR, Rockwell TH: Strategies of visual search by novice and experienced drivers, *Hum Fact 14:*225, 1972.
66. Bard C, Fleury ML: Analysis of visual search activity during sport problems situations, *J Hum Mov Studies 3:*214, 1976.
67. Bard C, Fleury M, Carriere L, et al: Analysis of gymnastic judges' visual search, *Res Q Exer Sci 51:*267, 1980.
68. Tyldesly DA, Bootsma RJ, Bomhoff GT: Skill level and eye movement patterns in a sports oriented reaction time task. In Rieder H, Mechling H, Reischle K, editors: *Motor learning and motor behaviour: contribution to learning in sports*, Cologne, Germany, 1982, Hoffmann, pp 290-296.
69. Ripoll H, Papin J, Guezennec J, et al: Analysis of visual scanning patterns of pistol performers, *J Sport Sci 3:*93, 1985.
70. Coulibaly Z, Ripoll H: Analysis of visual scanning patterns of volleyball players in problem solving tasks, In Unestaehl LE, editor: *Contemporary sports psychology proceedings from the VI World Congress in Sport Psychology,* Orebro, VEJE Publishing, 1986, pp 104.
71. Goulet C, Fleury M, Bard C, et al: Analysis of advance visual indices in receiving a tennis serve. *Can J Sport Sci 13:*79,1988.

72. Petrakis E: Visual observation patterns of tennis teachers, *Res Q Exer Sport 57:*254, 1986.
73. Ripoll H, Bard C, Paillard J: Stabilization of the head and eyes on target as a factor in successful basketball shooting, *Hum Mov Sci 5:*47, 1986.
74. Shank MD, Haywood KM: Eye movements while viewing a baseball pitch, *Percept Mot Skills 64:*1191, 1987.
75. Ripoll H: Uncertainty and visual strategies in table tennis, *Percept Mot Skills 68:*507, 1989.
76. Abrams R, Meyer DE, Kornblum S: Eye-hand coordination: oculomotor control in rapid aimed limb movements, *J Exp Psych Hum Percept Perform 16:*248, 1990.
77. Vickers JN: Gaze control in putting, *Perception 21:*117, 1992.
78. Helsen W, Pauwels JM: A cognitive approach to visual search in sport. In Brogan D, Gale A, Carr K, editors: *Visual search 2,* London, 1993, Taylor Francis, pp 379-388.
79. McMorris T, Copeman R, Corcoran D, et al: Anticipation of soccer goalkeepers facing penalty kicks. In Reilly T, Clarys J, Stibbe A, editors: *Science and football II,* London, 1993, E&FN Spon, pp 250-254.
80. Williams AM, Burwitz L: Advance cue utilisation in soccer. In Reilly T, Clarys J, Stibbe A, editors: *Science and football II,* London, 1993, E&FN Spon, pp 239-244.
81. Vickers JN: Control of visual attention during the basketball free throw, *Am J Sports Med 24:*S93, 1996.
82. Vickers JN: Visual control when aiming at a far target, *J Exp Psych Hum Percept Perform 22:*342, 1996.
83. Vickers JN, Adolphe RM: Gaze behavior during a ball tracking and aiming skill, *Int J Sports Vis 4:*18, 1997.
84. Singer RN, Williams AM, Frehlich SG, et al: New frontiers in visual search: an exploratory study in live tennis situations, *Res Q Exer Sport 69:*290, 1998.
85. Kato T, Fukuda T: Visual search strategies of baseball batters: eye movements during the preparatory phase of batting, *Percept Mot Skills 380:*94,2002.
86. Moreno FJ, Reina R, Luis V, et al: Visual search strategies in experienced and inexperienced gymnastic coaches, *Percept Mot Skills 95:*901, 2002.
87. Abernethy B, Russell DG: Expert-novice differences in an applied selective attention task, *J Sport Psych 9:*326, 1987.
88. Goulet C, Bard M, Fleury M: Expertise differences in preparing to returns a tennis serve: a visual information processing approach, *J Sport Psychol 11:*382, 1989.
89. Abernethy B: Expertise, visual search, and information pick-up in squash, *Perception 19:*63, 1990.
90. Ripoll H, Kerlirzin Y, Stein JF, et al: Analysis of information processing, decision making, and visual strategies in complex problem solving sport situations, *Hum Mov Sci 14:*325, 1995.
91. Williams AM, Davids K, Burwitz L, et al: Visual search strategies in experienced and inexperienced soccer players, *Res Q Exer Sport 65:*127, 1994.
92. Williams AM, Davids K: Anxiety, expertise and visual search strategies in karate, *J Sport Exer Psych 21:*362, 1999.
93. Honda H: Spatial localization in saccade and pursuit eye movement conditions: a comparison of perceptual and motor measures, *Percept Psychophysics 38:*41, 1985.
94. Hobson R, Henderson MT: A preliminary study of the visual field in athletics, *Proc Iowa Acad Sci 48:*331, 1941.
95. Johnson WG: *Peripheral perception of athletes and non-athletes, and the effect of practice* [thesis], 1952, University of Illinois.
96. Buchellew WF: *Peripheral perception and reaction time of athletes and non-athletes* [thesis], 1954, University of Illinois.
97. Stroup F: Relationship between measurements of field of motion perception and basketball ability in college men, *Res Q Am Assoc Health Phys Educ 28:*72, 1957.
98. Williams JM, Thirer J: Vertical and horizontal peripheral vision in male and female athletes and nonathletes, *Res Q Am Assoc Health Phys Educ 46:*200, 1976.

99. Berg WP, Killian SM: Size of the visual field in collegiate fast-pitch softball players and nonathletes, *Percept Mot Skills 81:*1307, 1995.
100. Semmelow J: Identification of peripheral visual images in a laterally restricted gaze field, *Percept Mot Skills 70:*175, 1990.
101. Loopeker K, Rowley B: *The effects of reduced ski goggle field and tint on stability and balance* [thesis], Forest Gove, OR, 2002, Pacific University.
102. Tyldesley DA: Motion prediction and movement control in fast ball games. In Cockerill IM, MacGilivary WW, editors: *Vision in sport,* Cheltenham, England, 1981, Stanley Thomas, pp 91-115.
103. de Groot AD: Perception and memory versus thought: some old ideas and recent findings. In Kleinmuntz B, editor: *Problem solving: research, method and theory,* New York, 1966, Wiley, pp 19-50.
104. Chase WG, Simon HA: Perception in chess, *Cog Psychol 4:*55, 1973.
105. Chase WG, Simon HA: The mind's eye in chess. In Chase WG, editor: *Visual information processing,* New York, 1973, Academic Press, pp 404-427.
106. Allard F, Graham S, Paarsalu ME: Perception in sport: basketball, *J Sport Psychol 2:*14, 1980.
107. Milne DC, Lewis RV: Sports vision screening of varsity athletes, *Sports Vis 1:*8, 1993.
108. Allard F, Burnett N: Skill in sport, *Can J Psychol 39:*294, 1985.
109. Starkes JL: Skill in field hockey: the nature of the cognitive advantage, *J Sport Psychol 9:*146, 1987.
110. Helsen W, Pauwels JM: The use of a simulator in the evaluation and training of tactical skills in football. In Reilly T, Lees A, Davids K, et al, editors: *Science and football,* London, 1987, E&FN Spon, pp 493-497.
111. Allard F, Starkes JL: Perception in sport: volleyball, *J Sport Psychol 2:*22, 1980.
112. Thiffault C: *Tachistoscopic training and its effect upon perceptual speed of ice hockey players* [thesis], 1974, University of Southern California, Los Angeles, CA.
113. Jones CM, Miles TR: Use of advanced cues in predicting the flight of a lawn tennis ball, *J Hum Mov Studies 4:*231, 1978.
114. Salmela JH, Fiorito P: Visual cues in ice-hockey goal tending, *Can J App Sport Sci 4:*56, 1979.
115. Isaacs LD, Finch AE: Anticipatory timing of beginning and intermediate tennis players, *Percept Mot Skills 57:*451, 1983.
116. Abernethy B, Russell DG: Advanced cue utilisation by skilled cricket batsmen, *Austr J Sci Med Sport 16:*2, 1984.
117. McLeod P: Visual reaction time and high-speed ball games, *Perception 16:*49, 1987.
118. Milgram P: A spectacle-mounted liquid crystal tachistoscope, *Behav Res Meth Instr Computers 19:*449, 1987.
119. Abernethy B: Visual search in sport and ergonomics: its relationship to selective attention and performer expertise, *Hum Perf 1:*205, 1988.
120. Abernethy B: The effects of age and expertise upon perceptual skill development in a racquet sport, *Res Q Exerc Sport 59:*210, 1988.
121. Wright DL, Pleasants F, Gomez-Meza M: Use of advanced visual cue sources in volleyball, *J Sport Excerc Psychol 12:*406, 1990.
122. Houlston DR, Lowes R: Anticipatory cue utilisation processes amongst expert and non-expert wicket-keepers in cricket, *Int J Sport Psychol 24:*59, 1993.
123. Starkes JL: A new technology and field test of advance cue usage in volleyball, *Res Q Excerc Sport 66:*162, 1995.
124. Paull G, Glencross D: Expert perception and decision making in baseball, *Int J Sport Psychol 28:*35, 1997.
125. Tremayne P, Barry RJ: Elite pistol shooters: physiological patterning of best vs worst shots, *Int J Psychophysiol 41:*19, 2001.

126. Pesce-Anzender C, Bosel R: Modulation of the spatial extent of the attentional focus in high-level volleyball players, *Eur J Cog Psychol 10:*247, 1995.
127. Mahoney M, Avener J: Psychology of the elite athlete: an exploratory study, *Cog Ther Res 1:*135, 1997.
128. Bjurwell C: Perceptual-motor behavior in sport: the double reaction, *Percept Mot Skills 72:*137, 1991.
129. Meyers AW, Cooke CJ, Cullen J, et al: Psychological aspects of athletic competitors: a replication across sports, *Cog Ther Res 3:*361, 1979.
130. Greenspan MJ, Feltz DL: Psychological interventions with athletes in competitive situations: a review, *Sport Psychol 3:*219, 1989.
131. Davis H: Cognitive style and nonsport imagery in elite ice hockey performance, *Percept Mot Skills 71:*795, 1990.
132. Finke RA: Mental imagery and the visual system, *Sci Am 254:*88, 1986.
133. MacKay DG: The problem of rehearsal or mental practice, *J Mot Behav 13:*274, 1981.
134. Hale BD: The effects of internal and external imagery on muscular and ocular concomitants, *J Sports Psych 4:*374, 1982.
135. Feltz DL, Landers DM: The effects of mental practice on motor skill learning and performance: a meta-analysis, *J Sports Psych 5:*25, 1983.
136. Kohl RM, Roenker DL: Mechanism involvement during skill imagery, *J Mot Behav 15:*179, 1983.
137. Feltz DL, Landers DM, Becker BJ: *A revised meta-analysis of the mental practice literature on motor skill learning,* Washington, DC, 1988, National Academy Press.
138. Requin J: Neural basis of movement representations. In Requin J, Stelmach GE, editors: *Tutorials in motor neurosciences,* Dordrecht, The Netherlands, 1991, Kluwer, pp 333-345.
139. Jeannerod M: The representing brain: neural correlates of motor intention and imagery, *Brain Behav Sci 17:*187, 1994.
140. Roland PE, Larsen B, Lassen NA, et al: Supplementary motor area and other cortical areas in organization of voluntary movement in man, *J Neurophysiol 43:*118, 1980.
141. Decety J, Ingvar DH: Brain structures participating in mental stimulation of motor behavior: a neuropsychological interpretation, *Acta Psychologica 73:*13, 1990.
142. Decety J, Kawashima R, Gulyas B, et al: Preparation for reaching: a PET study of the participating structures in the human brain, *NeuroReport 3:*761-764, 1992.
143. Decety J: Do imagined and executed actions share the same neural substrate? *Cog Brain Res 3:*87, 1993.
144. Jacobson E: Electrophysiology of mental activities, *Am J Psychol 44:*676, 1932.
145. Ulich E: Some experiments on the function of mental training in the acquisition of motor skills, *Ergonomics 10:*411, 1967.
146. McGuigan FJ: Covert oral behavior during the silent performance of language tasks, *Psychol Bull 74:*309, 1970.
147. Harris DV, Robinson WJ: The effects of skill level on EMG activity during internal and external imagery, *J Sport Psych 8:*105, 1986.
148. Decety J, Michel F: Comparative analysis of actual and mental movements times in two graphic tasks, *Brain Cog 11:*87, 1989.
149. Knapp BN: Simple reaction times of selected top-class sportsmen and research students, *Res Q 32:*409, 1961.
150. Whiting HTA, Sanderson FH: Dynamic visual acuity and performance in a catching task, *J Mot Behav 6:*87, 1974.
151. Blundell NL: Critical visual-perceptual attributes of championship level tennis players. In Howell ML, Wilson BD, editors: *Kinesiological sciences: Proceedings of the VII Commonwealth and International Conference on Sport, Physical Education, Recreation and Dance,* Brisbane, Australia, 1984, University of Queensland, pp 51-59.

152. Kioumourtzoglou E, Kourtessis T, Michalopoulou M, et al: Differences in several perceptual abilities between experts and novices in basketball, volleyball, and water-polo, *Percept Mot Skills 86:*899, 1998.
153. Harbin G, Durst L, Harbin D: Evaluation of oculomotor response in relationship to sports performance, *Med Sci Sports Exerc 21:*258, 1989.
154. Montes-Mico R, Bueno I, Candel J, et al: Eye-hand and eye-foot visual reaction times of young soccer players, *Optometry 71:*775, 2000.
155. Henry M: Stimulus complexity, movement, age, and sex in relation to reaction latency and speed in limb movements, *Res Q Sports Med 32:*353, 1961.
156. Keele S: Motor control. In Boff K, Kaufman L, Thomas J, editors: *Handbook of perception and human performance*, New York, 1986, John Wiley & Sons, pp 30-60.
157. Sherman A: A method for evaluating eye-hand coordination and visual reaction time in athletes, *J Am Optom Assoc 54:*801, 1983.
158. Mitchell JA, Nicholson DW, Maples WC: Standardization of the Wayne Saccadic Fixator, *J Behav Optom 1:*199, 1990.
159. Vogel GL, Hale RE: Initial norms using the Wayne Saccadic Fixator for eye-hand coordination and visual reaction times, *J Behav Optom 1:*206, 1990.
160. Robertson S, Collins J, Elliott D, et al: The influence of skill and intermittent vision on dynamic balance, *J Mot Behav 26:*333, 1994.
161. Robertson S, Elliott D: The influence of skill in gymnastics and vision on dynamic balance, *Int J Sport Psych 27:*361, 1996.
162. Robertson S, Elliott D: Specificity of learning and dynamic balance, *Res Q Exerc Sport 67:*69, 1996.
163. Witkin HA, Dyk RB, Paterson HF, et al: *Psychological differentiation,* New York, 1982, Wiley.
164. Witkin HA, Lewis HB, Hertzman M, et al: *Personality through perception,* Westport, CT, 1972, Greenwood.
165. Knapp B: *Skill in sport,* London, 1964, Routledge & Kegan Paul.
166. Jones MG: Perceptual studies: perceptual characteristics and athletic performance. In Whiting HTA, editor: *Sports psychology,* London, 1972, Kimpton, pp 96-115.
167. Kane JE: Personality, body concept and performance. In Kane JE, editor: *Psychological aspects of physical education and sport,* London, 1972, Western Printing Services, pp 91-127.
168. Sharp RH, Whiting HTA: Information processing and eye-movement behavior in a ball catching skill, *J Human Mov Studies 1:*124, 1975.
169. Franks IM, Weicker D, Robertson DGE: The kinematics, movement phasing and timing of a skilled action in response to varying conditions of uncertainty, *Hum Movement Sci 4:*91, 1985.
170. Bootsma RJ, van Wieringen PCW: Visual control of an attacking forehand drive. In Meijer OG, Roth K, editors: *Complex movement behavior: the motor-action controversy*, Amsterdam, 1988, North-Holland, pp 189-199.
171. Bootsma RJ: *The timing of rapid interceptive actions: perception-action coupling in the control and acquisition of skill*, Amsterdam, 1988, Free University Press.
172. Bootsma RJ: Accuracy of perceptual processes subserving different perception-action systems, *Q J Exp Psychol 41A:*489, 1989.
173. Bootsma RJ, van Wieringen PCW: Timing an attacking forehand drive in table tennis, *J Exp Psychol Hum Percept Perform 16:*21, 1990.
174. Bootsma RJ: Predictive information and the control of action, *Int J Sport Psychol 22:*271, 1991.
175. Savelsbergh GJP, Whiting HTA, Bootsma RJ: "Grasping" tau, *J Exp Psychol Hum Percept Perform 17:*315, 1991.

176. Bootsma RJ, Peper CE: Predictive visual information sources for the regulation of action with special emphasis on catching and hitting. In Proteau L, Elliott D, editors: *Vision and motor control,* Amsterdam, 1992, North-Holland, pp 285-314.
177. Bootsma RJ, Oudejans RRD: Visual information about time-to-collision between two objects, *J Exp Psychol Hum Percept Perform 19:*1041, 1993.
178. Siegel D: Response velocity, range of movement, and timing accuracy, *Percept Mot Skills 79:*216, 1994.
179. Barlow H, Blakemore CB, Pettigrew JD: The neural mechanism of binocular depth perception, *J Physiol 193:*327, 1967.
180. Pettigrew JD, Nikara T, Bishop PO: Binocular interaction on single units in cat striate cortex: simultaneous stimulation by single moving slit with receptive fields in correspondence, *Expl Brain Res 6:*391, 1968.
181. Cyander M, Regan D: Neurons in cat parastriate cortex sensitive to the direction of motion in three-dimensional space, *J Physiol 274:*549, 1978.
182. Wheatstone C: Contributions to the physiology of vision. Part the first. On some remarkable and hitherto unobserved, phenomena of binocular vision, *Phil Trans R Soc London 128:*371, 1838.
183. Ogle KN: The optical space sense. In Davson H, editor: *The eye,* vol 4, New York, 1962, Academic Press.
184. Julesz B: *Foundations of cyclopean perception*, Chicago, 1971, University of Chicago Press.
185. Regan D, editor: *Binocular vision,* London, 1991, Macmillan.
186. Beverley KI, Regan D: Evidence for the existence of neural mechanisms selectively sensitive to the direction of motion in space, *J Physiol 235:*17, 1973.
187. Richards W, Regan D: A stereo field map with implications for disparity processing, *Invest Ophthalmol Vis Sci 12:*904, 1973.
188. Beverly KI, Regan D: The relation between discrimination and sensitivity in the perception of motion in depth, *J Physiol 249:*387, 1975.
189. Regan D, Beverley KI, Cyander M: *Stereoscopic subsystems for position in depth and for motion in depth,* Proc Royal Soc London Series B, *204:*485, 1979.
190. Regan D, Beverly KI, Cyander M: The visual perception of motion in depth, *Sci Am 241:*136, 1979.
191. Poggio GF, Talbot WH: Mechanisms of static and dynamic stereopsis in foveal cortex of rhesus monkey, *J Physiol 315:*469, 1981.
192. Cyander M, Regan D: Neurons in cat visual cortex tuned to the direction of motion in depth: effect of positional disparity, *Vis Res 22:*967, 1982.
193. Regan D, Cyander M: Neurons in cat visual cortex tuned to the direction of motion in depth: effect of stimulus speed, *Inves Ophthalmol Vis Sci 22:*535, 1982.
194. Regan D, Erkelens CJ, Collewijn H: Visual field defects for vergence eye movements and for stereomotion perception, *Invest Ophthalmol Vis Sci 27:*806, 1986.
195. Hong X, Regan D: Visual field defects for unidirectional and oscillatory motion in depth, *Vis Res 29:*809, 1989.
196. Spileers W, Orban GA, Gulyan B, et al: Selectivity of cat area 18 neurons for direction and speed in depth, *J Neurophysiol 63:*936, 1990.
197. Regan D, Beverley KI: Illusory motion in depth: aftereffect of adaptation to changing size, *Vis Res 18:*209, 1978.
198. Beverley KI, Regan D: Separable aftereffects of changing-size and motion-in-depth: different neural mechanisms? *Vis Res 19:*727, 1979.
199. Regan D, Beverley KI: Looming detectors in the human visual pathway, *Vis Res 18:*415, 1978.
200. Regan D, Cyander M: Neurons in area 18 cat visual cortex selectively sensitive to changing size: non-linear interactions between responses to two edges, *Vis Res 19:*699, 1979.

201. Gibson JJ: *The perception of the visual world,* Boston, 1950, Houghton Mifflin.
202. Gordon DA: Static and dynamic fields in human space perception, *J Opt Soc Am 55:*1296, 1965.
203. Koenderink JJ, van Doorn AJ: Local structure of movement parallax of the plane, *J Opt Soc Am 66:*717, 1976.
204. Regan D, Beverley KI: Visually-guided locomotion: psychophysical evidence for a neural mechanism sensitive to flow patterns, *Science 205:*311, 1979.
205. Regan D, Beverley KI: Binocular and monocular stimuli for motion in depth: changing-disparity and changing-size feed the same motion-in-depth stage, *Vis Res 19:*1331, 1979.
206. Regan D: Visual judgments and misjudgments in cricket, and the art of flight, *Perception 21:*91, 1992.
207. Bahill AT, Karnavas WJ: The perception of baseball's rising fastball and breaking curveball, *J Exp Psychol Hum Percept Perform 19:*3, 1993.
208. Gogel WC: Convergence as a cue to absolute distance, *J Psychol 52:*287, 1961.
209. Foley JM, Richards W: Effects of voluntary eye movement and convergence on the binocular appreciation of depth, *Percept Psychophys 11:*423, 1972.
210. von Hofsten C: The role of convergence in visual space perception, *Vis Res 16:*193, 1976.
211. Regan D, Erkelens CJ, Collewijn H: Necessary conditions for the perception of motion in depth, *Inves Ophthalmol Vis Sci 27:*584, 1986.
212. Steinman RM, Collewijn H: Binocular retinal image motion during active head rotation, *Vis Res 20:*415, 1980.
213. Steinman RM, Cushman WB, Martins AJ: The precision of gaze: a review, *Hum Neurobiol 1:*97, 1982.
214. Steinman RM, Levinson JZ, Collewijn H, et al: Vision in the presence of known natural retinal image motion, *J Opt Soc Am 2:*226, 1985.
215. McLeod P, McLaughlin C, Nimmo-Smith I: Information encapsulation and automaticity: evidence from the visual control of finely timed actions. In *Attention and performance XI,* Hillsdale, NJ, 1985, Erlbaum, pp 391-400.
216. Judge SJ, Bradford CM: Adaptation to telestereoscopic viewing measured by one-handed ball-catching performance, *Perception 17:*783, 1988.
217. von Hofsten C, Rosengren K, Pick HL, et al: The role of binocular information in ball catching, *J Mot Behav 24:*329, 1992.
218. Savelsbergh GJP, Whiting HTA: The acquisition of catching under monocular and binocular conditions, *J Mot Behav 24:*320, 1992.
219. Graydon J, Bawden M, Holder T, et al: The effects of binocular and monocular vision on a table tennis striking task under conditions of spatio-temporal uncertainty, *Int J Sports Vis 3:*35, 1996.
220. Rosengren K, Pick HL, von Hofsten C: Role of visual information in ball catching, *J Mot Behav 20:*150, 1988.
221. von Hofsten C: Recalibration of the convergence system, *Perception 8:*37, 1979.
222. Redding GM, Rader SD, Lucas DR: Cognitive load and prism adaptation, *J Mot Behav 24:*238, 1992.
223. Redding GM, Wallace B: Effects of pointing rate and availability of visual feedback on visual and proprioceptive components of prism adaptation, *J Mot Behav 24:*226, 1992.
224. Lee DN: A theory of visual control of braking based on information about time-to-collision, *Perception 5:*437, 1976.
225. Lee DN, Young DS: Visual timing in interceptive actions. In Ingle DJ, Jeannerod M, Lee DN, editors: *Brain mechanisms and spatial vision,* Dordrecht, The Netherlands, 1985, Martinus Nijhoff, pp 1-30.
226. Lee DN: Visuo-motor coordination in space-time. In Stelmach G, Requin J, editors: *Tutorials in motor behavior,* Amsterdam, 1980, North-Holland, pp 281-293.
227. Lee DN, Reddish PE: Plummeting gannets: a paradigm of ecological optics, *Nature 293:*293, 1981.

228. Todd JT: Visual information about moving objects, *J Exp Psychol Hum Percept Perform 7:*795, 1981.
229. Lee DN, Lishman JR, Thomson JA: Visual regulation of gait in long jumping, *J Exp Psychol Hum Percept Perform 8:*448, 1982.
230. Wagner H: Flow-field variables triggering landing in flies, *Nature 297:*147, 1982.
231. Lee DN, Young DS, Reddish PE, et al: Visual timing in hitting an accelerating ball, *Q J Exp Psychol 35A:*333, 1983.
232. Warren WH, Young DS, Lee DN: Visual control of step length during running over irregular terrain, *J Exp Psychol Hum Percept Perform 12:*259, 1986.
233. Laurent M, Dinh Phung R, Ripoll H: What visual information is used by riders in jumping, *Hum Mov Sci 8:*481, 1989.
234. Stoffregen TA, Riccio GE: Responses to optical looming in the retinal center and periphery, *Ecol Psychol 2:*251, 1990.
235. Van der Horst ARA: *A time-based analysis of road user behaviour in normal and critical encounters,* Soest, The Netherlands, 1990, Practicum Drukkerij.
236. Laurent M: Visual cues and processes involved in goal-directed locomotion. In Patla AE, editor: *Adaptability of human gait: implications for the control of locomotion*, Amsterdam, 1991, North-Holland, pp 99-123.
237. Lee DN, Young DS, Rewt D: How do somersaulters land on their feet? *J Exp Psychol Hum Percept Perform 18:*1195, 1993.
238. Tresilian JR: Perceptual information for the timing of interceptive action, *Perception 19:*223, 1990.
239. Diggles VA, Grabiner MD, Garhammer J: Skill level and efficacy of effector visual feedback in ball catching, *Percept Mot Skills 64:*987, 1987.
240. Peper L, Bootsma RJ, Mestre DR, et al: Catching balls: how to get the hand to the right place at the right time, *J Exp Psychol Hum Percept Perform 20:*591, 1994.
241. Oudejans RRD, Michaels CF, Bakker FC, et al: The relevance of action in perceiving affordances: perception of catchableness of fly balls, *J Exp Psychol Hum Percept Perform 22:*879, 1996.
242. Cicciarella CF: Effects of loss of visual feedback in performance of two swimming strokes, *Percept Mot Skills 55:*735, 1982.
243. Mount J: Effectiveness of visual vs kinesthetic instruction for learning a gross motor skill, *Percept Mot Skills 65:*715, 1987.
244. Williams JG: Visual demonstration and movement production: effects of motoric mediation during observation of a model, *Percept Mot Skills 65:*825, 1987.
245. Miller G, Gabbard C: Effects of visual aids on acquisition of selected tennis skills, *Percept Mot Skills 67:*603, 1988.
246. Sewell LP, Reeve TG, Day RA: Effect of concurrent visual feedback on acquisition of a weightlifting skill, *Percept Mot Skills 67:*715, 1988.
247. Williams JG: Effects of kinetically enhanced video-modeling on improvement of form in a gymnastic skill, *Percept Mot Skills 69:*473, 1989.
248. Smith TL, Eason RL: Effects of verbal and visual cues on performance of a complex ballistic task, *Percept Mot Skills 70:*1163, 1990.
249. Bennett S, Davids K: The manipulation of vision during the powerlift squat: exploring the boundaries of the specificity of learning hypothesis, *Res Q Exerc Sport 66:*210, 1995.
250. Carnahan H, Hall C, Lee TD: Delayed visual feedback while learning to track a moving target, *Res Q Exerc Sport 67:*416, 1996.
251. Magill RA, Schoenfelder-Zohdi B: A visual model and knowledge of performance as sources of information for learning a rhythmic gymnastics skill, *Int J Sport Psych 27:*7, 1996.

252. Layton C, Avenell L: Differences in kata performance time and distance from a marker for experienced shotokan karateka under normal sighted and blindfolded conditions, *Percept Mot Skills 95:*47, 2002.
253. Dienes Z, McLeod P: How to catch a cricket ball, *Perception 22:*1427, 1993.
254. McBeath MK, Shaffer DM, Kaiser MK: How baseball outfielders determine where to run to catch fly balls, *Science 268:*569, 1995.
255. Letters, *Science 268:*1681, 1995.
256. Technical comments on catching fly balls, *Science 273:*256, 1995.
257. McLeod P, Dienes Z: Do fielders know where to go to catch the ball or only how to get there? *J Exp Psychol Hum Percept Perform 22:*531, 1996.
258. Adair RK: Running, fielding, and throwing. In *The physics of baseball*, New York, 2002, Perennial, pp 145-162.
259. Sim M, Shaw RE, Turvey MT: Intrinsic and required dynamics of a simple bat-ball skill, *J Exp Psychol Hum Percept Perform 23:*101, 1997.
260. Gyulai E: Perceptual inequality between two physically equal constant velocities, *Percept Mot Skills 71:*235, 1990.
261. Malamud B: *The natural,* New York, 1952, Noonday Press.
262. Ciborowski T: "Headiness" or "intelligence" for baseball in the collegiate athlete, *Percept Mot Skills 81:*795, 1995.
263. Kindel S: The hardest single act in all of sports, *Forbes 132:*180, 1983.
264. Williams T, Underwood J: *The science of hitting,* New York, 1986, Simon-Schuster.
265. Adair RK: The swing of the bat. In *The physics of baseball,* New York, 2002, Perennial, pp 29-46.
266. Osborne K, Rudrud E, Zezoney F: Improved curveball hitting through the enhancement of visual cues, *J Appl Behav Analys 23:*371, 1990.
267. Adams GL: Effect of eye dominance in baseball batting, *Res Q Am Assoc Health Phys Educ 36:*3, 1965.
268. Falkowitz C, Mendel H: The role of visual skills in batting averages, *Optom Weekly 68:*33, 1977.
269. Tieg D: *Major league baseball research project,* Ridgefield, CT, 1980, Institute for Sports Vision, pp 1-9.
270. Portal JM, Romano PE: Patterns of eye-hand dominance in baseball players, *N Engl J Med 319:*655, 1988.
271. Dunham P: Coincidence-anticipation performance of adolescent baseball players and nonplayers, *Percept Mot Skills 68:*1151, 1989.
272. Milne C, Buckolz E, Cardenas M: Relationship of eye dominance and batting performance in baseball players, *Int J Sports Vis 2:*17, 1995.
273. Classe JG, Daum KM, Semes LP, et al: Association between eye and hand dominance and hitting, fielding and pitching skill among players of the Southern Baseball League, *J Am Optometric Assoc 67:*81, 1996.
274. Goss DA: The relationship of eye dominance and baseball batting: a critical literature review, *J Behav Optom 9:*87, 1998.
275. Laby DM, Kirschen DG, Rosenbaum AL, et al: The effect of ocular dominance on the performance of professional baseball players, *Ophthalmol 105:*864, 1998.
276. Hubbard WA, Seng CN: Visual movements of batters, *Res Q Am Assoc Health Phys Educ 25:*42, 1954.
277. Ripoll H, Fleurance P: What does keeping one's eye on the ball mean? *Ergonomics 31:*1647, 1988.
278. Stark L, Michael JA, Zuber BL: Saccadic suppression: a product of the saccadic anticipatory signal. In Evans CR, Mulholland TB, editors: *Attention in neurophysiology: an international conference,* London, 1969, Butterworth, pp 281-303.
279. Matin E: Saccadic suppressions and the dual mechanism theory of direction constancy, *Vis Res 22:*335, 1982.
280. Messier SP, Owen MG: Bat dynamics of female fast pitch softball batters, *Res Q Exerc Sport 55:*141, 1984.

281. Adair RK: Properties of bats. In *The physics of baseball,* New York, 2002, Perennial, pp 112-144.
282. McKee SP: A local mechanism for differential velocity discrimination, *Vis Res 21:*491, 1981.
283. Orban GA, De Wolf J, Maes H: Factors influencing velocity coding in the human visual system, *Vis Res 24:*33, 1984.
284. Paull G, Glencross D: Expert perception and decision making in baseball, *Int J Sport Psych 28:*35, 1997.
285. Glencross DJ, Cibich BJ: A decision analysis of games skills, *Austr J Sports Med 9:*72, 1977.
286. Hick WE: On the rate of gain of information, *Q J Exp Psychol 4:*11, 1952.
287. Watts RG, Sawyer E: Aerodynamics of a knuckleball, *Am J Physics 43:*960, 1975.
288. McBeath MK: The rising fastball, baseball's impossible pitch, *Perception 19:*545, 1990.
289. Adair RK: Pitching. In *The physics of baseball,* New York, 2002, Perennial, pp 47-78.
290. Classe JG, Semes LP, Daum KM, et al: Association between visual reaction time and batting, fielding, and earned run averages among players of the Southern Baseball League, *J Am Optom Assoc 68:*43, 1997.
291. McLeod P: Visual reaction time and high-speed ball games, *Perception 16:*49, 1997.

4

Visual Performance Evaluation

CHAPTER OUTLINE

Case History
Static Visual Acuity
Dynamic Visual Acuity
Contrast Sensitivity
Refractive Status
Eye/Hand/Foot Preference
Ocular Alignment
Depth Perception
Vergence Function
Accommodative Function
Oculomotor Function
Speed of Recognition
Motor Response Time
Visual-Motor Reaction Time
Eye-Hand Coordination
Eye-Body Coordination
Visual Coincidence Anticipation
Vision and Balance
Field Dependence and Independence
Peripheral Awareness
Visualization and Imagery
Ocular Health Status
Developing a Sports Vision Evaluation

The search for the association between visual abilities and sports performance has a long, rich history. Many researchers and clinicians have sought to discover the vision skills that correlate to success in sports and to refine the procedures to assess the quality of those vision skills. In a 1982 literature review, the authors concluded that ample evidence supported the contention that athletes typically have better visual abilities than nonathletes and that top athletes benefit from visual abilities that often are superior to lower-level athletes.[1] In another extensive review of the literature in 1993, the authors agreed with these contentions but cautioned that the visual skills related to successful athletic performance are specific to the sport being investigated.[2] The authors further cautioned that attributes such as size, speed, quickness, psychological status, experience level, and influence of coaches confound the ability to predict performance quality solely based on an evaluation of visual skills. Further caution is warranted because a small percentage of top athletes demonstrate poor performance on some aspects of vision skills.

The quest for understanding all the elements that play a role in athletic success is being conducted globally across many disciplines. Each discipline seeks to identify factors that contribute to peak human performance by isolating and measuring specific functions, and most sports vision evaluations attempt the same approach.[3-5] The sports vision practitioner must identify the vision factors essential to performance of the visual tasks critical for success in the sport and evaluate the quality of those skills in the most appropriate, accurate,

and repeatable manner. Chapters 2 and 3 provide an approach to the task analysis process, a process that is essential to providing a suitable evaluation for each sport and position. This chapter provides an evidence-based description of each assessment area and the relative value of each assessment area in an evaluation. Appendix A and the CD-ROM accompanying this text provide testing protocols and normative information compiled by the American Optometric Association Sports Vision Section.

CASE HISTORY

The case history can be the most important part of any patient visit, and successful practitioners maximize the potential inherent in this opportunity. Every patient should be asked about sports activities because a vision issue related to recreational visual performance is an uncommon reason for seeking vision care. Providing vision care services that encompass all areas of a patient's activities is an excellent method for demonstrating an understanding of the patient's needs.

A working knowledge of the visual task demands for sports and recreational activities allows the practitioner to ask pertinent questions and better understand the responses provided by the athlete. The information in Chapters 2 and 3 should assist the practitioner in developing a list of relevant questions to address the specific visual needs of athletes in a wide variety of sports. The American Optometric Association Sports Vision Section guidebooks offer a collection of detailed insights into the many visual factors involved in a variety of sports.[6] Information concerning less-common recreational activities can easily be found by searching the Internet or consulting the many sports periodicals and books available.

The case history for an athlete should start with the basic elements of a history for a comprehensive vision examination, including questions regarding main concerns, secondary vision concerns, personal and family eye history, and personal and family medical history. Of special concern to the athlete are symptoms of blur, diplopia, or visual discomfort. Athletes report difficulty seeing more commonly than expected.[7] A preexamination checklist that the patient fills out before starting the examination is an effective tool to help the patient mentally prepare for the case history and for the doctor to identify areas to explore in greater depth.[8] The preexamination history is also a means of educating the patient about the implications of sports performance issues not commonly associated with eyes. A sample sports vision case history preexamination form can be found in Appendix A.

Vision correction and eye protection are crucial elements to investigate in the athlete's history, including history of vision correction. If the athlete is wearing spectacles during sport participation, the eye care practitioner is obligated to determine the type of frame and lenses used and warn the athlete of the risk of injury posed by ophthalmic materials that have limited impact resistance.[9] Similarly, the practitioner should assess the suitability of any protective eyewear used during sports. The practitioner should specifically probe for any eye injuries sustained during sports or recreational activities and ascertain any long-term effects of an injury. An understanding of how any injuries were evaluated and managed can help determine whether additional health procedures are indicated. Refractive correction with contact lenses should also be explored to determine the effectiveness of the lenses for the specific visual demands of the sport. The visual results from refractive surgery are important to determine in athletes, especially in those with critical vision demands. Chapter 6 discusses

the issues with types of vision correction and protection used in sports, and Appendix A has sample questions to include on the case history preexamination form.

An evaluation of the environmental conditions encountered during sports participation is useful in determining the most effective vision correction and protection for the athlete. The practitioner should question the athlete regarding any ocular hazards encountered, including dust and foreign body potential. Factors of humidity, wind, temperature, altitude, sweat, precipitation, and environmental variability can produce profound effects on the type of vision correction used. Additional environmental issues with lighting, glare, and variable target contrast should also be considered when determining the optimal vision prescription.

Supplementary questions can yield information concerning the athlete's visual performance during sports, such as the following[3,4,7,10-13]:

- Do you ever feel that your vision compromises your athletic performance?
- Do you notice inconsistency in your performance during a game or event?
  - Is that inconsistency noticed early or late in the competition?
  - Is that inconsistency noticed during critical competition situations?
  - Is that inconsistency noticed during day or night competition?
- Do you experience loss of concentration during sports performance?
- Do you ever have difficulty keeping your eyes on a moving object (e.g., ball, puck)?
- Do you have difficulty judging ball rotation?
- Do you ever notice difficulty with depth perception?
- Do you ever have difficulty knowing where the ball or other players are?
- Do you ever notice decreased peripheral vision during sports performance?
- Do you ever notice sensitivity to lights or difficulty recovering vision after looking into bright lights?
- Do you show little improvement in sports performance, even with dedicated practice and coaching?
- Do you make the same mistake time and time again in competition?
- Do you use visualization or imagery techniques?

These questions naturally lead the clinician to follow up with sport-specific performance details related to the expressed symptoms. Additional areas to probe in the case history are the goals and motivation of the athlete to determine potential receptiveness to the variety of possible intervention modes. The ultimate goal of the patient history is to raise the index of suspicion for vision inefficiencies that may interfere with peak performance. An effective case history can help select appropriate visual performance assessment procedures for the sports vision evaluation and ensure that visual problems are not interfering with maximal athletic performance.

STATIC VISUAL ACUITY

Static visual acuity (SVA) is "the ability to see a nonmoving target at a fixed distance."[5] SVA is measured at far (6 m) or simulated distance viewing and is a standard part of the vision evaluation of athletes.[3-5,13-36] SVA has been measured in athletes both monocularly and binocularly with the Keystone telebinocular (www.keystoneview.com), standard Snellen charts, Bailey-Lovie logMAR charts, and Landolt C optotypes. The author prefers to measure both monocular and binocular static visual acuities with Landolt C optotypes or the Bailey-Lovie logMAR chart at a distance of 6 m.

The athlete should be evaluated with the habitual correction used for sports participation. Interestingly, a large percentage of athletes have been reported to have a significant uncorrected refractive error; those athletes who do wear refractive correction either do not wear that correction for sports, or the athlete is undercorrected.[7,37] A measurement of SVA should also be performed with the best optical correction in place to assess any change in visual acuity produced by that correction. Recommendations for the use of, or change in, vision correction during sports participation are discussed in Chapter 6.

The measurement of SVA is an essential element of any vision evaluation because degraded visual acuity can have a detrimental effect on many other aspects of visual performance. Reduced visual acuity has been shown to affect dynamic visual acuity,[38] depth perception,[39,40] and accommodative accuracy.[41] Some studies have found better static visual acuity in athletes than in nonathletes,[3,28,42-44] and some have found no difference.[27] Some athletes may perform at a high level despite having deficient visual acuity.[14-16,18,43-45] Although the expected level of visual acuity depends on the visual task demands of each sport situation, at least 20/15 (6/4.5) static visual acuity OD, OS, OU has been recommended as a desired standard for competitive athletes.[3]

DYNAMIC VISUAL ACUITY

Many of the visual demands in sports require discrimination of information that is moving, such as judging the speed and trajectory of a tennis serve. Traditional static visual acuity measurements do not fully address the visual demands encountered in some types of sports, especially those in which judgments about rapidly moving objects are important. A significant amount of early research investigated the physiologic parameters of resolving visual targets in motion, referred to as *dynamic visual acuity* (DVA).[38,46-67] Ludvigh and Miller[48,50-53] were the first to use the term DVA, and it has been defined as the ability to resolve detail when relative movement exists between the observer and the test object.[68]

Many variables in the stimulus parameters can affect DVA, including target luminance, angular velocity, and the time exposure of the target.[38,46-67] Human attributes that can affect DVA include the resolving power of the retina, peripheral awareness, oculomotor abilities, and psychological functions that affect interpretation of visual information.[38,46-67,69,70] Several conclusions have been made concerning DVA that have emerged from the research: (1) Visual acuity for a moving target is reduced compared with that of a stationary target, and acuity becomes progressively more reduced with increasing velocity of the target. (2) The correlation between static visual acuity and DVA decreases with increasing target velocity. (3) A progressive decline in acuity occurs with advancing age that accelerates in older age groups and is more pronounced with DVA than SVA. (4) Males, in general, perform consistently better than females on DVA tasks.[59,61,62,71]

DVA research was stimulated by the theory that, for many activities, discrimination of moving objects (or stationary objects while the person is in motion) is a critical element of human performance.[62] This concept applies to sport situations as well as common daily tasks such as driving.[55,58,59,62] Several attempts have been made to determine the relation between DVA and visual task performance; however, further investigation is necessary to correlate clinical measurements of DVA with visual task performance.*

*References 19-23, 44, 48, 50-53, 55, 58, 59, 62, 71-76.

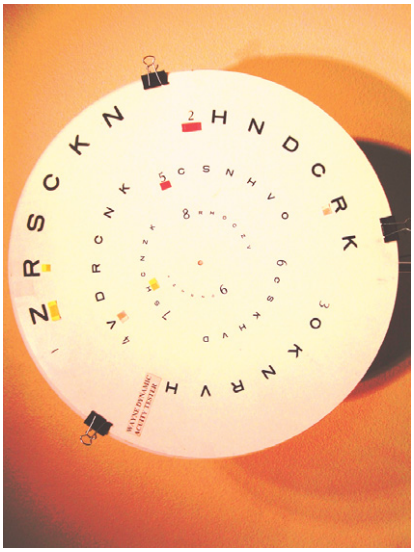


Figure 4-1. Wayne Robot Rotator with visual acuity chart for dynamic visual acuity testing.

Despite the significant amount of research conducted with DVA parameters and the many applications of DVA features to daily activities, limited resources are available to assess this ability. DVA is a widely recommended visual function to evaluate in athletes.* Significant variations in the clinical measurement of DVA have included the type of target, the size of the target, the direction of the stimulus movement (or subject movement), and the amount of time that the stimulus is exposed. This variability in measurement parameters has lead to several different recommendations for normative performance in athletes, as well as different performance characteristics for athletes compared with nonathletes.† Few DVA measurement systems are currently available, and most use a predictable rotator device (Fig. 4-1). Rotators are available from Wayne Engineering (www.wayneengineering.com) and JW Engineering (www.jtac.com), as well as other retailers. The *in*Vision package from NeuroCom (www.onbalance.com) is a system that "quantifies a patient's ability to maintain visual acuity and stable gaze while actively moving the head" (Fig. 4-2).[87] This system has shown promise as an effective diagnostic tool in a study to establish preliminary normative data[88] and has demonstrated acceptable test-retest reliability.[89]

CONTRAST SENSITIVITY

Contrast sensitivity measures the visual system's ability to process spatial or temporal information about objects and their backgrounds under varying lighting conditions.[68] Measurement of contrast sensitivity function (CSF) has been recommended in athletes because many sports involve visual discrimination tasks in suboptimal lighting because of environmental variability.[2,3,5] Snellen-type visual acuity measurements may not be sensitive to the subtle visual discrimination tasks inherent in many sports because the acuity task is usually performed only under high-contrast conditions. Consider the decreased contrast

*References 3-6, 13, 19-23, 26, 27, 30-33, 35, 36, 42, 44, 69, 77-82.
†References 3, 5, 13, 31-33, 37, 79-81, 83-86.

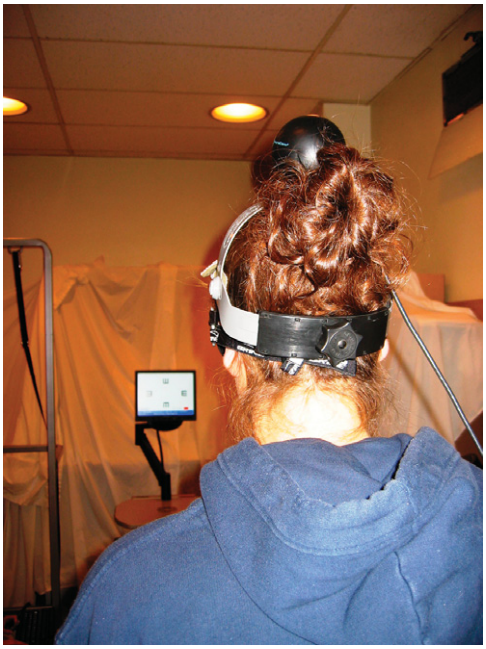


Figure 4-2. *in*Vision package to assess dynamic visual acuity.

effect of a white, cloudy sky as a background when judging the trajectory of a fly ball in baseball when the ball is also predominantly white. Ginsburg[90,91] has suggested that lower spatial frequencies provide spatial localization information about objects and that higher spatial frequencies are the first to be affected by poor illumination, movement, and increased viewing distance. In sports in which the athlete must process visual information from an object in motion (e.g., a baseball pitch), evaluation of CSF at high spatial frequencies may provide vital diagnostic information.

Several investigations have compared CSF in athletes by using gratings of varying spatial frequency.[3,31,42,92-100] The general results from these studies demonstrate elevated CSF across all spatial frequencies for athletes. Athletes may have a positive benefit in CSF with aerobic excercise.[101] Contrast sensitivity also may be degraded in contact lens wearers if the lenses are not optimal, even when visual acuity appears acceptable.[102-105] Therefore contrast sensitivity measurement is an essential part of the evaluation of athletes who wear contact lenses during sports participation.

Many systems are commercially available to measure CSF. Most use grating patterns that vary in spatial frequency and contrast level; however, fixed-chart and computer-generated symbols of varying contrast levels are also available. Contrast sensitivity measurements usually involve detection of a threshold contrast level at each spatial frequency, with the resultant CSF plotted on a graph.[106] The principal instruments used to measure CSF in athletes have been the Vistech Contrast Test System (www.vistechconsultants.com) and Vector Vision contrast sensitivity test (www.vectorvision.com). These systems were primarily chosen for the speed of test administration and portability of the tests.* The Vistech system

*References 3-5, 13, 31, 33, 42, 94-103, 105.

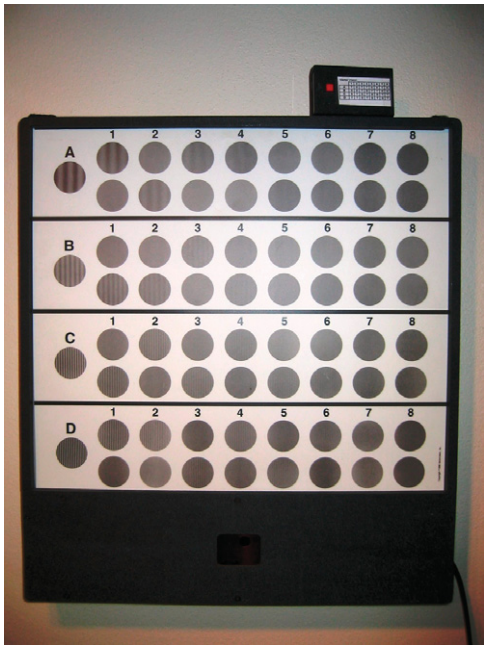


Figure 4-3. The CSV-1OOOE contrast sensitivity chart.

is externally lit and requires a light meter to calibrate, whereas the Vector Vision test is internally illuminated and somewhat self-calibrating (Fig. 4-3). Major concerns have been reported regarding the reliability and repeatability of the Vistech Contrast Test System for measuring CSF, although other studies have demonstrated adequate reliability and repeatability.[107-110]

Whatever CSF test system is chosen, evaluation is often recommended for athletes and should be performed binocularly with habitual sports correction in place.* If contact lenses are used in sports, or if more than a one-line difference in monocular static visual acuities exists, CSF testing should also be performed monocularly. A measurement of CSF should also be performed with the best optical correction in place to assess any change in CSF produced by that correction and with any performance tints used during sports participation (e.g., ski goggles).[111] The practitioner is encouraged to assess filter performance in natural sunlight because light levels are much more intense outdoors than under artificial lighting. Recommendations for the use of, or change in, vision correction or contact lenses used during sports participation is discussed in Chapter 6.

REFRACTIVE STATUS

Assessment of refractive status is an essential element of the visual evaluation of the athlete. Interestingly, it is such a basic element of a vision evaluation that it is rarely directly discussed in the extensive literature describing evaluation procedures for athletes. Ample data

*References 3-6, 13, 30, 31, 33, 42, 78, 80, 82.

are available concerning visual acuity performance, which has obvious implications for uncorrected refractive errors, but refractive status of the athletes is presented infrequently.* Therefore limited information is available concerning the percentage of athletes who have significant uncorrected refractive errors.[7,113]

Only a few reports in the literature concern the percentage of athletes who use vision correction (spectacles or contact lenses).[7,15,17,26] Beckerman and Hitzeman[7] recently found at the Junior Olympic Games that, of the approximately 20% of athletes who wore vision correction, 28% had less than 20/25 (6/7.5) visual acuity through their habitual sports correction. They found that 35% of right eyes had greater than ±0.75 D of uncorrected spherical refractive error, and 64% of right eyes had greater than −0.75 D of uncorrected astigmatism. The incidence of refractive error and visual symptoms found by Beckerman and Hitzeman is similar to that found in the general population, dispelling the perception that athletes have a lower incidence of refractive error and vision problems. In contrast, those athletes with significantly above-average visual acuity demonstrate corneae relatively free of high-order aberrations on videokeratography.[114]

Standardized examination procedures to evaluate refractive status are recommended for athletes, and prescribing recommendations are addressed in Chapter 6. The need for cycloplegic examination is left to the discretion of the practitioner and is usually based on concerns regarding latent hyperopia in the athlete. Of note, most young athletes are also students, and vision conditions that can affect school performance should be addressed as well.

EYE/HAND/FOOT PREFERENCE

The phenomenon of ocular dominance was first described by Giovanni Battista della Porta in 1593,[115] and interest in the relation between ocular dominance and performance has been active ever since. Dominance has been defined as any sort of physiologic preeminence, priority, or preference by one member of any bilateral pair of structures in the body when performing various tasks.[116] Many studies have attempted to determine the best method for assessing the types of eye dominance,[117-135] but tests of sighting preference are the most frequently used.

Many studies have investigated the relation between hand and foot preference and eye preference.[120,121,128,134,136-140] The preferred eye does not always correspond to the preferred hand or foot, and when they are different the condition is referred to as *crossed dominance.* Duke-Elder[137] reported that 33% of right-hand dominant people are left-eye dominant, 50% of left-hand dominant people are right-eye dominant, and an estimated 20% to 40% of the general population is crossed eye and hand dominant. Entangled in the issue of testing methods to determine eye preference are reports of dominance switching with hand used when sighting, and issues of central dominance in which neither eye is aligned with the sighted target (also sometimes referred to as *ambiocular*).[31,135,141-143]

Many theories have proposed advantages or disadvantages of having crossed eye and hand dominance in sports performance.[28,112,116,135,141-161] These speculations were further inspired by the findings of Coren and Porac,[133] who found that information from the dominant eye

*References 7, 11, 15-17, 26, 28, 30, 33, 36, 112.

is processed approximately 14 ms faster than information from the nondominant eye. Functional magnetic resonance imaging studies further demonstrate a larger activation area in the primary visual cortex of the dominant eye.[162] The effect of the dominant eye on batting in baseball has received considerable scrutiny. Although the findings have been somewhat contradictory, the preponderance of evidence indicates no relation between eye preference patterns and batting performance.* The only sports in which eye dominance appears to be important are "sighting" sports such as target shooting.† In these sports ipsilateral (same side) dominance offers advantages to acquiring the skills required for success.[157]

Although the role of ocular preference in sports success is inconclusive, evaluation of a preferred eye, hand, and/or foot has been included in many sports vision evaluations.‡ When assessment of ocular preference in athletes is important, a sighting test that uses an aperture or pointing paradigm is recommended. Preference can be qualified as strong, partial, none, or mixed.[112,142,143]

OCULAR ALIGNMENT

The precise alignment of the two eyes, triggered by retinal image disparity, is responsible for providing a significant amount of information regarding object location.[163] The amount of innervation exerted by each of the six extraocular muscles in each eye to align on a target or object provides some of the information necessary to judge depth and is logically a critical feature of sports performance when precise depth judgments are necessary for success. Studies have demonstrated that extraocular muscle tonus changes produced by altering the amount of heterophoria result in changes in perceived distance.[164-168] If a shift occurs in a relatively esophoric direction, perceived distances are increased; exophoric shifts induce a shortening of perceived distances. Athletes are commonly agreed to have better ocular alignment, especially when viewing at a far distance, than do nonathletes; however, results of studies comparing athletes with nonathletes have not been conclusive.[27,32,43,169] Early studies suggested that athletes have lower amounts of heterophoria,[43,169] but more recent studies have not confirmed these results.[27,32] Because changes in heterophoria produce changes in perceived distance, stability of vergence posture may be a more critical factor in spatial localization than the amount of heterophoria.

The measurement of ocular alignment is a common aspect of a sports vision evaluation; however, the methods used to assess this function vary considerably.§ The cover test is arguably the standard for assessment of ocular alignment, although the telebinocular, Maddox Rod, Brock String, and vonGraefe phorometry have all been recommended. Measurements of fixation disparity have been suggested to be more rewarding in sports that require precise spatial localization because it is assessed without dissociation and can potentially evaluate the accuracy and stability of eye alignment.[30,170-172] The AO Vectographic slide or similar apparatus can assess distance fixation disparity characteristics. Whatever methods are chosen, alignment should be measured in the pertinent gaze positions for the particular sport or position in addition to measurements in primary gaze. Ocular gaze and head position have been reported to influence fixation disparity and heterophoria.[173-175]

*References 116, 141, 142, 147, 149, 151, 159, 160.
†References 145, 146, 148, 150, 152, 153, 155, 157.
‡References 4, 6, 13, 28-31, 33, 112, 151.
§References 4-6, 11, 13-16, 20, 21, 25, 27, 29, 30, 32, 33, 170.

Coffey et al[176] found that instability of binocular visual alignment is related to errors in golf putting alignment. Therefore the measurements should be assessed at fixation distances relevant to the sport demands. Most sports require the athlete to fixate on objects or people at a relatively far distance and judge relative depth for decisions regarding performance; therefore far alignment should be assessed, with near alignment assessed when a relevant sport demand is present.

DEPTH PERCEPTION

The perception of depth has generated a considerable amount of interest relative to visual performance. Wheatstone[177] was the first to describe and demonstrate the illusion of depth by inducing retinal image disparity, and the psychophysical mechanisms and parameters of stereoscopic vision have been scrutinized extensively. Early research studied static stereoscopic vision,[178-180] whereas later research investigated the perception of depth in motion (dynamic stereopsis).[181-202] These factors are discussed more extensively in Chapter 3.

The relation between depth perception abilities and athletic performance was a logical correlation to explore because many sports tasks require judgments of spatial localization. Several studies have demonstrated that binocular vision can improve performance on certain tasks compared with performance by individuals using only one eye.[200,201,203-209] However, the results of research comparing performance on tests of static stereopsis with athletic populations have had mixed results.* The differences in study findings may be the result of the variety of testing procedures used, which have included tests with a telebinocular, Howard-Dolman devices, real-space distance judgments, and vectographic images. It has also been suggested that the lack of correlation in many studies is due to the static nature of the testing, and that testing of dynamic stereopsis may yield differential performance and discriminate sports-related visual abilities better.[216-224]

An assessment of depth perception is an almost universal element to a sports vision evaluation.† The author recommends an evaluation of stereopsis at a distance of 3 m or farther and to include an assessment of the speed of stereopsis. A procedure that measures real depth rather than simulated depth is also preferred, such as a Howard-Dolman device (Fig. 4-4). A procedure to evaluate dynamic stereopsis is desirable; however, no commercially available instrument is currently available to measure this function with validity and reliability.

VERGENCE FUNCTION

An assessment of vergence subsystem function is frequently recommended for athletes.‡ The underlying premise is that strength and flexibility in vergence function provide better stability of visual information to the athlete, particularly when the athlete must deal with excessive fatigue and psychological stress. A correlation between stability of vergence information and spatial judgment consistency has been assumed.[3]

*References 21, 27, 31, 32, 37, 42-45, 163, 169, 210-215.
†References 1, 3-6, 11, 13-16, 20, 21, 24-36, 37, 42-44, 77, 78, 80, 170.
‡References 3-6, 11, 13, 26, 27, 29-33, 36.

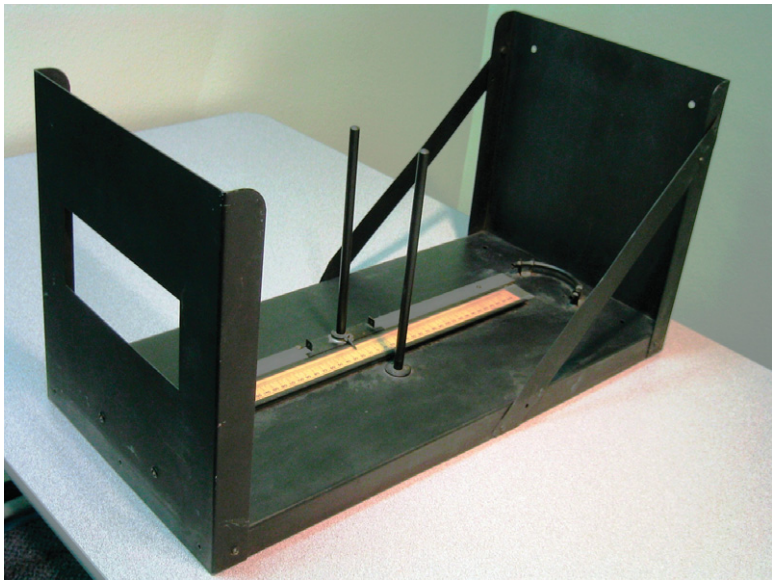


Figure 4-4. A homemade Howard-Dolman device for assessment of real-space depth perception.

Only two studies have reported on vergence range measurements in athletes. Coffey and Reichow[3] reported narrower vergence range findings at 6 m compared with published norms and discussed speculation that narrower vergence ranges relate to more precise spatial judgment ability. Hughes et al[32] found no statistically significant difference between the vergence ranges at 6 m in elite, intermediate, and novice table tennis competitors. The measurement of vergence ranges at 6 m may be valuable only as an assessment of motor compensation ability when an athlete has a large heterophoria at 6 m.

An assessment of the near point of convergence (NPC) has been studied as a visual factor in athletes. Christenson and Winkelstein[27] found that athletes performed better on the NPC test than did nonathletes, even though the test does not directly simulate the visual tasks found in most sports. The theory is that NPC testing is a dynamic procedure that requires simultaneous performance of oculomotor skills and vergence function and therefore may assess vergence function more globally than other procedures that isolate aspects of vergence function. Falkowitz and Mendel[149] found that the better batters in a cohort of baseball players had better NPC findings than those whose batting performance was poorest. However, another study found no statistically significant difference between athletes at different skill levels.[32]

An evaluation of vergence facility has been recommended because the visual demands of many sports involve the ability to adjust vergence posture rapidly.[3] Two methods have been used to measure vergence facility in athletes: the use of prisms to alter the vergence demands at a fixed distance[27,32,33] and the use of charts at two different distances, with fixation being rapidly alternated between the two charts.[3] Christenson and Winkelstein[27] found that athletes performed better on a vergence facility test using 8^{Δ} base out and 4^{Δ} base in at 6 m than nonathletes. However, Hughes et al[32] did not find significant differences among elite,

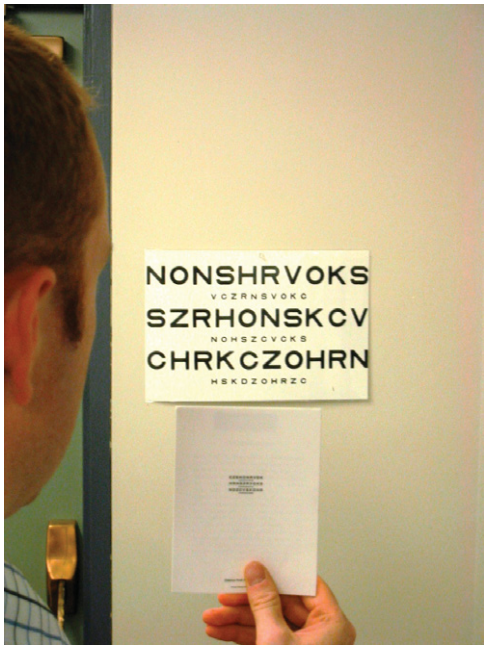


Figure 4-5. The Haynes distance rock test.

intermediate, and novice table tennis competitors using 10^{Δ} base out and 4^{Δ} base in.[32] Coffey and Reichow[225,226] advocate use of the Haynes distance rock test (Fig. 4-5), theorizing that it more closely simulates real-world accommodative vergence facility.[3] When a prism is introduced, the vergence system must adjust ocular alignment to regain image fusion; however, the accommodative system must remain focused close to the plane of the target. This separation of accommodation and vergence is a standard method to assess relative vergence facility at near in patients with asthenopia during near work,[227] but it is generally not a factor in the visual task demands of sports. Therefore use of a near-to-far alternating fixation procedure is recommended for assessing vergence facility in athletes. The performance results of a procedure such as the Haynes distance rock test are influenced by limitations in visual acuity, accommodative skills, and oculomotor skills (fixation and saccadic eye movements), and it will not reveal suppression tendencies.

ACCOMMODATIVE FUNCTION

An assessment of accommodation subsystem function is frequently recommended for athletes.* The underlying premise is that strength and flexibility in focusing ability provide better stability of visual information to the athlete, particularly when the athlete must deal with excessive fatigue and psychological stress. A correlation between rapid focusing and the visual judgments typically required in rapid-action sports has been assumed.

*References 3-6, 10, 11, 13, 25-27, 29-34, 36, 77, 78, 82.

The earliest study reporting accommodative function in athletes was part of a series of Russian studies. Normal accommodative amplitudes were found in 100 "well-trained" athletes.[169] Although accommodative amplitude is a common procedure for assessing accommodative function, the task of clearing letters at a very near distance does not reproduce the typical visual task demands encountered in sports. The approximately 0.6-second latency of the accommodative response has been suggested to preclude it as a factor in many rapid reactive sports.[40]

More recent studies have evaluated accommodative facility to more closely simulate the visual demands of many sports that involve the ability to adjust focus rapidly for a variety of distances. Two methods have been used to measure accommodative facility in athletes; lenses to alter the accommodative demands at a fixed distance[27,32] and charts at two different distances, with fixation rapidly alternated between the two charts.[3] Both studies that used lenses (at near and far distances) to assess accommodative facility in athletes found no significant difference in performance compared with nonathletes.[27,32] The study using the Haynes distance rock test presented normative data for a population of elite athletes and therefore did not compare performance with that of nonathletes.[3] When a lens is introduced, the accommodative system must adjust ciliary muscle tonus to regain image clarity; however, the vergence system must remain aligned with the plane of the target to prevent diplopia. This separation of accommodation and vergence is a standard method to assess relative accommodative facility binocularly at near in patients with asthenopia during near work,[227] but it is not generally a factor in the visual task demands of sports. Therefore the use of an alternating near-to-far fixation procedure is recommended for assessing accommodative facility in athletes. The performance results of a procedure such as the Haynes distance rock test are influenced by limitations in visual acuity, vergence skills, and oculomotor skills (fixation and saccadic eye movements), and it will not reveal suppression tendencies.

OCULOMOTOR FUNCTION

One of the most commonly heard coaching imperatives is, "keep your eyes on the ball (puck, opponent, target, etc.)." The ability to maintain fixation of a rapidly moving object is frequently a critical aspect for allowing visual processing of crucial information in sports. The ability to change fixation from one location to another rapidly and accurately is also an essential aspect of many sports tasks. In nondynamic sports such as precision target shooting, the ability to maintain steady fixation is a vital aspect of successful performance. Therefore the assessment of oculomotor function can include evaluation of pursuit eye movements, saccadic eye movements, and steadiness of fixation.[228-230] Another aspect of oculomotor function is searching eye movements, as discussed in Chapter 3. However, this function is much more difficult to assess in clinical practice.

An important aspect of oculomotor function is the physiologic time required for initiation of the requisite eye movement for the visual task. The average latency for initiation of a pursuit eye movement is typically 125 ms, and the average latency for initiation of a saccadic eye movement is 200 ms.[231] Studies have not shown that athletes have shorter latencies for the initiation of pursuit or saccadic eye movements.[28,32,232] However, if a target trajectory is predictable, reduction of the latency period for pursuit or saccadic eye movements can be learned.[233-237] A study of racquet-sport athletes found quicker saccadic responses to positive positional errors compared with nonathletes.[238] Positive positional errors are created by

displacing the saccadic target in the same direction as the saccadic movement after initiation of the saccade. These results open questions of innate skill versus motor learning through experience and the modulation of attention with eye movement performance. Pursuit eye movements have the capacity to follow targets at speeds of up to 40 degrees/second (or faster if the trajectory is predictable), and saccadic eye movements have the capacity for speeds up to 1000 degrees/second.[231] Studies comparing the speed of pursuit eye movements in athletes and nonathletes have found mixed results.[232,239]

The quality of pursuit and saccadic eye movements has been studied with clinical assessment procedures, and results suggest that athletes have better eye movement skills.[27,149,240] The quality of eye movement skills has been correlated to batting performance in two studies; however, the subjectivity of the eye movement assessments bring the reliability and validity of these studies into question.[149,240] One study evaluated the quality of saccadic eye movements objectively at 3 m by projecting the King-Devick Test (a test designed for clinical assessment of saccadic fixation eye movement at 40 cm) on a screen; even though results indicated superior performance by athletes compared with nonathletes,[27] the test does not control for visual-verbal automaticity differences.

An assessment of oculomotor function is a common element in a sports vision evaluation.* For clinical practice, a subjective assessment of pursuit and saccadic eye movement function using an observational method (e.g., Northeastern State University College of Optometry Oculomotor Test)[241] may be an acceptable screening procedure, but it may not be sensitive to the level of oculomotor function that is diagnostic in athletes. An objective assessment of saccadic function with a projected King-Devick Test is no longer appropriate because the test design has flaws that have been eliminated with the Developmental Eye Movement Test.[242] A projected Developmental Eye Movement Test is a suitable replacement for the King-Devick Test, but it assesses saccadic eye movement skills only in a simulated reading pattern; therefore it also may not be sensitive to oculomotor functions that are diagnostic for the visual tasks in sports.

The development of a clinically practical procedure to evaluate the oculomotor functions critical to the visual task demands of sports is needed. The *in*Vision device may offer the potential to measure maximal velocity of pursuit eye movements.[87] The use of visual search pattern assessment based on the processing of sport-specific visual information seems to offer the best avenue for discriminating subtle differences in oculomotor performance. However, this area has been largely ignored in clinical practice.[243,244] Eye movement recording systems that can superimpose eye position onto the scene being viewed are highly desirable; however, these systems are generally prohibitively expensive for most clinical practices. Hazel and Johnston[245] have described a relatively inexpensive and simple method to create the instrumentation necessary for potential use in the evaluation of athletes.

SPEED OF RECOGNITION

The ability to process visual information rapidly has been considered an essential element for success in fast-action sports. Athletes must analyze available temporal and spatial information during sports situations relatively quickly to make accurate decisions concerning performance responses. The processing speed can be measured psychophysically and has been referred to as *inspection time* (IT).[246,247] Shorter ITs allow accurate decisions to be made

*References 4, 6, 13, 25, 27, 29, 30, 32, 35, 36, 77, 78, 80.

from shorter stimulus durations than from longer ITs. Tachistoscopic procedures to evaluate speed and span of recognition have been used in research for many years.[213,248]

IT measurements have been shown to have a development pattern characteristic of many physical abilities, have good test-retest reliability, and correlate with measures of cognitive abilities.[249,250] Evoked potential findings suggest that IT may be an index of the speed of transfer of information from sensory registers to short-term memory.[251] IT measures may provide a valid and reliable method for evaluating speed of recognition abilities in athletes.[252]

Several studies have investigated speed of recognition abilities in athletes. Most studies have found that experienced athletes can evaluate information more rapidly than inexperienced observers; sport situations studied include cricket, volleyball, tennis, and "fast ball" sports.[252-256] McLeod,[257] however, did not find faster processing speeds in professional cricketers using film footage of cricket bowlers stopped at stages of the ball delivery, although the study was criticized for a small sample size and no statistical analysis. In addition, the study design evaluated only one of a number of important aspects concerning the movement of a ball in flight.[252]

Other studies have investigated both speed and span of recognition by evaluating the ability to recall a sequence of numbers presented tachistoscopically for 1/50 of a second and found no difference in athletes compared with nonathletes.[27,33] However, another study did find a significant difference in performance both for span of recognition and speed of recognition, even when distraction factors were added to the task to simulate competition conditions.[31] Despite these differences in research results, the general conclusion is that the use of numerical stimuli may confound the assessment of speed of recognition in athletes; use of target parameters that more closely simulate the visual information processed in sport situations may yield better discrimination of IT abilities that correlate with sports performance.[3,27] For example, the projection of photographs of baseball pitchers shown at the moment of ball release may better assess how rapidly a baseball player can identify the type of pitch being thrown. The use of tachistoscopic testing for speed of visual processing is frequently recommended as part of the vision assessment of athletes.*

MOTOR RESPONSE TIME

The motor response time, also referred to as the *motor reaction time,* has been defined as the actual time required to complete a simple, predetermined motor movement.[3] Visual-motor reaction time (RT) is the total time required by the visual system to process a stimulus plus the time needed to complete the motor response. Motor response time is a measure of the neuromuscular processing portion of the RT reflex, separate from the visual processing portion of RT.

Little has been published concerning the measurement of motor response time. One study used the motor RT program on the Wayne Saccadic Fixator (www.wayneengineering.com) (Fig. 4-6) and found significantly faster times in athletes than nonathletes.[27] Another study presented normative information from a population of elite athletes using a different device.[3] Devices for measuring motor response time are available from Wayne Engineering and Lafayette Instruments (www.lafayetteinstrument.com), and measuring eye-hand and eye-foot response time is a recommended procedure by some as part of a visual evaluation of athletes.[3,4,27,30]

*References 2, 6, 11, 25, 31, 35, 78.

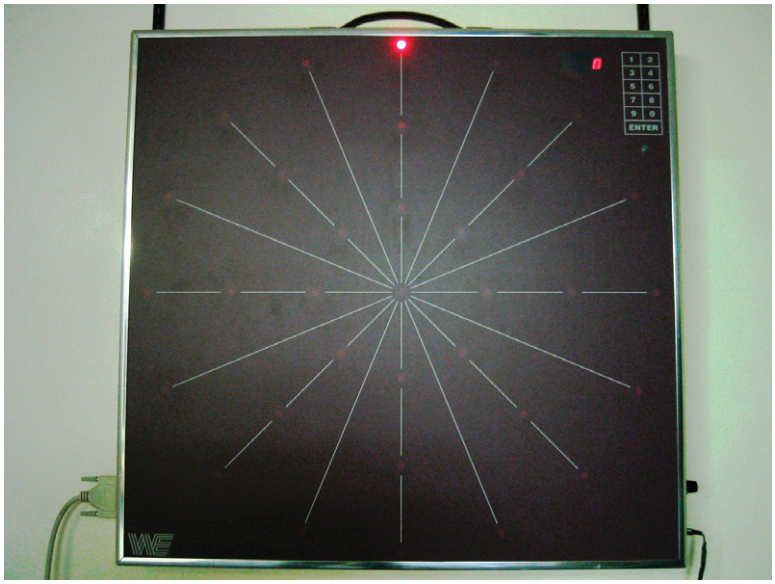


Figure 4-6. The Wayne Saccadic Fixator.

VISUAL-MOTOR REACTION TIME

Visual-motor RT refers to amount of time that elapses between the initiation of a visual stimulus and the completion of a motor response to the stimulus. This is the full completion of the RT reflex, including the period required for the retinal cells to detect the stimulus, the time necessary for the transmission of the retinal cell information to the visual cortex, and the time required for the neuromuscular system to send the information to the muscles that need to be stimulated to make the appropriate motor response. The neurophysiologic parameters of RT are discussed extensively in Chapter 3. Many sport situations require the athlete to make a specific motor response to visual information; therefore the speed of visual and neuromuscular processing is considered by many to be a valuable attribute for an athlete.*

The measure of a simple RT reflex represents the minimal amount of time required to process a visual stimulus presentation and perform a simple motor response to that stimulus. Several studies have found faster simple RTs in athletes (both eye-hand and eye-foot RTs) in various sports compared with nonathletes, or as a discriminator between expertise levels.† However, other studies have not found this correlation.[31,260,261] Visual reaction times have been shown to be impaired by factors such as reduced IQ,[249,250,267] cold,[268] fatigue,[269,270] exercise,[271] and restriction of peripheral visual fields with protective eyewear.[272,273] Gender differences have also been reported, with males achieving faster times than females on average.[3] Performance on complex visual-motor tasks is discussed in the speed of recognition and eye-hand coordination sections of this chapter.

The Wayne Saccadic Fixator, the Visual Choice Reaction Time Apparatus (www.lafayette-instrument.com), and the Multi-Operational Apparatus for Reaction Time (MOART)

*References 3, 5, 7, 31, 32, 215, 258-262.
†References 32, 73, 162, 215, 262-266.

system (www.lafayetteinstrument.com) are commercially available devices for measuring visual-motor response time; measuring eye-hand and eye-foot response time is a recommended procedure by some as part of a visual evaluation of athletes.[3-5,27,30-32,78]

EYE-HAND COORDINATION

Eye-hand coordination is the ability to make synchronized motor responses with the hands to visual stimuli. Many sports require the athlete to react with hand movements to rapidly changing visual information, such as in baseball, tennis, hockey, and football. This skill area is a repeated complex reaction time function for an extended period. A simple stimulus-response procedure that requires minimal cerebral processing results in a faster RT than a complex stimulus/response procedure that requires discrimination of visual information.[274,275]

Studies have been designed to provide normative information for athletes with available instrumentation to evaluate eye-hand coordination.[3,27,33,276-278] The instrumentation designed for evaluating eye-hand coordination has usually been a two-dimensional panel mounted on a wall with an array of lights. The athlete is required to press a randomly lit button as rapidly as possible with one hand; then another button is lit in a random position on the instrument and the RT reflex cycle is repeated for the established time period. The instruments are programmed to test in two primary modes: visual proaction time refers to a self-paced mode for a set period in which each light stays lit until the button is pressed, then the next random light is lit; visual RT refers to an instrument-paced stimuli presentation in which each light stays lit for a preset amount of time (typically 0.75 seconds) before automatically switching to another light whether the button is pressed or not. One study found better visual proaction times in youth athletes than nonathletes[279]; however, another study found no difference in visual proaction time between adult athletes and nonathletes.[27] Visual RT has been compared in athletes and nonathletes in only one study; athletes performed better on the visual RT setting with the Wayne Saccadic Fixator than did nonathletes.[27] The level of ambient room lighting affects performance on the Wayne Saccadic Fixator and the AcuVision 1000 (no longer available commercially) instruments; performance on the instruments significantly improves as room illumination is decreased.[280-282] Eye-hand coordination performance was shown to remain stable with perceived fatigue factors.[283] Artificially reducing depth perception has been shown to diminish eye-hand coordination accuracy in the hitting stroke of elite-level table tennis athletes.[284] Gender differences have also been reported that are most likely related to differences in visual reaction times, with males achieving faster times than females on average.[3,285]

The Wayne Saccadic Fixator, the SVT (www.sportsvision.com.au), Dynavision 2000 (www.dynavision2000.com), and the MOART system are commercially available devices for measuring eye-hand coordination; measuring eye-hand coordination is a recommended procedure by some as part of visual evaluation of athletes.*

EYE-BODY COORDINATION

Eye-body coordination is the ability to make synchronized motor responses with the body to visual stimuli. The procedure is similar to eye-hand coordination testing, with the difference being that the athlete is standing on a square board with a small square fulcrum

*References 3-6, 27, 30, 33-36, 77, 78, 80.

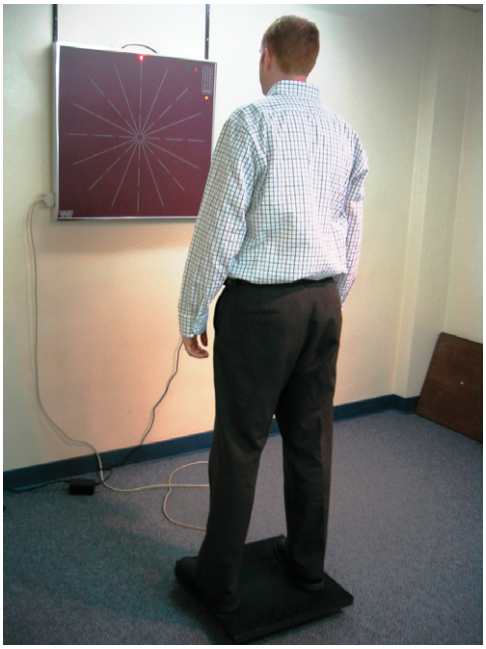


Figure 4-7. The Wayne Electronic Balance Board with the Wayne Saccadic Fixator.

underneath (Fig. 4-7). The athlete must establish balance on the board, then shift the center of balance of the body in response to the direction of the light stimulus on the wall-mounted panel. The stimulus lights are randomly alternated among the top, bottom, left, and right side of the panel, and the athlete must shift the center of balance forward, backward, left, or right, respectively, to engage the switch that extinguishes the light stimulus. Evaluation of eye-body coordination usually involves performance of the task for an established time period, and the number of correct body responses is tabulated.

Only one published study has evaluated this skill in athletes, and it provided normative data on a population of elite athletes.[3] Gender differences were reported that are most likely related to differences in visual RT, with males achieving higher scores than females on average.[3] No studies have compared performance of athletes with nonathletes or correlated performance on this procedure with athletic skills. The Wayne Saccadic Fixator is currently the only commercially available device for measuring eye-body coordination, although measuring eye-body coordination is a recommended procedure by some as part of a visual evaluation of athletes.[3-6,34,35,78] The Wayne Electronic Balance Board program has a significant validity problem because incorrect responses incur no penalty; therefore athletes can rapidly move the balance board in random directions and score fairly well. Newer versions of the program should attempt to account for incorrect responses.

VISUAL COINCIDENCE ANTICIPATION

Visual coincidence anticipation is the ability to predict the arrival of an object or stimulus at a designated place and is usually measured with a motor response. Theoretically, visual

coincidence anticipation timing contributes to the attempt to catch or hit an approaching ball in sports. Predictive visual information concerning the space-time behavior of critical factors in fast-action sports can provide a significant advantage in determining and executing the most appropriate motor responses.[76,286-298]

The Bassin Anticipation Timer (www.lafayetteinstrument.com) is the apparatus most often used to assess coincidence anticipation in laboratory experiments under the assumption that the task simulates actual anticipation tasks.[297,299-305] The Bassin Anticipation Timer consists of tracks of light-emitting diodes (LEDs) that can be fit together to make a "runway" of various lengths (Fig. 4-8). The LEDs are sequentially illuminated down the runway in rapid succession to simulate the apparent motion of the stimulus lights traveling at velocities of 1 to 500 mph. The task requires the athlete to anticipate when the target light will be illuminated as the LEDs are sequentially illuminated along the *z*-axis approaching the athlete and to make a motor response that coincides with the illumination of the target light. The velocity of the stimulus lights can be calibrated to simulate the action speeds encountered in the athletes' sport, in effect simulating the stimulus parameters experienced by the athlete (e.g., the pitch speeds in baseball batting). Research results have suggested that timing accuracy improves with increasing velocity and decreasing range of movement response[297] and that the terminating light chosen and length of the runway affect the accuracy of coincidence anticipation.[302,305] Studies investigating the results of performance on the Bassin Anticipation Timer to batting performance in baseball and softball have found that the two do not correlate.[301,304] Coincidence anticipation has been shown to be independent of visual acuity skills[76] but heavily influenced by direction of motion in depth.[298] The superior coincidence anticipation found in tennis players has been suspected to be influenced by better dynamic visual acuity skills and sport-specific experience.[290]

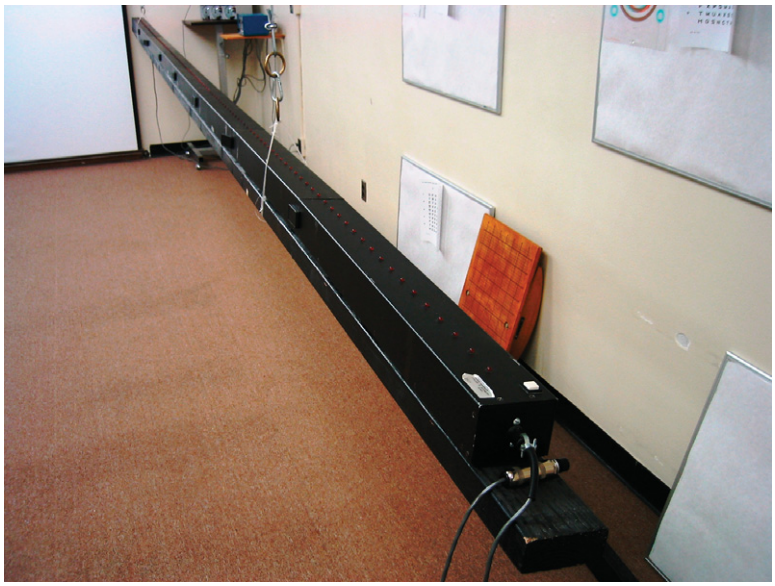


Figure 4-8. The Bassin Anticipation Timer suspended from the ceiling (height is controlled by a garage door opener).

The Bassin Anticipation Timer and the Wayne Speed-trac (www.wayneengineering.com) are commercially available devices for measuring visual coincidence anticipation; measuring visual coincidence anticipation is not a frequently recommended procedure as part of a visual evaluation of athletes.[4] This procedure is more commonly used for vision skill training and enhancement of visual concentration.

VISION AND BALANCE

The ability to maintain balance while processing complex, fast-action visual information is a task demand fundamental to many dynamic sports. The athlete is frequently required to preserve balance while the oculomotor system is engaged in pursuit and/or saccadic eye movements. The vision and balance test sequence was developed by Coffey and Reichow[3] to evaluate systematically some of the many types of vision and balance demands encountered by the competitive athlete. The sequence involves performance of several different tasks while the subject is either standing or moving on a balance rail secured to the floor. Maintenance of balance is subjectively rated during each task with a scale that defines levels of performance quality. Only one published study has investigated the vision and balance skills described by Coffey and Reichow, and the purpose of the study was to provide normative data on a population of elite athletes.[3] Investigations have evaluated the role of vision on dynamic balance in gymnastics, reporting that vision played an important role in skills acquisition.[306-308] It is not commonly recommended as part of a sports vision evaluation.[4,20] The visual skills involved in the assessment appear relevant; however, test validity and reliability are significant concerns.

FIELD DEPENDENCE AND INDEPENDENCE

Field dependence and independence refer to the cognitive style of processing information to discern relevant stimuli from an irrelevant stimulus background. The theory implies that field-dependent persons rely more on external cues during information processing, and field-independent persons use internal cues more.[309,310] Kane postulated that field dependence was an advantage in "open skill"[311,312] team sports (e.g., basketball, football, hockey) because athletes must make constant adjustments in performance to external factors (e.g., teammates, opponents).[313] Athletes competing in "closed skill"[311,312] sports (e.g., diving, gymnastics, track and field) tend to rely more on internal physical components such as body orientation.[313]

Many studies have concluded that field-independent individuals tend to have higher levels of athletic skills and are better at learning athletic skills.[314-326] Field independence has been determined to be related to fewer injuries in football,[327] and athletic training results in increased field independence on certain tests.[328,329] However, some studies have found equivocal or contradictory results; the difference in results has been suggested to be a result of the large variety of tests used in the research.[324] Tests that require subjects to respond to paper-and-pencil tasks (e.g., embedded figures test and group hidden figures test) yield different results than procedures that require the comparison of visual and vestibular information (e.g., rod and frame test). The rod and frame test (Fig. 4-9) appears to be a more reliable method for assessing athletes' relative preferences for visual or proprioceptive stimuli in a conflicting environment. With this test paradigm, athletes participating in closed-skill sports are more field independent than are those competing in open-skill sports,

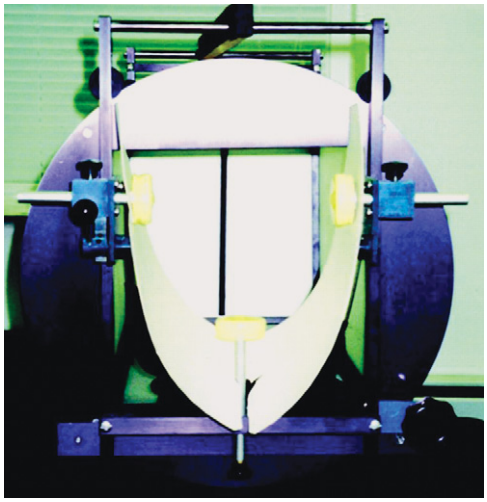


Figure 4-9. A rod and frame test.

and higher level athletes are more field independent than lower level athletes.[324,326] The rod and frame test is not routinely used or recommended by eye care providers.

PERIPHERAL AWARENESS

The visual field is the entire extent of the external world that can be seen without a change in fixation.[330] In many sports situations, especially team sports, processing of information from the peripheral visual fields is a beneficial element to successful performance. The factors involved in assessment of peripheral vision include the extent of the visual fields, the sensitivity of the visual fields, the visual response speed to peripheral information, and spatial localization accuracy of peripheral stimuli.

Early studies investigated the extent of visual fields in athletes compared with nonathletes. Results indicate that athletes have a larger extent of horizontal and vertical visual fields than do nonathletes,[169,213,215,331-336] and that athletes have better form recognition at more peripheral locations.[27,32,332,333] One study found no difference in the extent of visual field between varsity and junior varsity college football players, so it may not be a sensitive discriminator of skill level.[337] Some studies have found increases in the extent of visual fields with exercise[169,338-340]; however, these findings have been challenged more recently as being caused by the differences in visual field techniques, limited sample size, and lack of a control group in earlier studies.[341] Recently some studies have assessed synchronoptical ability: the ability to assess visual information occurring at two different locations simultaneously. For example, the judgment of a foot fault in tennis requires the line judge to determine whether the server's foot crossed the line before contact with the ball during the serve. This may be a relevant testing paradigm for sports in which the athlete must process both peripheral and central information simultaneously for optimal performance. Study results demonstrate that synchronoptical differentiation is difficult without support from audition,[342] but that the skill appears trainable.[343] Physical activity does not appear to increase peripheral perception

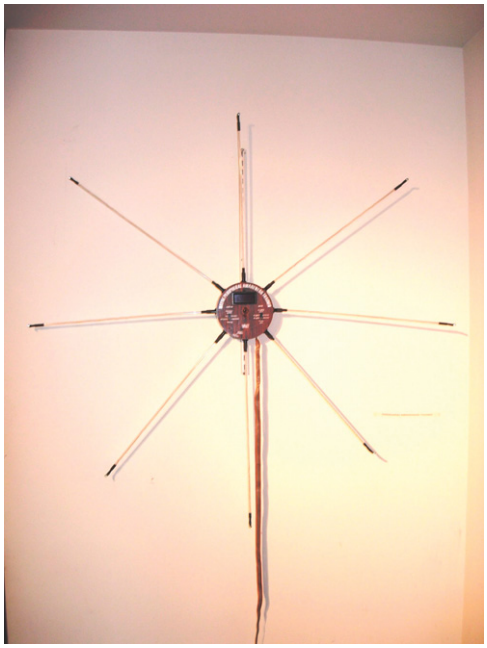


Figure 4-10. The Wayne Peripheral Awareness Trainer. (Courtesy Alan Berman, OD, Ridgefield, Conn.)

performance, but it does improve central perceptual performance.[344] Therefore the search for visual field defects in routine vision testing has a low yield in athletes yet should be performed as part of the vision examination for sports participation for general health purposes.

Sports vision practitioners recently have attempted to evaluate peripheral response speed with the Wayne Peripheral Awareness Trainer (PAT) (www.wayneengineering.com). The PAT has a central circular module that contains a central fixation light and has eight clear rods extending from it with red LEDs at each end (Fig. 4-10). The athlete holds a joystick, fixates centrally, and moves the joystick in the direction of an LED when it is perceived in peripheral vision. This system assesses only peripheral response speed, not accuracy, and fixation is not monitored in a controlled manner. The level of ambient room lighting affects performance on the Wayne PAT; performance on the instrument significantly improves as room illumination is decreased.[281] Some normative data have been published for the PAT,[3,281] but even though assessment of peripheral vision is recommended as part of a sports vision evaluation, further development is necessary to more closely simulate the visual task demands of sports.*

VISUALIZATION AND IMAGERY

Visualization, or mental imagery, is the act of constructing mental images of an object or event that resembles the actual appearance of the object or event. Studies have suggested that

*References 3-6, 10, 11, 13, 15, 16, 21, 27, 29-33, 35, 36, 77, 78, 80, 345.

mental imagery may share the same types of neural processes as visual perception, which has significant implications in sports.[346] Some studies have evaluated the differences between visual imagery and motor imagery and suggest they reflect different aspects of mental imagery.[347-350] Elite athletes have been repeatedly shown to use imagery strategies in preparation for performance.[351-354]

Many studies have suggested that mental imagery of motor skill performance shares cognitive processes with the actual performance of motor tasks.[355-361] Neuroimaging studies of subjects performing motor imagery demonstrate brain activity in the areas of motor preparation and performance.[347,362-364] Studies using electromyographic recordings show that mental imagery of a motor activity produces low-level motor effects that correspond to patterns of physical action; similar muscles and motor programs are activated.[356,358,365-369] Motion imagery has also been shown to correspond to attention for visuospatial imformation.[370] Expertise levels influence the amount of muscular response during skill imagery, in which higher levels of expertise produce increased electromyographic activity.[368] Task difficulty and expertise level have also been shown to affect the time required for mental imagery more than for physical performance.[369,371-374] Athletes with lower skill levels require more time to execute mental imagery of a physical performance than the actual time required to perform the physical act.

Suin[375-379] first described methods involving mental imagery and relaxation as a psychological intervention to affect motor performance favorably. The use of mental imagery has become a significant factor for athletes, coaches, sports psychologists, and some sports vision specialists.[353,359,380-383] Relatively few studies have investigated the effectiveness of mental imagery in actual competition; most investigate the effect on skill acquisition.[353,384] The results of studies in skill acquisition or skill improvement have been contradictory, although the athlete skill level and length of intervention have been confounding variables for study comparison.[357,385] Sports in which visual-motor tasks have been studied include basketball,[386-388] tennis,[389,390] karate,[391-394] swimming,[395] gymnastics,[396] racquetball,[397] archery,[384] and golf.[398-400]

Although the value of visualization and mental imagery in sports performance has been acclaimed, no objective assessment of individual ability exists. Many subjective assessment procedures are used by sports psychologists; however, use of these or other procedures to assess visualization skills is recommended but rarely used by sports vision practitioners.[5,6,36,77,345,401-403]

OCULAR HEALTH STATUS

A complete assessment of ocular health is an obligatory portion of a sports vision evaluation.[3-5,13,15,16,38] A complete assessment generally includes evaluation of the external adnexa, anterior segment of the eye with biomicroscopy, pupillary responses, intraocular pressure, posterior segment through a dilated pupil, and the visual fields of each eye. The presence of any ocular abnormality should be fully charted and photographed if possible, and the consequences of the abnormality explained in detail to the athlete. The potential risks of any abnormality to sports participation should be fully addressed and appropriate recommendations discussed for protection of the athlete. Chapters 6 and 7 cover these issues in detail.

DEVELOPING A SPORTS VISION EVALUATION

Most sports vision evaluations do not assess all the areas described in this chapter for all athletes. The practitioner's mission is to identify those areas that appear to be critical for

success in performing the visual tasks required of the athlete, as well as those areas that are beneficial to overall performance. The contents of this chapter should show that the visual skills that correlate with successful sports performance have not yet been definitively identified. The procedures that yield the most relevant assessment of critical visual skills have yet to be identified definitively as well. However, the critical and beneficial visual skill areas should be included in the evaluation of the athlete by using the best available protocols, when possible. Those areas not identified as critical or beneficial to performance may not require assessment. As the practitioner gains experience with a variety of sports, sport-specific evaluations can be formulated for use with subsequent evaluations of athletes involved in these sports. The assessment areas and procedures used can be modified as needed on the basis of the results of research and the clinician's own experience.

The results of the evaluation should be summarized for the patient, and a performance profile is recommended to highlight areas of strength or weakness. The development of a performance profile and strategies for reporting results and recommendations are presented in Chapter 5.

REFERENCES

1. Stine CD, Arterburn MR, Stern NS: Vision and sports: a review of the literature, *J Am Optom Assoc 53:*627, 1982.
2. Hitzeman SA, Beckerman SA: What the literature says about sports vision, *Optom Clin 3:*145, 1993.
3. Coffey B, Reichow AW: Optometric evaluation of the elite athlete, *Probl Optom 2:*32, 1990.
4. Berman AM: Clinical evaluation of the athlete, *Optom Clin 3:*1, 1993.
5. Gardner JJ, Sherman A: Vision requirements in sport. In Loran DFC, MacEwen CJ, editors: *Sports vision*, Oxford, 1995, Butterworth-Heinemann.
6. The AOA Sports Vision Section Guidebook Committee: *Sports vision guidebook: volumes I-V*, St Louis, 1984-2000, American Optometric Association.
7. Beckerman SA, Hitzeman S: The ocular and visual characteristics of an athletic population, *Optometry 72:*498, 2001.
8. Ettinger ER: *Professional communications in eye care*, Boston, 1994, Butterworth-Heinemann.
9. Classe JG: Sports related ocular trauma: a preventable epidemic, *J Am Optom Assoc 67:*96, 1996.
10. Etting GL: An optometrist's vision of sports, *Calif Optom 3:*25, 1977.
11. Getz DJ: Vision and sports, *J Am Optom Assoc 49:*385, 1978.
12. Gregg JR: *Vision and sports: an introduction*, Stoneham, MA, 1987, Butterworth Publishers, pp 103-104.
13. Berman AM: Sports vision for the primary care practitioner, *Eye Quest Magazine 4:*46, 1994.
14. Tussing L: The effect of football and basketball on vision, *Res Q Am Assoc Health Phys Educ 11:*16, 1940.
15. Martin WF: A research study on athletes' vision, *Contacto 7:*5, 1963.
16. Bauscher WA: Vision and the athlete, *Optom Weekly 59:*21, 1968.
17. Garner AI: What a practitioner should know about an athlete's vision, *Contacto 20:*24, 1976.
18. Garner AI: An overlooked problem: athletes' visual needs, *Phys Sportsmed 5:*75, 1977.
19. Beals RP, Mayyasi AM, Templeton AE, et al: The relationship between basketball shooting performance and certain visual attributes, *Am J Optom Arch Am Acad Optom 48:*585, 1971.
20. Pitts DG: The role of vision in sports and recreational activities, *South J Optom 16:*11, 1974.
21. Runninger J: Vision requirements of competitive sports, *South J Optom 17:*13, 1975.
22. Morris GS, Kreighbaum E: Dynamic visual acuity of varsity women volleyball and basketball players, *Res Q Am Assoc Health Phys Educ 48:*480, 1977.

23. White VW: Visual acuity versus visual skill in athletic performance, *Calif Optom 3:*22, 1977.
24. Erenstone R, Miller NP, Silagy ZS: Optometry at the 1980 Winter Olympics, *J Am Optom Assoc 52:*647, 1981.
25. Harris PA, Blum DS: AOA Sports Vision Section screening of basketball officials, *J Am Optom Assoc 55:*130, 1984.
26. Gregg JR: *Vision and sports: an introduction*, Stoneham, MA, 1987, Butterworth Publishers, pp 61-72.
27. Christenson GN, Winkelstein AM: Visual skills of athletes versus nonathletes: development of a sports vision testing battery, *J Am Optom Assoc 59:*666, 1988.
28. Fremion AS, DeMyer WE, Helveston EM, et al: Binocular and monocular visual function in world class tennis players, *Bin Vis 1:*147, 1986.
29. Wachs H: Sports vision, *Behav Optom 3:*215, 1991.
30. Sports vision gets gold at the Barcelona Olympics, *Calif Optom 18:*6, 1992.
31. Melcher MH, Lund DR: Sports vision and the high school student athlete, *J Am Optom Assoc 63:*466, 1992.
32. Hughes PK, Blundell NL, Walters JM: Visual and psychomotor performance of elite, intermediate and novice table tennis competitors, *Clin Exp Optom 76:*51, 1993.
33. Milne DC, Lewis RV: Sports vision screening of varsity athletes, *Sports Vis 1:*8, 1993.
34. Goldsmid MA: Visual fitness and performance in tennis athletes, *Eye Quest Magazine* p 38, 1994.
35. Berman AM: Sports performance vision testing, *Optom Today 4:*28, 1996.
36. Wilson TA, Falkel J: *Sports vision training for better performance*, Champaign, IL, 2004, Human Kinetics, pp 1-13.
37. Jendrusch G, Bornemann R, Froschauer M, et al: Visual performance profile of top skiers. In International Society for Ski Trauma and Safety, editors: *14th International symposium on ski trauma & skiing safety*, August 5-10, 2001, Queenstown, New Zealand, p 78.
38. Elkin EH: *The effect of target velocity, exposure time and anticipatory tracking time on dynamic visual acuity* [dissertation], Medford, MA, 1961, Tufts University.
39. Berry RN: Quantitative relations among vernier, real depth and stereoscopic depth acuities, *J Exp Psychol 38:*708, 1948.
40. Coffey B, Reichow AW, Johnson T, et al: Visual performance differences among professional, amateur, and senior amateur golfers. In Cochran AJ, editor: *Science and golf II*, London, 1994, E&FN Spon.
41. Moses RA: Accommodation. In Moses RA, Hart WM, editors: *Adler's physiology of the eye: clinical application*, St Louis, 1987, CV Mosby.
42. Laby DM, Rosenbaum AL, Kirschen DG, et al: The visual function of professional baseball players, *Am J Ophthalmol 122:*476, 1996.
43. Winograd S: The relationship of timing and vision to baseball performance, *Res Q Am Assoc Health Phys Educ 13:*481, 1942.
44. Jendrusch G, Kaczmarek L, Lange P, et al: Visual requirements and visual performance profile in soccer, *Med Sci Sports Exerc 38:*446, 2006.
45. Banister H, Blackburn JM: An eye factor affecting proficiency at ball games, *Br J Psychol 21:*382, 1931.
46. Blackburn RH: Perception of movement, *Am J Optom 14:*365, 1937.
47. Graham CH, Cook C: Visual acuity as a function of intensity and exposure time, *Am J Psychol 49:*654, 1937.
48. Ludvigh EJ: The gradient of retinal illumination and its practical significance, *Am J Ophthalmol 20:*260, 1937.
49. Langmuir I: The speed of the deer fly, *Science 87:*233, 1938.
50. Ludvigh E: Extrafoveal visual acuity as measured with Snellen test-letters, *Am J Ophthalmol 24:*303, 1941.

51. Ludvigh E: Visibility of the deer fly in flight, *Science 105:*176, 1947.
52. Ludvigh E: The visibility of moving objects, *Science 108:*63, 1948.
53. Ludvigh EJ: Visual acuity while one is viewing a moving object, *Arch Ophthalmol 42:*14, 1949.
54. Westheimer G: Eye movement responses to a horizontally moving visual stimulus, *AMA Arch Ophthalmol 52:*932, 1954.
55. Hulbert SF, Burg A, Knoll HA, et al: A preliminary study of dynamic visual acuity and its effects in motorist's vision, *J Am Optom Assoc 29:*359, 1958.
56. Ludvigh EJ, Miller JW: Study of visual acuity during the ocular pursuit of moving test objects. I. Introduction, *J Opt Soc Am 48:*799, 1958.
57. Miller JW: Study of visual acuity during the ocular pursuit of moving test objects. II. Effects of direction of movement, relative movement, and illumination, *J Opt Soc Am 48:*803, 1958.
58. Burg A, Hulbert SF: Dynamic visual acuity and other measures of vision, *Percept Mot Skills 9:*334, 1959.
59. Burg A, Hulbert S: Dynamic visual acuity as related to age, sex and static acuity, *J Appl Psych 45:*111, 1961.
60. Miller JW, Ludvigh E: The effect of relative motion on visual acuity, *Service Ophthalmol 7:*83, 1962.
61. Weissman S, Freeburne CM: Relationship between static and dynamic visual acuity, *J Exp Psychol 69:*141, 1965.
62. Burg A: Visual acuity as measured by dynamic and static tests: a comparative evaluation, *J Appl Psychol 50:*460, 1966.
63. Kirshner AJ: Dynamic acuity: a quantitative measure of eye movements, *J Am Optom Assoc 38:*460, 1967.
64. Barmack NH: Dynamic visual acuity as an index of eye movement control, *Vision Res 10:*1377, 1970.
65. Brown B: Resolution thresholds for moving targets at the fovea and in the peripheral retina, *Vision Res 12:*293, 1972.
66. Brown B: Dynamic visual acuity, eye movements and peripheral acuity for moving targets, *Vision Res 12:*305, 1972.
67. Brown B: The effect of target contrast variation on dynamic visual acuity and eye movement, *Vision Res 12:*1213, 1972.
68. Cline D, Hoffstetter HW, Griffin JR: *Dictionary of visual science*, ed 3, Radnor, PA, 1980, Chilton.
69. Hoffman LG, Rouse M, Ryan JB: Dynamic visual acuity: a review, *J Am Optom Assoc 52:*883, 1981.
70. Westheimer G: Eye movement responses to a horizontally moving visual stimulus, *AMA Arch Ophthalmol 52:*932, 1954.
71. Jendrusch G, Wenzel V, Heck H: The significance of dynamic visual acuity as a performance-influencing parameter in tennis [abstract], *Int J Sports Med 19:*46, 1998.
72. Dippner R, The relation between basketball ability and visual acuity in the unicorn, *Am J Optom Arch Am Acad Optom 50:*656, 1973.
73. Whiting HTA, Sanderson FH: Dynamic visual acuity and performance in a catching task, *J Mot Behav 6:*87, 1974.
74. Sanderson FH, Whiting HTA: Dynamic visual acuity, a factor in catching performance, *J Motor Behav 10:*7, 1978.
75. Starks JL: Skill in field hockey: the nature of the cognitive advantage, *J Sport Psychol 9:*146, 1987.
76. Millslagle D: Coincidence anticipation and dynamic visual acuity in young adolescents, *Percept Mot Skills 99:*1147, 2004.
77. Seiderman A, Schneider S: *The athletic eye: improved sports performance through visual training*, New York, 1983, Hearst Books.
78. Reichow AW, Stern NS: Athlete and optometrist: performance oriented, *OEP Curriculum II 59:*35, 1986.
79. Rouse MW, DeLand P, Christian R, et al: A comparison study of dynamic visual acuity between athletes and nonathletes, *J Am Optom Assoc 59:*946, 1988.

80. Sherman A: Sports vision testing and enhancement: implications for winter sports, In Casey M, Foster C, Hixson E, editors: *Winter sports medicine*, Philadelphia, 1990, FA Davis, pp 78-84.
81. Ishigaki H, Miyao M: Differences in dynamic visual acuity between athletes and nonathletes, *Percept Mot Skills 77:*835, 1993.
82. Teig D: Three sports vision skills every patient needs, *Contact Lens Spectrum 28:*19, 1993.
83. Long GM, Penn DL: Dynamic visual acuity: normative functions and practical applications, *Bull Psychonomic Soc 25:*253, 1987.
84. Long GM, Garvey PM: The effects of target wavelength on dynamic visual acuity under photopic and scotopic viewing, *Hum Fact 30:*3, 1988.
85. Coffey B, Reichow AW: Athletes vs non-athletes: static visual acuity, contrast sensitivity, dynamic visual acuity, [abstract], *Invest Ophthalmol Vision Sci 30:*517, 1989.
86. Long GM, Riggs C: Training effects on dynamic visual acuity with free head viewing, *Perception 20:*363, 1991.
87. NeuroCom International, Inc. Balance Manager products, http://www.onbalance.com/neurocom/products/inVision.aspx.
88. Coffey B, Richards L, Olmschenk S, et al: Preliminary normative data for a new device to measure dynamic visual acuity [abstract], *Optom Vis Sci* [suppl]:127, 2004.
89. Coffey B, Buchholz J, Miller K, et al: Test–re-test reliability for a new device to measure dynamic visual acuity [abstract], *Optom Vis Sci 82:*e-abstract 055184, 2005.
90. Ginsburg AP: *Visual information processing based on spatial filters constrained by biological data*, Springfield, VA, 1978, National Technical Information Service, pp 97-98.
91. Ginsburg AP: *Specifying relevant spatial information for image evaluation and display design: an explanation of how we see certain objects*. Proceedings of the SID, *21:*219, 1980.
92. Ginsburg AP: Contrast sensitivity: relating visual capability to performance, *USAF Medical Service Digest 34:*15-19, 1983.
93. Hoffman LG, Polan G, Powell J: The relationship of contrast sensitivity functions to sports vision, *J Am Optom Assoc 55:*747, 1984.
94. Kluka DA, Love PA, Allen S: Contrast sensitivity functions of selected collegiate female athletes, *Sports Vision 5:*18, 1989.
95. Kluka D, Love P: Contrast sensitivity in International Special Olympics, Women's Invitational Volleyball Championships, and recreational volleyball players, *Palaestra 8:*11, 1992.
96. Schneider HG, Kluka DA, Love PA: Contrast sensitivity in selected professional and collegiate football players, *J Optom Vis Dev 23(4):*23, 1992.
97. Schellart NA: Contrast sensitivity of air-breathing nonprofessional scuba divers at a depth of 40 meters, *Percept Mot Skills 75:*275, 1992.
98. Love PA, Kluka DA: Contrast sensitivity function in elite women and men softball players, *Int J Sports Vision 1:*25, 1993.
99. Kluka DA, Love PA, Sanet R, et al: Contrast sensitivity function profiling: by sport and sport ability level, *Int J Sports Vision 2:*5, 1995.
100. Kluka DA, Love PA, Covington K, et al: Performance profiles of the intercollegiate softball player and what they mean for the coach, *Sports Vision 16:*22, 2000.
101. Jendrusch G, Wittmann J, Herber F, et al: Strain-induced changes in visual efficiency as exemplified by contrast sensitivity [abstract], *Int J Sports Med 19:*46, 1998.
102. Grey CP: Changes in contrast sensitivity when wearing low, medium and high water content soft lenses, *J Br Contact Lens Assoc 9:*21, 1986.
103. Nowozyckyj A, Carney LG, Efron N: Effect of hydrogel lens wear on contrast sensitivity, *Am J Optom Physiol Opt 65:*263, 1988.

104. Oxenberg LD, Carney LG: Visual performance with aspheric rigid contact lenses, *Optom Vision Sci 66:*818, 1989.
105. Kluka DA, Love PA: The effects of daily-wear contact lenses on contrast sensitivity in selected professional and collegiate female tennis players, *J Am Optom Assoc 64:*182, 1993.
106. Ginsburg AP, Evans DW, Cannon MW, et al: Large sample norms for contrast sensitivity, *Am J Optom Physiol Opt 61:*80, 1984.
107. Corwin TR, Richman JE: Three clinical tests of the spatial contrast sensitivity function: a comparison, *Am J Optom Physiol Opt 63:*413, 1986.
108. Kennedy RS, Dunlap WP: Assessment of the Vistech contrast sensitivity test for repeated-measures applications, *Optom Vision Sci 67:*248, 1990.
109. Brown B, Yap MKH: Variability in repeated contrast sensitivity measures: implications for the individual patient, *Clin Exp Optom 74:*151, 1991.
110. Reeves BC, Wood JM, Hill AR: Vistech VCTS 6500 charts—within- and between-session reliability, *Optom Vision Sci 68:*728, 1991.
111. Tomlinson A, Mann G: An analysis of visual performance with soft contact lens and spectacle correction, *Ophthalmol Physiol Opt 5:*53, 1985.
112. Griffiths G: Eye dominance in sport: a comparative study, *Optom Today 15:*34, 2003.
113. Murphy HL: Sports and vision, *Optom Monthly 72:*20, 1981.
114. Lingelbach B, Dennhoven P, Jendrusch G, et al: *Shape of the cornea and visual acuity of athletes* [poster], ACSM Meeting, Denver, CO, June 2006.
115. Porta GB: *De refractione,* 1593.
116. Classe JG, Daum KM, Semes LP, et al: Association between eye and hand dominance and hitting, fielding and pitching skill among players of the Southern Baseball League, *J Am Optometric Assoc 67:*81, 1996.
117. Coons JC, Mathias RJ: Eye and hand preference tendencies, *J Genet Psychol 35:*629, 1928.
118. Miles WR: Ocular dominance demonstrated by unconscious sighting, *J Exp Psychol 12:*113, 1929.
119. Miles WR: Ocular dominance in human adults, *J Gen Psychol 3:*412, 1930.
120. Cuff NB: A study of eyedness and handedness, *J Exp Psychol 14:*164, 1930.
121. Eyre MB, Schmeeckle MM: A study of handedness, eyedness, and footedness, *Child Develop 4:*73, 1933.
122. Washburn MF, Faison C, Scott R: A comparison between the Miles A-B-C method and retinal rivalry as tests of eye dominance, *Am J Psychol 46:*633, 1934.
123. Buxton CE, Crosland HR: The concept of "eye preference," *Am J Psychol 49:*458, 1937.
124. Jasper HH, Raney ET: The phi test of lateral dominance, *Am J Psychol 49:*450, 1937.
125. Williams LL: A test to determine the dominant eye, *Optom Weekly 33:*33, 1942.
126. Crider B: A battery of tests for the dominant eye, *J Gen Psychol 31:*179, 1944.
127. Walls GL: A theory of ocular dominance, *AMA Arch Ophthalmol 45:*387, 1951.
128. Crovitz HF, Zener K: A group-test for assessing hand- and eye-dominance, *Am J Psychol 75:*271, 1962.
129. Gronwall DMA, Sampson H: Ocular dominance: a test of two hypotheses, *Br J Psychol 62:*175, 1971.
130. Coren S, Kaplan CP: Patterns of ocular dominance, *Am J Optom Arch Am Acad Optom 50:*283, 1973.
131. Porac C, Coren S: The dominant eye, *Psychol Bull 83:*880, 1976.
132. Metalis SA, Niemiec AJ: Assessment of eye dominance through response time, *Percept Mot Skills 59:*539, 1984.
133. Coren S, Porac C: Monocular asymmetries in visual latency as a function of sighting dominance, *Am J Optom Physiol Opt 59:*987, 1982.
134. Brown ER, Taylor P: Handedness, footedness, and eyedness, *Percept Mot Skills 66:*183, 1988.
135. Laby DM, Rosenbaum AL, Kirschen D: Ocular dominance, central, etc. and baseball, *Bi Vis Strabismus Q 13:*165, 1988.

136. Woo TL, Pearson K: Dextrality and sinistrality of hand and eye, *Biometrika 19:*165, 1927.
137. Duke-Elder WS: *Textbook of ophthalmology,* vol 1, St Louis, 1938, CV Mosby, pp 1056-1058.
138. Berner GE, Berner DE: Relation of ocular dominance, handedness, and the controlling eye in binocular vision, *AMA Arch Ophthalmol 50:*603, 1953.
139. Porac C, Coren S: Is eye dominance a part of generalized laterality? *Percep Mot Skills 40:*763, 1975.
140. Rymar K, Kameyama T, Niwa S-I, et al: Hand and eye preference patterns in elementary and junior high school students, *Cortex 20:*441, 1984.
141. Portal JM, Romano PE: Patterns of eye-hand dominance in baseball players, *N Engl J Med 319:*655, 1988.
142. Laby DM, Kirschen DG, Rosenbaum AL, et al: The effect of ocular dominance on the performance of professional baseball players, *Ophthalmology 105:*864, 1998.
143. Portal JM, Romano PE: Ocular sighting dominance: a review and a study of athletic proficiency and eye-hand dominance in a collegiate baseball team, *Bi Vis Strabismus Q 13:*125, 1998.
144. Stull RB: Study of hand and eye dominance and coordination of basketball players, *J Am Optom Assoc 31:*203, 1960.
145. Shapiro IL, Kropp L: Hand and eye dominancy in target shooting—part 1, *J Am Optom Assoc 35:*761, 1964.
146. Shapiro IL, Kropp L: Hand and eye dominancy in target shooting—part 2, *J Am Optom Assoc 35:*863, 1964.
147. Adams GL: Effect of eye dominance in baseball batting, *Res Q Am Assoc Health Phys Educ 36:*3, 1965.
148. Gregg JR: Your eyes for shooting, *Optom Weekly 58:*37, 1967.
149. Falkowitz C, Mendel H: The role of visual skills in batting averages, *Optom Weekly 68:*33, 1977.
150. Gregg JR: How to prescribe for hunters and marksmen, *J Am Optom Assoc 51:*675, 1980.
151. Tieg D: *Major league baseball research project*, Ridgefield, CT, 1980, Institute for Sports Vision, pp 1-9.
152. Gregg JR: Target the sharpshooters in your practice, *Optom Man 22:*65, 1986.
153. Gregg JR: *Vision and sports: an introduction*, Stoneham, MA, 1987, Butterworth Publishers, pp 148-154.
154. Dunham P: Coincidence-anticipation performance of adolescent baseball players and nonplayers, *Percept Mot Skills 68:*1151, 1989.
155. Noll JE: Vision considerations in shooting sports, *N Engl J Optom 42:*6, 1990.
156. Steinberg GM, Frehlich SG, Tennant LK: Dextrality and eye position in putting performance, *Percept Mot Skills 80:*635, 1995.
157. Jones LF, Classe JG, Hester M, et al: Association between eye dominance and training for rifle marksmanship: a pilot study, *J Am Optom Assoc 67:*73, 1996.
158. Robinson S, Jacobsen S, Heintz B: Crossed hand-eye dominance: prevalence in normal and athletic populations, *J Optom Vis Dev 28:*235, 1997.
159. Milne C, Buckolz E, Cardenas M: Relationship of eye dominance and batting performance in baseball players, *Int J Sports Vis 2:*17, 1995.
160. Goss DA: The relationship of eye dominance and baseball batting: a critical literature review, *J Behav Optom 9:*87, 1998.
161. Shick J: Relationship between depth perception and hand-eye dominance and free-throw shooting in college women, *Percept Mot Skills 33:*539, 1971.
162. Rombouts SA Barkhof F, Sprenger M, et al: The functional basis of ocular dominance: functional MRI findings, *Neurosci Lett 221:*1, 1996.
163. Schor CM, Flom MC: The relative value of stereopsis as a function of viewing distance, *Am J Optom Arch Am Acad Optom 46:*805, 1969.
164. Ebenholtz SM, Wolfson DM: Perceptual aftereffects of sustained convergence, *Percept Psychophysics 17:*485, 1975.

165. Paap KR, Ebenholtz SM: Perceptual consequences of potentiation in the extraocular muscles: an alternative explanation for adaptation to wedge prisms, *J Exp Psych Human Percept Perform 2:*457, 1976.
166. Paap KR, Ebenholtz SM: Concomitant direction and distance aftereffects of sustained convergence: a muscle potentiation explanation for eye-specific adaptation, *Percept Psychophysics 21:*307, 1977.
167. Ebenholtz SM, Fisher SK: Distance adaptation depends upon the plasticity in the oculomotor control system, *Percept Psychophysics 31:*551, 1982.
168. Shebilske WL, Karmiohl CM, Profit DR: Induced esophoric shifts in eye convergence and illusory distance in reduced and structured viewing conditions, *J Exp Psych Human Percept Perform 9:*270, 1983.
169. Graybiel A, Jokl E, Trapp C: Russian studies of vision in relation to physical activity and sports, *Res Q Am Assoc Health Phys Educ 26:*480, 1955.
170. Pickwell D: Binocular vision in sport, *Optom Today 26:*240, 1986.
171. Schor CM, Ciuffreda KJ: Vergence eye movements, London, 1983, Butterworth.
172. Sheedy JE: Actual measurement of fixation disparity and its use in diagnosis and treatment, *J Am Optom Assoc 51:*1079, 1980.
173. Stuart JA, Burian HM: Changes in horizontal heterophoria with elevation and depression of gaze, *Am J Ophthalmol 53:*274, 1962.
174. McKee MC, Young DA, Kohl P, et al: Effect of head and eye positions on fixation disparities, phorias, and ductions at near, *Am J Optom Physiol Opt 64:*909, 1987.
175. Coffey B, Reichow AW, Colburn PB, et al: Influence of ocular gaze and head position on 4 m heterophoria and fixation disparity, *Optom Vision Sci 68:*893, 1991.
176. Coffey B, Mathison T, Viker M, et al: Visual alignment considerations in golf putting consistency. In Cochran AJ, editor: *Science and golf: Proceedings of the First World Scientific Congress of Golf*, London, 1990, E&FN Spon, pp 76-80.
177. Wheatstone C: Contributions to the physiology of vision. Part the first. On some remarkable and hitherto unobserved, phenomena of binocular vision, *Phil Trans R Soc London 128:*371, 1838.
178. Hubel DH, Wiesel TN: Receptive fields of single neurones in the cat's striate cortex, *J Physiol 148:*574, 1959.
179. Nikara T, Bishop PO, Pettigrew JD: Analysis of retinal correspondence by studying receptive fields of binocular single units in cat striate cortex, *Exp Brain Res 6:*353, 1968.
180. Bishop PO, Henry GH, Smith CJ: Binocular interaction fields of single units in the cat striate cortex, *J Physiol 216:*39, 1971.
181. Regan D, Beverly KI: Electrophysiological evidence for existence of neurones sensitive to direction of depth movement, *Nature 246:*504, 1973.
182. Richards W, Regan D: A stereo field map with implications for disparity processing, *Invest Ophthalmol Vision Sci 12:*904, 1973.
183. Pettigrew JD: Binocular neurones which signal change of disparity in area 18 of cat visual cortex, *Nat New Biol 241:*123, 1973.
184. Zeki SM: Cells responding to changing image size and disparity in the cortex of the rhesus monkey, *J Physiol 242:*827, 1974.
185. Beverly KI, Regan D: The relation between discrimination and sensitivity in the perception of motion in depth, *J Physiol 249:*387, 1975.
186. Cynader M, Regan D: Neurones in cat parastriate cortex sensitive to the direction of motion in three-dimensional space, *J Physiol 274:*549, 1978.
187. Regan D, Beverley KI: Binocular and monocular stimuli for motion in depth: changing-disparity and changing-size feed the same motion-in-depth stage, *Vision Res 19:*1331, 1979.
188. Regan D, Beverley K, Cynader M: The visual perception of motion in depth, *Sci Am 241:*136, 1979.

189. Cynader M, Regan D: Neurons in cat visual cortex tuned to the direction of motion in depth: effects of positional disparity, *Vision Res 22:*967, 1982.
190. Toyama K, Kozasa T: Responses of Clare-Bishop neurones to three dimensional movement of light stimulus, *Vision Res 22:*571, 1982.
191. Schor CM, Wood IC, Ogawa J: Spatial tuning of static and dynamic local stereopsis, *Vision Res 24:*573, 1984.
192. Regan D, Erkelens CJ, Collewijn H: Necessary conditions for the perception of motion in depth, *Invest Ophthalmol Vision Sci 27:*584, 1986.
193. Regan D: Visual processing of four kinds of relative motion, *Vision Res 26:*127, 1986.
194. Regan D, Regan MP: Objective evidence for phase-independent spatial frequency analysis in the human visual pathway, *Vision Res 28:*187, 1988.
195. Hong X, Regan D: Visual field defects for unidirectional and oscillatory motion in depth, *Vision Res 29:*809, 1989.
196. Rouse MW, Tittle JS, Braunstein ML: Stereoscopic depth perception by static stereo-deficient observers in dynamic displays with constant and changing disparity, *Optom Vision Sci 66:*355, 1989.
197. Regan D: The Charles F. Prentice award lecture *1990:* specific tests and specific blindnesses: keys, locks and parallel processing, *Optom Vision Sci 68:*489, 1991.
198. Nemire K: Automated system for ball launching, visual occlusion, and data acquisition in a ball hitting task, *Behav Res Methods 23:*36, 1991.
199. Regan D: Visual judgments and misjudgments in cricket, and the art of flight, *Perception 21:*91, 1992.
200. Savelsbergh GJP, Whiting HTA: The acquisition of catching under monocular and binocular conditions, *J Mot Behav 24:*320, 1992.
201. von Hofsten C, Rosengren K, Pick HL, et al: The role of binocular information in ball catching, *J Mot Behav 24:*329, 1992.
202. Graydon J, Bawden M, Holder T, et al: The effects of binocular and monocular vision on a table tennis striking task under conditions of spatial-temporal uncertainty, *Int J Sports Vis 3:*35, 1996.
203. Sheedy JE, Bailey IL, Buri M, et al: Binocular vs monocular task performance, *Am J Optom Physiol Opt 63:*839, 1986.
204. Poffenberger AT: Reaction time to retinal stimulation with special reference to the time lost in conduction through nerve centers, *Arch Psychol New York 23:*1, 1912.
205. Ueno T: Reaction time as a measure of temporal summation at suprathreshold levels, *Vision Res 17:*227, 1977.
206. Blake R, Martens W, DiGianfilippo A: Reaction time as a measure of binocular interaction in human vision, *Invest Ophthalmol Vision Sci 19:*930, 1980.
207. Harwerth RS, Smith EL, Levi DM: Suprathreshold binocular interactions for grating patterns, *Percept Psychophys 27:*43, 1980.
208. Jones RK, Lee DN: Why two eyes are better than one: the two views of binocular vision, *J Exp Psychol (Hum Percept) 7:*30, 1981.
209. Woodman W, Young M, Kelly K, et al: Effects of monocular occlusion on neural and motor response times of two dimensional stimuli, *Optom Vision Sci 67:*169, 1990.
210. Clark B, Warren N: Depth perception and interpupillary distance as factors in proficiency in ball games, *Am J Psych 47:*485, 1935.
211. Dickinson J: *The relationship of depth perception to goal shooting in basketball* [dissertation], 1953, Ames, Iowa, Iowa State University.
212. Montebello RA: *The role of stereoscopic vision in some aspects of baseball playing ability* [thesis], 1953, Columbus, Ohio, Ohio State University College of Optometry.

213. Olsen EA: Relationship between psychological capacities and success in college athletics, *Res Q Am Assoc Health Phys Educ 27:*79, 1956.
214. Deshaies P, Pargman D: Selected visual abilities of college football players, *Percept Mot Skills 43:*904, 1976.
215. Ridini LM: Relationship between psychological functions tests and selected sport skills of boys in junior high, *Res Q Am Assoc Health Phys Educ 39:*674, 1968.
216. Weissman S: Sex differences in dynamic stereoacuity, *Proceedings of the 80th Annual Convention, American Psychological Association 7:*81, 1972.
217. Weissman S, Slonim P: Effects of knowledge of results on dynamic stereo acuity in males and females, *Percept Mot Skills 36:*964, 1973.
218. Slonim PS, Weissman S, Galzer E, et al: Effects of training on dynamic stereo acuity performance by males and females, *Percept Mot Skills 40:*359, 1975.
219. Solomon H, Zinn W: An introduction to dynamic sports vision, *Optom Monthly 74:*569, 1983.
220. Zinn WJ, Solomon H: A comparison of static and dynamic stereoacuity, *J Am Optom Assoc 56:*712, 1985.
221. Soloman H, Zinn HJ, Vacroux R: Dynamic stereoacuity: a test for hitting a baseball? *J Am Optom Assoc 59:*522, 1988.
222. Hofeldt AJ, Hoefle FB: Stereophotometric testing for Pulfrich's phenomenon in professional baseball players, *Percept Mot Skills 77:*407, 1993.
223. Laby DM, Kirschen DG: Dynamic stereoacuity: preliminary results and normative data for a test for the quantitative measurement of motion in depth, *Bi Vis Eye Muscle Surg Q 10:*191, 1995.
224. Hofeldt AJ, Hoefle FB, Bonafede B: Baseball hitting, binocular vision, and the Pulfrich phenomenon, *Arch Ophthalmol 114:*1490, 1996.
225. Haynes HM: The distance rock test: a preliminary report, *J Am Optom Assoc 50:*707, 1979.
226. Haynes HM, McWilliams LG: Effects of training on near-far response time as measured by the distance rock test, *J Am Optom Assoc 50:*715, 1979.
227. Garzia RP, Nicholson S: A study of binocular accommodative and vergence facility and predictive analysis of global stereopsis, *J Behav Optom 2:*3, 1991.
228. Griffin JR, Grisham JD: *Binocular anomalies: diagnosis and vision therapy*, Amsterdam, 2002, Butterworth-Heinemann, pp 22-39.
229. Scheiman M, Wick B: *Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders*, Philadelphia, 2002, Lippincott Williams & Wilkins, pp 26-33.
230. Maples WC: Oculomotor dysfunctions: classification of saccadic and pursuit deficiencies. In Press LJ, editor: *Applied concepts in vision therapy,* St Louis, 1997, Mosby, pp 120-136.
231. Feldon SE, Burde RA: The oculomotor system. In Moses RA, Hart WM, editors: *Adler's physiology of the eye: clinical application*, St Louis, 1987, CV Mosby, p 142.
232. Bahill AT, LaRitz T: Why can't batters keep their eyes on the ball? *Am Sci 72:*249, 1984.
233. Whittaker SG, Eaholtz G: Learning patterns of eye motion for foveal pursuit, *Invest Ophthalmol Vision Sci 23:*393, 1982.
234. McHugh DE, Bahill AT: Learning to track predictable target waveforms without a time delay, *Invest Ophthalmol Vision Sci 26:*932, 1985.
235. Carnahan H, Hall C, Lee TD: Delayed visual feedback while learning to track a moving target, *Res Q Exerc Sport 67:*416, 1996.
236. Adolphe RM, Vickers JN, Laplante G: The effects of training visual attention on gaze behavior and accuracy: a pilot project, *Int J Sports Vis 4:*29, 1997.
237. Elmurr P, Cornell E, Heard R: Saccadic eye movements (part 2): the effects of practice on saccadic reaction time, *Int J Sports Vis 4:*13, 1997.

238. Babu RJ, Lillakas L, Irving EL: Dynamics of saccadic adaptation: differences between athletes and nonathletes, *Optom Vision Sci 82:*1060, 2005.
239. Brown S, Couper T: Visual and ocular motility performance of one hundred cricketers, *Aust Orthoptic J 70:*175, 1990.
240. Trachtman JN: The relationship between ocular motilities and batting average in little leaguers, *Am J Optom Arch Am Acad Optom 50:*914, 1973.
241. Maples WC: *Oculomotor test manual*, Santa Ana, CA, 1995, Optometric Extension Program Foundation.
242. Garzia RP, Richman JE, Nicholson SB, et al: A new visual-verbal saccade test: the Developmental Eye Movement test (DEM), *J Am Optom Assoc 61:*124, 1990.
243. Abernethy B: Enhancing sports performance through clinical and experimental optometry, *Clin Exp Optom 69:*189, 1986.
244. Nagano T, Kato T, Fukuta T: Visual search strategies of soccer players in one-on-one defensive situations on the field, *Percept Mot Skills 99:*968, 2004.
245. Hazel CA, Johnston AW: Recording eye movements using coaxial cameras—applications for visual ergonomics and reading studies, *Optom Vision Sci 72:*679, 1995.
246. Vickers D, Nettlebeck T, Willson RJ: Perceptual indices of performance: the measurement of "inspection time" and "noise" in the visual system, *Perception 1:*263, 1972.
247. Vickers D, Smith PL: The rationale for the inspection time index, *Pers Individ Dif 7:*609, 1986.
248. Dumler MJ: A study of factors related to gains in the reading rate of college students trained with the tachistoscope and accelerator, *J Ed Res 52:*27, 1958.
249. Brand CR, Dreary IJ: Intelligence and "inspection time." In Eysenck HJ, editor: *A model for intelligence*, New York, 1982, Springer, pp 133-148.
250. Nettlebeck T: Inspection time and intelligence. In Vernon PA, editor: *Speed of information processing and intelligence,* Norwood, NJ, 1987, Ablex, pp 295-346.
251. Zhang Y, Caryl PG, Deary IJ: Evoked potential correlates of inspection time, *Pers Individ Dif 10:*379, 1989.
252. Dreary IJ, Mitchell H: Inspection time and high-speed ball games, *Perception 18:*789, 1989.
253. Isaacs LD, Finch AE: Anticipatory timing of beginning and intermediate tennis players, *Percept Mot Skills 57:*451, 1983.
254. Nettleton B: Flexibility of attention and elite athletes' performance in "fast ball games," *Percept Mot Skills 63:*991, 1986.
255. Goulet, C, Bard M, Fleury M: Expertise differences in preparing to returns a tennis serve: a visual information processing approach, *J Sport Psychol 11:*382, 1989.
256. Wright DL, Pleasants F, Gomez-Meza M: Use of advanced visual cue sources in volleyball, *J Sport Exerc Psychol 12:*406, 1990.
257. McLeod P: Visual reaction time and high-speed ball games, *Perception 16:*49, 1987.
258. Fullerton HS: Eye, ear, brain and muscle tests on 'Babe' Ruth, *W Optom World 13:*160, 1925.
259. Slater-Hammel AT, Stumpner RL: Batting reaction-time, *Res Q Am Assoc Health Phys Educ 21:*353, 1950.
260. Sanderson FH, Holton JN: Relationships between perceptual motor abilities and cricket batting, *Percept Mot Skills 51:*138, 1980.
261. Classe JG, Semes LP, Daum KM, et al: Association between visual reaction time and batting, fielding, and earned run averages among players of the Southern Baseball League, *J Am Optom Assoc 68:*43, 1997.
262. Montes-Mico R, Bueno I, Candel J, et al: Eye-hand and eye-foot visual reaction times of young soccer players, *Optometry 71:*775, 2000.

263. Knapp BN: Simple reaction times of selected top-class sportsmen and research students, *Res Q 32:*409, 1961.
264. Blundell NL: Critical visual-perceptual attributes of championship level tennis players, In Howell ML, Wilson BD, editors: *Kinesiological sciences.* Proceedings of the VII Commonwealth and International Conference on Sport, Physical Education, Recreation and Dance, Brisbane, 1984, University of Queensland, pp 51-59.
265. Kioumourtzoglou E, Kourtessis T, Michalopoulou M, et al: Differences in several perceptual abilities between experts and novices in basketball, volleyball, and water-polo, *Percept Mot Skills 86:*899, 1998.
266. Harbin G, Durst L, Harbin D: Evaluation of oculomotor response in relationship to sports performance, *Med Sci Sports Exerc 21:*258, 1989.
267. Taimela S: Factors affecting reaction-time testing and the interpretation of results, *Percept Mot Skills 73:*1195, 1991.
268. Currier DP, Nelson RM: Changes in motor conduction velocity induced by exercise and diathermy, *Phys Ther 49:*146, 1969.
269. Hancock S, McNaughton L: Effects of fatigue on ability to process visual information by experienced orienteers, *Percept Mot Skills 62:*491, 1986.
270. Hascelik Z, Basgore O, Turner K: The effects of physical training on physical fitness tests and auditory and visual reaction times of volleyball players, *J Sports Med Phys Fit 29:*234, 1989.
271. Baer AD, Gersten JW, Robertson BM, et al: Effects of various exercise programs on isometric tension, endurance and reaction time in the human, *Arch Phys Med Rehabil 36:*495, 1955.
272. Gallaway M, Aimino J, Scheiman M: The effect of protective sports eyewear on peripheral visual field and a peripheral visual performance task, *J Am Optom Assoc 57:*304, 1986.
273. Dawson ML, Zabik RM: Effect of protective eyewear on reaction time in the horizontal field of vision, *Percept Mot Skills 67:*155, 1988.
274. Henry M: Stimulus complexity, movement, age, and sex in relation to reaction latency and speed in limb movements, *Res Q Sports Med 32:*353, 1961.
275. Keele S: Motor control. In Boff K, Kaufman L, Thomas J, editors: *Handbook of perception and human performance*, New York, 1986, John Wiley & Sons, pp 30-60.
276. Sherman A: A method for evaluating eye-hand coordination and visual reaction time in athletes, *J Am Optom Assoc 54:*801, 1983.
277. Mitchell JA, Nicholson DW, Maples WC: Standardization of the Wayne Saccadic Fixator, *J Behav Optom 1:*199, 1990.
278. Vogel GL, Hale RE: Initial norms using the Wayne Saccadic Fixator for eye-hand coordination and visual reaction times, *J Behav Optom 1:*206, 1990.
279. Vogel GL, Hale RE: Does participation in organized athletics increase a child's scoring ability on the Wayne Saccadic Fixator? *J Behav Optom 3:*66, 1992.
280. Appler DV, Quimby CA: The effect of ambient room illumination upon Wayne Saccadic Fixator performance, *J Am Optom Assoc 55:*818, 1984.
281. Beckerman SA, Zost MG: Effect of lighting levels on performance on the Wayne Computerized Saccadic Fixator and Wayne Peripheral Awareness Trainer, *J Behav Optom 5:*155, 1994.
282. Beckerman S, Fornes AM: Effects of changes in lighting level on performance with the AcuVision 1000, *J Am Optom Assoc 68:*243, 1997.
283. Bayly MF, Clark KJ, Perrin DH: The effects of perceived fatigue on visual reaction time, *Int J Sports Vis 3:*18, 1996.
284. Mollenberg O, Jendrusch G, Heck H: Table tennis specific eye-hand (bat) coordination and visual depth perception. In Mester J, King G, Struder H, et al, editors: *Perspectives and profiles*, Sixth Annual

Congress of the European College of Sports Science, 15th Congress of the German Society of Sport Science, Cologne, July 2001, p 1249.
285. Klavora P, Esposito JG: Sex differences in performance on three novel continuous response tasks, *Percept Mot Skills 95:*49, 2002.
286. Sharp RH, Whiting HTA: Information processing and eye-movement behavior in a ball catching skill, *J Hum Mov Studies 1:*124, 1975.
287. Franks IM, Weicker D, Robertson DGE: The kinematics, movement phasing and timing of a skilled action in response to varying conditions of uncertainty, *Hum Mov Sci 4:*91, 1985.
288. Bootsma RJ, van Wieringen PCW: Visual control of an attacking forehand drive. In Meijer OG, Roth K, editors: *Complex movement behavior: the motor-action controversy*, Amsterdam, 1988, North-Holland, pp 189-199.
289. Bootsma RJ: *The timing of rapid interceptive actions: perception-action coupling in the control and acquisition of skill*, Amsterdam, 1988, Free University Press.
290. Jendrusch G, Tidow G, de Marees H: Precise determination of the contact point in tennis, *Int J Sports Med 5:*365, 1988.
291. Bootsma RJ: Accuracy of perceptual processes subserving different perception-action systems, *Q J Exp Psychol 41A:*489, 1989.
292. Bootsma RJ, van Wieringen PCW: Timing an attacking forehand drive in table tennis, *J Exp Psychol Hum Percept Perform 16:*21, 1990.
293. Bootsma RJ: Predictive information and the control of action, *Int J Sport Psychol 22:*271, 1991.
294. Savelsbergh GJP, Whiting HTA, Bootsma RJ: "Grasping" tau, *J Exp Psychol Hum Percept Perform 17:*315, 1991.
295. Bootsma RJ, Peper CE: Predictive visual information sources for the regulation of action with special emphasis on catching and hitting. In Proteau L, Elliott D, editors: *Vision and motor control*, Amsterdam, 1992, North-Holland, pp 285-314.
296. Bootsma RJ, Oudejans RRD: Visual information about time-to-collision between two objects, *J Exp Psychol Hum Percept Perform 19:*1041, 1993.
297. Siegel D: Response velocity, range of movement, and timing accuracy, *Percept Mot Skills 79:*216, 1994.
298. Gray R, Regan DM: Unconfounding the direction of motion in depth, time to passage and rotation rate on an approaching object, *Vision Res 46:*2388, 2006.
299. Shea CH, Krampitz JB, Northam CC: Information processing in coincidence timing tasks: a developmental perspective, *J Hum Mov Studies 8:*73, 1982.
300. Lee DN, Young DS, Reddish PE, et al: Visual timing in hitting an accelerating ball, *Q J Exp Psychol 35A:*333, 1983.
301. Petrakis E: Sex differences and specificity of anticipation of coincidence, *Percept Mot Skills 61:*1135, 1985.
302. Payne VG: The effects of stimulus runway length on coincidence-anticipation timing performance, *J Hum Mov Studies 12:*289, 1986.
303. Magill RA: *Motor learning: concepts and applications*, ed 4, Madison, WI, 1993, Brown & Benchmark.
304. Molstad SM, Kluka DA, Love PA, et al: Timing of coincidence anticipation by NCAA Division I softball athletes, *Percept Mot Skills 79:*1491, 1994.
305. Hart MA, Reeve TG: A preliminary comparison of stimulus presentation methods with the Bassin anticipation timing task, *Percept Mot Skills 85:*344, 1997.
306. Robertson S, Collins J, Elliott D, et al: The influence of skill and intermittent vision on dynamic balance, *J Mot Behav 26:*333, 1994.
307. Robertson S, Elliott D: The influence of skill in gymnastics and vision on dynamic balance, *Int J Sport Psych 27:*361, 1996.

308. Robertson S, Elliott D: Specificity of learning and dynamic balance, *Res Q Exerc Sport 67:*69, 1996.
309. Witkin HA, Dyk RB, Paterson HF, et al: *Psychological differentiation*, New York, 1962, Wiley.
310. Witkin HA, Lewis HB, Hertzman M, et al: *Personality through perception*, Westport, CT, 1972, Greenwood.
311. Knapp B: *Skill in sport*, London, 1964, Routledge & Kegan Paul.
312. Jones MG: Perceptual studies: perceptual characteristics and athletic performance. In Whiting HTA, editor: *Sports psychology*, London, 1972, Kimpton, pp 96-115.
313. Kane JE: Personality, body concept and performance. In Kane JE, editor: *Psychological aspects of physical education and sport*, London, 1972, Western Printing Services, pp 91-127.
314. Young HH: A test of Witkin's field-independence hypothesis, *J Abnorm Soc Psych 59:*188, 1959.
315. Elliott R, McMichael RE: Effects of specific training on frame dependence, *Percept Mot Skills 17:*363, 1963.
316. Gallahue DL: The relationship between perceptual and motor abilities, *Res Q 39:*948, 1968.
317. Gruenfeld L, Arbuthnot H: Field independence as conceptual framework for prediction of variability in ratings of others, *Percept Mot Skills 28:*31, 1969.
318. Meek F, Skubie V: Spatial perception of highly skilled and poorly skilled females, *Percept Mot Skills 33:*1309, 1971.
319. Svinicki JG, Bundgaard CJ, Schwensohn CH, et al: Physical activity and visual field-dependency, *Percept Mot Skills 39:*1237, 1974.
320. Pargman D, Bender P, Deshaies P: Correlation between visual disembedding and basketball shooting by male and female varsity college athletes, *Percept Mot Skills 41:*539, 1975.
321. Rotella RJ, Bunker LK: Field dependence and reaction time in senior tennis players (65 and over), *Percept Mot Skills 46:*585, 1978.
322. Docherty D, Boyd DG: Relationship of disembedding ability to performance in volleyball, tennis, and badminton, *Percept Mot Skills 54:*1219, 1982.
323. Raviv S, Nabel N: Field dependence-independence and concentration as psychological characteristics of basketball players, *Percept Mot Skills 66:*831, 1988.
324. Raviv S, Nabel N: Relationship between two different measurements of field-dependence and athletic performance of adolescents, *Percept Mot Skills 70:*75, 1990.
325. Terelak J: Field dependence/independence and eye-hands-legs coordination, *Percept Mot Skills 71:*947, 1990.
326. Liu WH: Review of recent Chinese research on field dependence-independence in high-level athletes, *Percept Mot Skills 83:*1187, 1996.
327. Pargman D: Visual disembedding and injury in college football players, *Percept Mot Skills 42:*762, 1976.
328. Gill NT, Herdtner TJ, Lough L: Perceptual and socioeconomic variables, instruction in body-orientation, and predicted academic success in young children, *Percept Mot Skills 26:*1175, 1968.
329. Leithwood KA, Fowler W: Complex motor learning in four-year-olds, *Child Dev 42:*781, 1971.
330. Ruch TC: Binocular vision and central visual pathways. In Fulton JA, editor: *A textbook of physiology*, Philadelphia, 1949, Saunders, p 471.
331. Hobson R, Henderson MT: A preliminary study of the visual field in athletics, *Proc Iowa Acad Sci 48:*331, 1941.
332. Johnson WG: *Peripheral perception of athletes and non-athletes, and the effect of practice* [thesis], 1952, University of Illinois.
333. Buchellew WF: *Peripheral perception and reaction time of athletes and non-athletes* [thesis], 1954, University of Illinois.
334. Stroup F: Relationship between measurements of field of motion perception and basketball ability in college men, *Res Q Am Assoc Health Phys Educ 28:*72, 1957.

335. Williams JM, Thirer J: Vertical and horizontal peripheral vision in male and female athletes and non-athletes, *Res Q Am Assoc Health Phys Educ 46:*200, 1976.
336. Berg WP, Killian SM: Size of the visual field in collegiate fast-pitch softball players and nonathletes, *Percept Motor Skills 81:*1307, 1995.
337. Deshaies P, Pargman D: Selected visual abilities of college football players, *Percept Motor Skills 43:*904, 1976.
338. Blundell NL: The contribution of vision to the learning and performance of sports skills. Part 2: the effects of exercise, altitude and visual training, *Aust J Sci Med Sport 17:*3, 1985.
339. Fleury M, Bard C: Fatigue metabolique et performancede taches visuelles, *Can J Sport Sci 15:*43, 1990.
340. Koskela PU: The effect of jogging on visual field indices, *Acta Ophthalmologica 68:*91-93, 1990.
341. Wood JM, Woods RL, Jack MP: Exercise does not increase visual field sensitivity, *Optom Vision Sci 71:*682, 1994.
342. Grall V, Lessing T, Jendrusch G, et al: Synchronoptical ability of differentiation—exemplified by the foot fault in tennis, *Int J Sports Med 19:*S45, 1998.
343. Grall V, Pfennig H, Jendrusch G, et al: Trainability of synchronoptical identification ability, *Int J Sports Med 19:*S45, 1998.
344. Opdenacker K, Jendrusch G, Heck H: Effect of physical activity on the performance of perceptual tasks in central and peripheral vision. In Mester J, King G, Struder H, et al, editors: *Perspectives and profiles*, Sixth Annual Congress of the European College of Sports Science, 15th Congress of the German Society of Sport Science, Cologne, July 2001, p 827.
345. Martin WF: *An insight to sports: featuring trapshooting and golf*, Seattle, 1984, SportsVision.
346. Finke RA: Mental imagery and the visual system, *Sci Am 254:*88, 1986.
347. Roland PE, Larsen B, Lassen NA, et al: Supplementary motor area and other cortical areas in organization of voluntary movement in man, *J Neurophysiol 43:*118, 1980.
348. Roland PE, Friberg L: Localization of cortical areas activated by thinking, *J Neurophysiol 53:*1219, 1985.
349. Deutsch G, Bourbon WT, Papanicolaou AC, et al: Visuospatial tasks compared via activation of regional cerebral blood flow, *Neuropsychologia 26:*445, 1988.
350. Naito E: Controllability of motor imagery and transformation of visual imagery, *Percept Motor Skills 78:*479, 1994.
351. Mahoney M, Avener J: Psychology of the elite athlete: an exploratory study, *Cognit Ther Res 1:*135, 1977.
352. Meyers AW, Cooke CJ, Cullen J, et al: Psychological aspects of athletic competitors: a replication across sports, *Cognit Ther Res 3:*361, 1979.
353. Greenspan MJ, Feltz DL: Psychological interventions with athletes in competitive situations: a review, *Sport Psychologist 3:*219, 1989.
354. Davis H: Cognitive style and nonsport imagery in elite ice hockey performance, *Percept Motor Skills 71:*795, 1990.
355. MacKay DG: The problem of rehearsal or mental practice, *J Motor Behav 13:*274, 1981.
356. Hale BD: The effects of internal and external imagery on muscular and ocular concomitants, *J Sports Psych 4:*374, 1982.
357. Feltz DL, Landers DM: The effects of mental practice on motor skill learning and performance: a meta-analysis, *J Sports Psych 5:*25, 1983.
358. Kohl RM, Roenker DL: Mechanism involvement during skill imagery, *J Motor Behav 15:*179, 1983.
359. Feltz DL, Landers DM, Becker BJ: *A revised meta-analysis of the mental practice literature on motor skill learning*, Washington, DC, 1988, National Academy Press.
360. Requin J: Neural basis of movement representations. In Requin J, Stelmach GE, editors: *Tutorials in motor neurosciences*, Dordrecht, The Netherlands, 1991, Kluwer, pp 333-345.

361. Jeannerod M: The representing brain: neural correlates of motor intention and imagery, *Brain Behav Sci 17:*187, 1994.
362. Decety J, Ingvar DH, Brain structures participating in mental stimulation of motor behavior: a neuropsychological interpretation, *Acta Psychologica 73:*13, 1990.
363. Decety J, Kawashima R, Gulyas B, et al: Preparation for reaching: A PET study of the participating structures in the human brain, *NeuroReport 3*:761, 1992.
364. Decety J: Do imagined and executed actions share the same neural substrate? *Cognit Brain Res 3*:87, 1996.
365. Jacobson E: Electrophysiology of mental activities, *Am J Psychol 44:*676, 1932.
366. Ulich E: Some experiments on the function of mental training in the acquisition of motor skills, *Ergonomics 10:*411, 1967.
367. McGuigan FJ: Covert oral behavior during the silent performance of language tasks, *Psychol Bull 74:*309, 1970.
368. Harris DV, Robinson WJ: The effects of skill level on EMG activity during internal and external imagery, *J Sport Psych 8:*105, 1986.
369. Decety J, Michel F: Comparative analysis of actual and mental movements times in two graphic tasks, *Brain Cognit 11:*87, 1989.
370. de'Sperati C, Deubel H: Mental extrapolation of motion modulates responsiveness to visual stimuli, *Vision Res 16:*2593, 2006.
371. Decety J, Jeannerod M, Preblanc C: The timing of mentally represented actions, *Behav Brain Res 34:*35, 1989.
372. Decety J: Motor information may be important for updating the cognitive processes involved in mental imagery of movement, *Eur Bull Cognit Psychol 4:*415, 1991.
373. Decety J, Jeannerod M: Fitts' law in mentally simulated movements, *Behav Brain Res 72:*127, 1996.
374. Reed CL: Chronometric comparisons of imagery to action: visualizing versus physically performing springboard dives, *Mem Cognit 30:*1169, 2002.
375. Suin R: Removing emotional obstacles to learning and performance by visuo-motor behavior rehearsal, *Behav Ther 3:*308, 1972.
376. Suin R: Behavior rehearsal training for ski racers, *Behav Ther 3:*519, 1972.
377. Suin R: Visual motor behavior rehearsal: the basic technique, *Scand J Behav Ther 13:*131, 1984.
378. Suin R: Imagery rehearsal applications to performance enhancement, *Behav Ther 8:*155, 1985.
379. Suin R: *Seven steps to peak performance: the mental training manual for athletes*, Toronto, 1986, Huber.
380. Sherman A: Overview of research information regarding vision and sports, *J Am Optom Assoc 51:*661, 1980.
381. Hall C, Buckoltz E, Fishburne G: Imagery and acquisition of motor skills, *Mem Cognit 7:*19, 1992.
382. Driskell JE, Copper C, Moran A: Does mental practice enhance performance? *J Appl Psychol 79:*481, 1992.
383. Salmon J, Hall C, Haslam I: The use of imagery by soccer players, *J Appl Sports Psychol 6:*116, 1994.
384. Zervas Y, Kakkos V: Visuomotor behavior rehearsal in archery shooting performance, *Percept Mot Skills 73:*1183, 1991.
385. Corbin CB: Mental practice. In Morgan WP, editor: *Ergonomic aids and muscular performance*, New York, 1972, Academic Press, pp 93-118.
386. Richardson A: *Mental imagery*, New York, 1969, Springer.
387. Hall E, Erffmeyer SE: The effect of visuo-motor behavior rehearsal with videotaped modeling on free throw accuracy of intercollegiate female basketball players, *J Sport Psychol 5:*343, 1983.
388. Gray SW, Fernandez S: Effects of visuo-motor behavior rehearsal with videotaped modeling on basketball performance, *Psychol J Human Behav 26*:41, 1989.

389. Noel RC: The effect of visuo-motor behavior rehearsal on tennis performance, *J Sport Psychol 2:*221, 1980.
390. Weinberg RS, Gould D, Jackson A, et al: Influence on cognitive strategies on tennis serves of high and low ability, *Percept Mot Skills 50:*663, 1980.
391. Weinberg RS, Seabourne TG, Jackson A: Effects of visuo-motor behavior rehearsal, relaxation, and imagery on karate performance, *J Sport Psychol 3:*228, 1981.
392. Weinberg RS, Seabourne TG, Jackson A: Effects of visuo-motor behavior rehearsal on state-trait anxiety and performance: is practice important? *J Sport Behav 5:*209, 1982.
393. Seabourne TG, Weinberg R, Jackson A, et al: Effect of individualized practice and training of visuo-motor behavior rehearsal in enhancing karate performance, *J Sport Behav 7:*58, 1984.
394. Seabourne TG, Weinberg R, Jackson A: Effect of individualized, nonindividualized and package intervention strategies on karate performance, *J Sport Psychol 7:*40, 1985.
395. Yamamoto K, Inomata K: Effects of mental rehearsal with past and whole demonstration models on acquisition of backstroke swimming skills, *Percept Mot Skills 54:*1067, 1982.
396. Lee AB, Hewitt J: Using visual imagery in a floatation tank to improve gymnastic performance and reduce physical symptoms, *Int J Sport Psychol 18:*223, 1987.
397. Gray SW: Effect of visuomotor rehearsal with videotaped modeling on racquetball performance of beginning players, *Percept Mot Skills 70:*379, 1990.
398. Meacci WG, Price EE: Acquisition and retention of golf putting skill through the relaxation, visualization and body rehearsal intervention, *Res Q Exer Sport 56:*176, 1985.
399. Meacci WG, Pastore DL: Golf: making short putts, *Strategies 5:*13, 1992.
400. Meacci WG, Pastore DL: Effects of occluded vision and imagery on putting golf balls, *Percept Mot Skills 80:*179, 1995.
401. Kavner RS: *Total vision*, New York, 1978, A&V Publishers.
402. Kubistant T: The uses of visualization in sports medicine, *Sportsmed Dig 4:*5, 1982.
403. Silva JM, Weinberg RS: *Psychological foundation of sport*, Champaign, IL, 1984, Human Kinetics.

5

Sports Vision Screening and Report Strategies

CHAPTER OUTLINE

Developing a Sports Vision Screening
Conducting the Sports Vision Screening
  Recording Forms
  Equipment and Supply List
  Screening Protocols and Staff Training
  The Flow of the Screening
Generating Reports for Sports Vision Screenings and Sports Vision Evaluations

Sports vision practitioners have may opportunities to be involved with vision services for an athletic team. A high percentage of professional and division I college and university sports teams in North America have a vision screening program, and many also have an optometrist or ophthalmologist as a vision consultant.[1] Many sports programs at all levels of competition use vision screening for their athletes, but many more do not have access to this service. A survey of professional, college, and university athletic programs and optometrists concluded that a significant unmet need exists for vision care services for athletes.[1]

Many reports of vision screening results from athletes have been published.[2-15] No single standardized sports vision screening has been used in any of the studies, and journal articles that discuss vision screening for athletes rarely specify a set of evaluation procedures with detailed protocols and normative data.[3,11,15-22] The procedures chosen for sports vision screening of a team or athletic program typically result from considerations of time, location, vision task demands, and the value of the information acquired from the procedures. The result should be an efficient, high-yield battery of tests that identify vision problems that can interfere with peak sports performance and also allow comparison of athletes based on a profile of the vision skills assessed.

The results from a sports vision screening should be reported to the appropriate team personnel and the individual athletes. Many possible methods can be used to deliver this information, and the ability to communicate the findings and management recommendations effectively distinguishes the provider as an "expert." Communication skills are at a premium if the objective is compliance with recommendations.

DEVELOPING A SPORTS VISION SCREENING

Most vision screenings are conducted at a location outside a sports vision practitioner's office. A full sports vision evaluation on each athlete is usually not possible to conduct

because of the limitations of time and location. The location of the screening may limit the use of some evaluation instruments because of space available, control of lighting, availability of electricity, and portability of equipment. The amount of time available for the screening dictates the extent of testing feasible based on the number of athletes to be screened. The practitioner must also consider the available personnel to conduct the screening and determine how the athletes will proceed through the screening procedures for maximal efficiency.

Before the factors of time and location can be deliberated, the practitioner must identify the visual factors that potentially contribute to peak human performance so that these specific functions can be isolated and measured in the screening, if possible. The visual demands critical to success in sports can vary tremendously between different sports or positions. Chapter 2 provides an approach to the task analysis process essential for providing appropriate vision care to the athletes. The evaluation procedures that are judged to yield the most relevant assessment of critical visual skills should be identified and contemplated for inclusion in the screening. The list of desirable procedures should then be reduced to the number of procedures that are feasible within the limitations of time and location. When determining which procedures should be selected, procedures that are the most suitable for sampling the vision skill areas identified as critical to performance are most commonly chosen.

In addition to the evaluation procedures chosen for the sports vision screening, the athlete's history must be ascertained. The limitation of time is a factor with this part of the screening as well, and a questionnaire is commonly used to improve efficiency. The questionnaire should include some of the basic elements of a history for a comprehensive vision examination, including questions regarding main concerns, secondary vision concerns, and personal eye and medical history. The use of vision correction and eye protection is a crucial element to investigate in the athlete history questionnaire. Supplementary questions are listed in Chapter 4 that yield information concerning the athlete's visual performance during the sport; these can be listed in the questionnaire. The ability to relate symptoms elicited on the questionnaire to the vision skills assessed in the screening is advantageous. The athlete history questionnaire should be verbally reviewed with the athlete, and thorough follow-up information should be obtained if time permits.

The decision of whether to include procedures for the evaluation of ocular health status on a screening is difficult. The range of procedures necessary to assess internal and external health is challenging to perform within the limitations of time and location. With the advent of new ocular health imaging technologies, documentation of elements of the athlete's ocular health may be possible; however, these new technologies should be combined with a thorough ocular health assessment and not used in isolation. Because an incomplete assessment of the elements of ocular health can be intolerably misleading, it is not recommended as part of a sports vision screening. A legal disclaimer stating the limitations of the screening and recommendation of routine comprehensive vision care should be included in the report materials provided to the team (see sample vision screening form in Appendix B).

As the practitioner gains experience with a variety of teams and sports, sport-specific screenings can be developed for use in subsequent screenings. The assessment areas and procedures used can be modified as needed on the basis of the results of further research and the practitioner's own experience.

CONDUCTING THE SPORTS VISION SCREENING

Many aspects of a successful sports vision screening must be addressed before conducting the screening. Recording forms for the athlete data, a list of equipment and supplies to bring to the screening site, assessment protocols for each procedure, training of any ancillary staff who will be assisting in data collection, and development of the flow of athletes through the screening are all required elements.

Recording Forms

The recording forms for the screening should be developed in a manner that enhances the efficiency of the screening. Each assessment procedure should have a recording method that minimizes the amount of time needed to record each athlete's results. Because a comparison of vision skills among athletes on the team is often performed, the screening form should also facilitate easy transfer to the comparison instrument that will be used. Ideally, athlete data would be directly entered on a computer spreadsheet for assessment at the conclusion of the screening, eliminating the need for paper forms. If a copy of the sports vision screening form will be provided to the team personnel and/or athlete, it will need to be designed in a manner that clearly communicates the results and recommendations and have a professional appearance.

Equipment and Supply List

For an off-site screening, the instrumentation selected for the screening should be portable and prepared for transportation. Some equipment will need to be adapted for use at the screening site. For example, the AcuVision (no longer available commercially) and Wayne Saccadic Fixator (www.wayneengineering.com) usually require a method for setting up on location (Figs. 5-1 and 5-2). Lighting can be a factor that should be prepared for. Any supplies and

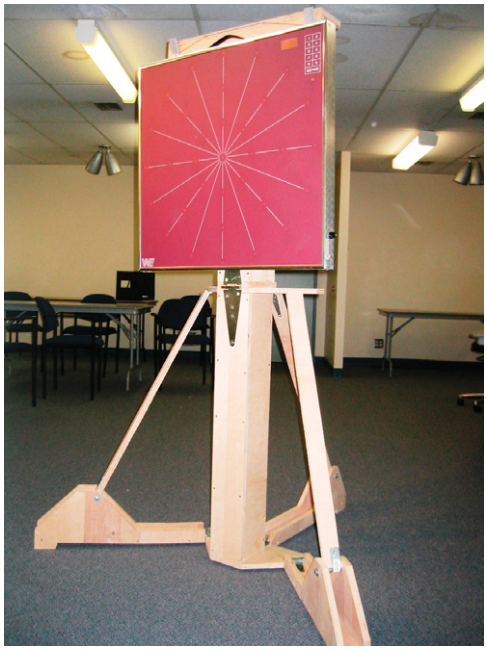


Figure 5-1. Wayne Saccadic Fixator set up on a homemade portable stand for out-of-office testing.



Figure 5-2. Wayne Saccadic Fixator set up on a homemade portable stand during the American Optometric Association Sports Vision Section screening for the Amateur Athletic Union Junior Olympic Games.

spare parts that may be needed for any piece of equipment should be included in the list of items to bring, such as extra light bulbs, batteries, electrical adaptors, extension cords, and power strips. Administrative supplies are usually needed, including clipboards, pens, staplers, masking tape, measuring tape, and nametags. The functioning of all equipment should be checked, and any batteries should be charged before departing for the screening.

Screening Protocols and Staff Training

Stringent assessment protocols should be established for each procedure used in a screening. If the goal is to compare vision skill performance of the team members, all team members must receive the same instructions and feedback. The instructions to the athlete before evaluation with each procedure should be standardized as much as possible to minimize the influence of variable instructions on performance. Modification of the instructions or screening protocols during the screening may be tempting; however, any modifications diminish the ability to compare athlete performance. The best way to avoid modifying

assessment protocols is to master the procedures and fine tune the instructions before conducting the screening. A trial run through the screening with a volunteer "athlete" is a good way to find any issues that need adjusting, and it should also provide an estimation of the time needed for each athlete to complete the screening.

The screening staff should all be thoroughly trained to administer the procedures with the established protocols. If the staff masters the procedure administration, the screening will be much more efficient. The protocols should include methods to motivate the athletes to demonstrate peak performance and ignite their competitive nature. On a procedure such as eye-hand coordination, the highest score achieved (so far) on that procedure by the team could be posted next to the apparatus to motivate each athlete to try to post the highest score for the team. Other than the use of the highest score on a particular procedure, each athlete should get minimal feedback on performance during the screening. For each procedure, the athlete should be told he or she is doing well and the results of the screening will be communicated at a later time. Under no circumstances should the athlete be told that he or she has failed any portion of the screening or that visual performance is below normal. The communication of visual performance results is highly sensitive and should be conducted in a manner that facilitates effective management. Therefore communication of screening results is typically reserved for the report to the team personnel and the athlete.

The instructions to each athlete for each procedure should educate him or her about the nature of the vision skill being evaluated. The relevance of the vision skill to specific task demands of the sport should be explained to the athlete to help encourage proper motivation during the screening. The better the athlete is motivated to perform on each procedure, the more accurate the measurement of ability becomes. The staff conducting the screening should also be trained to elicit any additional case history information as the athlete proceeds through the screening.

The Flow of the Screening

How the athletes will flow through the screening should be determined in advance. One common set-up is to have a number of stations that the athlete moves through where specific assessment procedures are conducted. Ideally, each station should take the athlete the same amount of time to complete so that backup does not occur at certain stations. This ideal situation is not always possible when one procedure takes significantly more time to administer than other procedures in the screening.

Consideration should be given to the importance of the sequence of the screening because altering the sequence of the screening may be tempting for some athletes if a considerable backup is present at particular stations. However, in general every athlete should go through the screening sequence identically to facilitate comparison of athlete performance. For example, if one athlete performed a visual motor speed assessment at the beginning of the screening and another performed it at the end of the screening, the results may be tainted by the difference in screening sequence.

The station-to-station approach can be efficient because the staff have mastered the administration of the procedures at their particular station (Figs. 5-3 and 5-4). However, if a group of sports vision practitioners is conducting the screening, each practitioner may take individual athletes through every station of the screening. By having a single practitioner conduct all the procedures, the practitioner may develop more insight into the performance and issues with each individual athlete. The additional insight gained by the practitioner



Figure 5-3. The eye-hand reaction time station at the American Optometric Association Sports Vision Section screening for the Amateur Athletic Union Junior Olympic Games.

conducting all the screening procedures may be translated into more effective recommendations for that athlete.

No matter which method of screening athletes is chosen, each athlete should proceed through the screening expeditiously. For the team personnel, the time available as a team is extremely valuable. The impression that the team's time is being wasted sitting or standing around during a screening should be avoided. A meeting with the team personnel before the screening is highly recommended to discuss potential scheduling schemes for the team. A reasonable flow of athletes through the screening can be scheduled in coordination with other team training activities. Demonstrating an understanding of the needs of the team and creativity in finding mutually beneficial solutions are greatly appreciated by team personnel.

A meeting time in advance of the screening also affords an excellent opportunity to preview the screening area that will be used. This preview should provide valuable information for designing the floor plan for the screening stations and developing the most effective flow for the screening. Team personnel should also complete the sports vision screening because this will impart useful first-hand experience with the visual skills assessed. The consultation with the team personnel to discuss the screening results is more effective if the team personnel have first-hand knowledge of the vision skills being discussed.

An additional consideration when developing a sports vision screening is the need for supplementary testing. A vision problem may be detected in an athlete during the screening that requires further testing. For example, a strabismus may be revealed during measurement of ocular alignment, and the practitioner may want more information about the nature of the strabismus in that athlete. The practitioner will need to decide what additional



Figure 5-4. The far stereopsis station at the American Optometric Association Sports Vision Section screening for the Amateur Athletic Union Junior Olympic Games.

testing may be needed on site and bring the necessary equipment to conduct that testing. Conversely, the practitioner may choose to simply refer any athletes for follow-up care when vision problems are identified during the course of a screening.

GENERATING REPORTS FOR SPORTS VISION SCREENINGS AND SPORTS VISION EVALUATIONS

Reporting the results of a sports vision screening or a sports vision evaluation is absolutely critical for the success of any sports vision program. The report should be communicated to the team personnel and/or individual athletes in a timely manner, such as within 2 weeks of the screening or evaluation. Keep in mind that the interested parties need to know the following five W's[22]:

- *What* needs to be done?
- *When* does it need to be done?
- *Who* should carry out the recommendations?
- *Where* does it need to be done?
- *Why* does it need to be done?

Many methods can be used to construct a report letter for a vision evaluation, and no single method is superior.[23] When reporting the results of a sports vision assessment, the inclusion of a vision skill performance profile is recommended to communicate the relative strengths and weaknesses demonstrated by the athlete. The development of a performance profile is easier when conducting a team assessment because the peer group data are available for direct comparison. When an individual assessment has been performed on an athlete, the practitioner must use available normative data or compare performance with other athletes previously evaluated. See Appendix C for a sample sports vision evaluation summary letter for an individual athlete.

Many computer programs are available that provide a simple method for comparing vision skill performance by athletes on a team. The data from each athlete can be entered on a spreadsheet when numeric results are present, allowing calculation of performance averages and standard deviations for each procedure. Most data spreadsheet programs have functions for making many statistical calculations. The practitioner must appraise each performance average and standard deviation to determine whether the values are appropriate for comparison and recommendations. For example, if a team has demonstrated an unusually high level of visual acuity and 20/20 (6/6) is more than one standard deviation below average performance, what recommendations will be made for an athlete who achieved "only" 20/20 visual acuity? Team data can also be compared with available normative data to help determine the validity of the results.

Many possible methods can be used to present visual performance profile information to the team personnel and athletes. The presentation should be easy to interpret by the intended audience. A simple bar graph can be effective for showing relative strengths and weaknesses. The average performance on each skill should be apparent from each athlete's profile, and a benchmark scale illustrating relative performance should also be readily apparent. When appropriate, a scale of 1 to 5 for the vertical axis of a bar graph can be used, with 3 always representing the performance average for the team on each procedure (see Appendix D). The standard deviation for performance on each procedure is represented by each whole number step on the graph. Specifically, the average is represented by number 3 on the *y*-axis, and one standard deviation above and below the average is represented by numbers 4 and 2, respectively.

To perform a statistical analysis of the visual skill performance of an individual athlete compared with team data or normative data in the context of the scale from 1 to 5, two simple calculations can be performed. If a higher numeric value indicates better performance, such as a score on eye-hand coordination, the following calculation is applied:

$$[(\text{Athlete score} - \text{Average score})/\text{Standard deviation}] + 3$$

Therefore if an athlete scored 85 on the eye-hand coordination test, and the performance average for his team was 79, he would have a performance profile rating of 4.20 when the standard deviation is 5, as follows:

$$[(85 - 79)/5] + 3 = 4.20$$

A lower number indicates better performance on many visual skill procedures, such as visual acuity. The calculation for this statistical analysis is performed in the same manner, with the exception that the athlete score is subtracted from the average as follows:

$$[(\text{Average score} - \text{Athlete score})/\text{Standard deviation}] + 3$$

Therefore if an athlete scored 20/25 on the assessment of binocular static visual acuity, and the performance average for her team was 20/15, she would have a performance profile rating of 1.57 when the standard deviation is 7, as follows:

$$[(15 - 25)/7] + 3 = 1.57$$

Most computer spreadsheet programs will produce a graphic presentation of data selected from a spreadsheet. The performance profile rating for each visual skill is selected for inclusion in the bar graph, and the *x*-axis coordinates are labeled to match a description key for the visual skill areas. The description key is a short summary of each skill assessed and its relevance to sports performance. The description key is vital for successful communication of the relevance of each factor in the performance profile, and the language used in the description key should be routinely fine tuned to enhance the efficacy of this important tool.

The result of the statistical analysis is a graphic presentation of the performance profile for each individual athlete, with an explanation of the sports performance value of each visual skill assessed. Additional graphs can be generated for the team personnel that compare performance on any individual assessment procedure for all members of the team. For example, the coach may want to see a relative ranking of performance on visual-motor reaction times for the team. To protect athlete identity, numbers are assigned to each athlete for this type of graph. A key denoting which individual athlete corresponds to which athlete number is provided to the appropriate team personnel with an explanation of the issues regarding health care confidentiality. To be compliant with Health Insurance Portability and Accountability Act regulations in the United States, each athlete should sign a release of health care information before the release of any information to team personnel.

A short narrative should be provided for each athlete's performance on a sports vision screening. This narrative can be in paragraph form or presented as a bulleted list. The narrative should summarize any issues revealed during the athlete history, as well as the relative strengths and weaknesses of the athlete's performance on the screening. Recommendations for further vision care should be clearly stated with an explanation of the potential benefits of that care. The disclaimer regarding health assessment is included in the athlete narrative. See Appendix D for a sample athlete profile and narrative.

Meeting with the team personnel to review the reports is tremendously valuable. Many issues and questions can be properly addressed at this time. If possible, a short consultation with each athlete in the presence of the appropriate team personnel or other interested parties represents the best opportunity for effective communication of the results and recommendations. A fundamental aspect of these consultations is discussing how to use the acquired information to improve the athletic performance of the athletes and the team. As previously mentioned, the word "fail" should not be used when describing the visual performance of an athlete. More positive word selection minimizes any negative impact on athlete confidence, such as describing how visual performance may limit the potential for peak sports performance.[15] The time with the team personnel is also an appropriate occasion to review issues of contact lens replacement, eye protection, and eye injury management.

Sports vision screenings are a common aspect of sports vision care. A practitioner's ability to maximize the potential inherent in this opportunity often determines success. Proper preparation for a team screening and timely and effective communication of the

screening results can provide the foundation for a successful relationship with a team or organization. Success often is determined by the length of relationships with teams or organizations rather than by how many solitary opportunities are obtained.

REFERENCES

1. Zieman BS, Reichow AW, Coffey B, et al: Optometric trends in sports vision: knowledge, utilization, and practitioner role expansion potential, *J Am Optom Assoc 64*:490, 1993.
2. Martin WF: A research study on athletes' vision, *Contacto 7*:5, 1963.
3. Bauscher WA: Vision and the athlete, *Optom Weekly 59*:21, 1968.
4. Garner AI: What a practitioner should know about an athlete's vision, *Contacto 20:*24, 1976.
5. Garner AI: An overlooked problem: athletes' visual needs, *Phys Sportsmed 5:*75, 1977.
6. Erenstone R, Miller NP, Silagy ZS: Optometry at the 1980 Winter Olympics, *J Am Optom Assoc 52:*647, 1981.
7. Harris PA, Blum DS: AOA Sports Vision Section screening of basketball officials, *J Am Optom Assoc 55:*130, 1984.
8. Sports vision gets gold at the Barcelona Olympics, *Calif Optom 18:*6, 1992.
9. Milne DC, Lewis RV: Sports vision screening of varsity athletes, *Sports Vision 1*:8, 1993.
10. Goldsmid MA: Visual fitness and performance in tennis athletes, *Eye Quest Magazine* p 38, 1994.
11. Berman AM: Sports performance vision testing, *Optom Today 4:*28, 1996.
12. Laby DM, Rosenbaum AL, Kirschen DG, et al: The visual function of professional baseball players, *Am J Ophthalmol 122:*476, 1996.
13. Beckerman SA, Hitzeman S: The ocular and visual characteristics of an athletic population, *Optometry 72:*498, 2001.
14. Wilson TA, Falkel J: *Sports vision training for better performance*, Champaign, IL, 2004, Human Kinetics, pp 1-13.
15. Reichow AW, Stern NS: Guidelines for screening and testing the athlete's visual system—part I, *OEP Curriculum II 59:*243, 1987.
16. Jones DE, Gillilan RW: Optometric services for the athletic department, *J Am Optom Assoc 44:*1060, 1973.
17. Screening athletes: how important is sports vision care? *Rev Optom 114:*14, 1977.
18. Farnsworth CL: How to serve sports vision patients, *Rev Optom 121:*64, 1984.
19. Berman AM: Starting a sports vision practice, *Optom Management 25*:30, 1990.
20. Schwartz CA: Sports screening for success, *Optom Econ 4*:12, 1994.
21. Wilson TA: Sports vision: getting into the game, *Optom Management 32*:20s, 1997.
22. Hubbs L: Take it from the pros part I: 10 steps for attracting sports-minded patients, *Optom Management 35*:116, 2000.
23. Ettinger ER: *Professional communications in eye care*, Boston, 1994, Butterworth-Heinemann.

6

Prescribing for the Athlete

CHAPTER OUTLINE

Refractive Compensation
Nonprotective Sports Eyewear
  Lens Treatment Options
Protective Eyewear
  Racquet Sports
  Ice Hockey
  Lacrosse
  Baseball
  Paintball
  Alpine Skiing
  Swimming and Water Sports
  Soccer
  Other Sports
  Issues with Protective Eyewear
  Functionally Monocular Athletes
  Clinicolegal Issues for Protective Eyewear
Prescribing Filters and Performance Sun Eyewear
  Neutral Gray Tints
  Yellow-Brown Range Tints
  Green-Range Tints
  Red-Range Tints
  Blue-Range Tints
  Purple-Range Filters
  Polarized Filters
  Photochromic Filters
  Lens Coatings
Contact Lenses
  Considerations for Performance Contact Lenses
  Performance-Tinted Contact Lenses
  Contact Lens Recommendations
  Rigid Lens Suggestions
  Soft Lens Recommendations
  Visual Performance Variables with Contact Lenses
  Contact Lenses and Water Sports
  Orthokeratology (Corneal Reshaping)
  Issues with Contact Lenses for Athletes
Refractive Surgery
  Incisional Methods
  Laser Ablation Procedures
  Intracorneal Ring Segments

The eye care practitioner is in a unique position to provide expert consultative services to athletes regarding vision correction and the potential uses and benefits of ophthalmic products. The practitioner should consider the nature of the athletic activity (contact versus noncontact sports), as well as the weather and atmospheric conditions that may be encountered by the athlete. These aspects oblige the practitioner to consider and analyze the following environmental factors:

- The presence of ocular hazards
- The need for protection from impact for the eye, face, and head
- The need for protection from solar radiation
- Issues of visibility and mechanical forces with protection
- Issues with sunlight conditions (variability and glare)

- Issues with artificial lighting (color perception and glare)
- Temperature issues that may affect ophthalmic products
- Humidity conditions, especially low humidity with contact lens wear
- Altitude factors that may affect oxygen transmission in contact lens wear
- Dust and foreign body potential
- Sweat, fogging, and precipitation effects with ophthalmic products
- The need for product flexibility because of environmental variability

These environmental factors will be addressed in the following sections to assist the practitioner in determining the advantages and disadvantages of the available options. Each athlete has specific variables that affect ophthalmic recommendations. The gender, age, level of participation, combination of sports activities, and previous history of product use influence the choice of available options. Some athletes seek a single product to meet all visual performance needs, whereas others seek the optimal products for a variety of highly specific uses. Effective patient counseling begins with a thorough history to determine the specific needs and profile for the individual. Many patients would like to make informed decisions about the use of ophthalmic products; therefore a thorough case history coupled with comprehensive education and recommendations establish the practitioner as a valuable resource for the athlete.

REFRACTIVE COMPENSATION

The incidence of refractive error and visual symptoms found at the Junior Olympic Games is similar to that found in the general population (approximately 20%), dispelling the idea that athletes have a lower incidence of refractive error and vision problems.[1] Athletes who currently use vision correction require an evaluation to determine whether the prescription is providing optimal visual performance for the specific sport demands. A task analysis of the sport will assist in determining the specific visual demands, and a careful refractive analysis can establish the best refractive compensation for use in that sport. For example, a myopic baseball player may benefit from an additional 0.25 D of minus to improve contrast judgment or when playing in twilight conditions. This prescription becomes the sport-specific prescription and is not intended for general use. Other sports, such as billiards, have specific viewing distances that should be considered, especially for the presbyopic athlete. The eye care practitioner should advise athletic patients about the advantages and disadvantages of spectacles, contact lenses, and refractive surgery. The athlete should be able to make an informed decision about the best option for his or her individual needs. If spectacles are an option, the athlete should be counseled on the best lens characteristics, frame designs, tint characteristics, and protection factors. Contact lenses offer a method to minimize many of the disadvantages found with most spectacle corrections, specifically poor optics, distortion, lack of safety, and frame comfort.[2-4] Refractive surgery offers the potential advantage of eliminating the need for optical devices; however, surgical procedures have safety and suboptimal vision performance outcome concerns. Orthokeratology offers an option to refractive surgery for some athletes.

For the approximately 80% of athletes who do not use vision correction, some may benefit from a sport-specific refractive prescription. To determine the possible benefits of a refractive prescription, the eye care provider should consider the athlete's entering unaided visual acuities, the visual demands of the sport, and the effort exerted by the athlete to

TABLE 6-1 **Guidelines for Refractive Compensation in Athletes**

Refractive Status	Consider Prescribing at:
Myopia	–0.25 D or more
Hyperopia	+1.00 D or more
Astigmatism	0.50 D or more*
Anisometropia	0.50 D or more†

*Against-the-rule and oblique astigmatism are more detrimental than with-the-rule astigmatism.
†Consider meridional effects with asymmetric astigmatism.

achieve clarity. For example, a golfer with unaided visual acuities of 20/25 (6/7.5) may appreciate the improved ability to judge the terrain of the course and find the ball when wearing a –0.25 DS prescription. This amount of myopia is typically insignificant, but the lack of compensation may have an impact on golf performance. Similarly, an uncorrected hyperope may find relief from eye strain with a prescription when playing tennis.

Guidelines have been published to assist the practitioner in determining when refractive compensation should be considered[5] (Table 6-1). Any patient with myopia of –0.25 D or more should be counseled on the possible benefits of refractive compensation. Astigmatism has a similar effect on visual resolution as does myopia, especially against-the-rule and oblique astigmatism. Refractive compensation should be considered with –0.50 D or more astigmatism, although with-the-rule astigmatism compensation may not yield as much improvement on clinical measures. Low amounts of hyperopia are often well tolerated without correction; however, hyperopia of +1.00 D or greater may require a significant amount of effort from the athlete to achieve and maintain clarity. Low amounts of anisometropia are not always compensated for, especially when the refractive errors are low. Anisometropia of 0.50 D or more can have a detrimental effect on depth perception, and some athletes may be sensitive to that effect. In addition, the effects of meridional anisometropia should be considered in athletes with asymmetric astigmatism. The guidelines are useful for the practitioner to trigger the discussion of the potential benefits of a refractive prescription; the athlete ultimately makes the decision whether to experiment with the prescription.

When an athlete decides to experiment with a refractive prescription and he or she has not previously worn a correction, the timing of the experimentation should be discussed. The best time to experiment is during the off season. The athlete is typically not competing at that time, so adaptation to the prescription will not directly affect critical performance. Athletes generally use the off season to rest, work on biomechanical skills, and prepare their physical conditioning for the next season. This presents a perfect opportunity to experiment with refractive compensation. If a new prescription is introduced during the competitive season, the athlete may find that performance is negatively affected during the adaptation to the magnification effects induced by spectacle lens wear. For example, a basketball player who wears a myopic prescription for the first time will need to adjust to the change in spatial perception induced by the lenses (e.g., the basket can appear closer).

Presbyopia potentially presents a prescribing challenge in some sports activities. In many sports, a near addition is unnecessary because near visual acuity has a minimal impact on performance.

In tennis, for example, clarity of near vision provides no advantage to performance. In golf, near visual acuity does not affect performance; however, clear near vision is desirable for seeing the score card and identifying one's ball during play. A spectacle prescription with near addition lenses can interfere with the golfer's view when addressing the ball and adjusting swing mechanics. A small, low-set segment set in one lens in the opposite viewing direction from the putting view angle has been recommended as a solution to this problem. For example, offset the segment in right gaze (lower temporal corner of the lens) for a right-handed golfer.[6] A better option may be contact lenses for playing the game and a near prescription (e.g., half eyes) to use when scoring. Alternatively, a progressive addition lens (PAL) may be prescribed with a short corridor and narrow near zone set low to minimize peripheral distortion effects. Pilots and boat operators may require a double segment design, with positioning of the near additions to allow them to read instruments in downgaze and upgaze positions. Placing a small segment at the top of the lens and a traditional segment at the bottom of the lens typically provides a solution to the near vision challenge (although this lens design is not currently available with polycarbonate lenses). Billiards players often use a single-vision intermediate-distance prescription for use during play, and the optical centers may need to be carefully measured in the billiards viewing position with strong prescriptions to minimize induced prism effects. Scuba divers may need a multifocal contact lens or prescription bonded to the face mask or attached as an insert within the mask to allow the diver to see the equipment, instruments, and underwater environment clearly. In these cases, the prescription must be adjusted for the significant increase in vertex distance created by the mask. For reactive sports, spectacle lenses produced better reaction times at near in presbyopes than do contact lenses.[7] Several companies offer PALs in high base (wrap) designs for use in sports.

The toughest challenge with presbyopia is created by shooters. Shotgun shooters are not significantly affected by the loss of accommodation because the task does not require critical alignment of sights on the target.[8] Rifle shooting requires that the shooter clearly focus the target at a far distance while carefully aligning the front and rear sights of the rifle with the target. For the presbyope, the rifle's front sight (intermediate distance) and rear sight (just beyond the spectacle plane) cannot be viewed with the same clarity as they were before the onset of presbyopia, and bifocal, trifocal, and multifocal lens designs do not offer an effective solution. Some shooters are happy with the distance correction slightly overplussed, creating a tolerable amount of blur for both the target and sights.[9] Telescopic sights also have been recommended for this situation to allow clarity and accurate alignment without the need for near accommodation.[8] Aiming scopes are available for archery as well; however, the increased magnification offered by these converging lenses does not improve visual acuity of the target because of the presence of significant dioptric blur.[10] If spectacles are worn by the shooter, the lens material should protect the athlete and the eye relief distance should be sufficient to protect against rifle recoil.[8,9] As described with billiards, the optical centers may need to be carefully marked with the athlete in the shooting position(s) with a strong refractive prescription to minimize the induced prism effects.

Pistol shooters are particularly affected by presbyopia because the front and rear sights must be aligned with exacting precision as a result of the shorter length of the weapon. Again, the front sight is positioned at an intermediate distance from the eyes, and the difference in accommodative demand between the sights and the far target creates significant blur for one distance when focusing at the other. Presbyopic pistol shooters are particularly disturbed

by the loss of image clarity and often want a solution that provides image clarity at both distances. A pinhole aperture can be created by punching a tiny hole in black electrical tape and carefully aligning the tape on the spectacle lens of the aiming eye to allow adequate acuity at both distances for the early presbyope.[8] As the pistol shooter approaches absolute presbyopia, the pinhole will no longer provide adequate relief, and a bifocal spectacle will need to be carefully measured to allow clarity of the distant target through the upper lens and clarity of the pistol sights through the near addition lens. This movement between the distance correction and near correction should occur with 1 mm of head movement up or down when in the shooting position, and the practitioner should meticulously measure this position (with clear tape to simulate the add position) for a special-purpose shooting prescription.[8] An executive or FT40 segment design will not induce a vertical image jump when moving into the near segment. A flip-down lens design that would allow clarity at two distances also has been recommended,[8,9] but the effect on alignment created by flipping the lenses may be unacceptable.

NONPROTECTIVE SPORTS EYEWEAR

A nonprotective spectacle correction is recommended only for use in noncontact sports. In sports with a low incidence of contact (e.g., volleyball), other risks for eye injury exist, such as injury from the ball. In most sports the use of contact lenses or appropriate protective eyewear is preferred over the use of dress eyewear. Dress eyewear does not offer the impact resistance necessary to protect the wearer from the possible hazards encountered in many sports.

The American National Standards Institute (ANSI) has established industry standards for the impact resistance of ophthalmic lenses. Dress eyewear performance standards are detailed in the ANSI Z80.1 standard,[11] and the industrial strength (safety) eyewear standards are detailed in the ANSI Z87.1 standard.[12] The use of polycarbonate, Trivex (PPG Industries, Pittsburgh, Penn.), or NXT (Intercast Europe, Parma, Italy) lens materials can provide significantly improved impact attenuation properties over conventional glass and CR-39 lens materials.[6,13-17] However, the frame construction of fashion eyewear does not withstand the forces encountered in many sports. The ANSI Z80.3 standard for nonprescription sunglasses and fashion eyewear and standards for sports protective eyewear are discussed later in this chapter.

Spectacle prescriptions are not commonly recommended for use in sports. The main concerns in addition to the lack of adequate eye protection provided by dress eyewear are the potential impact of optical aberrations of the lenses and visual field restriction created by the frames. Four of the seven monochromatic, or Seidel, lens aberrations can degrade the optical image transmitted through the off-center portions of the lens; radial or oblique astigmatism, power error caused by the curvature of the lens, lateral chromatic aberration, and distortion can each decrease the useful field of view through a lens.[15,18] The reduction in the useful field of view can have a detrimental impact on performance in sports. For example, a right-handed golfer viewing the hole during a putt looks through the left field portions of his or her spectacle lenses, and the image can be significantly altered in large refractive errors because of these aberrations. Stronger refractive prescriptions also produce larger amounts of prismatic effects when viewing away from the optical centers of the lenses, and the effect is increased with larger angles of view as approximated by Prentice's rule.[15,19] Therefore lens design and optical center measurements are critical features of crafting the optimal spectacle

correction for an athlete. Wrap lens designs potentially can eliminate or reduce some of the aberration and visual field problems found in nonwrap lenses; however, these designs are more commonly found in performance sun eyewear rather than dress eyewear.

Spectacle lenses may be a good prescribing option for noncontact sports and recreational athletes who do not require high-performance optics. Many who participate in golf, tennis, running, cycling, fishing, archery, and shooting sports perform satisfactorily with spectacle corrections. These athletes should be prescribed a suitable impact-resistant lens material and counseled regarding the risks of eye injury with dress eyewear. These athletes also may appreciate the visual performance benefits of contact lenses, such as elimination of the four field-of-view aberrations and expanded visual fields. Many shooters and archers prefer spectacles over contact lenses because of the stability of clear vision obtained with spectacle lenses. Because peripheral vision is not a significant factor in most aiming sports, the enhanced visual field does not offer a significant benefit. In addition, contact lens movement on the eye can produce undesirable visual fluctuations during the prolonged gaze behavior (without blinking) that many shooters and archers develop. The shooter or archer is not typically bothered by lens aberrations off the optical center; however, the lenses may need to be fit with the optical centers set for eye position used when aiming with strong prescriptions. The athlete should bring the weapon, carefully unloaded, to the office for this measurement. The practitioner can also arrange to meet the athlete at his or her training facility to make the measurement to generate interest in sports vision services.

Lens Treatment Options

Ophthalmic lenses are available with a variety of lens treatment options. Most athletes will be bothered by reflections from the lens surface, and reflections off the back surface of the lens are particularly distracting. For example, the golfer who sees a reflection of the leaves on a tree behind him or her fluttering in a breeze will not be pleased by this distraction during a critical putt. Antireflective coatings are a particularly valuable lens treatment option, and the improvements in technology that allow multilayer antireflective coating have improved the performance of this lens option.[15] The athlete should be warned that antireflective coatings are easy to scratch if the spectacles are not cleaned properly or not kept in a protective case when not in use and that the coating will make dirt and smudges more visible. If polycarbonate lenses are prescribed, an abrasion-resistant coating is provided by the manufacturer because polycarbonate is an inherently soft material and is easily scratched.

Lens fogging and precipitation are two other factors that should be considered in spectacle wearers who compete in predisposing environmental conditions. Condensation appears on spectacle lenses when the temperature of the lenses is lower than the dew point of the surrounding air.[15] Rain, fog, and other moisture in the environment also will produce water drops on the lens surface that can dramatically degrade the athlete's vision through the lenses. Antifog coatings are available to make the lens surface more wettable so that the moisture forms a thin film on the lens rather than droplets.[15] These coatings also help slough water off the lens surface quicker in wet environments. An antifog coating does, however, interfere with the efficacy of an antireflective coating.

Lens coatings reduce the impact resistance properties of the lens because of the change in surface tension created by the coatings. Polycarbonate and Trivex lens materials with antireflection coatings have reduced penetration resistance to sharp objects, especially in lenses with reduced center thickness.[17,20]

PROTECTIVE EYEWEAR

In many sports, participation exposes the athlete to significant risk for eye injury. Sports involving a ball or fast-moving object, a racquet, stick, bat, or body contact have a significant potential for eye injuries.[21] Prevent Blindness America estimates that more than 40,000 eye injuries occur each year from sports participation in the United States, as reported by the U.S. Consumer Product Safety Commission (Table 6-2).[22] This estimate is recognized as only a fraction of the true incidence of sports-related eye injuries because these injuries represent only those reported from a core of hospital emergency departments in the United States and its territories.[23] A better estimate is 2.5 times higher than the amount reported in hospital emergency departments, indicating a more accurate incidence of approximately 100,000 sports-related eye injuries per year in the United States.[22] Many of the eye injuries sustained during sports participation are preventable with the use of appropriate eye protection. Primary eye care providers must educate all patients about the risks for eye injury during vocational and avocational pursuits, provide information regarding the options for prevention of eye injuries, and direct the patient to ophthalmic services for ocular protection during sports and recreational activities.

As previously discussed, dress eyewear or occupational safety eyewear does not offer the impact resistance necessary to protect the wearer from the possible hazards encountered in many sports. Polycarbonate, Trivex, or NXT lens materials provide significantly improved impact attenuation.[13-17] However, the frame construction of fashion eyewear cannot withstand the forces encountered in many sports. Similarly, contact lenses do not offer eye protection for athletes; in fact, rigid contact lenses may increase the damage to the cornea if they break from a blunt trauma.[24] Many manufacturers have designed eyewear and equipment to protect the athlete during sports participation, and performance standards have been developed to ensure adequate protection for specific sport purposes.[25,26]

TABLE 6-2 **Sports and Recreational Eye Injury Reports and National Estimates**

	National Injury Rate	National Injury Rate Estimates
Ball sports	N = 20	
Baseball	N = 108	3,137
Basketball	N = 212	6,114
Combative sports	N = 12	
Football	N = 72	1,768
Golf	N = 212	
Hockey	N = 17	
Racket sports	N = 60	
Soccer	N = 53	1,822
Water/pool sports	N = 54	2,076
Total	**N = 413**	15,358

Source: The U.S. Consumer Product Safety Commission, 2004.

The American Society for Testing of Materials (ASTM) is a nongovernmental group that has developed performance standards (F803) for eye and head protection in many sports, including basketball, baseball, racquet sports, field hockey, and women's lacrosse. The work item WK4175 revision of F803 considers the impact differences between the balls and sticks used in field hockey and women's lacrosse. A stick penetration test is needed for eye protection, and the differences in ball density should be considered in the standard. A work item for eye protection in soccer (WK1237) is currently under a committee for F803.

ASTM performance standards are established for each sport individually, and the forces potentially encountered in a sport are used to determine appropriate testing parameters. Typically, the protective eyewear is placed on a standard head form and the ball, puck, stick, finger, or elbow is directed at the eyewear from a variety of angles at the predetermined velocity. For example, the eyewear designed for racquet sports must protect the eye and orbit from a squash or racquetball projected at 90 mph from several angles. More details regarding the development of standards and evaluation methods can be found at the ASTM Web site (www.astm.org). Additional ASTM standards are available for sports in which traditional eyewear designs are inadequate, including protection attached to a helmet for youth baseball batters and base runners (F910), ice hockey (F513), paintball (F1776), and skiing goggles and shields (F659). All protective eyewear also is tested for standard D1003, which covers the evaluation of specific light-transmitting and wide-angle, light-scattering properties of transparent materials.

Several groups certify equipment to ensure compliance with the ASTM standards for various sports. The Canadian Standards Association (CSA) certifies products that meet Canadian standards for racquet sports (similar to the ASTM standards). The Protective Eyewear Certification Council (PECC) certifies protectors that meet ASTM F803 standards. The Hockey Equipment Certification Council certifies helmets and face shields for use in hockey. For baseball and football helmets and face protectors for football and men's lacrosse, the National Operating Committee on Standards for Athletic Equipment offers certification. Athletes should use equipment that displays the logo of these certifying bodies to ensure safety (Fig. 6-1). The ASTM standards have proven to be extremely effective in preventing sports eye injuries; no severe eye injuries have been reported for an athlete wearing appropriate eye protection.

To assist athletes in selecting appropriate sports eye protection, the American Academy of Ophthalmology issued a joint policy statement with the American Academy of Pediatrics containing recommended eye protectors for selected sports (Table 6-3).[27] Many publications have provided recommendations for eye protection in sports.[21,28-46] Two basic types of protective eyewear designs are available: a goggle style worn similarly to street eyewear (Fig. 6-2) and shield-style protection attached to a helmet (Fig. 6-3). Protective sports eyewear must be correctly fit to ensure adequate protection for the athlete. If a young athlete has facial features that are too small to fit any available protective sports eyewear correctly, polycarbonate lenses of 3 mm center thickness should be placed in a children's frame that meets ANSI Z87.1 standards. This design offers the best chance of eye protection in this situation, although it may not completely protect the athlete from the forces encountered in many sports.[21]

Eye protection can prevent ocular damage in many sports. This chapter focuses on the more common sports in which eye protection is used.

Racquet Sports

As discussed in Chapter 7, a significant portion of sports-related eye injuries are caused by racquet sports.[25,47-52] Racquet sports include badminton, handball, racquetball, squash, and



Figure 6-1. Certifying logos from the Protective Eyewear Certification Council **(A),** Hockey Equipment Certification Council **(B),** Canadian Standards Association **(C),** and National Operating Committee on Standards for Athletic Equipment **(D).** (Courtesy Paul Vinger, MD, Concord, Mass.)

tennis; the CSA and ASTM F803 standard is designed to provide protection for any racquet sport. The ball or shuttlecock is hit with tremendous force and can travel at dramatic speeds (Table 6-4). As previously mentioned, the eyewear must protect the eye and orbit from a squash or racquetball projected at 90 mph from several angles, including the side. The hinges are also tested to ensure protection from the forces directed at this potentially weak area. Hingeless frames with straps are recommended when feasible.

Even though the balls used in some racquet sports are larger than the average orbital opening, the compression forces can push the ball deep inside the orbit.[25] The first protective eyewear was designed for use in handball and consisted of a lensless rubber-covered wire frame to reduce the orbital opening (Fig. 6-4). These open eye guards were subsequently

TABLE 6-3 **Recommended Eye Protectors for Selected Sports***

Sport	Minimal Eye Protector	Comment
Baseball/softball (youth batter and base runner)	ASTM F910	Face guard attached to helmet
Baseball/softball(fielder)	ASTM F803 for baseball	ASTM specifies age ranges
Basketball	ASTM F803 for basketball	ASTM specifies age ranges
Bicycling	Helmet plus streetwear/fashion eyewear	
Boxing	None available; not permitted in sport	Contraindicated for functionally one-eyed athletes
Fencing	Protector with neck bib	
Field hockey (men and women)	ASTM F803 for women's lacrosse Goaltender full-face mask	Protectors that pass for women's lacrosse also pass for field hockey
Football	Polycarbonate eye shield attached to helmet-mounted wire face mask	
Full-contact martial arts	None available; not permitted in sport	Contraindicated for functionally one-eyed athletes
Ice hockey	ASTM F513 face mask on helmet Goaltenders ASTM F1587	HECC or CSA certified Full-face shield
Lacrosse (men)	Face mask attached to lacrosse helmet	
Lacrosse (women)	ASTM F803 for women's lacrosse	Should have option to wear helmet
Paintball	ASTM F1776 for paintball	
Racquet sports (badminton, tennis, paddle tennis, handball, squash, and racquetball)	ASTM F803 for selected sport	
Soccer	ASTM F803 for selected sport	
Street hockey	ASTM 513 face mask on helmet	Must be HECC or CSA certified
Track and field	Streetwear with polycarbonate lenses/fashion eyewear†	
Water polo, swimming	Swim goggles with polycarbonate lenses	
Wrestling	No standard available	Custom protective eyewear can be made

*Joint policy statement of the American Academy of Pediatrics Board of Directors, February 1996, and the American Academy of Ophthalmology Board of Trustees, February 1995. Revised and approved by the American Academy of Pediatrics Board of Directors, October 2003, and the American Academy of Ophthalmology Board of Trustees, November 2003.

†Javelin and discus have a small but definite potential for injury. However, good field supervision can reduce the extremely low-risk injury to near negligible.

used for protection in squash and racquetball. Studies demonstrated that the lack of a protective lens allowed penetration of the ball, potentially resulting in significant eye trauma.[53-58] The ability of the lensless eye guard to compress the ball actually may increase the risk to the ocular tissues by essentially funneling the ball into the orbit.[56,58] In addition, lensless eye guards offer only limited protection from a racquet injury and are never recommended for use.

Many have advocated for protective eyewear use in squash and racquetball and promote education regarding the ineffective protection provided by dress eyewear.[52-69] Dress eyewear with glass or CR39 lenses may increase the risk of severe ocular trauma in racquet sports if the lens shatters on impact.[48,54,59,62,70,71] Most racquet sport organizations for handball,



Figure 6-2. Goggle-style sports eye protectors: Liberty MAXX frame with temples **(A)** and Liberty MAXX frame with straps **(B).** (Courtesy Liberty Optical/Rec Specs, Fairfield, NJ.)

racquetball, and squash mandate the use of appropriate protective eyewear during competition, and many athletic clubs have instituted eye protection requirements for club play.

Ice Hockey

In ice hockey the most common cause of eye injury is from the stick, followed by the puck or opponent.[25,47,72-79] With the mandate for face protection in all levels of hockey except the National Hockey League, the incidence of eye injuries has significantly declined.[80-84] No eye injuries have been reported with a full-face shield in use; however, significant trauma has been incurred with a half-face shield.[84] It is an unfortunate situation that the National Hockey League has resisted issuing a mandate for face protection, and each season produces examples of the ocular effects of this decision. There are many styles of face protection approved for hockey by ASTM (F513 and F1587) and CSA (CAN3-Z262.2-M78) standards: full-face masks for goaltenders and full-face masks or half visors for other positions (Fig. 6-5). Because of the improved eye safety profile, full-face shields are recommended. The ASTM F803 standard is recommended for eye protection in field hockey.

Lacrosse

Lacrosse has risks for eye injury that are similar to hockey in that the stick and ball present significant hazards. Men's lacrosse mandates head and face protectors, thereby minimizing the risk for ocular injury. Women's lacrosse did not mandate face protection until recently, and the incidence and severity of eye injuries caused many to advocate for compulsory eye protection.[25,85-90] The ASTM F803 standard is recommended for protection in women's lacrosse, and wire mesh protectors are favored by the athletes (Fig. 6-6). The women's lacrosse ball is shot at 45 mph at the eyewear during ASTM testing to determine effective

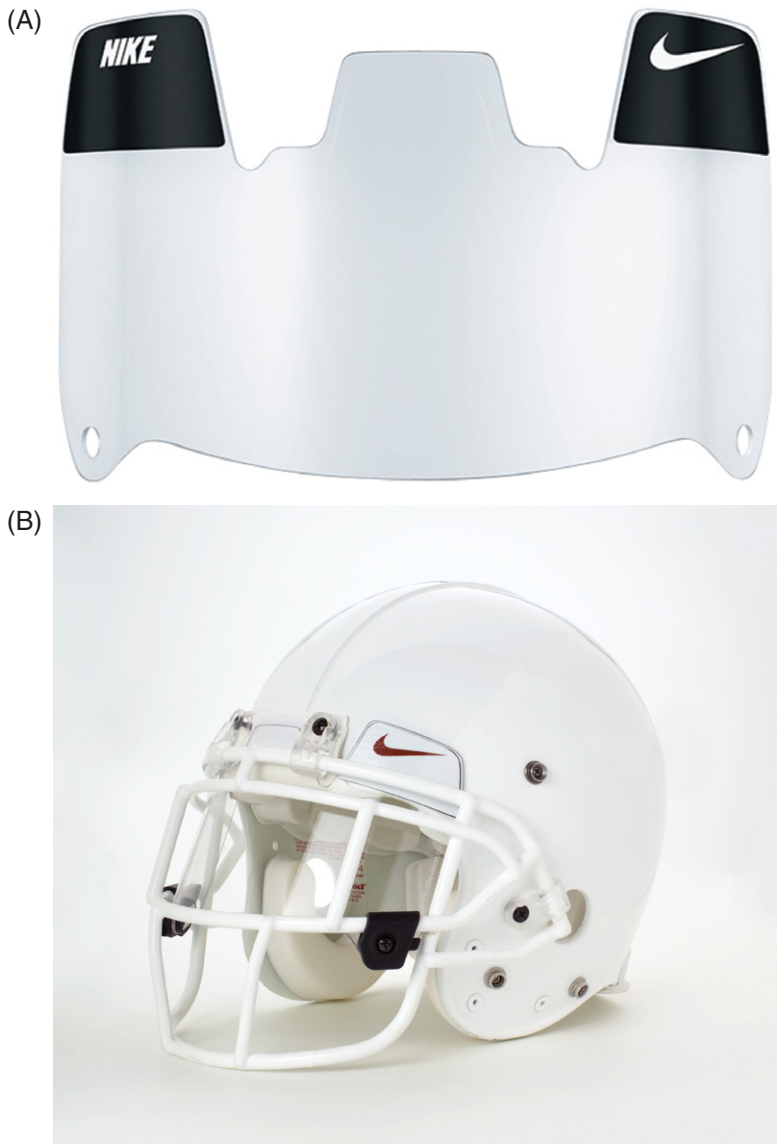


Figure 6-3. Nike Vision Eye Shield (**A** and **B**).

attenuation of the forces encountered in the sport. As previously mentioned, a work item to revise the F803 standard to reflect the ball and stick impact issues in lacrosse is currently under review.

Baseball

Baseballs have a high incidence of reported eye injuries in the United States, and the sport of baseball has been reported as the leading cause of sports-related eye injuries in children in

TABLE 6-4 **Estimated Ball or Shuttlecock Speeds in Selected Racquet Sports**

Sport	Shot Type/Record	Speed
Badminton	Smash speed	162 mph*
Racquetball	Serve	~110 mph
	Return	~70 mph
Squash	Record	151-170 mph
Table tennis	Smash record	~70 mph
Tennis	Men's serve record	153 mph*
	Women's serve record	127 mph*

*Folkand C: Guinness World Records 2006, New York, 2005, Bantam.

the United States.[25,52,91-94] Risks include being hit with a pitch or a batted or thrown baseball. Spectators are also at risk of injury from batted balls or errant throws. The hardness of the ball has been related to the potential risk for head injury but does not have a significant impact on ocular injuries; the harder the ball, the greater the risk for head and brain injury.[95] The ASTM F910 standard is designed to provide protection for batters and base runners in youth baseball. Approved faceguards have provided excellent protection and have good acceptability by athletes and parents.[96] A significant portion of youth baseball players reported vision obstruction (40%) and discomfort (23%) and that they played worse with the faceguard (12%); however, 81% believed playing with the faceguard was acceptable.[96]



Figure 6-4. Lensless eye guard previously used for racquet sports.



Figure 6-5. Hockey face and eye protection. (Courtesy NXi Defense Systems, Lake Orion, Mich.)



Figure 6-6. Wire mesh eye protector for women's lacrosse.

Paintball

War games with paintball guns present a tremendous risk for ocular injury when proper protection is not used.[97-105] The paint pellet is shot with sufficient energy to cause severe eye trauma; the ASTM F1776 standard therefore establishes specifications for eye protection (Fig. 6-7). Eye injuries have not been reported with the use of ASTM F1776 approved eyewear, although eye injury can occur from a shot that displaces loosely fitting eyewear.[101] Other shooting sports are not specifically covered by ASTM standards; however, the ASTM F803 standard is generally recommended for use as "combat goggles,"[41] and polycarbonate lenses with side shields have been recommended to protect against shotgun spray.[106]

Alpine Skiing

The risk of ocular trauma is relatively low for cross-country and downhill skiers. Tree branches can cause problems, and ski pole tips can result in significant damage.[107] The ASTM F659 standard is designed to protect against lens breakage from a ski pole impact. Because the amount of ultraviolet (UV) radiation markedly increases at higher elevations, and snow reflects 85% of the UV radiation, additional risk of photokeratitis exists when appropriate UV filters are not used.[108] Many goggle designs are available with prescription inserts for those who do not wear contact lenses, although contact lenses are typically the preferred method for refractive compensation.



Figure 6-7. Eye and face protection for paintball.

Swimming and Water Sports

Swimming and water sports also do not present a significant risk of eye injury. A study of ocular pathology prevalence in swimmers using goggles for at least 5 years compared with nonswimmers found no significant differences.[109] The elastic band tension, however, can cause swim goggles to snap back and cause severe ocular injuries.[25] Many swim goggles are commercially available, and many designs are available with prescription lenses.[110,111] Most swimmers and divers use a goggle or face mask so that no adjustment is necessary to the habitual prescription to compensate for the difference in the index of refraction of the water medium.[41] Some goggle designs have ventilation holes to reduce lens fogging in highly active water sports such as water skiing, surfing, windsurfing, and endurance swimming.[111] A variety of dive masks also are available with prescription inserts or corrective lenses affixed to the face plate. The air space of the dive mask eliminates the need to change the habitual prescription; however, the increased vertex distance may necessitate an adjustment to the prescription. Water polo presents a risk of blunt trauma from fingers, elbows, or the ball to the improperly protected eye. Swim goggles for water polo should contain polycarbonate lenses to prevent lens breakage, particularly for goalkeepers, who are at a higher risk for facial injury from the ball.

Soccer

The soccer ball is responsible for most ocular trauma in soccer, although the incidence of eye injuries is relatively low.[50,52,112-117] Although the soccer ball is significantly larger than the orbital opening, a portion of the ball will deform and enter the orbit during contact with the high velocities at which the ball is kicked.[116,117] As previously mentioned, a work item for eye protection in soccer (WK1237) is under a committee for F803. Most practitioners recommend use of ASTM F803 standard eyewear for racquet sports with a secure strap for protection in soccer.

Other Sports

Eye protection may be desirable in many other sports and recreational activities, although no standards exist for those activities. Protective eyewear that meets the ASTM standard for squash (F803) often offers the best available protection for the athlete unless custom-fabricated protective eyewear can be acquired.

Issues with Protective Eyewear

Some of the common issues causing athletes to be resistant to using protective eyewear are eyewear discomfort, adjustment to wearing eyewear, lens fogging, poor vision (especially visual field constriction), cosmetic appearance, and the perception that it is unnecessary. Athletes who do not habitually wear a spectacle prescription have more difficulty adjusting to wearing eyewear. Adjustment can occur quickly if the eyewear is worn for an extended time period (e.g., several hours continuously), and this should be done outside the sport situation to minimize athlete stress during adaptation. This eyewear adaptation training should also help the athlete adjust to the change in peripheral visual field size that may be induced by the frame.

Early studies found that sports protective eyewear constricted the peripheral visual field.[118-120] The constricted visual field was perceived by 12.5% of subjects using racquetball protectors[118] and was reported to affect visual reaction time (especially with flat lens design eyewear).[120] A study of several types of protective eyewear found that all restricted peripheral

vision to some degree but that the restriction did not affect a peripheral reaction task.[119] Some fairly recent studies did not find that sports eye protectors constricted visual fields,[121,122] whereas a comparison of hockey visor and sports goggles did find field restrictions but no effect on visual acuity, contrast sensitivity, color vision, or foveal threshold.[123] The decision to wear eye protection becomes a balance between the cost to peripheral vision versus the risk of vision loss.

For highly active sports in humid conditions, problems with eyewear fogging can occur. All approved protective eyewear has an antifog coating on the lenses, and additional antifog solutions are available for supplemental use. Athletes should remove the eyewear when not actively participating in the sport to prevent the rising body heat from condensing on the lenses.[59]

Many athletes are concerned about cosmetic appearance, and protective eyewear is not typically appealing to the athlete. Fortunately, protective eyewear has evolved into more fashionable designs and has earned greater acceptability in some sports. There will always be athletes and sports in which a prevailing attitude of machismo impedes the use of appropriate eye protection.

Squash is a sport with a significant risk for eye injury and has received the attention of several studies to determine the issues related to the low rates of protective eyewear use in the sport. Many players believe that prescription dress eyewear offers adequate protection,[65-67] and lensless eye guards continue to be sold as protection.[61] Of those who do not wear any eyewear during squash, most believed that protective eyewear was unnecessary because of inadequate knowledge of the risks.[66,67,124] The misperception that experience and expertise reduce the risk for eye injury in squash also exists[124]; in fact, the amount of time playing squash and the increased speeds encountered at higher levels of play actually increase the risk for injury.[62,125] Some squash players were concerned with poor vision and comfort[45]; however, studies suggest that education regarding injury risk and prevention is an effective motivator to increase eye protection use (especially because a previous eye injury increases utilization).[61,64,66-68,123,124,126-128]

Functionally Monocular Athletes

Some athletes would like to compete in sports but have some level of loss of function in one eye. Best-corrected visual acuity less than 20/40 (6/12) often is used to determine loss of visual function because this level of impairment begins to affect academic and occupational performance, as well as driving privileges. A study of children with an enucleated eye found good compliance with protective eyewear use in sports and that subsequent eye injury to the remaining eye had been successfully averted.[35] In the functionally monocular athlete, the main risk is for severe injury to the better eye. The presence of amblyopia increases the risk of blindness by more than 150% in children (1.75/1000 compared with 0.11/1000), and trauma (including sports trauma) accounts for more than 50% of the resulting blindness.[129]

One-eyed athletes should use protective eyewear that meets relevant standards for participation in all sports activities.[33] These same athletes should wear well-built dress eyewear frames containing polycarbonate or Trivex lenses for nonsport activities. Functionally monocular athletes should be discouraged from participating in sports with a risk for serious eye injury in which an effective method of eye protection does not exist, such as boxing, wrestling, and martial arts.[33,129a]

Athletes who have had eye trauma or eye surgery that has resulted in a weakening of the ocular tissues should be counseled about the risk of eye trauma in sports. Recommendations

for eye protection in sports and recreational activities are similar to those for the one-eyed athlete.[21] Specifically, athletes who have undergone radial keratotomy should be adequately counseled because the procedure significantly weakens the corneal integrity.[25]

Clinicolegal Issues for Protective Eyewear

Eye care providers are in a position that requires appropriate patient counseling regarding eye injury risks and suitable prevention measures. All prescribed or recommended ophthalmic materials are potential sources of legal liability. Legal liability claims can be based on either practitioner negligence or product-based liability resulting from problems with the lenses or frames.[130-133] Plano eyewear and plano sun eyewear can also be a source of potential liability for the practitioner if proper counseling is not provided. Contact lens patients also need appropriate counseling regarding supplemental eye protection during sports and recreational activities.[134]

Good patient counseling begins with a thorough patient history to determine the specific needs and risk profile for the individual. A lack of knowledge regarding a patient's sports participation does not protect a practitioner in a liability case if an attempt to elicit that information was not made. Any eyewear recommendations must be made with a thorough knowledge of how that eyewear will be used.

A claim of professional negligence is particularly troubling for a practitioner. Negligence claims involving sports and recreational eyewear typically stem from failure to prescribe the appropriate lens material, failure to warn of potential for breakage (especially with non–impact-resistant materials), or failure to inspect and verify the eyewear before dispensing.[130,132] Industry standards play an important role in determining legal liability, and practitioners are expected to understand and comply with those standards. As previously mentioned, polycarbonate or Trivex lenses offer increased impact resistance compared with glass or CR-39; therefore these materials clearly are the recommended choice.[13-17] The lens material preference should be clearly stated on the prescription provided to the patient; if the patient refuses the recommended lens material, that fact should be adequately documented in the patient record and the patient should be warned of the diminished impact resistance of the alternate material. The impact resistance of a lens material should be discussed without using the words shatterproof or unbreakable, because even polycarbonate material shatters if hit with sufficient force.[130] If a practitioner offers ophthalmic dispensing services, the ancillary personnel responsible for verification and dispensing should be properly educated regarding the industry standards. The lenses should be inspected to ensure that the impact resistance is not compromised by surface treatments[17] or improper edging.[130]

Eye care practitioners also are obligated to counsel the patient on suitable frames for sports and recreational activities. The frames should meet any prevailing ASTM performance standards, and the practitioner and dispensing personnel must understand the proper uses for the eyewear and any liability issues. For example, claims have resulted from the recommendation of lensless eye guards for racquetball.[131,135] If a patient selects a frame that is not suitable for protection, that fact should be adequately documented in the patient record and the patient should be warned of the diminished impact resistance of both the frame and the lenses (because the frame may not adequately prevent the lenses from displacing back into the eye on impact).

PRESCRIBING FILTERS AND PERFORMANCE SUN EYEWEAR

Athletes who participate in outdoor sports and recreational activities require protection from solar radiation. On a bright sunny day, illuminance ranges from 1000 to 10,000 foot-lamberts, saturating the retina and reducing finer levels of contrast sensitivity.[136] Dark sunglasses aid in recovery of contrast sensitivity and dark adaptation after photoreceptor saturation.[137] The commonly accepted benefits of sun eyewear include protection from sun exposure and ocular trauma and the reduction of eye fatigue and squinting. The ability of properly selected filters to reduce glare and improve contrast may also produce an enhancement in the ability to discern crucial details and judge depth.

The ocular effects of UV radiation depend on the duration of exposure and the wavelength of the radiation.[138] Prolonged exposure to the middle UV-B waveband has been associated with a variety of ocular problems, including pterygium, pinguecula, cataract, and keratopathy.[139-141] UV protection provides patients with decreased risks of cataracts, photokeratitis, corneal burns, anterior uveitis, and retinal lesions.[139,140] The American Optometric Association recommends 99% to 100% protection from near and middle UV (UV-A, UV-B) radiation for sun eyewear.[142]

Research on the blue light hazard, defined by European sunglass standards as 380 to 500 nm, has shown that short wavelength visible light may create deleterious retinal changes, specifically retinal lesions.[143,144] The most harmful wavelength in the visible spectrum for the production of retinal injury appears to be radiation near 440 nm.[141]

The visible light portion of the electromagnetic spectrum is between approximately 380 and 760 nm (Fig. 6-8). The human eye is capable of discerning the entire spectrum of color because of the different wavelengths of light that compose the chromatic spectrum. Part of the eye's ability to see artificial (or enhanced) depth is because of the natural chromatic aberration that occurs when monochromatic light is focused on the retina. Because of the differences of wavelength, different colors will refract through the ocular media with different focal points. The difference in focal power between the shorter wavelengths (blue spectrum) and the longer wavelengths (red spectrum) is approximately 2.3 D of focal length.[145] This chromatic aberration results in image blur. Chromatic aberration is cited as the most significant aberration in the well-corrected human eye,[145,146] and filters that

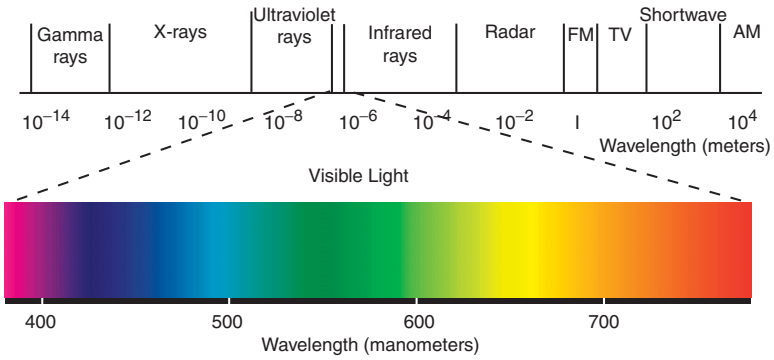


Figure 6-8. Electromagnetic spectrum.

diminish transmission of the short wavelength (blue) portion of the visible light spectrum improve retinal image quality by reducing the amount of chromatic aberration.[147]

Visible light is responsible for glare that can cause significant interference with an athlete's ability to see the visual details critical for successful performance. For example, direct glare from the sun is evident in a blue sky because it affects the visibility of a lofted ball. Reflected glare is exceptionally troubling for athletes when the sun is reflected off surfaces such as water, snow, pavement, and sand. These surfaces reflect horizontally polarized light that can produce substantial glare, particularly water surfaces that are constantly moving. Vertically polarized filters are effective by virtually eliminating horizontally polarized light in the environment.

For an athlete who must compete during the twilight transition hours, the exposure to bright sunlight impedes the initial phase of dark adaptation.[138,148-150] The final level of dark adaptation is elevated, and daily prolonged sun exposure can produce decrements in visual acuity and contrast sensitivity.[148,149,151] Excessive exposure to bright visible light can result in erythropsia, which is often reported as "red vision" when the individual returns indoors after many hours in the sun.[152] The judicious use of sun eyewear can minimize the impact of bright sunlight on the dark adaptation process and thereby assist the athlete during the transition to artificial lighting conditions. In addition, the transmission levels of sun eyewear lenses may need to be periodically adjusted in changing sun conditions (e.g., variable cloud cover). An athlete may benefit from a variety of sun eyewear products or a single product with interchangeable lenses or photochromic lenses. Skeet and trap shooters are particularly sensitive to the effects of changing light levels and typically possess eyewear incorporating several filter hues with several tint densities (Fig. 6-9).



Figure 6-9. A shooter's tint selection.

Sun eyewear is a tremendous market, and growth in the sports sun eyewear segment has been impressive. Significant innovations in frame design have been made to suit sports demands better, and a trend toward sport-specific lens tinting has been growing. Many manufacturers have invested heavily in research and design to develop light transmission characteristics that purportedly offer performance enhancement features for specific sport demands. Continued innovation in this area can be expected as frame and lens technologies continue to push the envelope of individualized and sport-specific performance. Separating the hype from solid evidence of performance benefits often is difficult, and tint preference is still broadly influenced by individual variations. The transmittance characteristics for each filter are based on the tint colors used, the amount of tint used, and the lens material used.[137,144,153] The resulting spectral transmission curve often is proprietary for the manufacturer and protected by patent law. The general filter recommendations in this text are presented as a guide.

Neutral Gray Tints

Neutral gray tints absorb all wavelengths of the visible light spectrum approximately equally; therefore the natural appearance of colors is preserved. These filters are preferred by athletes who are sensitive to color information in their sport and who do not appreciate even subtle alteration of the natural environment. Neutral gray tints are often favored by those participating in golf, skiing, and mountaineering activities. Athletes must make critical performance decisions based on subtle terrain details in these sports, and distortion of natural contour cues can lead to poor decisions.

Yellow-Brown Range Tints

The process of filtering some of the visible spectrum through the attenuation of the transmittance of the shorter wavelength colors (blue) decreases the chromatic aberration between the longer red wavelengths and the transmitted mid-range greens. The reduction in chromatic aberration leads to improved image clarity, and the selective transmission of yellow wavelength light concentrates the visible information at the most sensitive portion of the visible light spectrum. Therefore yellow-range tints filter the glare produced by the short wavelength light while transmitting peak visible light information with reduced chromatic aberration. Studies have not always been successful in quantifying the improvement in visual acuity and contrast sensitivity reported with yellow tints.[137] Yellow filters have been shown to improve depth perception, contour recognition, and reaction times.[154-166] Of note, many of these studies were conducted under artificial lighting conditions that are far below the intensity (in candelas per square meter) of natural sunlight, and this factor may obfuscate the enhancement effects.

Many athletes appreciate the improvement in contrast with yellow-range tints, especially in low-light conditions such as twilight (dawn and dusk), fog, and heavy cloud cover. Early studies found that objects were more visible in fog with a yellow tint in front of a light.[167,168] Of note, outdoor low-light conditions are still substantially more intense than indoor artificial lighting. The common response is that the filters brighten and sharpen the details while enhancing subtle contrast features; however, the effect may be uncomfortable for photosensitive athletes. The improved contrast judgment is most likely caused by the reduction in chromatic aberration induced by the filter. Yellow and brown tints are popular with shooting and snow sport athletes and perform well in fog and low-light conditions.[169]

Mountaineers use yellow tints in whiteout conditions to enhance the contrast of environmental features.[170] Thick fog and whiteout conditions produce a Ganzfeld effect, and the reduced chromatic aberration serves to enhance the visibility of low-contrast images. Yellow tints have been used for driving, boating, or flying in low-light conditions; however, the filters distort color perception and can cause problems with traffic signal recognition. A yellow-range tint may be helpful in sports in which an object must be located or tracked against the background of a blue or overcast sky, such as tennis, baseball, and soccer. Studies have demonstrated improved perception of low-contrast contours and faster reaction time for low-contrast targets with yellow tints.[154,155]

Green-Range Tints

Information in the green portion of the visible light spectrum is selectively transmitted by green-range tints. This allows green information to be enhanced and other colors to be relatively muted. Green tints may be preferred in golf, tennis, and woodland shooting. For golf, the green tint enhances the contour information of the grass, and the tint will accentuate the contrast of a brown animal against the green foliage for hunters. Green-range tints have been advocated in tennis to enhance the contrast of the yellow tennis ball against the blue sky; however the tint can effectively mask the ball against a green background—a common paint color for the court surface and windscreen around the court.[171]

Red-Range Tints

Red-range tints are designed to transmit information selectively at the far end of the visible light spectrum. These filters are widely used in trap and skeet shooting because the reddish-orange sporting clay is enhanced against the background of brown dirt, grass, green foliage, or blue sky. Red-range filters also absorb short wavelength light that contributes to the poor image quality effects of chromatic aberration. These tints are popular in sports in which sharp image clarity is crucial, especially in heavy overcast or foggy conditions. Skiers favor red-range tints for "flat" light conditions and often report enhancement of contrast judgment and depth information with red-range goggles.

Blue-Range Tints

Blue-range tints do not offer a substantive benefit for most sports. The selective transmission of short wavelength visible light does not serve to diminish glare or enhance contrast. In fact, most athletes report that contrast sensitivity is degraded when blue tints are worn outdoors. Some performance sun eyewear appears to have blue-tinted lenses; however, this impression is created by the metallic or iridescent coatings applied to the lens surface.

Purple-Range Filters

Purple is a unique form of monochromatic violet because it is a combination of red and blue. The Nike Max Golf Tint (www.nike.com) contains a purple tint to enhance the visibility of the fluorescing agent used on Nike golf balls (Fig. 6-10).

Polarized Filters

As previously mentioned, polarized filters are excellent for reducing the effects of reflected glare off horizontal surfaces, especially water, snow, pavement, and sand. Polarized lenses are available in gray, brown, and photochromic lens options. The athlete can choose the lens



Figure 6-10. The Nike golf tint.

option best suited for his or her sport demands. Many sports performance sun eyewear products are available with polarized filters and are potentially beneficial for fishing, water sports, driving, and cycling (especially useful for wet surfaces). Despite the widespread acceptance of polarized filters, they may remove important details in some sports. Although the amount of reflected glare from the snow surface is considerable in downhill skiing, crucial details regarding surface contours can be masked by the filters. Several companies offer a variety of golf sun eyewear with polarized lenses; however, one study found that polarized filters did not offer any statistically significant advantage or disadvantage on putting performance over nonpolarized filters.[172]

Photochromic Filters

Photochromic lenses change transmission characteristics in response to changes in light or UV radiation.[173] Photochromic lenses were initially available only in glass lenses, making them unsuitable for many sports activities. Photochromic lenses are now available in CR-39 and polycarbonate lens materials, which significantly improve their suitability for some sports. Most photochromic lenses have a gray or brown tint that darkens with exposure to intense sunlight; a photochromic lens that darkens with a polarized filter is also now available. Photochromic lenses can be an excellent option for recreational athletes who participate in noncontact sports and who wish to have sun eyewear that is flexible with changing environmental conditions. Many persons who participate in golf, tennis, running, cycling, and fishing perform satisfactorily with spectacle corrections containing photochromic tints. For the competitive athlete, the optical performance of this option may not provide the high performance sought in performance sun eyewear.

Lens Coatings

Premium sun lenses typically have coatings to help achieve a higher level of optical performance. Most manufacturers use high-vacuum technology to apply several thin layers of coatings. These vacuum deposition coatings are designed to reduce reflections, attenuate transmission of UV and infrared radiation, selectively transmit portions of the visible spectrum (in particular, reduce transmission of short wavelength light), minimize lens fogging, and improve scratch resistance.[174] The exact nature of the lens coatings, the sequence of the coatings, and the number of layers applied remain proprietary information protected by the manufacturer.

Metallic coatings are used to create a mirrored surface on the front of the lens that effectively reflects incident light. The use of metallic coatings significantly decreases the amount of light reaching the eye; these coatings are exceptionally effective in sports in which

sun intensity can be high, such as snow sports, water sports, beach volleyball, running, and cycling.

The ANSI standard Z80.3 establishes impact and UV attenuation standards for plano (nonprescription) dress eyewear applied to sun eyewear.[175,176] Athletes should be counseled regarding the modest protection offered by premium sun eyewear with polycarbonate lenses compared with glass or CR-39 lenses. Sun eyewear should offer protection from both UV-A and UV-B radiation, although manufacturer transmittance claims have been shown to be overestimated.[177] The transmittance curve of a lens product helps determine the level of UV protection. Any polycarbonate lens offers better UV protection than do uncoated glass or CR-39 lenses.

Prismatic effects induced by the lens design of the sun eyewear are another factor that may be noticed by athletes. Contributing factors to prismatic effects include the steep front and back lens curves, the tilt of the lens, lens thickness, and manufacturing abnormalities. Premium sports eyewear was found to have significant amounts of prism in both primary and lateral gaze.[178] Prismatic effects induced by eyewear designs may affect the athlete's ability to judge depth and location. For example, with yoked horizontal prisms the image is displaced laterally, but if the prisms are oriented in opposing horizontal directions both the perceived size and distance of the object appear to change.[179] Changes in lateral displacement or apparent size and distance may cause critical errors in sport situations such as golf putting. Most ophthalmic professionals are concerned about the amount of optical distortion present in sun eyewear.

Face-form (wrap) design sun eyewear offers improved coverage of the ocular surface tissues and a wider field of view than traditional designs. The improved coverage increases UV protection by preventing light leakage around the frame and protects the eye from the harmful effects of wind and dust. The expanded visual field afforded by wrap-design eyewear is often offset by the induced prismatic effects of this design. Several eyewear manufacturers have used innovative optical designs to minimize the amount of induced prism, especially in the peripheral aspects of the lens. The result has been wrap-design lenses with an enhanced "sweet spot" viewing area with minimal prismatic distortion. The Nike and Oakley (Oakley.com) eyewear designs were found to have the least amount of induced prism in both primary gaze and 30 degrees of lateral gaze directions.[178] Of note, prescription eyewear with a wrap design may need to have the prescription power adjusted to compensate for the wrap.[180]

An excellent fit is required when dispensing sun eyewear for sports use. The frame needs to fit snugly to the face to prevent issues with vertex distance and visual field obstruction from the frame; however, a snug fit can reduce wind exposure while creating fogging problems. Many sports frames are designed to minimize fogging through improved ventilation around the frame and through the nosepiece (Fig. 6-11). The frame should also stay secured to the head so that movement does not dislodge the eyewear. Many manufacturers use rubber and silicone to softly grip the frame to the head at its contact points on the nose bridge and around the ears. The frames should be adjusted so that the touch points of the frame do not create discomfort and the optical centers are aligned in the primary viewing position. Some sports frames have adjustable or changeable temples and nose bridges to provide the athlete with the best possible fit. The specific needs of the female athlete have begun to be addressed by the sun eyewear industry, resulting in better-fitting frames and sport-specific designs.[181] Eyewear designs obviously need to be aesthetically pleasing for any athlete to use them!

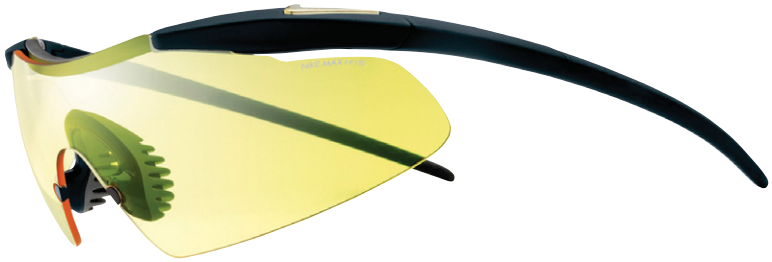


Figure 6-11. Sun eyewear highlighting ventilation and nosepiece design to prevent fogging.

CONTACT LENSES

The value of "plastic" contact lenses for refractive compensation in athletes has been readily recognized since the advent of plastic lenses.[182-186] The advent of contact lenses provided many young athletes with significant refractive conditions the potential to compete with the rest of their peers. Testimonials were written by elite athletes regarding the marvels of contact lenses for sports purposes.[187,188] Many of the disadvantages of spectacle corrections are eliminated by the use of contact lenses, especially in contact sports in which eyewear can become a limitation to the athlete. The available options for eye care practitioners increased from the limited applications of custom-fit scleral (haptic) lenses and polymethylmethacrylate lenses to modern rigid gas-permeable (RGP) and hydrogel (soft) lens choices. Indeed, contact lenses have become the method of choice for refractive compensation in most sports.

Considerations for Performance Contact Lenses

The field-of-view aberrations, visual field restriction, optical distortion, frame comfort, frame stability, surface reflections, lens fogging, and precipitation issues described with spectacle lenses can largely be avoided by moving the optics onto the cornea. The induced prismatic effects evident with most spectacle lenses when the athlete views off the optical centers of the lenses are eliminated by contact lenses. The potential visual field impediment created by eyewear frames is eliminated with contact lenses, as are the issues of lens reflection and fogging that compromise visual performance with eyewear. The peripheral visual field is increased by approximately 15% with contact lenses.[189] Athletes often report compromised comfort from eyewear frames as well, and the precision of the frame fit is often further compromised by the handling of the eyewear. Contact lenses are an excellent option in highly dynamic sports because no frame can be dislodged and the lenses do not fog up. Dynamic sports include baseball, basketball, football, gymnastics, hockey, racquet sports, skiing sports, skating sports, soccer, surfing sports, and volleyball (see Box 2-3). Although contact lens comfort certainly is an issue to contend with, the frame issues of eyewear are removed with this option. The combination of these advantages elevates the use of contact lenses to the method of choice for refractive compensation for most athletes.

The main objective with contact lens corrections is to provide an excellent optical image that is stable in all conditions encountered during sports performance. Excellent visual acuity

is typically a critical factor in sports performance, and measurement of visual acuity through the contact lenses is a standard part of an assessment. Snellen-type visual acuity measurements may not be sensitive to the subtle visual discrimination tasks inherent in many sports because the acuity task is usually performed only under high-contrast conditions. Measurement of contrast sensitivity function has been recommended in athletes because many sports involve visual discrimination tasks in suboptimal lighting caused by environmental variability (see Chapter 4). Contrast sensitivity also may be degraded in contact lens wearers if the lenses are not optimal, even when visual acuity appears acceptable.[190-193] Therefore contrast sensitivity measurement is an essential part of the evaluation of athletes who wear contact lenses during sports participation.

Spherical refractive errors are most easily compensated for with contact lenses, whereas astigmatism can present a complex fitting predicament. If excellent visual acuity cannot be achieved with a spherical lens, a soft toric lens or RGP lens should be considered. The amounts of corneal and lenticular astigmatism combine to result in the manifest astigmatism, and this combination ultimately affects the lens choices for optimal compensation. Many options are available in hydrogel and RGP materials to provide the best features for the athlete.

Aiming sports typically require prolonged fixation to achieve proper alignment with the target. As previously mentioned, many shooters and archers prefer spectacles over contact lenses because of the stability of clear vision obtained with spectacle lenses. Lens dehydration and surface irregularities can create significant problems in athletes with insufficient blinking or tear quality.[2] Contact lens movement on the eye can also produce undesirable visual fluctuations during prolonged gaze behavior (without blinking) that many shooters and archers develop. Contact lens movement has been shown to degrade contrast sensitivity.[194]

Many sports involve rapid saccadic movements as the athlete quickly assesses crucial visual information. The amount of lens movement during saccadic eye movements relates to the stability of the vision achieved with the contact lenses. A tighter fit is generally preferred for contact lenses used during sports to minimize the effects of lens movement on visual performance. Lens centration should also be carefully evaluated to ensure excellent optical performance. Centration is important to assess in the pertinent gaze positions for the particular sport or position in addition to measurements in primary gaze. Because many sports require the athlete to view information in nonprimary gaze directions (see Chapter 2), visual performance of the contact lenses in these gaze directions is a critical aspect to assess. For example, in cycling much of the visual information is acquired in an upgaze eye position. Contact lens performance for a cyclist should be assessed in upgaze position, and the factors of wind and debris should be addressed for that athlete with lens materials and supplemental protection.

The length of time that the athlete participates in the sport activity may direct the contact lens choices. An analysis of sports determined that the majority of competitions are completed within 2 hours.[3] Even considering the travel time to participate, a sport-specific contact lens can be prescribed to avoid potential physiologic consequences from different fit characteristics used by some practitioners.[2,111,195,196] The sport-specific contact lens is worn solely for use during sports participation, and a habitual prescription is used the remainder of the time. Some endurance sports necessitate a lens modality for extended use. These lenses ideally remain on the eyes throughout the event and require minimal care.

In high-altitude mountaineering, long-distance sailing, or long-distance motor racing, the athlete experiences extreme conditions over a long period. The contact lenses should provide excellent visual performance throughout the event while sustaining good ocular health. For example, in high-altitude mountaineering, the lens needs to provide good oxygen transmission and visual performance. Removal and insertion of lenses is not practical in an extremely cold climate, and the care solutions may freeze. Contact lenses have been successfully worn on climbs of Mount Everest, and they offer a degree of protection from low temperatures and wind-driven ice and snow without fogging or breaking in the cold.[196-200] To maximize oxygen transmission at high altitudes, a higher water content hydrogel lens must be used (e.g., 70% water content) even though higher-water-content lenses dehydrate faster in the cold, dry climate of high mountains. The performance of these lenses should be assessed after a period of extended wear before participation in an endurance event.

Contact lens wearers must contend with the effects of environmental conditions on contact lens performance. For athletes, issues of humidity, debris, wind, and UV exposure may need to be addressed when determining the best contact lens option. As previously mentioned, low-water-content lenses typically perform better in low-humidity climates. Larger, thicker lenses are beneficial to prevent further dehydration. Low-humidity climates include desert environments, alpine environments, and artificial indoor environments. These same lens recommendations apply to sports in which considerable wind or air flow hits the face. Wind hastens drying of the lenses, so the athlete needs additional counseling in proficient blink behavior and the benefits of supplemental eyewear or goggles. For problems with dirt and debris, soft lenses are preferred because they do not trap debris under the lenses as readily as rigid lenses. Supplemental protection may also be warranted in sports with significant exposure to UV radiation. Some soft lenses are available with a UV-absorbing tint to reduce the effects of intense UV exposure on the ocular tissues. UV-absorbing contact lenses provide only protection to the ocular tissues covered by the contact lens; therefore they provide the best protection when used in combination with quality sun eyewear. UV-absorbing contact lenses may also offer a degree of protection for athletes at risk for pterygium formation or those who have had surgical treatment for pterygia. Light incident at the temporal cornea is focused by the peripheral anterior eye to the nasal limbus, the usual site of pterygium formation.[201]

Many athletes are affected by dry eye syndrome. Many events precipitate or exacerbate the pathophysiologic conditions implicated in the development of dry eye disease.[202] For athletes, the cumulative effects of UV exposure and dehydrating conditions (e.g., low humidity, wind exposure, air flow) can play a significant role in the development of dry eye problems. In addition, sympathetic responses to competitive stress and the effects of heightened attention on blink behavior further contribute to the pathogenesis of dry eye disease. Athletes who are contact lens wearers typically have dry eye symptoms more often than do those who do not wear contact lenses. Many excellent pharmaceutical agents are designed to treat specific aspects of dry eye disease,[202] and athletes should receive aggressive treatment of this condition so that it does not interfere with sports performance. Several contact lens materials and lens care products are designed to minimize the effects of dry eye on contact lens wear, and these options should be considered for the athlete with dry eye syndrome. In addition to pharmaceutical treatment, the athlete should be thoroughly educated on proper lid hygiene, good blink behavior, the potential benefits of rehydrating drops for the contact lenses, and the rewards of a suitable diet and fluid consumption.

Performance-Tinted Contact Lenses

Tints designed to enhance performance have been incorporated into contact lenses for use in certain sports. By moving the tint from the spectacle plane to the corneal plane, the numerous benefits of tinted spectacles are combined with the advantages inherent with contact lens wear. Former homerun champion Mark McGwire reported increased peripheral vision and glare reduction, as well as clearer and crisper vision, while wearing amber-tinted contact lenses.[203]

Some practitioners tint commercially available lenses with in-office systems, and some manufacturers have developed sport-specific tints. Suntacts was originally a green-tinted contact lens designed for surfers.[204] The manufacturer of this product claimed generalization to other sports, such as baseball and golf, and this company has announced a reemergence of a line of tinted contact lenses.[205] Prosoft was a teal-tinted contact lens based on Bolle's Competivision tint in sun eyewear that claimed to provide a visual performance edge for tennis players.[206] However, no published studies have confirmed the efficacy of either Suntacts or Prosoft for performance enhancement, and one study demonstrated that the Prosoft tint may actually mask the appearance of a tennis ball.[171]

SportsSight contact lens technology began as a gray tint with a 20% visible light transmission in a gas-permeable contact lens designed to reduce glare and brightness.[207] Subsequent tint developments evolved from gray to yellow and finally to amber and gray-green tinted Nike MAXSIGHT soft contact lenses (Fig. 6-12).[208] The tints enhance certain aspects of subjective and objective visual information and improve contrast recognition by filtering short-wavelength light in the visible spectrum and manipulating transmission of wavelengths above 500 nm.[208] The amber lens was developed for use in dynamic reactive sports to cause the ball or other moving objects to "pop" out from the background environment. The gray-green lens was engineered to enhance details of the environment, such as the grass on a golf course or the water's surface in activities such as kayaking, surfing, windsurfing, or kite-boarding. Preliminary research results indicate that the Nike MAXSIGHT lenses offer superior contrast discrimination, speed of visual recovery, and subjective visual performance compared with tinted spectacles or clear contact lenses.[209,210]

Contact Lens Recommendations

The practitioner is fortunate to have a large selection of contact lens materials and designs from which to choose. A review of all commercially available lenses is beyond the scope of this chapter; a discussion of general recommendations is presented to guide the practitioner in focusing on specific lens features. As previously discussed, the first step in choosing the best lens option is to determine the specific demands of the sport and the individual athlete.

The first major decision is to determine the best lens category for the sport. The main decision compares performance aspects of rigid versus soft contact lenses, although scleral lenses or combination lens designs may also factor into the decision. Rigid lenses may offer a slight advantage in terms of visual clarity, especially in athletes with significant corneal astigmatism. However, for most athletes the advantages of soft lenses far outweigh this slim advantage. RGP lenses have a considerably greater risk of dislodgement in contact and water sports, are more susceptible to debris under the lenses, may produce flare symptoms in low-light conditions, and require a drastically longer adaptation period to adjust to the discomfort of lens wear. The subjective discomfort of rigid lens wear, with the requisite adaptation period, is perhaps the most discouraging feature for athletes, especially those

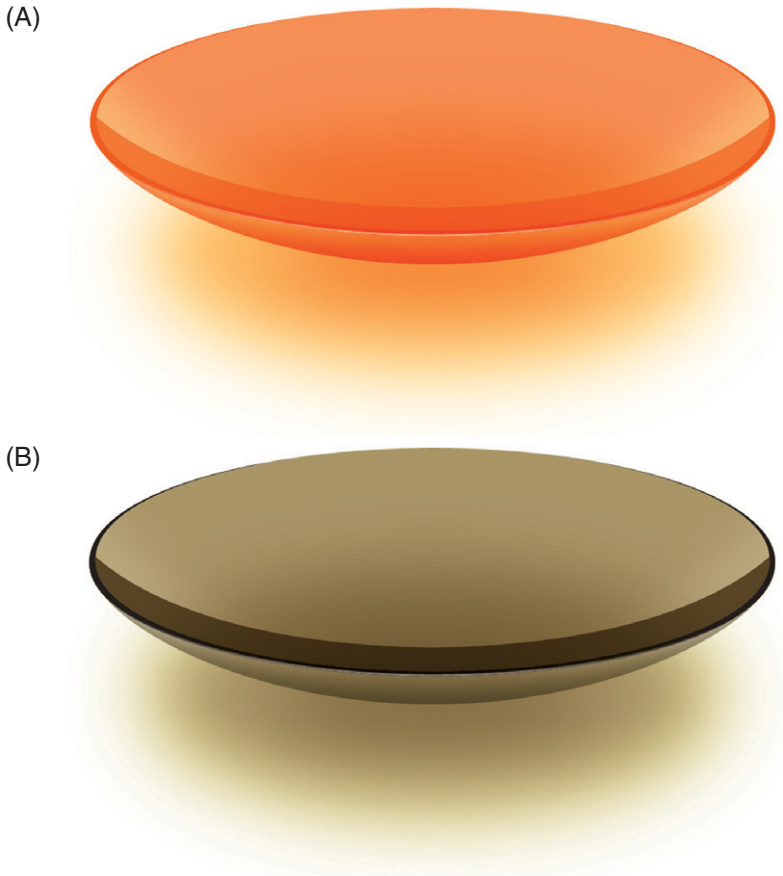


Figure 6-12. Nike MAXSIGHT amber and gray-green contact lenses.

who need to use the lenses only during sports participation. Soft lenses offer a solution to most of the disadvantages of rigid lens designs: good optical clarity, minimal risk of dislodgement, reduced risk of foreign material under the lens, marginal reports of flare in low-light conditions, and virtually instantaneous lens comfort. In addition, soft lenses offer the potential for extended wear and disposable wear modalities.

Scleral lenses are similar to rigid lenses and offer the advantage of virtually no risk of dislodgement. Scleral lenses were used for athletes in contact sports early in the development of contact lenses; however, they must be custom made by one of a few producers and cannot be worn for more than a few hours. This lens type is rarely prescribed now for these reasons. Combination rigid and hydrogel lens options have been produced to provide the visual clarity of an RGP lens with the comfort of a soft lens. The SoftPerm lens is available for athletes who may benefit from this design, especially those with a large amount of corneal astigmatism or keratoconus. Some practitioners find that a "piggyback" setup offers better performance for the athlete than the SoftPerm lens does. A piggyback design is a soft lens fit underneath an RGP lens; the soft lens is often a lens with high oxygen transmission, such as a silicone hydrogel lens.

Larger-diameter rigid and soft lenses are frequently recommended for athletes to compensate for some of the environmental challenges encountered in sports.* Larger lens diameters are useful in RGP lenses to improve lid attachment, enlarge the optic zone to reduce flare symptoms, or diminish lens lag during large saccadic eye movements.[2,211] Soft lenses with larger diameters are recommended to improve lens stability during extreme body movements and forceful contact, enhance visual performance in extreme gaze positions and following saccadic eye movements, and resist dehydration from air flow and low humidity.[3] Large-diameter soft lenses are also recommended in water sports to minimize the probability of lens loss.[212]

Rigid Lens Suggestions

The basic fit of RGP lenses can be modified to create a more stable fit during saccades and body movement. Typically, the modifications include a larger diameter (with an enlarged optic zone to account for pupil size), a slightly steeper lens to make the fit tighter, and steeper peripheral curves to improve adherence to the eye. A lid attachment design, also known as a *Korb lens,* offers good lens positioning and stability by the positioning of the lens with the superior lid.[2] Lens materials should be chosen that have negligible flexure during blinking and that wet well for use in low-humidity or high–air flow conditions. A lens that is not wetting properly may need a robust cleaning or replacement. The peripheral curve can be modified with heavy blends to prevent irritation and edema from a tight-fitting lens and to enhance the tear exchange under the lens.[2] As previously mentioned, the lens positioning should be assessed in relevant gaze directions for the sport.

Soft Lens Recommendations

The main considerations for hydrogel lenses are the material composition and water content and the diameter and thickness of the lens prescribed. In general, higher-water-content lenses dehydrate faster than low-to-medium-water-content lenses. Therefore thicker low-to-medium-water-content lenses or silicone hydrogel lenses should be used to preserve lens hydration for athletes who have dehydration problems.[195] High-water-content lens materials may be needed for prolonged lens wear situations in which oxygen transmission is a crucial factor. As previously mentioned, larger-diameter lenses are also recommended when better stability and hydration are needed.[213-215]

The ultimate goal of the soft lens fit is stability of lens positioning and visual performance. Contact lenses for sports use should fit tighter than traditional fitting practices dictate. The lens should have minimal movement after a blink and maintain a good centering position in extreme gaze directions. For athletes, the lens material should also handle easily so that insertion and removal can be readily performed under adverse conditions.

An alternative to engineering a specialty lens for an athlete is the use of 1-day disposable lenses. The advent of disposable lenses offered an excellent alternative for many athletes who want the advantages of contact lenses for sports without the hassles of caring for the lenses. These lenses are wonderful for the weekend athlete or recreational scuba diver, for example, to provide the correction benefits of contact lenses. It is also an outstanding option for elite athletes who want immaculately clean and fresh lenses before starting a competition and uncomplicated replacement of lenses at any time during competition. The main obstacle to success with disposable lenses is the temptation to overuse them. The potential risks of overwear or overnight wear should be clearly communicated to the athlete.

*References 2, 3, 195, 196, 211, 212.

Visual Performance Variables with Contact Lenses

First and foremost, the fit of the lenses and ocular health of the athlete should be meticulously evaluated. Any indications of trouble with the fit or anterior segment health should be aggressively managed. The visual acuity through the lenses should be assessed as well as dynamic visual acuity for sports with dynamic vision demands. As previously mentioned, contrast sensitivity measurement is essential with contact lenses to ensure optimal performance. For athletes receiving a first refractive prescription, the effect of the lenses on ocular alignment should be measured to determine any potential impact on spatial localization. An adaptation period for any new prescription is strongly encouraged before use in competition when feasible.

Contact Lenses and Water Sports

Good vision is important for athletes who participate in water sports. With the development of contact lenses, the application of this form of vision correction to aqueous environments was investigated. Early literature explored the use of haptic or scleral lenses for underwater vision correction without a dive mask.[216-220] However, most eye care practitioners focus on providing vision correction with a combination of contact lenses and masks or goggles. Contact lenses offer an advantage over prescription masks or goggles through reduced tendency for lens fogging and less restriction on peripheral vision.[221-224] The main concerns regarding contact lens wear in water sports are lens loss and risk for infection.

Lens loss is a concern for any athlete participating in water sports. The risk for lens loss is considerably greater with rigid lenses than soft lenses. Many studies have demonstrated that hydrogel lenses adhere to the cornea when exposed to hypotonic water, such as fresh water and swimming pools.[221,225-232] The intensity of the lens adherence increases as the salinity of the water decreases. The adherence of the lens is theoretically caused by the osmolarity gradient between the precorneal tear film and the aqueous environment, as well as the resulting increase in overall diameter of the hydrophilic lens when immersed in water with low salinity. Lens adherence and larger overall diameter are cited as major factors in the low incidence of lens loss with soft lenses in many water sports.* A low incidence of soft lens loss has also been reported with ocean sports despite the hypertonic environment of salt water.[222,235] The use of large-diameter lenses is credited for minimizing lens loss in this environment. The athlete should splash some water in his or her eyes before entering the water to facilitate adhesion of the soft lenses to the cornea. Removal of the lenses should be avoided for at least 30 minutes after water activity to allow the adhesion of the lens to the corneal epithelium to diminish.[227] Saline may also be instilled in the eyes to shorten the recovery time to normal lens movement and prevent corneal denuding.[224,227,229,230] Rigid lenses do not typically adhere to the cornea in water environments,[229] so the risk of lens loss is significant unless the lids can adequately hold the lens in place. The athlete should understand the risks of lens loss in water sports and be properly counseled on precautions to minimize lens loss. Precautions include lid closure with a hard entry into the water, squinting when splashed, and the use of goggles or masks. Excessive water on the eyes should be removed by rapid blinking rather than eye rubbing.[224]

The risk for eye infection or tissue damage from contact lens wear is another concern that must be addressed. Despite proper sanitation practices, public swimming pools contain bacteria that pose a potential risk for infection.[236] The presence of *Acanthamoeba* species is a particular concern because of the destructive nature of a potential keratitis. Athletes should

*References 222, 223, 226, 229, 230, 232-235.

therefore remove and thoroughly clean contact lenses shortly after water activity or discard disposable lenses.[224,230] The risk for infection is elevated when the integrity of the corneal epithelium has been compromised.[237] Rigid lenses have a greater chance of compromising the integrity of the cornea, and scuba diving may result in bubble formation under the lens that can cause corneal edema.[221,234,237] Polymethylmethacrylate lenses, and some RGP lenses, inhibit the nitrogen and carbon dioxide gas exchange during decompression. For swimmers, hydrogel lenses prevent the corneal thickness changes, stipple staining, and superficial corneal erosions noted in swimmers with no lenses,[226,230] although the use of goggles can prevent this problem. Synchonized swimmers must compete without goggles, so hydrogel lenses are recommended for all swimmers to prevent the corneal damage incurred during extended exposure to chlorinated pool water.

Large-diameter lenses should be used for athletes who participate in water sports. The larger diameter lens will reduce the risk of lens loss and improve the stability of vision through the lenses.[212,215,222,233] The water content of the hydrogel lens material may have an impact on the adherence of the lens in water,[231] although no measurable difference in corneal or conjunctival response has been noted.[230] Lens wear is contraindicated in athletes with compromised corneal integrity or a history of poor lens care compliance.

Orthokeratology (Corneal Reshaping)

Orthokeratology is a procedure used to temporarily reduce myopia and astigmatism with specially designed rigid lenses. First described by Jessen in 1962,[238] the methods for attaining predictable and effective results were revolutionized in the 1980s and 1990s with the advent of gas-permeable contact lens materials and innovative lens designs. Current orthokeratology uses rigid lenses to flatten the central corneal curvature to reduce myopia and improve visual acuity.[239-245] Reverse geometry lens designs with uniquely constructed curves on the posterior lens surface have been responsible for allowing greater myopia reduction in shorter periods of time. The corneal response to orthokeratology appears to be robust in patients younger than 36 years, with a reduced response with increasing age (older than 36 years).[246] The lenses are typically worn overnight during sleep and are removed shortly after awakening in the morning. Studies have demonstrated immediate corneal flattening and precorneal tear film chemistry changes after a single night of reverse geometry lens wear.[247-250] The corneal changes caused by lens wear at night remain for several hours during the day and allow clear vision without corrective lenses. The treatment effect with overnight wear of reverse geometry lenses is typically achieved in 7 to 40 days.[251-254]

Recently many reverse geometry lens designs have been marketed for overnight orthokeratology; however, the fitting methods for each of these designs vary. The use of computer-assisted keratoscopes offers an effective means for controlling the procedure effects, and fitting adjustments can be made to achieve a more desirable outcome. The exact nature of the mechanisms involved in producing the corneal effects of orthokeratology are not currently well understood. Studies demonstrate thinning of the central corneal epithelium with thickening of the mid-peripheral cornea.[246,252,254-258] Some evidence shows that the posterior corneal surface is also flattened with reverse geometry lenses.[258] The procedure appears to be safe regarding maintenance of corneal integrity, and the effects are reversible with discontinuation of lens wear.[242,246,256,259,260] Some concern still exists regarding the long-term safety of the procedure for children[261] and for the increasing incidence of corneal pigmented arc formation with prolonged orthokeratology.[262] Concern also exists over the

incidence of the development of microbial keratitis in orthokeratology patients, although whether the incidence is higher than in general contact lens wearers in not clear.[263,264] The issues highlight the importance of appropriate patient selection and follow-up care in the success of orthokeratology.[244,265]

Orthokeratology offers a reasonable alternative to traditional refractive correction for athletes with myopia between −0.75 D and −4.00 D.[240] It is also potentially beneficial for with-the-rule astigmatism less than 1.50 D.[240] The potential disadvantage for the athlete is the increased presence of higher-order aberrations and spherical aberration after orthokeratology.[266,267] The increase of higher-order aberrations is speculated to cause a reduction in low-contrast visual acuity, and this reduction is exacerbated with increasing pupil size.[267] However, orthokeratology remains an attractive option for athletes, especially young myopic athletes who are not yet eligible for refractive surgery.

Issues with Contact Lenses for Athletes

Special considerations apply to athletes who wear contact lenses during sports. The main concern is the availability of replacement lenses during sports participation, especially during competition. At least one set of spare lenses should be immediately available for the athlete, and care solutions should be easily accessible to manage any issues with the lenses. Team personnel (e.g., coaches and athletic trainers) should be aware of contact lens needs of the athlete, and the appropriate support personnel should be facile in contact lens insertion, removal, and problem solving. This situation offers an excellent consultation opportunity for the eye care practitioner.

The athlete should be thoroughly counseled in the care of the contact lenses, including replacement schedule, cleaning regimen, troubleshooting of common problems, and follow-up care. Every effort should be made to instill the importance of excellent compliance with contact lens recommendations. The athlete's family and support personnel should also help the athlete maintain outstanding compliance. Most contact lens patients are not 100% compliant with at least one step in the care recommendations, and athletes are no exception. The most common compliance problems are failure to wash the hands before handling lenses and failure to replace lenses at the recommended interval. Describing the potential effects of noncompliance on ocular health and vision may be valuable, as well as connecting those issues to the potential impact on athletic performance.

Athletes often gravitate to contact lenses to avoid using eyewear during sports. However, the eye care practitioner must counsel athletes who participate in sports that expose the athlete to significant risk of eye injury regarding the need for supplemental protective eyewear. Contact lenses offer almost no protection to the ocular tissues, and adequate protective eyewear is essential for preventing serious injury.

REFRACTIVE SURGERY

Refractive surgery offers the allure of "perfect" vision without the use of spectacles or contact lenses. For an athlete with significant refractive error, this is a very appealing prospect. A few high-profile athletes have reported successful outcomes with refractive surgery and even suggested that sports performance is enhanced by the results. Similar to orthokeratology, the candidate for refractive surgery has moderate amounts of myopia or astigmatism; however, larger amounts of myopia and astigmatism can be corrected by contemporary procedures,

and low to moderate hyperopia may also be effectively managed. Also similar to orthokeratology, refractive surgery modifies the corneal curvature to produce refraction results at or near emmetropia. The differences compared with orthokeratology are that some refractive surgery results have limited potential to be reversed, and candidates must be adults (generally older than 21 years) with stable refractive error. All athletes must meet the relevant profile for success before proceeding with any refractive surgery procedure.

The main surgical methods apply incisions, corneal implants, or laser ablation to the corneal surface. Many procedure variations exist; some have widespread acceptance and application, and others are rarely used. The refractive surgery options available in the United States include radial keratotomy (RK), astigmatic keratotomy (AK), limbal relaxing incisions, photorefractive keratectomy (PRK), laser in situ keratomileusis (LASIK), laser subepithelial keratomileusis (LASEK), intracorneal ring segments, laser thermokeratoplasty, conductive keratoplasty, phakic intraocular lenses, clear lens extractions, and scleral expansion.[268]

Incisional Methods

RK is the most common procedure using corneal incisions to reduce myopic refractive error. The method involves radial incisions made in the mid-peripheral cornea to flatten a central optical zone (usually 3.0 to 4.5 mm in diameter). For AK, arcuate incisions are applied in the mid-periphery, and RK and AK can be combined for compound myopia. Before the innovations afforded with laser technology, RK and AK were popular methods of refractive surgery. The use of incisional methods has significantly declined since the advent of PRK and LASIK approaches. The main visual disadvantages of RK and AK are glare from the peripheral wounds, and fluctuating vision throughout the day. For athletes in particular, the incisions may increase the potential for significant damage to the cornea in blunt eye trauma. The cornea is weakened with RK and AK, and blunt trauma forces may cause globe rupture at the site of the corneal incisions.[25,269-271] The positive aspect of RK compared with laser ablation procedures is that the central cornea is not directly altered, thereby preserving a central optical zone.

Laser Ablation Procedures

LASIK is the most common refractive surgery performed for refractive errors between −8.00 and +3.00 D; PRK and LASEK are also commonly used.[268] Many surgeons are performing custom ablations with wavefront-guided LASIK to reduce both lower- and higher-order aberrations[272-274]; it also allows for the creation of larger corneal topographic effective optical zones compared with standard LASIK.[274] In LASIK, a microkeratome is used to create a thin flap in the corneal tissue. The flap is raised and the excimer laser ablates the exposed stromal bed, creating a specified ablation zone. LASEK entails the same procedures, except the corneal flap is created by the laser. Subsequent laser ablation procedures are usually required to achieve optimal results, referred to as *enhancements*. PRK was a precursor procedure to LASIK and LASEK. PRK removes a very thin layer of anterior corneal surface tissue with an excimer laser to alter the curvature of the central cornea and results in some degree of subepithelial tissue deposition responsible for haze symptoms. Laser ablation procedures all affect the central cornea and include a risk for corneal haze or scarring.

Common symptoms after laser refractive surgery include glare, halo, and other night vision disturbances. These symptoms may appear in daylight conditions if the athlete has

physiologically large-diameter pupils. Dry eye symptoms are a common complication after LASIK surgery.[275-282] The cause of dry eye symptoms is most likely related to the integration of the ocular surface and lacrimal gland function. Damage to the ocular surface under dry eye conditions can produce continued alteration in tear production, creating a recurring cycle of chronic dry eye symptoms.[282,283] The presence of higher-order aberrations and chronic dry eye tissue changes may be responsible for most of the visual symptoms after LASIK. The athlete should also be counseled that mid-peripheral visual field sensitivity may also be reduced after LASIK.[284] Despite anecdotal reports of improved sports performance after LASIK, an analysis of batting performance of professional baseball players did not reveal any statistically or practically significant differences in performance.[285]

Laser ablation procedures do not impair the corneal integrity to the same degree as incisional methods. The potential for globe rupture from blunt trauma in post-LASIK eyes is equivalent to that of normal eyes. The main risk is for corneal flap dislocation, which is more likely to occur within days of the procedure. The long-term susceptibility to flap-related trauma is uncertain; however, some indications exist that sports-related ocular trauma can cause flap dislocation.[286,287] PRK does not appear to involve a risk for weakened corneal integrity and does not entail a risk of flap dislocation.

Intracorneal Ring Segments

The implantation of intrastromal corneal rings to correct low myopia has been studied and approved in the United States.[288,289] The procedure involves the insertion of polymethylmethacrylate ring segments into the corneal stroma to alter the corneal curvature. Unlike laser ablation procedures, intracorneal ring segments (ICRS) do not directly disturb the central cornea, and no corneal flap is generated. ICRS is a reversible procedure and the rings can be explanted in the event that adequate success is not achieved.[290] The effects of trauma in athletes with ICRS are relatively unknown; however, the stromal healing profile does not indicate increased fragility.[271]

All athletes considering refractive surgery should receive comprehensive counseling regarding the potential visual and ocular affects, as well as potentially increased vulnerability in the event of ocular trauma. All athletes who have had refractive surgery should be encouraged to be conscientious in the use of appropriate protective eyewear during participation in sports.

The eye care practitioner has a variety of resources to help the athlete attain the best vision for his or her sports pursuits. Consideration must be given to the athlete's individual profile, the task demands of the sport, and the environmental conditions encountered by the athlete. For athletes requiring vision correction, the eye care practitioner should present the advantages and disadvantages of spectacle correction, sun eyewear and filter options, protective eyewear, contact lenses, and refractive surgery. All athletes who participate in outdoor sports should receive counseling in sun eyewear to protect the ocular tissues, and all athletes should be encouraged to use appropriate protective eyewear if they participate in sports that expose them to significant risk of eye injury. The eye care practitioner has a duty to correct and protect the athlete and may offer options to enhance sports performance.

REFERENCES

1. Beckerman SA, Hitzeman S: The ocular and visual characteristics of an athletic population, *Optometry 72:*498, 2001.

2. Spinell MR: Contact lenses for athletes, *Optom Clin 3:*57, 1993.
3. Efron N: Sports vision correction with contact lenses. In Loran DFC, MacEwen CJ, editors: *Sports vision*, Oxford, 1995, Butterworth-Heinemann, pp 127-147.
4. Zieman B, Reichow A, Coffey B: Optometric trends in sports vision: knowledge, utilization, and practitioner role expansion potential, *J Am Optom Assoc 64*:490, 1993.
5. Obstfeld H, Pope R: Sports vision correction with spectacles. In Loran DFC, MacEwen CJ, editors: *Sports vision*, Oxford, 1995, Butterworth-Heinemann.
6. Brown B, Collins MJ, Bowman KJ: Reaction times in a complex task by presbyopic observers with spectacle and contact lens corrections, *Clin Exp Optom 71:*94, 1988.
7. Runninger J: Rx for sports, *Optom Management 15*:55, 1979.
8. Breedlove HW: Prescribing for marksmen and hunters, *Optom Clin* 3:77, 1993.
9. Gregg JR: Prescribing for the sports nut, *Optom Management 10:*19, 1974.
10. Long WF, Haywood KM: The optical characteristics of aiming scopes in archery, *J Am Optom Assoc 61:*777, 1990.
11. American National Standards Institute: *Ophthalmics: prescription ophthalmic lenses—recommendations*, New York, 2005, American National Standards Institute.
12. American National Standards Institute: *Occupational and educational personal eye and face protection devices*, New York, 2003, American National Standards Institute.
13. Davis JK: Perspectives on impact resistance and polycarbonate lenses. In Vinger P, editor: *Prevention of ocular sports injuries*, Boston, 1981, Little, Brown, pp 215-218.
14. Stern NS: The effects of racquetball impact on spectacles and lenses, *Optom Monthly 73:*343, 1982.
15. Stephens GL, Davis JK: Spectacle lenses. In Duane TD, Jaeger EA, editors: *Clinical ophthalmology*, Philadelphia, 1994, Harper & Row.
16. Vinger PF: Eye safety testing and standards, *Ophthalmol Clin N Am 12:*345, 1999.
17. Chou BR, Hovis JK: Effect of multiple antireflective coatings on impact resistance of Hoya Phoenix spectacle lenses, *Clin Exp Optom 89:*86, 2006.
18. Fry GA: *Geometrical optics*, Philadelphia, 1969, Chilton, p 177.
19. Fannin TE, Grosvenor T: *Clinical optics,* Boston, 1987, Butterworth-Heinemann.
20. Chou BR, Gupta A, Hovis JK: The effect of multiple antireflective coatings and center thickness on resistance of polycarbonate spectacle lenses to penetration by pointed missiles, *Optom Vis Sci 82:*964, 2005.
21. Vinger PF: A practical guide for sports eye protection, *Physician Sportsmed 28:*49, 2000.
22. Prevent Blindness America: *Sports eye safety*, www.preventblindness.org/safety/sportspage1.html. Accessed June 2, 2005.
23. US Consumer Product Safety Commission: *National Electronic Injury Surveillance System (NEISS) online*, www.cpsc.gov/library/neiss.html Accessed June 15, 2006.
24. Easterbrook M: Eye protectors for sport. In Loran DFC, MacEwen CJ, editors: *Sports vision*, Oxford, 1995, Butterworth-Heinemann.
25. Vinger PF: The eye and sports medicine. In Duane TD, Jaeger EA, editors: *Clinical ophthalmology*, Philadelphia, 1994, Harper & Row.
26. Vinger PF, Parver L, Alfaro DV 3d, et al: Shatter resistance of spectacle lenses, *JAMA 277:*142, 1997.
27. Protective eyewear for young athletes. A joint statement of the American Academy of Pediatrics and the American Academy of Ophthalmology, *Ophthalmology 103:*1325, 1996.
28. Protective eyewear for young athletes, *Ophthalmology 111:*600, 2004.
29. Gregg JR: Sighting in on sports, *Optom Management 15:*86, 1979.
30. Kleinstein RN: Preventing eye injuries in athletes, *Optom Monthly 70:*168, 1979.
31. Vinger PF: Sports-related eye injury: a preventable problem, *Survey Ophthalmol 25:*47, 1980.

32. Vinger PF, Easterbrook M, Hirschfelder D: Sports eye injuries: a model for prevention, *JAMA 250:*3322, 1983.
33. Vinger PF: The one-eyed athlete [editorial], *Phys Sportsmed 15:*48, 1987.
34. Knuttgen HG: Eye injuries and eye protection in sports: a position statement from the International Federation of Sports Medicine, *Int J Sports Med 9:*474, 1988.
35. Drack A, Kutschke PJ, Stair S, et al: Compliance with safety glasses wear in monocular children, *J Pediatr Ophthalmol Strabismus 30:*249, 1993.
36. Kirman S, Kirman G, Kirman B, et al: Make your dispensary special, *Optom Management 28*:37, 1993.
37. Vinger PF: Prescribing for contact sports, *Optom Clin 3:*129, 1993.
38. Jeffers JB: Concepts of eye protection, *Ophthalmol Clin N Am 12:*407, 1999.
39. Monica ML: Sports and eye safety: patient awareness prevents injuries and builds the practice, *Refract Eyecare Ophthalmol 3:* 1999.
40. Vinger PF: Injury prevention: where do we go from here? *J Am Optom Assoc 70:*87, 1999.
41. Woods TA: Protective eyewear, *Ophthalmol Clin N Am 12:*381, 1999.
42. Vinger PF, Woods TA: Prescription safety eyewear: impact studies of lens and frame failure, *Optometry 71:*91, 2000.
43. Halstead DP: Performance testing updates in head, face and eye protection, *J Athl Train 36:*322, 2001.
44. Rodriguez JO, Lavina AM, Agarwal A: Prevention and treatment of common eye injuries in sports, *Am Fam Physician 67:*1481, 2003.
45. Protective eyewear for young athletes, *Ophthalmology 111:*600, 2004.
46. Sinclair SA, Smith GA, Xiang H: Eyeglasses-related injuries treated in US emergency departments in 2002-2003, *Ophthalmic Epidemiol 13:*23, 2006.
47. Diamond GR, Quinn GE, Pashby TJ, et al: Ophthalmologic injuries, *Prim Care 11:*161, 1984.
48. Easterbrook M: Ocular injuries in racquet sports, *Int Ophthalmol Clin 28:*232, 1988.
49. Jones NP: One year of severe eye injuries in sport, *Eye 2:*484, 1988.
50. Jones NP: Eye injury in sport, *Sports Med 7:*163, 1989.
51. Jones NP: Eye injuries in sport. In Loran DFC, MacEwen CJ, editors: *Sports vision*, Oxford, 1995, Butterworth-Heinemann.
52. Orlando RG, Doty JH: Ocular sports trauma: a private practice study, *J Am Optom Assoc 67:*77, 1996.
53. Bishop PJ, Kozey J, Caldwell GC: Performance of eye protectors for squash and racquetball, *Physician Sportsmed 10:*63, 1982.
54. Easterbrook M: Eye injuries in squash and racquetball: an update, *Physician Sportsmed 10:*47, 1982.
55. Pashby TJ, Bishop PJ, Easterbrook M: Eye injuries in Canadian racquet sports, *Can Fam Physician 28:*967, 1982.
56. Feigelman MJ, Sugar J, Jednock N, et al: Assessment of ocular protection for racquetball, *JAMA 250:*3305, 1983.
57. Clemett RS, McKenzie KD, Glogau TH, et al: Eye protectors for squash players, *Aust N Z J Ophthalmol 15:*151, 1987.
58. Easterbrook M. Eye protection in racket sports: an update, *Physician Sportsmed 15:*180,, 1987.
59. Easterbrook M: Prevention of eye injuries in racquet sports, *Ophthalmol Clin N Am 12:*367, 1999.
60. US Squash: *Protective eyewear policy*, www.us-squash.org/ussra/protectiveeyewear.html. Accessed May 1, 2007.
61. David DB, Shah P, Whittaker C, et al: Ocular protection in squash clubs: time for a change? *Eye 9:*575, 1995.
62. Easterbrook M: Eye injuries in squash: a preventable disease, *Can Med Assoc J 118:*298, 1978.
63. Easterbrook M: Eye protection in racquet sports, *Clin Sports Med 7:*253, 1988.
64. Eime R, McCarty C, Finch CF, et al: Unprotected eyes in squash: not seeing the risk of injury, *J Sci Med Sport 8:*92, 2005.

65. Eime R, Finch C, Owen N, et al: Do squash players accurately report use of appropriate protective eyewear? *J Sci Med Sports 8:*352, 2005.
66. Eime RM, Finch CF, Sherman CA, et al: Are squash players protecting their eyes? *Inj Prev 8:*239, 2002.
67. Finch C, Vear P: What do adult squash players think about protective eyewear? *Br J Sports Med 32:*155, 1998.
68. Genovese MT, Lenzo NP, Lim RK, et al: Eye injuries among pennant squash players and their attitudes towards protective eyewear, *Med J Aust 153:*655, 1990.
69. Leyland B: Eye protection for squash players, *Aust J Optom 55:*225, 1972.
70. Ingram DV, Lewkonia I: Ocular hazards of playing squash rackets, *Br J Ophthalmol 57:*434, 1973.
71. North IM: Ocular hazards of squash, *Med J Aust 1:*165, 1973.
72. Stuart MJ, Smith AM, Malo-Ortiguera SA, et al: A comparison of facial protection and the incidence of head, neck, and facial injuries in junior A hockey players: a function of individual playing time, *Am J Sports Med 30:*39, 2002.
73. Pashby TJ, Pashby RC, Chisholm LD, et al: Eye injuries on Canadian hockey, *Can Med Assoc J 113:*663, 1975.
74. Vinger PF: Ocular injuries in hockey, *Arch Ophthalmol 94:*74, 1976.
75. Pashby TJ: Eye injuries in Canadian hockey. Phase II, *Can Med Assoc J 117:*677, 1977.
76. Pashby TJ: Eye injuries in Canadian amateur hockey, *Am J Sports Med 7:*254, 1979.
77. Pashby TJ: Eye injuries in Canadian hockey. Phase III, *Can Med Assoc J 121:*643, 1979.
78. Pashby TJ: Ocular injuries in hockey, *Int Ophthalmol Clin 28:*228, 1988.
79. Benson B, Meeuwisse W: Ice hockey injuries. In Maffulli N, Caine DJ, editors: Epidemiology of pediatric sports injuries: team sports, *Med Sport Sci*, *49:*86, 2005.
80. Antaki S, Labelle P, Dunas J: Retinal detachment following ice hockey injury, *Can Med Assoc J 117:*245, 1977.
81. Horns RC: Blinding hockey injuries, *Minn Med 60:*255, 1977.
82. Pashby TJ: Summary of eye injuries in Canadian sports, *Can J Ophthalmol 25:*284, 1990.
83. Pashby RC, Pashby TJ: Ocular injuries. In Torg JS, Welsh P, Shephard R, editors: *Current therapy in sports medicine*, St Louis, 1990, Mosby–Year Book, p 241.
84. Devenyi RG, Pashby RC, Pashby J: The hockey eye safety program, *Ophthalmol Clin N Am 12:*359, 1999.
85. Lapidus CS, Nelson LB, Jeffers JB, et al: Eye injuries in lacrosse: women need their vision less than men? *J Trauma 32:*555, 1992.
86. Livingston LA, Forbes SL: Eye injuries in women's lacrosse: strict rule enforcement and mandatory eyewear required, *J Trauma 40:*144, 1996.
87. Webster DA, Bayliss GV, Spadaro JA: Head and face injuries in scholastic women's lacrosse with and without eyewear, *Med Sci Sports Exerc 31:*938, 1999.
88. O'Grady C: Safety in the women's game, *Lacrosse Magazine 26:*73, 2002.
89. Waicus KM, Smith BW: Eye injuries in women's lacrosse players, *Clin J Sport Med 12:*24, 2002.
90. Mantz SO, Nibbelink G: Injuries in intercollegiate women's lacrosse, *Am J Sports Med 32:*608, 2004.
91. Vinger PF: The incidence of eye injuries in sports. In Vinger PF, editor: *Ocular sports injuries*, Boston, 1981, Little, Brown, pp 21-46.
92. Strahlman E, Elman M, Daub E, et al: Causes of pediatric eye injuries: a population-based study, *Arch Ophthalmol 108:*603, 1990.
93. Napier SM, Baker, RS, Sanford DG, et al: Eye injuries in athletics and recreation, *Surv Ophthalmol 41:*229, 1996.
94. Witherspoon CD, Kuhn F, Morris R, et al: Epidemiology of general and sports eye injuries, *Ophthalmol Clin N Am 12:*333, 1999.

95. Vinger PF: Baseball hardness as a risk factor for eye injuries, *Arch Ophthalmol 117:*354, 1999.
96. Danis RP, Hu K, Bell M: Acceptability of baseball face guards and reduction of oculofacial injury in receptive youth league players, *Inj Prev 6:*232, 2000.
97. Easterbrook M, Pashby TJ: Eye injuries associated with war games, *Can Med Assoc J 133:*415, 1985.
98. Randall KA: War games: a new sport that can cause eye casualties, *Sightsaving 54:*2, 1985.
99. Ryan EH, Lissner G: Eye injuries during "war games," *Arch Ophthalmol 104:*1435, 1986.
100. Tardif D, Little J, Mercier M, et al: Ocular trauma in war games, *Physician Sportsmed 14:*90, 1986.
101. Martin PL, Magolian JJ: Eye injury during "war games" despite the use of goggles, *Arch Ophthalmol 105:*321, 1987.
102. Easterbrook M, Pashby TJ: Ocular injuries and war games, *Int Ophthalmol Clin 28:*222, 1988.
103. Wellington DP, Johnstone MA, Hopkins RJ: Bull's-eye corneal lesion resulting from war game injury, *Arch Ophthalmol 107:*1727, 1989.
104. Hargrave S, Weakley D, Wilson C: Complications of ocular paintball injuries in children, *J Pediatr Ophthalmol Strabismus 37:*338, 2000.
105. Fineman MS: Ocular paintball injuries, *Curr Opin Ophthalmol 12:*186, 2001.
106. Varr WF, Cook RA: Shotgun eye injuries: ocular risk and eye protection efficacy, *Ophthalmology 99:*867, 1992.
107. Eichler J: Eye accidents due to ski pole injuries [in German], *Dtsch Gesundheitsw 375:*375, 1972.
108. Classe JG: Prescribing for noncontact sports, *Optom Clin 3:*111, 1993.
109. Dyer B, Masci D, Sakkas D, et al: Ocular protection for competitive swimmers, *Clin Exp Optom 3:*74, 1989.
110. Morgan E: In the swim, *Eyecare Bus 14:*82, 2000.
111. Legerton JA: Prescribing for water sports, *Optom Clin 3:*91, 1993.
112. Larrison WI, Hersh PS, Kunzweiler T, et al: Sports-related ocular trauma, *Ophthalmology 97:*1265, 1990.
113. Burke MJ, Sanitato JJ, Vinger PF, et al: Soccerball-induced eye injuries, *JAMA 249:*2682, 1983.
114. Horn EP, McDonald HR, Johnson RN, et al: Soccer ball-related retinal injuries: a report of 13 cases, *Retina 20:*604, 2000.
115. Capao-Filipe JA, Fernandes VL, Barros H, et al: Soccer-related ocular injuries, *Arch Ophthalmol 121:*687, 2003.
116. Capao-Filipe JA: Soccer (football) ocular injuries: an important eye health problem, *Br J Ophthalmol 88:*159, 2004.
117. Vinger PF, Capao-Filipe JA: The mechanism and prevention of soccer eye injuries, *Br J Ophthalmol 88:*167, 2004.
118. Yee CT, Drescher RJ: The effect of racquetball goggles on peripheral vision and distortion, *Optom Monthly 75:*220, 1984.
119. Gallaway M, Aimino J, Scheiman M: The effect of sports eyewear on peripheral visual field and a peripheral visual performance task, *J Am Optom Assoc 57:*304, 1986.
120. Dawson ML Zabik RM: Effect of protective eyewear on reaction time in the horizontal field of vision, *Percept Mot Skills 67:*115, 1988.
121. Wingert TA, Long WF, Martin WG: Hockey faceguards and visual field scotomas, *Can J Optom 54:*143, 1992.
122. Miller BA, Miller SJ: Visual fields with protective eyewear, *J Orthop Sports Phys Ther 18:*470, 1993.
123. Ing E, Ing T, Ing S: The effect of a hockey visor and sports goggles on visual function, *Can J Ophthalmol 37:*161, 2002.
124. Eime RM, Finch CF: Have the attitudes of Australian squash players towards protective eyewear changed over the past decade? *Br J Sports Med 36:*442, 2002.

125. Eime R, Finch C, Owen N, et al: Knowledge, beliefs and attitudes of squash venue operators relating to use of protective eyewear, *Inj Control Saf Promot 11:*47, 2004.
126. Loran D: Eye injuries in squash, *Optician 204*:18, 1992.
127. Eime R, Owen N, Finch C: Protective eyewear promotion: applying principles of behaviour change in the design of a squash injury prevention programme, *Sports Med 34:*629, 2004.
128. Eime R, Finch C, Wolfe R, et al: The effectiveness of a squash eyewear promotion strategy, *Br J Sports Med 39:*681, 2005.
129. Tommila V, Tarkkanan A: Incidence of loss of vision in the healthy eye in amblyopia, *Br J Ophthalmol 65:*575, 1981.
129a. Keates RH: Preventing eye injuries in sports: some questions and answers, *Phys Sportsmed 16:*122, 1988.
130. Classe JG, Scholles J: Liability for ophthalmic materials, *J Am Optom Assoc 57:*470, 1986.
131. Classe JG: Legal aspects of prescribing for athletes and sportsmen, *J Am Optom Assoc 58:*674, 1987.
132. Classe JG: Legal aspects of sports vision, *Optom Clin 3:*27, 1993.
133. Classe JG: Sports related ocular trauma: a preventable epidemic, *J Am Optom Assoc 67:*66, 1996.
134. Miller PJ: Sports vision—are you legally prepared? *Contact Lens Forum 15:*11, 1990.
135. Classe JG, Gold AR, Harris MG: A review of five recent cases of significance for optometrists, *J Am Optom Assoc 59:*964, 1988.
136. Michaels D: *Visual optics and refraction: a clinical approach*, ed 3, St Louis, 1985, Mosby, pp 12-13.
137. Clark BAJ: Color in sunglass lenses, *Am J Optom Arch Am Acad Optom 46:*825, 1969.
138. Sliney DH: Ocular injury due to light toxicity, *Int Ophthalmol Clin 28:*246, 1988.
139. West SK, Duncan DD, Muñoz B, et al: Sunlight exposure and risk of lens opacities in a population based study, *JAMA 280:*714, 1999.
140. Pitts DG: The ocular effects of ultraviolet radiation, *Am J Optom Physiol Optics 55:*19, 1978.
141. Pitts D, Kleinstein R: *Environmental vision,* Boston, 1993, Butterworth-Heinemann, pp 164-177, 306.
142. *Ocular ultraviolet radiation hazards and sunlight: a cooperative initiative of National Society to Prevent Blindness (Prevent Blindness America), the American Academy of Ophthalmology, and the American Optometric Association. A position statement*, 1993. Available at: http://www.aoa.org/Documents/ocular ultra-violet.pdf.
143. Ham WT, Mueller HA, Sliney DH: Retinal sensitivity to damage from short wavelength light, *Nature 260:*153, 1976.
144. European Committee for Standardization: *Personal eye protection—sunglasses and sunglare filters for general use*, Brussels, 1997, European Standards 6 EN 1836.
145. Thibos LN, Bradley A, Zhang X: Effect of ocular chromatic aberration on monocular visual acuity, *Optom Vis Sci 68:*599, 1991.
146. Bradley A: Glen A Fry Award Lecture *1991:* Perceptual manifestations of imperfect optics in the human eye: attempts to correct for chromatic aberration, *Optom Vis Sci 69*:515-521, 1992.
147. Chou BR, Cullen AP: Spectral characteristics of sports and occupational tinted lenses, *Can J Optom 47:*77, 1985.
148. Clark B, Johnson ML, Dreher RE: The effect of sunlight on dark adaptation, *Am J Ophthalmol 29:*828, 1946.
149. Hecht S, Hendley CD, Ross S, et al: The effect of exposure to sunlight on night vision, *Am J Ophthalmol 31:*1573, 1948.
150. Bergmanson J, Sheldon T, Cullen A: A sting in the rays, *Optician 212:*17, 1996.
151. Kinney JAS: Night vision sensitivity during prolonged restriction from sunlight, *J Appl Psychol 47*:828, 1963.
152. Hart WM: Visual adaptation. In Moses RA, Hart WM, editors: *Adler's physiology of the eye. Clinical application*, St Louis, 1987, Mosby–Year Book, p 413.

153. Borgwardt B, Fishman GA, Meullen DV: Spectral transmission characteristics of tinted lenses, *Arch Ophthalmol 99:*293, 1981.
154. Kinney JS, Schlichting CL, Neri D, et al: *Various measures of the effectiveness of yellow goggles: Naval Submarine Medical Research Laboratory, report no. 941*, Groton, CT, 1980, Naval Submarine Medical Research Laboratory.
155. Kinney JS, Schlichting CL, Neri DF, et al: Reaction time to spatial frequencies using yellow and luminance-matched neutral goggles, *Am J Optom Physiol Optics 60:*132, 1983.
156. Kinney JAS, Luria SM, Schlichting CL, et al: The perception of depth contours with yellow goggles, *Perception 12:*363, 1983.
157. Kelly SA, Goldberg SE, Banton TA: Effect of yellow-tinted lenses on contrast sensitivity, *Am J Optom Physiol Optics 61:*657, 1984.
158. Yap M: The effect of a yellow filter on contrast sensitivity, *Ophthalmol Physiol Opt 4:*227, 1984.
159. Corth R: The perception of depth contours with yellow goggles—an alternative explanation, *Perception 14:*377, 1985.
160. Kinney JAS: The perception of depth contours with yellow goggles—comments on letter by Richard Corth, *Perception 14:*378, 1985.
161. Kelly SA: Effect of yellow-tinted lenses on brightness, *J Opt Soc Am A7:*1905,1990.
162. Zigman S: Vision enhancement using a short wavelength light-absorbing filter, *Optom Vis Sci 67:*100, 1990.
163. Rieger G: Improvement of contrast sensitivity with yellow filter glasses, *Can J Ophthalmol 27:*137, 1992.
164. Zigman S: Light filters to improve vision, *Optom Vis Sci 69:*325, 1992.
165. Rabin J, Wiley R: Differences in apparent contrast in yellow and white light, *Ophthalmol Physiol Opt 16:*68, 1996.
166. Lee JE, Stein JJ, Prevor MB, et al: Effect of variable tinted spectacle lenses on visual performance in controlled subjects, *CLAO J 28:*80, 2002.
167. Luckiesh M: *Color and its applications*, New York, 1915, Van Nostrand. pp 116-160.
168. Luckiesh M, Moss FK: *The science of seeing*, New York, 1937, Van Nostrand, pp 400-453.
169. Jendrusch G, Senner V, Schaff P, et al: Vision—an essential factor for safety in skiing: visual acuity, stereoscopic depth perception, effect of colored lenses. In Johnson RJ, editor: *Skiing trauma and safety,* vol 12, West Conshohocken, PA, 1999, American Society for Testing and Materials, pp 23-34.
170. Ross J: Sunglasses: skiers must emphasize substance over style, *Optom Management 26:*52, 1991.
171. Marmor MF: Double fault! Ocular hazards of a tennis sunglass, *Arch Ophthalmol 119:*1064, 2001.
172. Reichow AW, Citek K, Erickson GE, et al: The effect of polarized lenses on golf putting performance [abstract], *Optom Vis Sci 79*:239, 2002.
173. Stephens GL, Davis JK: Ophthalmic lens tints and coatings. In: Duane TD, Jaeger EA, editors: *Clinical Ophthalmology.* Philadelphia, 1994, Harper & Row, pp 11-13.
174. Woods TA: Ophthalmic lenses for athletes and sportsmen, *Optom Clin 3:*33, 1993.
175. American National Standards Institute. ANSI Z80.3-2001, Ophthalmics—Non-prescription sunglasses and fashion eyewear requirements. New York, 1986, American National Standards Institute.
176. Davis JK: The sunglass standard and its rationale, *Optom Vis Sci 67:*414, 1990.
177. Dain SJ, Hoskin AK: Ultraviolet protection in spectacle and sunglass lenses: claims vs performance, *Clin Exp Optom 76:*136, 1993.
178. Cooper SC, Smith JA, Katz M, et al: Nonprescription tinted eyewear optical accuracy study, *Optometry 72:*510, 2001.
179. Scheiman M, Wick B: *Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders*, Philadelphia, 2002, Lippincott Williams & Wilkins, pp 130-131.
180. Stephens GL: Sports eyewear takes off, *Optom Econ 4*:10, 1994.
181. Morgan E: The women's movement, *Eyecare Business* April:42-47, 2001.

182. Player HS: An investigation on the use and satisfaction of contact lenses in sports. *J Am Optom Assoc 30*:33-36, 1958.
183. Yarwood RA: The use on contact lenses in all kinds of sports, *J Am Optom Assoc 31:*633, 1960.
184. Levey EM: The sports wearer of contact lenses—a new approach, *Am J Optom Arch Am Acad Optom 42:*21, 1965.
185. Jessen GN: Baseball and contact lenses—possible solution to the problem, *Am J Optom Arch Am Acad Optom 43:*320, 1966.
186. Firestone LE: Contact lens use for sports, *J Am Optom Assoc 42:*279, 1971.
187. Tym A: Contact lenses for tennis players, *Optom Weekly 61:*41, 1970.
188. Berry R: Contact lenses for contact sports, *Optom Management 11:*16, 1975.
189. Benjamin WL: Visual optics of contact lenses. In Bennett ES, Weissman BA, editors: *Clinical contact lens practice*, Philadelphia, 1991, JB Lippincott.
190. Grey CP: Changes in contrast sensitivity when wearing low, medium and high water content soft lenses, *J Br Contact Lens Assoc 9:*21, 1986.
191. Nowozyckyj A, Carney LG, Efron N: Effect of hydrogel lens wear on contrast sensitivity, *Am J Optom Physiol Opt 65:*263, 1988.
192. Oxenberg LD, Carney LG: Visual performance with aspheric rigid contact lenses, *Optom Vis Sci 66:*818, 1989.
193. Kluka DA, Love PA: The effects of daily-wear contact lenses on contrast sensitivity in selected professional and collegiate female tennis players, *J Am Optom Assoc 64:*182, 1993.
194. Ridder WH, Tomlinson A: Blink-induced temporal variations in contrast sensitivity, *Int Contact Lens Clin 18:*231, 1991.
195. Gardner JJ: Doctor's playbook: the X's and O's of fitting athletes, *Rev Optom 138*:73, 2001.
196. Bennett ES: Athletics. In: Bennett ES, Weismann BA, editors: *Clinical contact lens practice,* Philadelphia, 1991, Lippincott.
197. Kolstad A, Opsahl R: Cold injury to corneal epithelium: a cause of blurred vision in cross country skiers, *Acta Ophthalmol 47*:656, 1969.
198. Clarke C: Contact lenses at high altitude: experience on Everest south-west face 1975, *Br J Ophthalmol 60*:479, 1976.
199. Socks JF: Contact lenses in extreme cold environments: responses of rabbit corneas, *Am J Optom Physiol Optics 59*:297, 1982.
200. Socks JF: Use of contact lenses for cold weather activities. Results of a survey, *Int Contact Lens Clin 10*:82, 1983.
201. Maloof AJ, Ho A, Coroneo MT: Influence of corneal shape on limbal light focusing, *Invest Ophthalmol Vis Sci 35*:2592, 1994.
202. Gilbard JP: The scientific context and basis of the pharmacologic management of dry eyes, *Ophthalmol Clin North Am 18*:475, 2005.
203. Kopp JD: Eye on the ball: an interview with Dr. C. Stephen Johnson and Mark McGwire, *J Am Optom Assoc 70*:79, 1999.
204. Petersen WL: Contact lenses and surfing: the need to ensure safety in the sport has prompted some interesting studies, *Contact Lens Spectrum 159*:59, 1989.
205. *Coming soon: Suntacts*, http://www.eyecolor.stores.yahoo.net/suntacts.html, accessed July 15, 2006.
206. *When the ball stands out your play stands out*, http://www.aclens.com/prosoft_info.asp, accessed July 15, 2006.
207. *Sportsight GP,* http://www.rgpcontactlenses.com/sportsight-gp.htm, accessed July 15, 2006.
208. Nike MAXSIGHT sport-tinted contact lenses (polymacon), http://www.bausch.com/en_US/ecp/vision-care/ product/softcontacts/nike_maxsight_ecp.aspx, accessed July 15, 2006.

209. Citek K, Reichow AW: Visual performance comparisons of performance-tinted soft contact lenses and tinted spectacles [abstract], *Optom Vis Sci 81(Suppl)*:84, 2004.
210. Erickson GB, Horn FC, Barney T: Contrast discrimination with Nike MAXSIGHT contact lenses in natural light [abstract], *Optom Vis Sci* E-abstract 060057, 2006.
211. Bennett ES: Rigid gas permeable contact lenses for athletes, *NASV Sports Vision Newsletter 5:*30, 1989.
212. Legerton JA: Prescribing for water sports, *Optom Clin 3*:91, 1993.
213. Efron N: *Contact lenses A-Z*. Oxford, 2002, Butterworth-Heinemann, pp 174-177.
214. Katz HD, Malin AH: A new lens for sports proves an excellent troubleshooter, *Contact Lens Spectrum 5:*27, 1990.
215. Legerton JA: Large dynamic lenses for dynamic water sports, *Sportsvision 6*:12, 1990.
216. Nagel C, Monical JB: The design and development of a contact lens for underwater seeing, *Am J Optom Arch Am Acad Optom 31*:468, 1954.
217. Grant AH: SCAL: skindivers contact air lens, *Opt J Rev Optom 55*:17, 1963.
218. Faust KJ, Beckman EL: Evaluation of a swimmer's contact air-water lens system, *Mil Med 131:*779, 1966.
219. Bayshore CA: Underwater contact lenses, *Contacto 12*:6, 1968.
220. Hurlock R, Malin AH: Case report: underwater contact lens correction, *Am J Optom Arch Am Acad Optom 50*:653, 1973.
221. Hoelting C, Egan DJ, Bennett ES: The use of contact lenses in swimming and scuba diving, *Can J Optom 46*:12, 1984.
222. Shoji PJ, Yamane SJ: Surfing with soft lenses, *Contact Lens Forum 10*:15, 1985.
223. Cotter J: Soft contact lens testing on fresh water scuba divers, *Contact Intraocul Lens Med J 7*:324, 1981.
224. Josephson JE, Caffery BE: Contact lens considerations in surface and subsurface aqueous environments, *Optom Vis Sci 68*:2, 1991.
225. Mandell RB: Sticking of gel contact lenses, *Int Contact Lens Clin 2*:28, 1975.
226. Solomon J: Swimming with soft lenses, *South J Optom 19*:13, 1977.
227. Stein HA, Slatt BJ: Swimming with soft contact lenses, *Contact Intraocul Lens Med J 3*:24, 1977.
228. Solomon J: Hydrophilic lenses for swimming, *Contact Intraocul Lens Med J 4*:93, 1978.
229. Lovsund P, Nilsson SEG, Oberg PA: The use of contact lenses in wet or damp environments, *Acta Ophthalmol (Kbh) 58*:794, 1980.
230. Soni PS, Pence NA, DeLeon C, et al: Feasibility of extended wear lens use in chlorinated swimming pools, *Am J Optom Physiol Optics 63*:171, 1986.
231. Diefenbach CB, Soni PS, Gillespie BJ, et al: Extended wear contact lens movement under swimming pool conditions, *Am J Optom Physiol Optics 65*:710, 1988.
232. Galkin KA, Semes L: Risk of loss of Soflens during water skiing, *J Am Optom Assoc 54*:267, 1983.
233. Banks LD, Edwards GL: To swim or not to swim, *Contact Lens Spectrum 6*:46, 1987.
234. Bennett QM: The use of contact lenses for diving (sport and commercial), *Contact Lens J 16*:171, 1988.
235. Peterson WL: Contact lenses and surfing, *Contact Lens Spectrum 8*:59, 1989.
236. Vesaluoma M, Kalso S, Jokipii L, et al: Microbiological quality in Finnish public swimming pools and whirlpools with special reference to free living amoebae: a risk factor for contact lens wearers? *Br J Ophthalmol 79*:178, 1995.
237. Simon DR, Bradley ME: Corneal edema in divers wearing hard contact lenses, *Am J Ophthalmol 85*:462, 1978.
238. Jessen G: Orthofocus techniques, *Contacto 6*:200, 1962.
239. Lui W-O, Edwards MH, Cho P: Contact lenses in myopia reduction—from orthofocus to accelerated Orthokeratology, *Contact Lens Ant Eye 23*:68, 2000.
240. Caroline PJ: Contemporary orthokeratology, *Contact Lens Ant Eye 24*:41, 2001.

241. Barr JT, Rah MJ, Jackson JM, et al: Orthokeratology and corneal refractive therapy: a review and recent findings, *Eye Contact Lens 29*:S49, 2003.
242. Walline JJ, Rah MJ, Jones LA: The Children's Overnight Orthokeratology Investigation (COOKI) pilot study, *Optom Vis Sci 81*:407, 2004.
243. Sorbara L, Fonn D, Simpson T, et al: Reduction of myopia from corneal refractive therapy, *Optom Vis Sci 82*:512, 2005.
244. Walline JJ, Holden BA, Bullimore MA, et al: The current state of corneal reshaping, *Eye Contact Lens 31*:209, 2005.
245. Swarbrick HA: Orthokeratology review and update, *Clin Exp Optom 89*:124, 2006.
246. Jayakumar J, Swarbrick HA: The effect of age on short-term Orthokeratology, *Optom Vis Sci 82*:505, 2003.
247. Sorbara L, Kort R, Lu F, et al: Overnight refractive and keratometric effects of corneal refractive therapy, *Optom Vis Sci 79(suppl)*:127, 2002.
248. Sridharan R, Swarbrick H: Corneal response to short-term orthokeratology lens wear, *Optom Vis Sci 80*:200, 2003.
249. Wang J, Fonn D, Simpson TL, et al: Topographical thickness of the epithelium and total cornea after overnight wear of reverse-geometry rigid contact lenses for myopia reduction, *Invest Ophthalmol Vis Sci 44*:4742, 2003.
250. Choy CKM, Cho P, Benzie IFF, et al: Effect of one overnight wear of orthokeratology lenses on tear composition, *Optom Vis Sci 81*:414, 2004.
251. Mountford J: An analysis of the changes in corneal shape and refractive error induced by accelerated Orthokeratology, *Int Contact Lens Clin 24*:128, 1997.
252. Nichols JJ, Marsich MM, Nguyen M, et al: Overnight Orthokeratology, *Optom Vis Sci 77*:252, 2000.
253. Rah MJ, Jackson JM, Jones LA, et al: Overnight orthokeratology: preliminary results of the Lenses and Overnight Orthokeratology (LOOK) study, *Optom Vis Sci 79*:598, 2002.
254. Lui W-O, Edwards MH: Orthokeratology in low myopia. Part 1: efficacy and predictability, *Contact Lens Ant Eye 23*:77, 2000.
255. Swarbrick HA, Wong G, O'Leary DJ: Corneal response to Orthokeratology, *Optom Vis Sci 75*:791, 1998.
256. Lui W-O, Edwards MH: Orthokeratology in low myopia. Part 2: corneal topographic changes and safety over 100 days, *Contact Lens Ant Eye 23*:90, 2000.
257. Alharbi A, Swarbrick HA: The effects of overnight orthokeratology lens wear on corneal thickness, *Invest Ophthalmol Vis Sci 44*:2518, 2003.
258. Owens H, Garner LF, Craig JP, et al: Posterior corneal changes with Orthokeratology, *Optom Vis Sci 81*:421, 2004.
259. Soni PS, Nguyen TT, Bonanno JA: Overnight orthokeratology: visual and corneal changes, *Eye Contact Lens 29*:137, 2003.
260. Soni PS, Nguyen TT: XO Overnight Orthokeratology Study Group. Overnight orthokeratology experience with XO material, *Eye Contact Lens 32*:39, 2006.
261. Kwok LS, Pierscionek BK, Bullimore M, et al: Orthokeratology for myopic children: wolf in sheep's clothing? *Clin Exp Ophthalmol 33*:343, 2005.
262. Cho P, Cheung SW, Mountford J, et al: Incidence of corneal pigmented arc and factors associated with its appearance in orthokeratology, *Ophthalmol Physiol Opt 25*:478, 2005.
263. Watt K, Swarbrick HA: Microbial keratitis in overnight orthokeratology: review of the first 50 cases, *Eye Contact Lens 31*:201, 2005.
264. Sun X, Zhao H, Deng S, et al: Infectious keratitis related to Orthokeratology, *Ophthalmol Physiol Opt 26*:133, 2006.
265. Cheung SW, Cho P: Subjective and objective assessments of the effect of orthokeratology—a cross-sectional study, *Curr Eye Res 28*:121, 2004.

266. Joslin CE, Wu SM, McMahon TT, et al: Higher-order wavefront aberrations in corneal refractive therapy, *Optom Vis Sci 80*:805, 2003.
267. Berntsen DA, Barr JT, Mitchell GL: The effect of overnight contact lens corneal reshaping on higher-order aberrations and best-corrected visual acuity, *Optom Vis Sci 82*:490, 2005.
268. Duffey RJ, Leaming D: US trends in refractive surgery: 2003 ISRS/AAO survey, *J Refract Surg 21*:87, 2005.
269. Beran RF, Stewart C, Doty J: Refractive surgery and the athlete, *J Ophthalmic Nursing Tech 14*:11, 1995.
270. Vinger PF, Mieler WF, Oestreicher JH, et al: Ruptured globes following radial and hexagonal keratotomy surgery, *Arch Ophthalmol 114*:129, 1996.
271. Dudenhoefer EJ, Vinger PF, Azar DT: Trauma after refractive surgery, *Int Ophthalmol Clin 42*:33, 2002.
272. Seiler T, Mrochen M, Kaemmerer M: Operative correction of ocular aberration to improve visual acuity, *J Refract Surg 16*:S619, 2000.
273. Mrochen M, Kaemmerer M, Seiler T: Clinical results of wavefront-guided laser in situ keratomileusis three months after surgery, *J Cataract Refract Surg 27*:201, 2001.
274. Racine L, Wang L, Koch DD: Size of corneal topographic effective optical zone: comparison of standard and customized myopic laser in situ keratomileusis, *Am J Ophthalmol 142*:227, 2006.
275. Aras C, Ozdamar A, Bahcecioglu H, et al: Decreased tear secretion after laser in situ keratomileusis for high myopia, *J Refract Surg 16*:362, 2000.
276. Lee JB, Ryu CH, Kim J, et al: Comparison of tear secretion and tear film instability after photorefractive keratectomy and laser in situ keratomileusis, *J Cataract Refract Surg 26*:1326, 2000.
277. Battat L, Macri A, Dursun D, et al: Effects of laser in situ keratomileusis on tear production, clearance, and the ocular surface, *Ophthalmology 108*:1230, 2001.
278. Patel S, Perez-Santonja JJ, Alio JL, et al: Corneal sensitivity and some properties of the tear film after laser in situ keratomileusis, *J Refract Surg 17*:17, 2001.
279. Toda I, Asano-Kato N, Komai-Hori Y, et al: Dry eye after laser in situ keratomileusis, *Am J Ophthalmol 132*:1, 2001.
280. Albietz JM, Lenton LM, McLennan SG: Effect of laser in situ keratomileusis for hyperopia on tear film and ocular surface, *J Refract Surg 18*:113, 2002.
281. Donnenfeld ED, Solomon K, Perry HD, et al: The effect of hinge position on corneal sensation and dry eye after LASIK, *Ophthalmology 110*:1023, 2003.
282. Goto T, Zheng X, Kylce SD, et al: Evaluation of the tear film stability after laser in situ keratomileusis using the tear film stability analysis system, *Am J Ophthalmol 137*:116, 2004.
283. Stern ME, Beuerman RW, Fox RI, et al: The pathology of dry eye: the interaction between the ocular surface and lacrimal glands, *Cornea 17*:584, 1998.
284. Brown SM, Bradley JC, Xu KT, et al: Visual field changes after laser in situ keratomileusis, *J Cataract Refract Surg 31*:687, 2005.
285. Laby DM, Kirschen DG, DeLand P: The effect of laser refractive surgery on the on-field performance of professional baseball players, *Optometry 76*:647, 2005.
286. Melki SA, Talamo JH, Azar DT, et al: Late traumatic dislocation of laser in situ keratomileusis corneal flaps, *Ophthalmology 107*:2136, 2000.
287. Booth MA, Koch DD: Late laser in situ keratomileusis flap dislocation caused by a thrown football, *J Cataract Refract Surg 29*:2032, 2003.
288. Nose W, Neves RA, Schanzlin DJ, et al: Intrastromal corneal ring: one-year results of first implants in humans: a preliminary nonfunctional eye study, *Refract Corneal Surg 9*:452, 1993.
289. Schanzlin DJ, Asbell AA, Buris TE, et al: The intrastromal corneal ring segments: phase II results for correction of myopia, *Ophthalmology 104*:1067, 1997.
290. Guell JL: Are intracorneal rings still useful in refractive surgery? *Curr Opin Ophthalmol 16*:260, 2005.

7

Jason Brumitt, MSPT, SCS, ATC, CSCS, OD, and
Graham B. Erickson, OD, FAAO, FCOVD

Ocular Injuries in Sports: Assessment and Management

CHAPTER OUTLINE

Sideline Management of Sports Ocular Injuries
- Preparticipation Physical Examination
- Prevention
- Selecting Eyewear
- Immediate Management of Sports-Related Ocular Emergencies
- Blunt Trauma
  - Foreign Object
  - Superficial Injury to the Eyelid
  - Burns
- Recognition of Specific Eye and Facial Injuries
  - Facial Fractures
  - Nasal Fractures
  - Orbital Fractures
  - Zygomatic Fractures
  - Frontal Bone Fracture
  - Eye Trauma
  - Corneal Injuries
  - Hyphema
  - Rupture of the Globe
  - Retinal Injury
  - Orbital Hemorrhage
  - Periorbital Contusion
  - Detached Retina
  - Conjunctivitis
  - Subconjunctival Hemorrhage
  - Lacerations
  - Lens Dislocation
  - Nontraumatic Eye Injuries or Conditions

Clinical Management of Sports Ocular Injuries
- Sports
  - Baseball and Softball
  - Basketball
  - Boxing
  - Fishing
  - Football
  - Golf
  - Hockey
  - Lacrosse
  - Mountaineering
  - Racquet Sports
  - Scuba Diving
  - Soccer
  - Swimming and Water Sports
  - Paintball
- Blunt Trauma
  - Eyelids
  - Orbital Contents
  - Bone Structures
  - Conjunctival and Scleral Injuries
  - Corneal Injuries
  - Anterior Chamber and Uvea
  - Crystalline Lens
  - Vitreous Body
  - Retinal Injuries
  - Optic Nerve
  - Choroid
  - Visual Fields
- Penetrating Trauma
- Chemical Injuries

Follow-Up Co-Management

SIDELINE MANAGEMENT OF SPORTS OCULAR INJURIES

Sports-related ocular injuries account for 33,000 to 100,000 of the estimated 2.4 million eye injuries that occur in the United States annually.[1,2] Sports-related eye injuries range from a minor injury to a critical situation requiring immediate medical management. Referral to an eye care specialist is necessary in most cases. Inpatient hospital care is often required for severe injuries, with 12.5% to 42% of athletes requiring advanced care.[3-5]

Participation in sports carries with it a risk of sustaining an eye injury. Millions of adolescents and young adults participate in organized sports each year. Millions more will participate in nonleague or unorganized sporting events.[6] More than 50% of all eye injuries are estimated to occur before age 25 years, with upward of 160,000 school-age children sustaining ocular trauma in the United States each year.[7,8] In 2000 approximately 42,000 sports- and recreation-related eye injuries were reported in the United States.[9] Of those sustaining sports-related eye injuries in 2000, 72% occurred in individuals younger than 25 years (Box 7-1).

Eye injuries are the number one cause of blindness and ocular morbidity in children.[10] Children and teens may be more susceptible to sports-related eye injuries because of poor supervision or poor coaching, athletic immaturity, or aggressive play.[11-15] Sports medicine professionals play a crucial role in the prevention of sports-related eye injuries, immediate first-aid management if an eye injury occurs, referral of the athlete to an eye care specialist, and follow-up care for the athlete who has sustained an eye injury. Medical and allied health professionals providing sports medicine care for athletic teams (both on the field and in the clinic) may include the team physician, optometrist or ophthalmologist, athletic trainer, and sports physical therapist. With the high number of eye injuries that occur each year nationally combined with the severity of certain eye injuries, the sports medicine professionals providing practice or game coverage must be familiar with sports-related ocular emergency protocols.

Preparticipation Physical Examination

Each year athletes receive a preparticipation physical examination (PPPE) before the start of the sports season. The PPPE is performed to identify athletes at risk of sudden death; identify medical conditions, including orthopedic conditions, that require further evaluation and treatment; identify at-risk individuals for substance abuse, sexually transmitted diseases, violence, and depression; and satisfy legal requirements of sport governing bodies (state high school athletic associations and the National Collegiate Athletic Association, for example).[16] Sports medicine professionals must be aware of the PPPE process performed in their respective regions. The PPPE meets the legal requirement for athletes to participate in sport, but as sports medicine physicians will attest, "it is a mistake to assume, based on a signed waiver, that an athlete is in good health."[16]

BOX 7-1 PERCENTAGE OF EYE INJURIES OCCURRING BY AGE[9]

- 72% occurred in individuals younger than 25 years
- 43% occurred in individuals younger than 15 years
- 8% occurred in individuals younger than 5 years

The Committee on Sports Medicine and Fitness recommends that all youths involved in organized sports should be encouraged to wear appropriate eye protection (Box 7-2). The committee strongly recommends that functionally one-eyed athletes wear appropriate eye protection during all sports, recreational, and work-related activities.[11,12] A functionally one-eyed athlete is defined as an individual who has a best-corrected visual acuity of worse than 20/40 in the poorer eye.[9,11,12,15] Athletes who have sustained eye trauma or have had eye surgery should also be evaluated by an ophthalmologist or optometrist.[11,12] Athletes who fall into this category may need eye protection or should be restricted from particular sports (see Box 7-2).[11,12] If the provider performing the PPPE fails to identify eye conditions requiring further evaluation, an athletic trainer who is familiar with an athlete's health history can serve as a back-up by referring the athlete to an eye care specialist.

Prevention

An ounce of prevention is truly worth a pound of cure when avoiding sports-related ocular injuries.[17] For example, the prevalent use of head and facial protection has all but eliminated facial and ocular injuries sustained in elite and professional ice hockey.[18] It only makes sense that protective face and eyewear should be worn when a rubber hockey puck is moving at speeds of 100 mph. Not all governing bodies of elite ice hockey amateur teams, however, require the use of full facial protection.[18] A cohort of elite ice hockey players was examined

BOX 7-2 RECOMMENDATIONS OF THE COMMITTEE ON SPORTS MEDICINE AND FITNESS

1. All youths involved in organized sports should be encouraged to wear appropriate eye protection.
2. The recommended sports-protective eyewear should be prescribed. Proper fit is essential. Because some children have narrow facial features, they may be unable to wear even the smallest sports goggles. These children may be fitted with 3-mm polycarbonate lenses in ANSI standard Z87.1 frames designed for children. The parents should be informed that this protection is not optimal and the choice of eye-safe sports should be discussed.
3. Because contact lenses offer no protection, athletes who wear contact lenses should be strongly encouraged to also wear the appropriate eye protection.
4. An athlete who requires prescription spectacles has three options for eye protection: (a) polycarbonate lenses in a sports frame that passes ASTM standard F803 for the specific sport, (b) contact lenses plus an appropriate protector, or (c) an over-the-glasses eye guard that conforms to the specifications of ASTM standard F803 for sports in which an ASTM standard F803 protector is sufficient.
5. All functionally one-eyed athletes should wear appropriate eye protection for all sports.
6. Functionally one-eyed athletes and those who have had an eye injury or surgery must not participate in boxing or full-contact martial arts. (Eye protection is not practical in boxing or wrestling and is not allowed in full-contact martial arts.) Wrestling has a low incidence of eye injury. Although no standards exist, eye protectors that are firmly fixed to the head have been custom made. The wrestler who has a custom-made eye protector must be aware that the protector design may be insufficient to prevent injury.
7. For sports in which a face mask or helmet with an eye protector or shield must be worn, functionally one-eyed athletes are strongly encouraged to also wear sports goggles that conform to the requirements of ASTM standard F803 (for any selected sport). This is to maintain some level of protection if the faceguard is elevated or removed, such as for hockey or football players on the bench. The helmet must fit properly and have a chinstrap for optimal protection.
8. Athletes should replace sports eye protectors that are damaged or yellowed with age because they may have become weakened and no longer protective.

by analyzing the relation between facial injuries sustained and the level of face and head protection worn.[18] The risk of eye injury was 4.7 times greater for players wearing no protection (helmet only) compared with those who at least wore partial protection (helmet and partial face guard). Better yet, the authors of the study found that those who wore full facial protection had incurred no eye injuries.[18]

Despite the epidemiologic evidence that the use of protective eyewear reduces the risk of injury, some leagues, teams, coaches, and players are still considerably resistant to their use.[19] This resistance is based primarily on fears that the use of protective eyewear may have a negative effect on overall performance.[20]

Baseball and basketball have been identified as the youth sports with the highest numbers of eye injuries experienced in the United States.[20,21] Both sports are played by millions of American youths each year. A nonrandomized, prospective cohort study compared the incidence of injury in those who used a baseball faceguard consisting of a polycarbonate arch attached to the ear flaps of the baseball helmet versus just the standard baseball helmet. The authors experienced resistance from the league to their proposed randomization design, so those who used the face guards did so on a voluntary basis. The teams using the faceguards reported a 28% lower incidence of facial impacts or injuries versus the control group.[20]

Selecting Eyewear

Chapter 6 in this text provides information on how to select appropriate eyewear for the athlete.

Immediate Management of Sports-Related Ocular Emergencies

The American Optometric Association has developed an emergency management protocol to be used by sports medicine professionals in the event a sport-related ocular injury is sustained in practice or during a game. Many sports-related eye injuries could be serious and require immediate medical attention. The sports medicine professional must recognize the signs of a severe eye injury, administer first aid, make return to play decisions, and refer the athlete for appropriate follow-up care.

An athlete who has sustained an apparent sport-related ocular injury should be evaluated first for a mild traumatic brain injury (MTBI), also referred to as a *concussion*. Many of the same injury mechanisms that cause eye trauma may also cause a concussion. Failure to recognize and treat an MTBI may result in a more serious and potentially life-threatening situation.

Eye injuries and MTBI share some similar signs and symptoms (Boxes 7-3 and 7-4). These include blurred vision; unequal, dilated, or nonreactive pupils; and headache or head-related pain.

BOX 7-3 GENERAL MTBI SIGNS AND SYMPTOMS

Loss of consciousness
Amnesia
Balance problems
Memory and concentration difficulties
Headache
Ringing in ears
Nausea

BOX 7-4 CRITICAL MTBI INJURY SIGNS

SIGNS REQUIRING IMMEDIATE REFERRAL TO NEAREST EMERGENCY DEPARTMENT

Deterioration of neurologic function
Decreasing level of consciousness
Decreased or irregular respirations
Decreased or irregular pulse
Unequal, dilated, or unreactive pupils
Spine or skull fracture; bleeding
Mental status changes
Seizure activity

SIGNS REQUIRING REFERRAL ON THE DAY OF INJURY

Loss of consciousness on the field
Amnesia lasting longer than 15 minutes
Increase in blood pressure
Cranial nerve deficits
Vomiting
Motor, sensory, balance, or cranial nerve deficits subsequent to initial field evaluation
Postconcussive symptoms that worsen
Symptoms at end of game

If an athlete has sustained a concussion, the National Athletic Trainers' Association guidelines should be followed.[22] If the athlete meets any of the criteria listed in Box 7-4, immediately refer the athlete to a local emergency department. A secondary assessment may be performed, including evaluation for any potential eye injuries, once the primary survey for a serious or life-threatening injury has been completed.

Blunt Trauma

Most sports-related ocular injuries in the United States happen in baseball and basketball games. Getting hit by an errant elbow in a basketball game or by a foul ball in baseball can cause a blunt trauma injury (Fig. 7-1). When evaluating the athlete after a blunt trauma, the sports medicine professional must assess the following regarding the eye: Is the lid swollen shut? Is blood present inside the eye? Is the cornea white or hazy? Is the pupil irregularly shaped, fixed, dilated, or constricted? Is the athlete experiencing problems with vision (e.g., seeing stars, floaters, distortion)? If the athlete has any of these signs or symptoms, apply a cold compress and immediately refer the athlete to an eye care professional. If eye pain is the only symptom, the injury sustained usually is not emergent. If an immediate referral is not required, have the athlete apply ice for 15- to 20-minute periods during the first 24 hours after injury. The athlete should be referred to an eye care professional within 24 to 36 hours after the event (Table 7-1). Athletes who have sustained a blunt trauma injury should have a dilated fundus examination performed by an eye care professional within 96 hours.

Foreign Object

Sliding into a base head first in baseball is one example of how an athlete can sustain a foreign object eye injury. Foreign objects can be of great nuisance, causing pain and irritation,

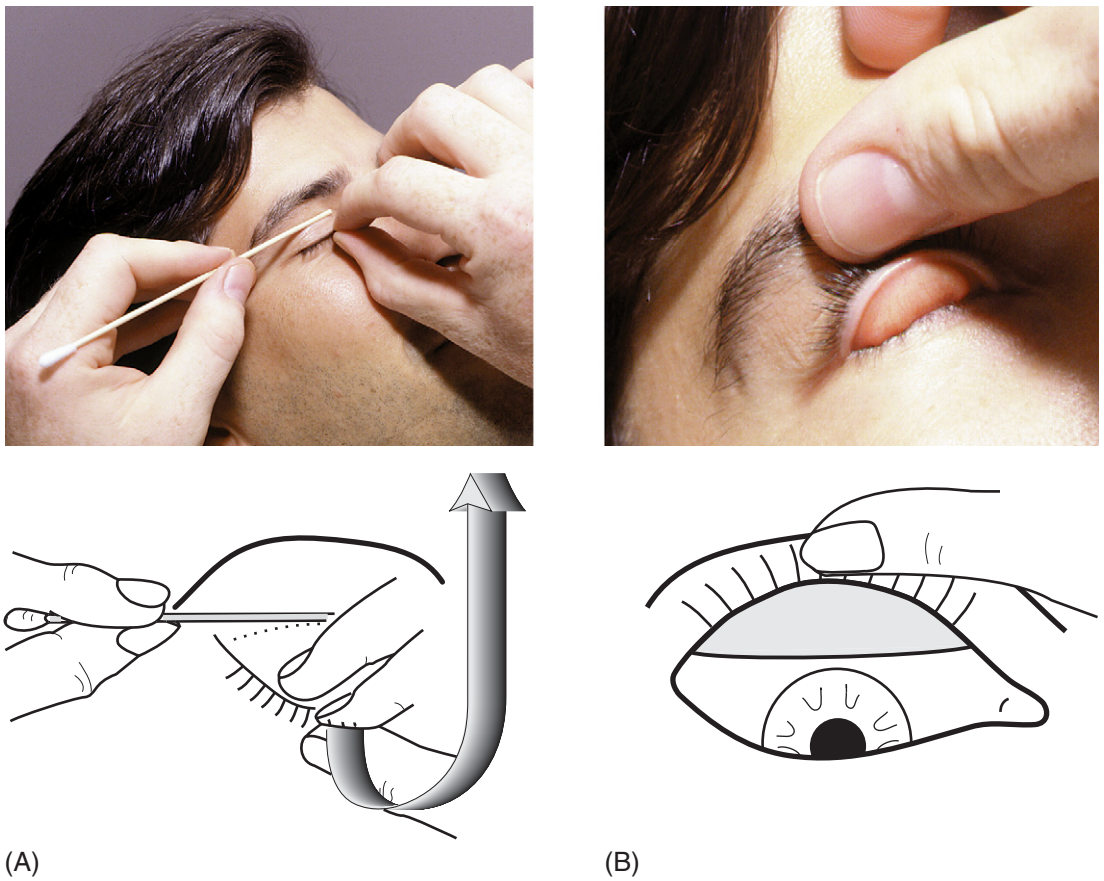
Figure 7-1. Right orbital floor blowout fracture seen with blunt trauma. **A,** Mild bruising, superficial laceration, and dilated pupil after fundus examination. **B,** Restricted elevation. **C,** Mild enophthalmos. (Reprinted from Kanski JJ: *Clinical ophthalmology,* ed 5, Boston, 2003, Butterworth Heinemann.)

TABLE 7-1 **Treatment of Sports-Related Ocular Emergencies**

Emergency Situation	Treatment
FOREIGN OBJECT IN EYE/EYE PAIN	
Visible object, not embedded	Lift object gently with tissue or cotton moistened with sterile eye solution. If solution is not available, use water.
Object not visible	Gently grasp lashes of upper lid and pull lid forward and down. Allow tears to wash out foreign body.
Visible object that cannot be removed	See eye care professional the same day.
Possible penetration of the globe of the eye or surrounding tissue by the object	Do not attempt to remove object; see eye care professional immediately.
Blood seen in the eye	See eye care professional immediately.
Object possibly trapped behind the upper lid	See eye care professional immediately.
Vision problems	See eye care professional immediately.
Eye pain	See eye care professional the same day.
BLUNT TRAUMA	
Patient should have a dilated fundus examination performed by an eye care professional within 96 hours of the event because serious internal eye injuries may have occurred. Apply cold compress for the first 24 hours unless one of the signs below is present. If no improvement occurs, see an eye care professional within 24 to 36 hours of the traumatic event.	
Lid swollen shut	See eye care professional immediately.
Blood inside the eye	See eye care professional immediately.
Cornea (front of the eye) white or hazy	See eye care professional immediately.
Pupil irregularly shaped, fixed, dilated, or constricted	See eye care professional immediately.
Problem with vision (e.g., stars, floaters, distortion)	See eye care professional immediately.
Eye pain	See eye care professional the same day.
Superficial injury to eyelid	Gently apply direct pressure to stop bleeding. Cleanse wound and apply sterile dressing taped in place or apply a bandage encircling head. See eye care professional immediately.
BURNS	
In the event of a chemical burn, do not attempt to neutralize the acid or alkali. Do not use an eye cup. Do not bandage the eye. When irrigating, ensure that the chemical does not wash into the other eye. If sterile eye solution is not available, use water.	
Ultraviolet burn (most commonly occurs in water and snow sports)	See eye care professional the same day.
Chemical is a strong base (alkali; e.g., drain opener, see cleaner, lime, cement, plaster)	Irrigate 30 minutes with sterile eye solution and lids forced open. See eye care professional immediately.
Chemical is a strong acid (e.g., battery acid)	Irrigate at least 15 minutes with sterile eye solution and lids forced open. See eye care professional immediately.
Chemical is a mild acid or base (e.g., pool chlorine, bleach, gasoline)	Irrigate at least 15 minutes with sterile eye solution and lids forced open. See eye care professional the same day.

as well as costing the athlete valuable practice or game time. Tearing by the athlete may help remove the object. If a foreign object injury is suspected and the athlete has been unable to remove the object on his or her own, the sports medicine professional may be able to assist with the removal. If an object is visible (and not embedded) then lift the object gently with tissue or cotton moistened with sterile eye solution (or water if solution is not available). If the object cannot be seen the eyelid must be everted (Fig. 7-2). Allow tears to wash out the foreign body.

If the object is difficult to remove, if the athlete has vision problems or blood in the eye, or if the foreign object has penetrated the globe or surrounding tissue, immediately refer the patient to an eye care professional (see Table 7-1).



(A) (B)

Figure 7-2. Steps to evert the upper eyelid. **A,** Ask the athlete to look down while keeping his or her eyes open. Grab the eyelash and the tarsal plate close to the edge of the eyelid and gently pull forward and down. The eyelid should not be pulled up or out *(top)*. Place a cotton-tipped applicator or lid evertor just above the tarsal plate of the eyelid. While still holding the eyelashes, evert the eyelid over the applicator *(bottom)*. **B,** The eye can then be examined with the eyelid held against the superior bony ridge of the orbit *(top)*. Instruct the athlete to look upward and blink. This will return the lid to its normal position *(bottom)*. (Reprinted from Palay DA, Krachmer JH: *Primary care ophthalmology*, ed 2, St Louis, 2005, Mosby.)

Superficial Injury to the Eyelid

In the case of a superficial injury to the eyelid, gently apply direct pressure to stop the bleeding. Cleanse the wound and apply a sterile dressing taped in place or a bandage encircling the head. Refer the athlete to an eye care professional for follow-up care of the injury.

Burns

In the event of a chemical burn, do not attempt to neutralize acids or alkalis. In addition, do not use an eyecup or bandage the eye. Chemical burns are initially treated by irrigating the eye for 30 minutes with sterile eye solution or water while the lids are kept opened, making sure the chemical does not wash into the other eye (see Table 7-1). A burn caused by a strong base (e.g., drain cleaner, lime) or acid (e.g., battery acid) is treated by irrigating the eye for 30 minutes with sterile eye solution while the lids are kept opened. The athlete should also be immediately referred to an eye care professional.

Ultraviolet burns occur most often in outdoor water or snow sports. Although sports medicine professionals are not traditionally present in these venues, the athlete should be referred to an eye care professional the day the injury occurs.

Recognition of Specific Eye and Facial Injuries

Facial Fractures

Trauma to the head and face can result in severe, emergent injuries. The sports medicine specialist must be able to identify signs consistent with a facial fracture and immediately remove the athlete from sport. Failure to do so may lead to further injury, including damage to the eye.

As with any head trauma, the patient should immediately be evaluated for potentially life-threatening injuries. Life-threatening injuries take precedence over all other injuries. Once the injuries have been determined to be non–life-threatening, the sports medicine specialist should rule out the presence of an MTBI.

During the secondary survey the sports medicine professional collects information from the athlete regarding symptoms, determines the mechanism of injury, examines the athlete, makes an assessment, treats, and makes the appropriate referral.

If a fracture is suspected, the athlete should be removed from play immediately. Failure to do so may lead to further injury, including damaging the eye. Immediate treatment should include gentle application of a cold compress or ice pack to the injured region to control pain and swelling. If a nosebleed accompanies a fracture, apply digital pressure to control the bleeding. All suspected fractures must be referred to an emergency department for immediate medical attention.

Nasal Fractures

The nose is the most frequently fractured facial bone.[23] These fractures occur during collision or fighting sports. An errant elbow during a basketball rebound or a punch thrown during a boxing match can cause a nasal fracture. As many as 15% of nasal fractures are recurring, plaguing the athlete and potentially leading to functional breathing difficulties and changes in cosmetic appearance.[23] Nasal fractures usually occur from either a lateral or an anteriorly directed force.[23,24]

An athlete with a possible nasal fracture will have the following signs: epistaxis, swelling, crepitus and mobility of the nasal bones, bruising around the eyes, and deformity.[23,24] Immediate management by the athletic trainer should include controlling the nosebleed with digital pressure to the anterior nose and applying ice to decrease pain and swelling. Nasal fractures will likely be obvious and should immediately be referred to a medical doctor. Any athlete returning to contact sports after a nasal injury should use a protective facial device to reduce the risk of reinjury.

Orbital Fractures

The frontal, zygomatic, nasal, and maxilla bones form the orbital rim. This bony orbit houses and protects the eye. The orbit helps spare the eye from injury from blows caused by large objects such as a basketball. Impact from a smaller object, such as a baseball or an elbow, could potentially fracture any region of the orbital rim. Although a fracture can occur anywhere along the orbital rim, fractures to the inferior rim are the most common (Fig. 7-3).[23] Orbital fractures are classified as either internal (orbital wall) or external (orbital rim).[25,26] A blowout fracture and medial wall fracture of the orbit are examples of an internal fracture.[25] External fractures occur at the orbital rim superiorly and laterally.[25]

An external or orbital rim fracture is usually caused by a direct blow[27,28]; the internal or orbital wall fracture is caused by trauma to the eye.[26] When an object, such as a baseball, strikes the eye, the eye deforms and a subsequent increase in intraorbital pressure may occur. An increase in pressure may lead to fracturing of the inferior orbit or orbital floor. This fracture, known as a blowout fracture, can entrap the inferior rectus muscle, preventing concentric gaze, and result in double vision (see Fig. 7-1). The athlete will report pain at the site of injury and with movement of the eye. Visual inspection reveals hyphema, swelling, numbness of the ipsilateral cheek, a protruding or a sunken eye, vertical dystopia, and periorbital hematoma.[23,24,29]

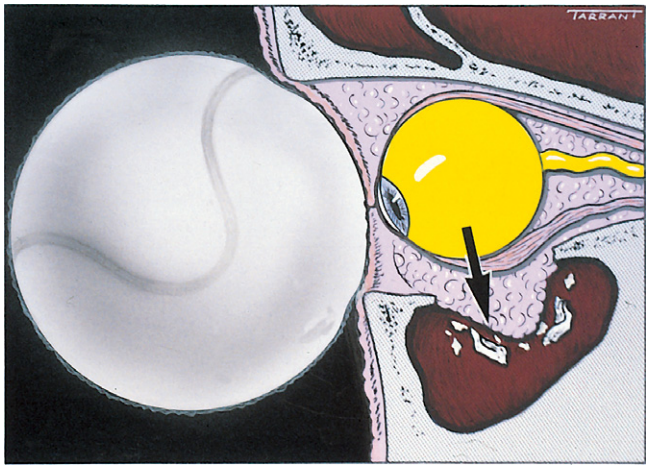


Figure 7-3. Mechanism of an orbital floor blowout fracture. (Reprinted from Kanski JJ: *Clinical ophthalmology*, ed 5, Boston, 2003, Butterworth-Heinemann.)

An athlete presenting with signs consistent with a blowout fracture should have a sterile eye pad placed over the eye to prevent him or her from looking around. The athlete may require bilateral eye pads to further reduce the chance of eye movement. The use of ice will help with pain modulation while the athlete is transferred to the emergency department.

A retrospective review of National Football League players found the most common signs and symptoms experienced immediately after an orbital fracture included decreased visual acuity, decreased eye movements, hyphema, and infraorbital numbness.[26] The mechanism of injury was either a digital poke or a blunt facial trauma.[26] To highlight the seriousness of orbital fractures, 15 of the 19 cases reviewed required surgical reconstruction.[26] Two of the football players were unable to return to football because of residual visual impairment.[26]

Protective eyewear or a protective facial device should be used when returning to sport after an eye injury. Many injuries of this type can be prevented by appropriate sport-specific protective eyewear. Any athlete who sustains a significant blow to the bridge of the nose also should refrain from blowing the nose until normal eye movements are restored. If an inferior orbital fracture has occurred, blowing the nose may cause the maxillary sinus to enter the orbit.

Zygomatic Fractures

A fracture of the zygomatic bone usually occurs from a powerful force directed at the cheek or from a fall.[24] Signs of a possible zygomatic bone fracture include epistaxis, periorbital ecchymosis, numbness about the cheek, enophthalmos, restriction of upward gaze and diplopia, subconjunctival hemorrhage, a depressed cheekbone, and an inability to open the mouth.[23,24] Concomitant injury to the infraorbital nerve will cause hypesthesia or anesthesia of the ipsilateral upper lip, lower eyelid, lateral nose, and medial cheek.[24] Palpation of the area often reveals a bony discrepancy or step-off deformity. If a fracture is suspected, apply ice to control edema and immediately refer the patient to a physician.

As with other fractures, healing will take a minimum of 6 to 8 weeks. The athlete should wear protective face equipment or eyewear when returning to sport.[23]

Frontal Bone Fracture

A frontal bone fracture can occur from a severe blow to the supraorbital region. An example of a potential mechanism for this type of injury is two heads colliding during a soccer match.[30] A visible or palpable depression superior to the frontal sinus should cue the sports medicine specialist to a possible fracture.[30] Crepitus or depression in the frontal sinus may be noted, as well as numbness in the supraorbital region.[29] Immediate management by a physician is necessary.

Eye Trauma

Blunt trauma to the eye can result in minor to severe injuries. Athletes most often at risk for blunt trauma injuries play collision team sports or sports involving projectiles moving at high velocities. For example, basketball players may sustain blunt trauma to the eye while playing in the key. With the physical play that occurs in the post, both offensive and defensive players are susceptible to a finger poke in the eye or an errant elbow striking the orbit. Baseball players and those playing racquet sports are susceptible to direct trauma caused by fast-moving balls. Even balls larger than the bony orbit can cause significant injury. Laboratory experiments confirm that a soccer ball can deform on impact with the face, creating a "knuckle" of the ball that can enter the orbit and strike the globe (Fig. 7-4).[31,32]

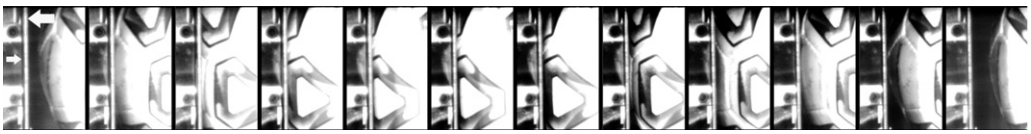


Figure 7-4. Soccer ball impact on an artificial orbit. The orbit (anterior plane, *small arrow*) is penetrated 8.1 mm by the 18 m/s (40 mph) size 3 soccer ball, which compresses on the steel plate surrounding the orbital fixture *(large arrow)*. The compression phase of the ball, which drives a small knuckle of the ball into the orbit (1 to 4 ms), is easily seen by studying the dark triangles on the ball. During rebound, the slow orbital exit of the ball compared with the rebound from the plate (5 to 10 ms) produces a secondary suction effect on the orbital contents. (Courtesy Paul Vinger, MD, Concord, MA.)

A secondary suction effect is produced on the eye during the rebound. This suctioning potentially explains why eye injuries sustained in soccer are often more severe than other sports-related eye injuries.[31,32]

Corneal Injuries

Corneal abrasions frequently occur in sports such as basketball, in which a finger or fingernail can scratch the eye. The cornea also may be abraded when an athlete attempts to remove or rub away a foreign object. Common signs of an abraded cornea include watering of the eye, pain, and photophobia.[16] Athletes may report pain with each blink of the eyelid.

Immediate management by the sports medicine specialist includes removing any readily visible foreign bodies (see Table 7-1), covering or patching the eye, instructing the athlete not to rub the eye, and referring the athlete to an eye care specialist. The use of fluorescein dye and illumination of the eye are necessary to ascertain the extent of damage. Primary providers usually handle small abrasions, whereas larger abrasions require referral to an eye care specialist.[16]

A less-common corneal injury is an alkali burn caused by contact with chalk line markings. The eye should be irrigated with sterile saline or water for at least 20 minutes and the athlete then referred for medical attention (see Table 7-1).

Removing Contact Lenses. Many individuals forgo the use of glasses and instead use contact lenses to correct visual limitations. Contact lenses should never be used as a form of protective eyewear. The National Collegiate Athletic Association recommends the use of eye protection for all athletes participating in collision and contact sports who use corrective lenses.[33] Nonetheless, many will go without appropriate protective wear when wearing contact lenses. Contact lenses should be removed from the eye in the case of minor injuries such as a corneal abrasion.[16] In cases in which the eye exhibits serious surface trauma, the contact lens should be left in place until the eye can be more thoroughly evaluated by a physician or an eye care specialist.

Hyphema

A hyphema is a collection of blood within the anterior chamber of the eye (Fig. 7-5). A hyphema can be caused by a tear of the iris, stroma, or ciliary body.[25,34] A hyphema occurs in more than 25% of all sport-related eye injuries. Signs of a hyphema include a reddish tinge in the anterior chamber initially after the injury. Visual acuity may be affected with a large bleed. Within a few hours the blood will settle in the inferior eye or fill the

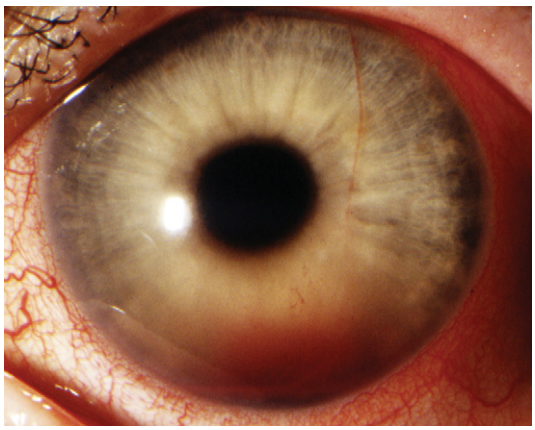


Figure 7-5. Traumatic hyphema (magnified view) with blood pooled in lower portion of the anterior chamber. (Reprinted from Palay DA, Krachmer JH: *Primary care ophthalmology*, ed 2, St Louis, 2005, Mosby.)

entire chamber.[35] A hyphema is a serious eye injury that requires immediate medical management. Continued bleeding may lead to uncontrollable glaucoma or staining of the cornea.[25]

The sports medicine professional should recognize the signs of a hyphema and immediately refer the athlete to an optometrist or ophthalmologist.[36] The patient should be transported to the emergency department in a sitting or upright position.[16] The athletic trainer should advise the family to avoid giving aspirin or other antiinflammatory medication, which may increase the bleeding.

Rupture of the Globe

Blunt trauma to the eye by a small object such as a racquetball can create pressure intense enough to rupture the globe. In this type of injury, the athlete complains of double vision (diplopia), decreased visual acuity, and intense pain.[35] Signs of a ruptured globe include leakage around the orbit and irregular pupils.[35] Immediately refer the athlete to the emergency department.

Retinal Injury

Hemorrhaging of the retina can occur as a result of a direct blow to the eye, blow or trauma to the back of the head, or a Valsalva maneuver when weightlifting. Peripheral hemorrhaging will likely be asymptomatic, whereas central hemorrhaging causes blurred vision. Athletes who have sustained a concussion should be evaluated for retinal hemorrhaging.

Orbital Hemorrhage

An orbital hemorrhage may present with proptosis (eyeball bulging) and decreased extraocular motility.[37] Furthermore, visual loss may occur as a result of a compromised vascular supply to the retina and optic nerve.[37] Immediate management includes application of an ice pack and referral to an eye care professional.

Periorbital Contusion

A "black eye" occurs from a rupturing of small blood vessels in the subcutaneous tissue of the eyelid.[26] The presence of a black eye is a cue to evaluate the eye and face further, with subsequent referral of the patient to an eye care professional.

Detached Retina

Retinal detachment is a painless injury caused by blunt trauma to the eye.[35] Individuals with myopia are predisposed to retinal detachments.[26] The athlete may describe the symptoms as "a curtain falling in front of the eye" or as lights "flashing on and off."[26,35] The athlete may also see black specks floating across the eye. A detached retina is a serious eye injury requiring immediate referral to a physician. The athletic trainer should use a protective eye shield or the base of a paper cup to cover the eye.

Conjunctivitis

An irritant such as dirt, a contact lens, or dust may lead to inflammation of the conjunctiva. The athlete will report pain, swelling of the eyelids, tearing, some discharge, photophobia, and possibly altered vision. Removal of the irritant should rapidly improve symptoms.[37]

Conjunctivitis can also be caused by viral or bacterial infections, chemicals, or allergies.[35] Athletes who experience eyelid swelling or discharge should be treated by an eye care specialist.

Subconjunctival Hemorrhage

A subconjunctival hemorrhage (SH) (Fig. 7-6) is a rupturing of tiny blood vessels within the conjunctiva. This type of hemorrhaging can occur from benign activities such as sneezing or coughing or by a traumatic event such as a blow to the eye. An SH often accompanies a contusion or corneal abrasion. An SH will present as a bright red region within the white conjunctiva. The "red eye" may make this form of injury appear serious in nature, but in many cases this form of hemorrhage will not require medical attention. If visual impairments,

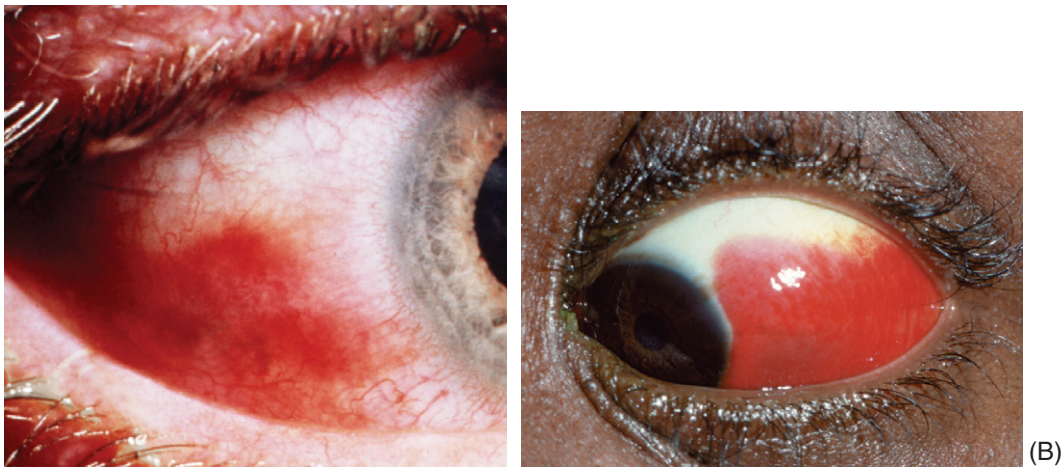


Figure 7-6. Examples of subconjunctival hemorrhages. (Reprinted from Palay DA, Krachmer JH: *Primary care ophthalmology*, ed 2, St Louis, 2005, Mosby.)

photophobia, or extensive hemorrhaging are apparent, then the athlete should be referred to an eye care specialist.

Lacerations

Athletic trainers routinely manage lacerations on most regions of the athlete's body. If an athlete sustains a laceration during a game or practice, he or she typically is able to return to sport after first-aid management by the athletic trainer. Lacerations to the eye (Fig. 7-7), on the other hand, require special care and evaluation. Special circumstances do exist in which an athlete may be treated and sutured immediately after sustaining a facial or eye laceration. For example, boxers have a team to suture cuts and lacerations during a bout if the need arises.

If a corneal abrasion is suspected or the pupil appears tear shaped, the athlete should immediately be referred to an ophthalmologist or optometrist. Place a protective pad or shield over the eye. Covering both eyes may be necessary to reduce bilateral eye movement. If the laceration crosses the margin of the lid, suturing by an eye expert is necessary. Lid deformities (ectropion) from scarring may result if the athlete does not receive proper care.

Laceration of the upper or lower lacrimal canaliculi (tear duct) also requires suturing by an ophthalmologist. If the tear duct is not repaired, the patient may have permanent epiphora (watering of the eye).

Mild lacerations sustained at a competition away from the athlete's hometown may wait to receive medical treatment until the athlete returns home.[26] The laceration should be bandaged and cleaned, with antibiotic coverage.

Lens Dislocation

A sign that the lens has become dislocated (Fig. 7-8) is a quivering of the iris when the athlete moves the eye. Immediately refer the athlete to an eye care practitioner or emergency department.

Nontraumatic Eye Injuries or Conditions

The athletic trainer may be called on to examine a nontraumatic eye injury. Many individuals may not seek medical attention if not for the evaluation performed by the athletic trainer and the subsequent referral to an eye care specialist.

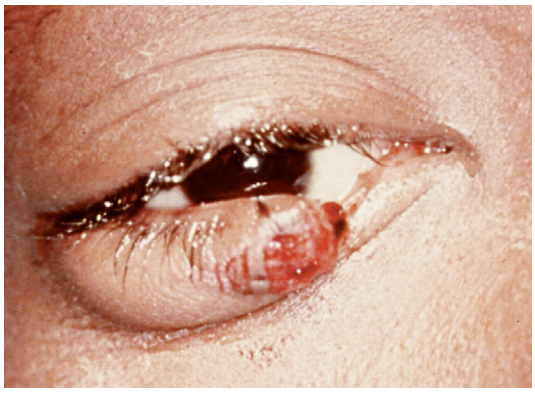


Figure 7-7. Eyelid margin laceration. (Reprinted from Palay DA, Krachmer JH: *Primary care ophthalmology*, ed 2, St Louis, 2005, Mosby.)

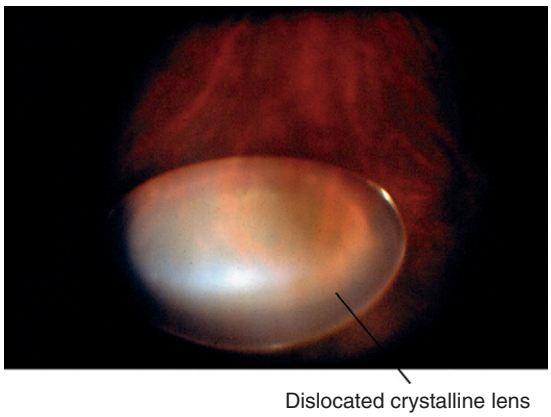


Figure 7-8. Dislocated crystalline lens resting on the retina. (From Kaiser PK, Friedman, NJ: *The Massachusetts Eye and Ear Infirmary illustrated manual of ophthalmology*, ed 2, Philadelphia, 2004, WB Saunders.)

Keratitis. Keratitis is an infection or inflammation of the cornea. Keratitis frequently is caused by an outbreak of herpes simplex infection. A lid laceration may also lead to exposure keratitis.[25] The athlete will complain of a foreign body sensation, decreased visual acuity, photophobia (intolerance to light), and tearing. The sports medicine specialist may notice clear discharge from the eye.

Stye. The small glands or the hair follicles around the eyelashes may become infected by a staphylococcal organism and result in a stye.[35] A stye firsts presents as erythematic. Within a few days it develops into a painful pustule (Fig. 7-9).[35] Refer the athlete for treatment to an eye care specialist.

Eye Injuries from Nontraditional Sports. Modern athletes often participate in a variety of sports. During the past century, and even the past decade, the world has witnessed the advent of many new sports (e.g., extreme sports such as bungee jumping) or new twists on old favorites (e.g., beach volleyball). Athletes also often seek out alternative sports (e.g., martial arts) to

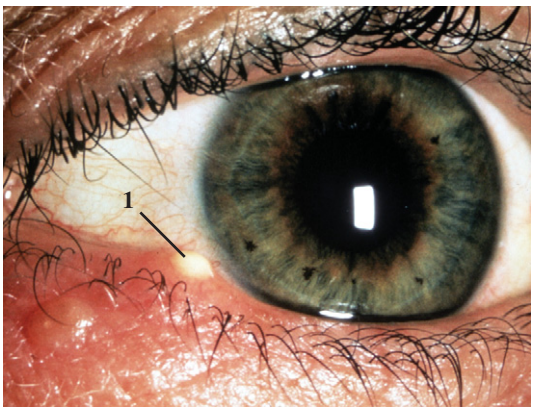


Figure 7-9. A lower lid stye *(1)*. (Reprinted from Palay DA, Krachmer JH: *Primary care ophthalmology*, ed 2, St Louis, 2005, Mosby.)

supplement current strength and conditioning programs. Eye injuries may also occur in other nonsport recreational pursuits (e.g., paintball).[38]

Although the sports medicine professional may not be directly involved in the immediate management of any sustained injuries, he or she should recognize that athletes may participate in these sports despite requests from coaches otherwise.

The athletic trainer can serve two important roles to help reduce the risk of eye injuries from nontraditional sports. First, the trainer should work to foster a trusting relationship with the athletes he or she serves. If the athlete believes that he or she can openly share and consult with the athletic trainer without the potential for negative repercussions, then the trainer will be able to educate the athlete about risk behaviors and risk-reduction strategies. Many eye injuries can be prevented if protective eyewear is worn.[38] The athletic trainer often serves as the initial medical team member and sometimes the only health care provider with whom the athlete has contact. Recognition and appropriate referral comprise the second role the athletic trainer serves.

CLINICAL MANAGEMENT OF SPORTS OCULAR INJURIES

The eye care practitioner may see athletes for initial triage and management of sports and recreational eye injuries and therefore follow some of the recommendations previously described. Many reports have been published regarding the incidence of eye injuries occurring during sports and recreational activities.[1,4,7,39-67] The athlete may not present immediately for health or vision care if an injury seems treatable with basic first-aid measures, so the practitioner may also see the results of long-standing trauma. In any case, the eye care practitioner has a legal and ethical responsibility to provide a thorough evaluation of the eye and orbit to determine the extent of any damage. A thorough, methodical evaluation of an eye injury facilitates appropriate management recommendations. Systematic approaches for assessment of ocular sports injuries have been summarized in the literature and include assessment of visual acuity, ocular motilities, pupillary function, external adnexa, intraocular pressure, and anterior and posterior segment structures.[68,69]

The practitioner should take a comprehensive case history to determine the nature of the injury and elicit any long-standing conditions that may be present. A detailed account of symptoms should be noted as well as a complete description of how the injury was treated after the incident. The ultimate goal of the patient history is to raise the index of suspicion for eye and vision effects from an injury. Although a thorough eye health evaluation should be performed on all athletes with a history of ocular trauma, an effective case history can be particularly valuable for selecting appropriate assessment procedures for the symptoms reported and type of injury. For example, a basketball player who was struck with considerable force by an opponent's elbow presents with the potential for eyelid damage, hemorrhaging and damage to the orbital contents, orbital bone fractures, corneal trauma, angle recession, hyphema, uveal structure damage, vitreous detachment, and retinal and choroidal ruptures. If the athlete reports sudden onset of diplopia after the injury, the practitioner is further alerted to assess extraocular muscle function and determine whether orbital bone fractures are present.

Before proceeding with any other evaluation procedures, an assessment of visual acuity should be made. Visual acuity information is useful for differential diagnosis and management decisions, but it may also be crucial for medicolegal issues.[70] Practitioners commonly use an anterior-to-posterior approach to ocular health assessment; however, this chapter considers

the types of eye injuries that commonly occur in sports. A trauma typically is classified as either a closed-globe or open-globe injury, and the Birmingham Eye Trauma Terminology System (BETTS) was developed to standardize descriptions of damage.[69] This chapter considers the cause of the injury—blunt trauma, penetrating trauma, or chemical trauma—following brief descriptions of common eye injury mechanisms by sport.

The U.S. Consumer Product Safety Commission created the National Electronic Injury Surveillance system (NEISS) to monitor the incidence of injuries from consumer products, including eye injuries. Currently 100 emergency departments at hospitals of various sizes and geographic locations, including children's hospitals, participate in the reporting system. The injury rate data from these emergency departments are extrapolated to generate estimates of eye injuries by cause, and the online database is searchable by a variety of factors.[71] Table 7-2 shows the data retrieved for 2004 by sport category. An estimated 15,358 sports- and recreation-related eye injuries occurred in the United States in 2004, although this represents only injuries serious enough to warrant attention at a hospital emergency department. The incidence of eye injuries incurred during sports and recreational activities is much greater than the NEISS data estimate, because many athletes seek care outside hospitals, if care is sought at all.[62]

Sports

Baseball and Softball

There is a high incidence of reported eye injuries from baseballs in the United States, and baseball has been reported as the leading cause of sports-related eye injuries in children.[7,39,58,59,65] The hardness of the baseball, combined with the forces at which it is thrown and hit, produce potentially devastating damage to the eye and orbit.[36] When the baseball is rotating at a high rate, additional tractional forces can be transferred to the ocular tissues by the raised seam on the ball.[64] Similar patterns of eye injury can be found in cricket.[64,72,73] The incidence of eye injuries with softballs is not well known.[65] The softness of

TABLE 7-2 **Summary of NEISS Data on Sports and Recreational Eye Injury Reports (2004)**

Sport Category	Injury Reports from Participating Emergency Departments	Estimate for all Emergency Departments (if Available)
Ball sports	20	
Baseball	108	3,137
Basketball	212	6,114
Combatives	12	
Football	72	1,768
Golf	21	
Hockey	17	
Racket sports	60	
Soccer	53	1,822
Water/pool sports	54	2,076
Total	413	15,358

the ball reduces the risk of injury, but the forces of a thrown or hit ball are significant enough to cause substantial damage to the eye.[74] The risk of ocular foreign body also exists from the playing field environment.

Basketball

Basketball accounts for a large percentage of eye injuries in sport because of the intense contact encountered during play[21,75,76] and the large number of people who play the game. It has become the most common sport to cause an eye injury in the United States.* Common injuries include eyelid abrasions or lacerations, orbital contusions and fractures, and corneal abrasions.[78] Eye injuries are rarely caused by the ball, but rather by fingers or elbows.

Boxing

Ocular trauma is a common result of boxing, and the extensive nature of ocular injuries has been well documented in the literature.[79-91] Most of the ocular injuries are the result of contusion forces on the orbital and periorbital bones and ocular contents. Damage to the lids and soft tissues is common, and more extensive damage to internal ocular structures and extraocular muscles can occur. The thumb is capable of transmitting the largest force to the globe and therefore can result in the most significant damage to the eye.[65] Although some studies have suggested that the prevalence of severe ocular trauma is lower than others have reported,[90,91] most studies confirm the serious nature of ocular injuries in boxing.[79-89]

Fishing

Fishing is an activity pursued by many, and injury is periodically expected. Although eye injuries do not occur with high frequency, the reported cases are often quite serious.[92-99] The fish hook presents a challenge to remove without increasing tissue damage, and several removal methods have been discussed.[93-97] The anterior segment structures are most commonly damaged by fish hook penetration, including the cornea, iris, and lens tissues. Bystanders are also at risk for injuries caused by whipped pole tips, lures, weights, and fishing spears.[98,99] The most common injuries include corneal laceration, hyphema, and globe ruptures.[98]

Football

The incidence of face and eye injuries in football was dramatically reduced with the mandate for faceguards. However, standard faceguards offer incomplete protection for the eyes; specifically, a finger can enter with enough force to cause significant ocular trauma.[100,101] The risk of ocular foreign body from the playing field environment also exists.

Golf

The golf ball can be struck with considerable force, and this hard sphere can cause considerable ocular damage because it fits inside the bony orbit. Similarly, the golf club head is quite hard and can directly transmit a large amount of force to the globe. Golf-related ocular injuries are relatively rare; however, the results are often quite severe.[65,102-108] Blunt trauma from a golf ball or golf club head that results in a ruptured globe typically has a poor prognosis, and the rate of enucleation is high.[104,106,108] A closed-globe blunt trauma has a better visual outcome potential than an open-globe trauma.

*References 7, 39, 58, 59, 65, 77.

Hockey

Because of the mandate for face protection at all levels of ice hockey except the National Hockey League, eye injuries in hockey have been virtually eliminated. Eye injuries are typically incurred only during unsupervised play, from improper use of face protection, or in the National Hockey League.[18,65,109] The most common cause of eye injury is from the hockey stick, followed by the puck or opponent.[18,65,109-116] The tip of the hockey stick can transmit considerable force to the ocular tissues because it fits inside the orbital rim, and severe blunt trauma can result. Injuries from the puck and the aggressive play of opponents can also cause considerable damage. A similar risk profile exists for other forms of hockey, such as field hockey, floor hockey, and street hockey.

Lacrosse

Lacrosse has risks for eye injury that are similar to hockey, in which the stick and ball present significant hazards. Men's lacrosse mandates head and face protector use, thereby minimizing the risk for ocular injury. Women's lacrosse did not mandate face protection until recently; the incidence and severity of eye injuries had been a contentious issue in the sport.[65,117-121] Aggressive stick play and ball-related accidents can cause extensive blunt trauma force to the ocular tissues.

Mountaineering

When mountaineers make ascents above approximately 3000 m, high-altitude retinopathy risk increases as climbers become more susceptible to acute mountain sickness. The decrease in atmospheric pressure for those unaccustomed to such heights can lead to observable tortuosity and increases in the diameter of retinal arteries and veins, as well as optic disc hyperemia.[122-129] A faster rate of ascent, a higher altitude reached, and a longer length of time at altitude typically will increase the incidence of retinal hemorrhage, retinal nerve fiber layer defects, and other retinal vasculature changes.[129] The coughing problems commonly experienced with high-altitude climbing and the physical exertion from carrying heavy loads have been suggested to play a role in triggering retinal hemorrhages in the compromised vasculature.[125] Most climbers do not notice any symptoms of altitude retinopathy, although the more severe vasculature problems can produce permanent vision loss.[126,129,130] Because the amount of ultraviolet radiation markedly increases at higher elevations, and snow reflects 85% of the ultraviolet radiation, additional risk of photokeratitis exists when appropriate filters are not used.[131]

Racquet Sports

A significant portion of sports-related eye injuries are caused by racquet sports.* Racquet sports include badminton, handball, racquetball, squash, and tennis. The ball or shuttlecock is hit with tremendous force and can travel at dramatic speeds (see Table 6-4). Even though the balls used in some racquet sports are larger than the average orbital opening, the compression forces can push the ball deep inside the orbit.[65] The shuttlecock has a diameter of 0.75 inches and easily penetrates the orbital opening. The ocular trauma usually results from severe blunt force trauma caused by the racquet or ball, including a high

*References 42, 47, 49, 59, 64, 65, 132.

prevalence of hyphema, traumatic glaucoma, commotio retinae, and retinal detachment.[65,132-141] In tennis and badminton, doubles play significantly increases the risk of eye injury because of the proximity of the doubles partner. The ocular damage may be increased with inappropriate eyewear (see Chapter 6). Many of the ocular injuries require in-hospital care, and the ocular damage may cause permanent vision changes.[133,134,136-138,140-142] The retinal detachments from squash injuries been reported to have a worse prognosis than other rhegmatogenous detachments.[141] The experience and expertise level of the athlete have not been shown to reduce the risk of eye injury during racquet sports.[136,139]

Scuba Diving

The increased ambient pressure encountered in scuba diving must be equalized by exhaling through the nose during descent to avoid mask barotrauma. The increased pressure of the mask pulls the eyes and surrounding tissues into the air space of the mask unless it is equalized, potentially causing hemorrhaging and edema in the ocular tissues.[65,143-148] Fortunately most mask barotrauma is self-resolving, and the only treatment is supportive (e.g., ice packs) with patient reassurance.

Decompression sickness (DCS) can result from surfacing too quickly, causing the rapid release of gas accumulated in the body's tissues during the period of high compression. Many neurologic ocular manifestations of DCS have been reported in the literature, including nystagmus, diplopia, visual field defects, cortical blindness, central retinal artery occlusion, and optic neuropathy. The ocular manifestations of DCS are successfully managed with recompression therapy and hyperbaric oxygen.

If a diver wears contact lenses, soft lenses are preferred.[149-151] Rigid lenses, particularly polymethylmethacrylate lenses, can cause corneal edema from nitrogen gas bubble formation under the lens during outgassing of decompression. If a diver has had an ophthalmic surgical procedure, Butler recommends minimal convalescent periods before clearing the patient for diving (Table 7-3).[147] The main risk involves infection from the rich microbial environment of water during wound healing. The increased pressure associated with diving does not pose a significant risk for patients with corneal or refractive surgery, glaucoma, or vitreoretinal disorders.[147]

Soccer

The soccer ball is responsible for most ocular trauma in soccer, although the incidence of eye injuries is relatively low.* Although the soccer ball is significantly larger than the orbital opening, a portion of the ball will deform and enter the orbit during contact with the high velocities at which the ball is kicked.[31,32] A study found that, although the soccer ball did not penetrate the orbital opening as deeply as smaller sports balls (e.g., baseballs, golf balls, tennis balls, squash balls), the ball remains inside the orbital space considerably longer than the other ball types.[32] An appreciable rebound effect also occurs after the initial compression phase that produces a suction distortion to the globe, potentially increasing the severity of the blunt force trauma (see Fig. 7-4). The predilection for retinal lesions in the superotemporal quadrant is proposed to be caused by the more exposed temporal retina when the compression forces expand the globe equatorially; the nose offers some protection from the forces transmitted to the nasal retina.[32]

*References 1, 31, 32, 49, 52, 152-154.

TABLE 7-3 **Recommended Minimum Convalescent Periods before Diving after Ophthalmic Surgery**

Procedure	Recommended Convalescent Period
ANTERIOR SEGMENT SURGERY	
Penetrating keratoplasty	6 months
Corneal laceration repair	6 months
Cataract surgery	
Noncorneal valve incisions	3 months
Corneal valve incisions	
Clear corneal	2 months
Scleral tunnel	1 month
Radial keratotomy	3 months
Astigmatic keratotomy	3 months
Glaucoma filtering surgery	2 months (relative contraindication)
Photorefractive keratectomy	2 weeks
Pterygium excision	2 weeks
Conjunctival surgery	2 weeks
Corneal suture removal	1 week
Argon laser trabeculoplasty or iridectomy	No wait necessary
YAG laser capsulotomy	No wait necessary
VITREORETINAL SURGERY	
Vitrectomy	2 months (contraindicated until intraocular gas absorbed)
Retinal detachment repair	2 months
Pneumatic retinopexy	2 months (contraindicated until intraocular gas absorbed)
Retinal cryopexy or laser photocoagulation for breaks	2 weeks
OCULOPLASTIC SURGERY	
Sutured wound	2 weeks
Skin graft or granulating wound	Until epithelialization is complete
Enucleation	2 weeks (contraindicated with hollow orbital implants)
STRABISMUS SURGERY	2 weeks

Reprinted from Butler FK: Diving and hyperbaric ophthalmology, *Surv Ophthalmol* 39:347, 1995.

Swimming and Water Sports

Swimming and water sports do not present a significant risk of eye injury. Swimming goggles can potentially cause a blunt trauma injury if they slip during removal or when cleared. The elastic band can cause the goggles to snap back and cause severe injuries, including globe ruptures.[65] Water polo presents a risk of blunt trauma from fingers, elbows, or the ball to the improperly protected eye. Other risks include infections in soft contact lens wearers who are

not adequately compliant with appropriate lens cleaning and pingueculae and pterygia in outdoor water sports (e.g., surfing, windsurfing, kiteboarding, kayaking).[65,155]

Paintball

War games with paintball guns present a tremendous risk for ocular injury when proper protection is not used. The paint pellet is shot with sufficient energy to cause severe eye trauma, including corneal lacerations, hyphema, traumatic cataract, and retinal pathology.[156-164]

Blunt Trauma

Most eye injuries reported from sports and recreational activities result from objects larger than the orbit, producing blunt trauma, and objects smaller than the orbit resulting in penetrating trauma.[64-67,70,165,166] Blunt trauma to the head can also result in damage to the visual pathway.[25,65] In cases in which only one eye is injured, the other eye should also be thoroughly assessed for either recent or long-standing damage.

Blunt trauma is produced by significant pressures exerted on the orbital contents. The ocular damage is usually produced by direct injury to the local site of the trauma (coup effects) or the forces transferred through the ocular tissues along the path of the shock waves (contrecoup effects).[70,167-169] Ocular damage may also result from the compression forces exerted when the orbital contents are compacted within the bony orbit.[64,70] In ocular compression injuries, the globe is compressed along the anterior-posterior direction and must compensate by expanding equatorially or rupture (Fig. 7-10). Each of these mechanisms is capable of causing significant harm to the delicate orbital bones and ocular tissues. Most blunt eye trauma is caused by a ball, stick, finger, or other object or body part during sports participation, as previously described. The examination should also determine whether any penetrating intraocular foreign body injury occurred that was not reported in the trauma history.

Eyelids

The eyelids should be assessed for any lacerations or limitation of lid movement or closure. Substantial lacerations typically require surgical repair, and a broad-spectrum

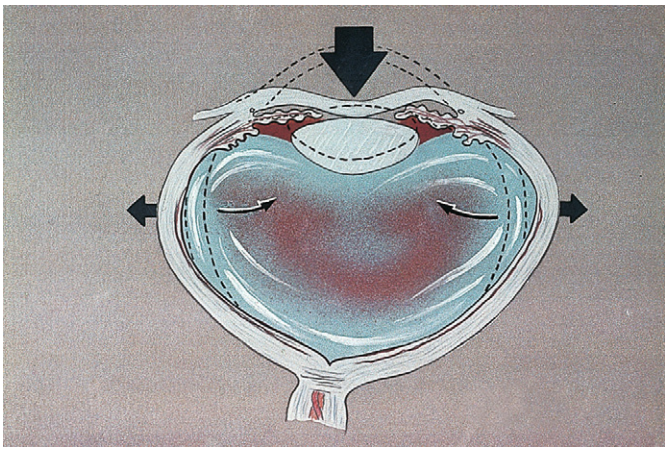


Figure 7-10. Mechanism of ocular damage by blunt trauma. (Reprinted from Kanski JJ: *Clinical ophthalmology*, ed 5, Boston, 2003, Butterworth-Heinemann.)

topical antibiotic should be applied to prevent secondary infection if possible. Incomplete lid closure may necessitate treatment with ocular lubricants to prevent exposure keratitis until surgical lid repair can be performed. The lids should be specifically assessed for damage to cranial nerves III and VII, the levator muscle, the orbicularis muscle, and the lacrimal system.[25,170] A referral to an oculoplastic specialist may be indicated when lid involvement is substantial.

Orbital Contents

The athlete may sustain orbital hemorrhaging, leading to ecchymosis, proptosis, and extraocular muscle abnormalities.[165,166] A simple black eye should be examined as if the eye had sustained serious trauma until proven otherwise.[67] Hematomas can have many ocular sequelae, necessitating a thorough internal health evaluation and assessment of intraocular pressure. Visual acuity, color vision, pupillary responses, and intraocular pressure should be carefully assessed. In addition, severe proptosis can compromise the function of the optic nerve and retinal vasculature, requiring rapid diagnosis to determine whether orbital decompression or corticosteroid treatment is necessary. Many orbital hemorrhages completely resolve with no direct treatment, but closely monitoring the athlete throughout the recovery period is prudent.

Any head trauma can result in direct damage to the extraocular muscles (EOMs) or cranial nerves III, IV, or VI. The practitioner needs to determine whether the muscle abnormality is caused by hemorrhage or edema around the muscle or direct damage such as a muscle tear or disinsertion. Orbital fractures may also entrap extraocular muscles and directly affect muscle function. These direct causes of muscle damage usually produce symptoms of pain, diplopia, and gaze restrictions.[25,170] If the damage has occurred to the cranial nerves, the patient will report the same symptom, but is less likely to report any pain. Cranial nerve damage is a sign of significant closed-head trauma or compression of an expanding intracranial hematoma and should immediately be treated.[67]

Differential diagnosis for concomitancy of EOM function is achieved with version testing, alternate cover testing in the diagnostic action fields, Hess-Lancaster test, red lens or Maddox rod testing in the diagnostic action fields, or the Park three-step test.[171-173] The diagnostic action fields are the gaze positions where the individual action of each EOM is isolated (Table 7-4). Passive and forced duction testing can help determine whether mechanical damage of the muscle(s) has occurred or whether the damage occurred in the innervation from the cranial nerves.[174,175] Management of EOM abnormalities includes monitoring for spontaneous resolution,

TABLE 7-4[171] **Diagnostic Action Fields of Extraocular Muscles**

Eye Position	Right Eye	Left Eye
Right gaze	Lateral rectus	Medial rectus
Left gaze	Medial rectus	Lateral rectus
25 degrees right gaze and up	Superior rectus	Inferior oblique
25 degrees left gaze and up	Inferior oblique	Superior rectus
25 degrees right gaze and down	Inferior rectus	Superior oblique
25 degrees left gaze and down	Superior oblique	Inferior rectus

prism prescriptions, occlusion (usually partial occlusion in the affected field), orthoptic vision therapy to assist recovery of muscle function, botulinum toxin therapy,[176-178] and surgical interventions.

Bone Structures

Blunt trauma to the bony orbit can cause external fractures to the orbital rim; however, the more fragile internal orbital walls are more prone to fractures.[25,64,165,166,170] Lang[179] was the first to postulate the mechanism for what would later be referred to as a *blowout fracture.*[180] The blunt trauma to the eye forces the globe back into the orbit, and the hydraulic pressure of the compressed globe can break through one or two orbital walls. The term *blowout fracture* is used to describe fractures of the internal orbital floor (separating the maxillary sinus) without fractures of the external orbital rim. The medial wall (lamina papyracea) separating the ethmoid sinus may also be fractured during a blowout fracture.[165,170] Medial wall fractures may also cause orbital emphysema from air forced into the orbit from the nasal sinuses (Fig. 7-11), most noticeable when blowing the nose or during a Valsalva maneuver. These fractures are confirmed by a computed tomographic scan or radiograph of the orbit (Fig. 7-12) and often produce pain, EOM restrictions, and eventual enophthalmos (see Fig. 7-1). Significant fractures necessitate surgical interventions to minimize enophthalmos and EOM restrictions.[165,170]

Jones[181] reported that one third of orbital blowout fractures are the result of sports activities, with soccer being the most common sport involved in the United Kingdom. Aggressive play was identified as the most common cause of the fractures, typically through high-energy blows by an opponent's fingers, fists, elbows, knees, or boots.

Conjunctival and Scleral Injuries

Fingers commonly cause damage to the conjunctival tissue in contact sports. A simple subconjunctival hemorrhage often is the sole result of such contact, and the condition self-resolves with no long-term consequences. However, determination of whether more extensive scleral lacerations or ruptures may be hidden by the blood and chemosis is important. Small scleral lacerations may be managed with a prophylactic broad-spectrum antibiotic ointment, whereas larger lacerations may require suturing.[166] Examination of the athlete should entail a thorough assessment of the internal structures that may also have sustained damage, including Seidel testing with fluorescein to determine whether a rupture or penetrating injury has occurred. Fluorescein leakage near the injury site indicates a rupture of penetrating wound,[182] and a surgical consultation is warranted. The limbus region and EOM insertion areas are most prone to scleral rupture,[70] and previous eye injuries or surgeries make the globe more vulnerable.[67]

Corneal Injuries

The cornea is a frequent site of damage from both blunt and penetrating or foreign body trauma. Injuries to the corneal epithelium are particularly painful because of the high concentration of sensory nerve innervation, leading to photophobia and reflexive tearing. Athletes participating in contact sports are at particular risk for finger injuries, and a fingernail can cause significant harm to the corneal tissues. The practitioner must therefore perform a careful evaluation of the layers of the cornea with a biomicroscope to determine the depth and extent of the damage. Fortunately epithelial wounds heal rather rapidly without sequelae

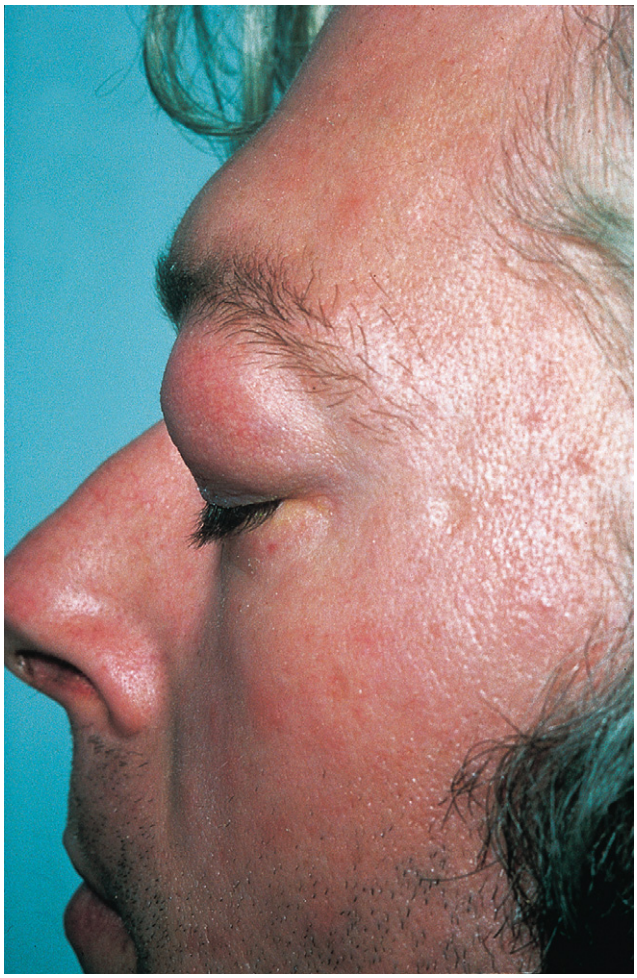


Figure 7-11. Subcutaneous emphysema in a patient with a medial orbital wall blowout fracture. (Reprinted from Kanski JJ: *Clinical ophthalmology*, ed 5, Boston, 2003, Butterworth-Heinemann.)

unless Bowman's layer has been involved. Injuries to Bowman's layer increase the incidence of residual scarring, which can affect visual clarity. Athletes whose corneal injuries involved vegetative matter should be carefully monitored for subsequent fungal infections. Corneal lacerations (Fig. 7-13) that are large and not self-sealing require protection with a Fox shield and referral for surgical consultation.

Pressure patching has been the standard approach to management of corneal abrasions (Fig. 7-14); however, the reduction of oxygen to the epithelium and increased temperature produced by patching can retard healing and increase the risk of infection.[166,183] The use of topical antibiotics and cycloplegics without patching may yield faster healing rates while improving patient comfort and protecting from secondary infection.[184] Aggressive use of ocular lubricants can improve patient comfort and promote healing, especially the use of lubricant ointments at bedtime. Because of the significant pain associated with epithelial



Figure 7-12. Coronal computed tomographic scan of a right orbital floor blowout fracture. (Reprinted from Kanski JJ: *Clinical ophthalmology,* ed 5, Boston, 2003, Butterworth-Heinemann.)

injuries, oral nonsteroidal antiinflammatory agents are frequently prescribed. Because antiinflammatory agents can slow tissue healing, their use should be limited to twice daily. The use of topical anesthetics to improve patient comfort is specifically contraindicated because of significant interference with corneal healing and increased risk of infection.[166]

A bandage contact lens can be an effective management tool for corneal injuries, although these lenses may also slow healing. The lens can protect the epithelium without significantly reducing the oxygen supply or increasing the corneal temperature like traditional pressure patching does. A contact lens offers the additional benefit to the athlete of allowing use of the eye during healing. For the athlete who is already a contact lens wearer, this is an

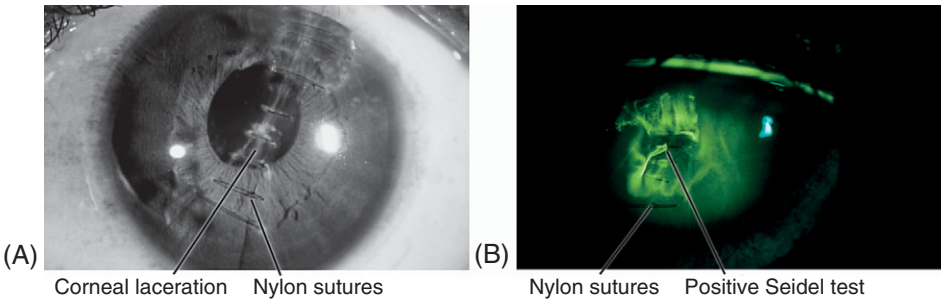


Figure 7-13. A, Large corneal laceration through visual axis. Note linear scar from the wound and around the multiple interrupted nylon sutures of various lengths used to repair the laceration. **B,** Corneal laceration demonstrating positive Seidel test (bright stream of fluorescein around the central suture). (Reprinted from Kaiser PK, Friedman, NJ: *The Massachusetts Eye and Ear Infirmary illustrated manual of ophthalmology*, ed 2, Philadelphia, 2004, WB Saunders.)



Figure 7-14. Pressure patching to manage corneal abrasions. The examiner applies an eye pad to the closed eyelids, either lengthwise or folded in half **(A)**. The examiner places a second patch lengthwise over the first patch **(B)**. Finally the examiner secures the patches with tape placed from the center of the forehead to the angle of the jaw across the patched eye. (Reprinted from Palay DA, Krachmer JH: *Primary care ophthalmology,* 2e, St. Louis, MO, Mosby, 2005).

excellent management approach. The athlete should be encouraged to use rewetting drops frequently to maintain good ocular lubrication.

A particular problem with corneal injuries inflicted by fingernails is the chance of recurrent corneal erosions. Most epithelial injuries heal well, but 7% to 8% of injuries result in recurrent erosions.[185,186] Management is designed to reestablish the adhesion complex between the epithelium and Bowman's layer and includes sequential use of topical hyperosmotic agents, bandage contact lens wear, surgical debridement, stromal micropuncture, and excimer laser ablation.[166,186-191]

The forces generated in many fast ball and contact sports can result in ruptures to all layers of the cornea. Damage to Descemet's membrane or the endothelium results in considerable corneal edema and possibly corneal blood staining. The corneal edema and blood staining typically resolve spontaneously; however, the disruption in the endothelial cell junctions can be permanent.[70,192] Injuries with sufficient force to rupture the deeper corneal layers often result in damage to the adjoining sclera as well.[193,194] Athletes who have had corneal refractive surgery may be at higher risk for ruptures and should be strongly counseled regarding the use of appropriate protective eyewear.

Anterior Chamber and Uvea

The pressure forces generated with blunt trauma in sports can result in damage to the iris or ciliary body tissues. Contusion pressure forces the cornea, iris-lens diaphragm, and ciliary body to rapidly expand posteriorly and circumferentially.[64,166,195,196] The resulting damage can lead to anterior chamber angle and pupillary effects and traumatic hyphema problems.

A relatively mild trauma may cause injury to the iris stroma, resulting in iritis that spontaneously recovers with time. Topical cycloplegic agents are prescribed to decrease the pain and photophobia produced by the iritis. The iris sphincter may rupture in one or more locations, causing characteristic triangular defects and notched pupillary borders that are permanent (Fig. 7-15). The iris and ciliary body may respond to blunt trauma with temporary miosis, mydriasis, cycloplegia, or spasm of accommodation. More severe trauma may

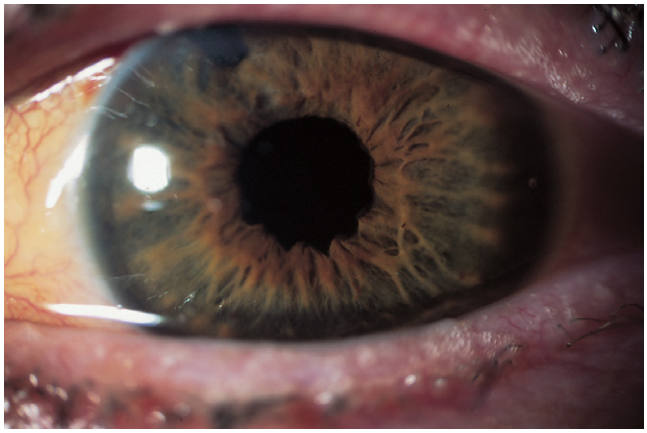


Figure 7-15. Rupture of the iris sphincter. (Reprinted from Kanski JJ: *Clinical ophthalmology,* ed 5, Boston, 2003, Butterworth-Heinemann.)

result in iridoschisis (detachment of an anterior mesodermal leaf) or iridodialysis (base of the iris separates from the ciliary body). Iridodialysis typically produces a substantial hyphema that makes the injury difficult to detect until the hyphema clears. Iridodialysis may not require treatment unless it has created monocular diplopia because of an accessory pupil.

The ciliary body is also at risk for damage from blunt trauma, usually producing a cleft in the anterior ciliary body and causing angle recession (Fig. 7-16).[64,70,166,195] Angle recession can occur with or without bleeding and affects anterior chamber drainage by damage to the trabecular meshwork. Gonioscopy studies suggest that most injuries that result in traumatic hyphemas also produce angle recession.[197,198] Angle recession is responsible for glaucoma, often unilateral in cases in which only one eye received the trauma. The secondary open-angle glaucoma can occur within 2 months to 2 years after the injury or even 10 to 15 years after the injury.[199] The incidence of secondary glaucoma with angle recession is estimated

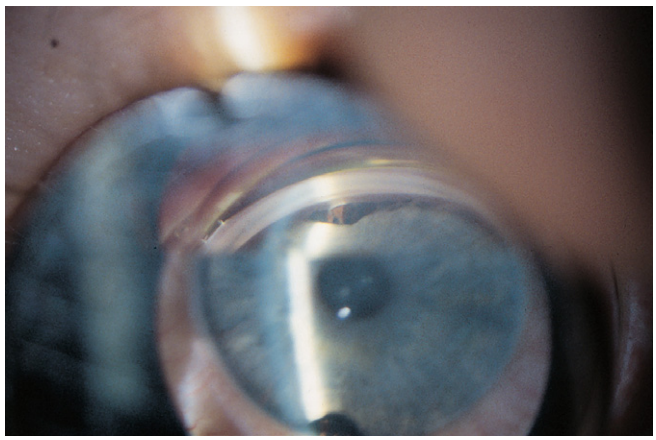


Figure 7-16. Severe angle recession. (Reprinted from Kanski JJ: *Clinical ophthalmology,* ed 5, Boston, 2003, Butterworth-Heinemann.)

BOX 7-5 GRADING SYSTEM FOR HYPHEMA[195]

Grade 1: Layered blood occupying less than one third of the anterior chamber
Grade 2: Blood filling one third to one half of the anterior chamber
Grade 3: Layered blood filling one half to less than total
Grade 4: Total clotted hyphemas, often referred to as "black ball" or "eight ball" hyphema

to be approximately 7%,[195] and eyes with angle recessions larger than 180 degrees are at greater risk of developing glaucoma.[199,200] Athletes who have angle recession injuries should be frequently monitored throughout life for development of glaucoma. Rarely, a 360-degree ciliary detachment can occur (cyclodialysis) and cause hypotony and phthisis bulbi, requiring surgical managment.[166]

Damage to the iris and ciliary body tissues often results in bleeding in the anterior chamber, and the resulting hyphema presents a considerable diagnostic and management challenge. The hyphema can obscure the clinician's view of the internal ocular structures, making evaluation of the extent of damage quite difficult. Nevertheless, a thorough case history and evaluation should be performed to the degree possible. The extent of the hyphema should be carefully noted, including notation of the presence and location of a clot. A grading system for traumatic hyphema is useful for recording and communicating the extent of the bleeding (see Box 7-5).[195]

Traumatic hyphema has many consequences, including elevated intraocular pressure during the acute phase of the hyphema, secondary hemorrhage, anterior and posterior synechiae formation, corneal blood staining, and optic atrophy. Transient elevated intraocular pressure is presumably caused by blockage of the trabecular meshwork and typically returns to normal quickly as the hyphema resolves. This mechanism is similar to the exercise-induced elevations in intraocular pressure found with pigmentary dispersion syndrome.[201] Athletes with sickle cell disease, and undiagnosed athletes of African or Hispanic descent, are at a higher risk for elevated intraocular pressure and subsequent central retinal artery obstruction because the sickled erythrocytes cannot pass through the trabecular meshwork.[202-206] Secondary bleeding presents a significantly worse prognosis for vision recovery[198,206,207] and secondary glaucoma.[206,208,209] Synechiae formation in traumatic hyphema is often caused by associated iritis and angle closure, and changes in pupillary responses may be noted.[198,207] Optic atrophy can result from the trauma itself or from prolonged periods of significantly elevated intraocular pressure.[198,207]

All these complications, along with the absence of a definitive treatment approach, present a complex and difficult clinical problem.[206,210] Many medical and surgical treatment options must be carefully considered. Conventional initial treatment of traumatic hyphema has included strict bed rest, bilateral patching, sedation, and hospitalization. Medical management is most appropriate for patients with grade 3 or less hyphema and surgical intervention considered for grade 4 hyphemas that do not respond to medical management within approximately 4 days.[195]

Crystalline Lens

The crystalline lens can be damaged from both coup and contrecoup effects of the trauma. If the globe is compressed enough to push the cornea posteriorly until it makes contact with

the lens, a permanent Vossius ring may result from the contact between the iris pupillary ruff and anterior lens surface.[25,64,68] More significant force can produce a transient rosette cataract, although the cataract often remains and can become progressively worse. Removal of the cataract can be complicated by the presence of hyphema and damage to other structures, especially the zonules. If the lens capsule has been ruptured, further complications of uveitis and phacolytic glaucoma may result.

In more severe cases of ocular trauma, the lens can become subluxated or completely dislocated. The pressure of the injury may rupture the zonules and cause the lens to tilt anteriorly or posteriorly, potentially leading to fluctuations in vision and diplopia. If this patient requires dilation, care must be taken to preclude having the subluxated lens shift into the anterior chamber. If the displaced lens is in contact with the iris, or if the vitreous has prolapsed into the anterior chamber, it often requires surgical intervention. In the rare occasion when the zonules have been completely severed, the lens can be dislocated internally into the anterior chamber or the vitreous, or suprachoroidally.[166,211-213] The lens may also dislocate externally in severe trauma, especially in globe rupture. In addition to the poor vision resulting from lens dislocation, the clinician may also observe iridodonesis (quivering of the iris).[68] A dislocated lens presents a poor prognosis, and the ensuing complications increase if the capsule has ruptured. The best treatment for lens dislocation is removal of the lens with a complete pars plana vitrectomy.[166]

Vitreous Body

The vitreous body can be directly affected in ocular trauma by vitreous base avulsion or posterior vitreous detachment or indirectly affected by hemorrhaging into the vitreous. Many uveal and retinal sites of possible bleeding exist, which highlights the need for a thorough posterior segment evaluation. If the views of the retina are obscured by blood in the vitreous, B-scan ultrasonography may be necessary to evaluate the integrity of the retina. Vitreal hemorrhaging can spontaneously resolve after several weeks; however, indications for vitrectomy may be present. The cells of the hemorrhage can migrate into the anterior chamber to produce ghost cell glaucoma, often requiring treatment with a vitrectomy.[166,196,214]

Vitreous traction can produce tears from the locations where the vitreous is attached. Most commonly, the vitreous base can be torn away along the anterior retina and pars plana and is pathognomonic for blunt trauma.[70] The vitreous base avulsion can cause the vitreous base to hang over the peripheral retina, creating a "bucket handle" appearance.[64,166] The vitreous base avulsion can often cause detachment of the peripheral retina as well. The vitreous is also strongly attached to the retina around the optic nerve, macula, and retinal vessels. Traction from blunt trauma can produce posterior vitreous detachment and subsequent retinal detachment. Detachment of the anterior or posterior vitreous can be monitored unless the traction on the retina necessitates surgical intervention.[166]

Retinal Injuries

The retina is often affected by ocular trauma. Many effects are possible, several of which cause permanent loss of visual function and require surgical treatment. Athletes with high myopia or otherwise compromised retinas are at particular risk of retinal damage from trauma.

Commotio retinae is a fairly common contrecoup injury first described by Berlin in 1873.[215] The contusion causes a white, opaque appearance to the damaged retina (Fig. 7-17)

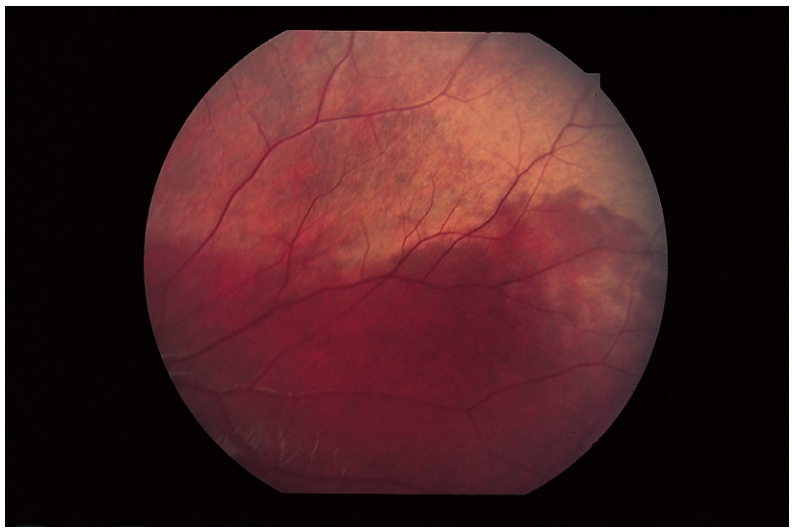


Figure 7-17. Peripheral commotio retinae. (From Kanski JJ: *Clinical ophthalmology,* ed 5, Boston, 2003, Butterworth-Heinemann.)

that often resolves without intervention unless permanent damage to the photoreceptors or retinal pigment epithelium occurs.[70,166,196,214] Commotio retinae can occur to peripheral retina or the central macular region (known as *Berlin's edema*) and have varying effects on visual acuity. Considerable damage to the retinal pigment epithelium can occur, eventually leading to granular pigmentation and bone corpuscular appearance of the affected retina resembling retinitis pigmentosa.[216-218] The athlete should also be evaluated for serous retinal detachment, which also diminishes the prognosis for vision recovery.[219]

Traumatic macular holes are relatively common with blunt trauma, and the possible mechanisms include necrosis, vitreous traction, and subfoveal hemorrhage.[166,196,220,221] The vision is usually poor with a full-thickness macular hole, and it is frequently associated with injuries to other internal ocular tissues.[222] Surgical success for recovering vision lost to traumatic macular holes, especially in younger patients, has recently improved.[221,223-232]

Retinal dialysis, a separation at the anterior edge of the ora serrata with the vitreous remaining attached to the posterior edge, is the most common traumatic retinal break.[233] The dialysis frequently occurs during the trauma,[234,235] and the vitreous attachment is most likely responsible for the gradual development of retinal detachment. Retinal dialysis may be difficult to observe and diagnose; however, prophylactic surgical treatment can prevent progression to retinal detachment.[166]

Many varieties of retinal tears and detachments can result from ocular trauma. The clinician should be skilled at identifying horseshoe tears, holes with operculum, stretch tears, giant retinal tears, necrotic tears, and rhegmatogenous retinal detachments.[70,166] Retinal detachment may not present immediately after the trauma; therefore frequent monitoring and athlete education regarding detachment symptoms is strongly recommended after trauma. Most tears and detachments require surgical treatment to prevent progression of retinal damage; however, no evidence exists that surgically induced adhesions offer protection against retinal detachment in high-contact sports such as boxing or martial arts.[236]

Optic Nerve

The optic nerve can be damaged by many direct and indirect causes. The most common form of optic nerve injury is from indirect contrecoup forces damaging the nerve itself or the supply vasculature for the nerve or through edematous compression (e.g., orbital emphysema).* In more rare cases, the optic nerve can be directly damaged by intraocular foreign bodies or bone fragments from orbital fractures, or a partial or complete avulsion of the optic nerve may occur from shearing or compression forces.[29,165,166,239,240] Athletes are at particular risk for finger injuries in the orbit, which have been reported to cause optic nerve avulsion.[241-243] As previously discussed, prolonged elevation of intraocular pressure can also produce damage to the optic nerve. Imaging is essential in trauma affecting the optic nerve to determine the nature of the damage.

Many treatment options have been promoted for traumatic optic neuropathy. High-dose corticosteroids and surgical decompression are the most common approaches, either separately or in combination.[165,166,170] Although vision recovery has been reported to occur spontaneously,[244] treatment is recommended to improve the chances of recovery. Optic nerve avulsion has a poor prognosis for visual recovery, although some suggest high-dose intravenous corticosteroid treatment.[166]

Choroid

Ruptures to the choroidal vasculature, Bruch's membrane, or the overlying retinal pigment epithelium can result from blunt trauma. Choroidal ruptures most often occur as a contrecoup injury from compression in the posterior pole, and ruptures of the choriocapillaris often produce significant subretinal hemorrhages in the optic disc and macular areas (Fig. 7-18). The hemorrhage may take weeks to resolve, and a yellow-white scar may result (Fig. 7-19).

*References 25, 70, 165, 166, 237, 238.

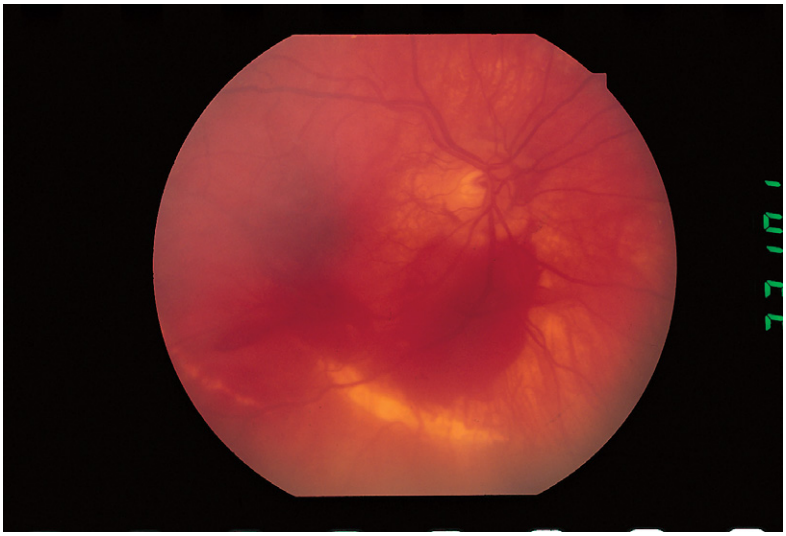


Figure 7-18. Acute chorodial rupture scar. (Reprinted from Kanski JJ: *Clinical opthalmology,* ed 5, Boston, 2003, Butterworth-Heinemann.)



Figure 7-19. Old choroidal rupture scar. (Reprinted from Kanski JJ: *Clinical ophthalmology,* ed 5, Boston, 2003, Butterworth-Heinemann.)

The visual prognosis can be relatively good unless hemorrhaging has occurred under the fovea. If Bruch's membrane has been ruptured, choroidal vessels can develop under the retina.[245-247] Photocoagulation therapy may be useful for prevention of retinal detachments and subretinal neovascular membrane formation that can even occur many years after the choroidal rupture.[70,196]

Direct trauma to the choroid commonly produces damage more anteriorly and can affect the uveal structures as well. The location of anterior choroidal ruptures makes visualization of the damage difficult; therefore the practitioner must be purposeful in the assessment of the posterior segment. If a large area of the choroid detaches, extreme secondary glaucoma can result that is resistant to treatment.[195]

Visual Fields

The forces that cause eye injuries can also result in closed-head trauma.[25] Closed-head injuries involving cerebral edema, hemorrhaging, compression, or ischemia can damage the visual pathway. Visual field, pupillary reflex, visual acuity, and color testing can be useful adjunct information for other health professionals in determining the nature and extent of the damage.

Penetrating Trauma

A penetrating intraocular injury is relatively rare in sports, particularly when protective eyewear is worn by the athlete. Common penetrating objects include fish hooks, darts, weapon-related objects (e.g., BBs), and inappropriate spectacle lenses and frames.[248] Although glass is generally well tolerated inside the eye, the sharp edges of shattered glass can cause considerable secondary progressive damage.[248] A detailed case history is crucial for determining the exact nature of the injury and potential intraocular foreign object. In cases of small, fast objects such as BBs, signs of external damage may be limited. All ocular tissues should be thoroughly assessed and Seidel testing performed to help detect any entry points.

A computed tomography scan is often essential for locating the presence and position of the foreign object. Penetration of the ocular tissues causes many complications; the cornea may remain scarred, the iris may remain partially impaired, the crystalline lens may need to be removed, the vitreous may need to be removed, and the retina may have long-term problems.[64,166]

Many metallic and organic foreign bodies have a high risk for causing intraocular infection and inflammation; therefore, prophylactic treatment with broad-spectrum antibiotics is recommended for all foreign bodies.[165] The management of intraocular foreign bodies is determined by "the composition of the foreign body, the mechanical effect of the retained foreign body, and the presence of infection."[165] Foreign materials that are not well tolerated in the eye or have potential for causing secondary damage should be removed when possible. Infection, especially from organic foreign materials, is not successfully treated by antibiotics alone; removal of the object is often necessary. The surgeon must consider the location, composition, and infection issues when determining whether to remove the foreign object and how to accomplish the removal with minimal surgical damage to the ocular tissues.

Perforating injuries from blunt trauma often have a worse prognosis than nonperforating contusions or penetrating foreign objects. The extent of damage to ocular tissues and structures typically is significant when blunt trauma force has caused an open-globe injury. In addition, the scarring from perforating injuries can cause even more extensive damage than the initial injury.[166] Management with vitrectomy and other medical and surgical options should be initiated as soon as possible.

Chemical Injuries

Chemical burns (Fig. 7-20) are fairly rare in sports. Swimmers may present with chemosis and irritation from swimming pools that have been chemically treated improperly. Occasionally an athlete may get chalk in his or her eyes from field markings in sports such as football and baseball. These chemical injuries are almost always mild, and meticulous irrigation with water may be the only treatment necessary. If the chemical agent is a solid, scrupulous examination of the fornices is recommended to remove any retained substance.

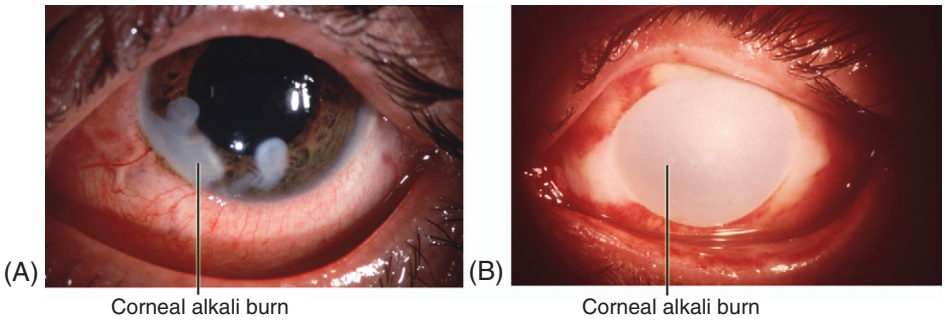


Figure 7-20. Alkali burn demonstrating corneal burns and conjunctival injection on the day of the accident **(A)** and complete destruction 7 days after the burn **(B)**. (Reprinted from Kaiser PK, Friedman, NJ: *The Massachusetts Eye and Ear Infirmary illustrated manual of ophthalmology,* ed 2, Philadelphia, 2004, WB Saunders.)

If the corneal epithelium has been compromised, prophylactic treatment with a broad-spectrum antibiotic is advocated.[249] If iridocyclitis develops, usually from corneal epithelial damage, treatment with a cycloplegic agent is necessary to prevent posterior synechiae.[249]

FOLLOW-UP CO-MANAGEMENT

The athlete returning to sport after a sports-related ocular injury requires continued assessment and management by the entire sports medicine team to ensure an optimal outcome. After the eye care specialist has managed the athlete's injury, the athlete and the athletic trainer should receive detailed instructions regarding further treatment, indications for returning to the eye care specialist, and eyewear recommendations.

Communication between the eye care specialist and the on-site sports medicine provider (usually the certified athletic trainer) is paramount. This communication is most effective if it is delivered both in writing and verbally. Written communication should contain sufficient detail to enhance the potential for excellent compliance. Verbal communication allows the athlete and other professionals to ask specific questions regarding what needs to be done, where it needs to be done, when it should occur, who should carry out the recommendations, and why it needs to be done. Also, educating the family and the head coach will increase the athlete's compliance with the physician's orders.

The athletic trainer serves a valuable role in that he or she can assess the injury daily and refer the athlete to the physician if necessary. If the eye care specialist is unfamiliar with the athlete's sport, the athletic trainer can provide invaluable information about practice and game situations. The athletic trainer can also improve compliance by ensuring that the athlete returns for recommended follow-up care.

REFERENCES

1. Larrison WI, Hersh PS, Kunzweiler T, et al: Sports-related ocular trauma, *Ophthalmology 97:*1265, 1990.
2. Vinger PF: Sports eye injuries a preventable disease, *Ophthalmology 88:*108, 1981.
3. Barr A, Baines PS, Desai P, et al: Ocular sports injuries: the current picture, *Br J Sports Med 34:*456, 2000.
4. Ghosh F, Bauer B: Sports-related eye injuries, *Acta Ophthalmol Scand 73:*353, 1995.
5. MacEwen CJ: Eye injuries: a prospective survey of 5671 cases, *Br J Ophthalmol 73:*888, 1989.
6. Kyle S: *Youth baseball protective equipment project final report*, Washington, DC, 1996, Consumer Products Safety Commission.
7. Strahlman E, Elman M, Daub E, et al: Causes of pediatric eye injuries: a population-based study, *Arch Ophthalmol 108:*603, 1990.
8. *Prevention of blindness, data analysis*: *vision problems in the US*, New York, 1978, National Society for the Prevention of Blindness, pp 24-33.
9. Consumer Products Safety Commission: *Sports and recreational eye injuries*, Washington, DC, 2000, Consumer Products Safety Commission.
10. National Society to Prevent Blindness: *Fact sheet*, New York, 1980, National Society to Prevent Blindness.
11. American Academy of Pediatrics Committee on Sports Medicine and Fitness: Protective eyewear for young athletes. Policy statement, *Pediatrics 113:*619, 2004.
12. American Academy of Pediatrics Committee on Sports Medicine and Fitness: American Academy of Ophthalmology, Eye Health and Public Information Task Force. Protective eyewear for young athletes, *Ophthalmology 111:*600, 2004.

13. Nelson LB, Wilson TW, Jeffers JB: Eye injuries in childhood: demography, etiology, and prevention, *Pediatrics 84:*438, 1989.
14. Grin TR, Nelson LB, Jeffers JB: Eye injuries in childhood, *Pediatrics 80:*13, 1987.
15. Jeffers JB: An on-going tragedy: pediatric sports-related eye injuries, *Semin Ophthalmol 5:*21, 1990.
16. Landry GL, Bernhardt DT: *Essentials of primary care sports medicine*, Champaign, IL, 2003, Human Kinetics.
17. Weber TS: Training room management of eye conditions, *Clin Sports Med 24:*681, 2005.
18. Stuart MJ, Smith AM, Malo-Ortiguera SA, et al: A comparison of facial protection and the incidence of head, neck, and facial injuries in Junior A hockey players, *Am J Sports Med 30:*39, 2002.
19. Morris DS: Ocular blunt trauma: loss of sight from an ice hockey injury, *Br J Sports Med 40:*e5, 2006.
20. Danis RP, Hu K, Bell M: Acceptability of baseball face guards and reduction of oculofacial injury in receptive youth league players, *Inj Prev 6:*232, 2000.
21. Meeuwisse WH, Sellmer R, Hagel BE: Rates and risks of injury during intercollegiate basketball, *Am J Sports Med 31:*379, 2003.
22. Guskiewicz KM, Bruce SL, Cantu RC, et al: National athletic trainers' position statement: management of sport related concussion, *J Athletic Training 39:*280, 2004.
23. Schenck RC, Barnes RP, Behnke RP, et al, editors: *Athletic training and sports medicine*, Sudbury, MA, 1999, Jones and Bartlett.
24. Guyette RF: Facial injuries in basketball players, *Clin Sports Med 12:*247, 1993.
25. Vogel MS: An overview of head trauma for the primary care practitioner: part II—ocular damage associated with head trauma, *J Am Optom Assoc 63:*542, 1992.
26. Williams RJ, Marx RG, Barnes R, et al: Fractures about the orbit in professional American football players, *Am J Sports Med 29:*55, 2001.
27. Forrest LA, Schuller DE, Strauss RH: Management of orbital blow out fractures. Case reports and discussions, *Am J Sports Med 17:*217, 1989.
28. Kulwin DR, Leadbetter MG: Orbital rim trauma causing a blowout fracture, *Plast Reconstr Surg 73:*969, 1984.
29. Kaufman BR, Heckler FR: Sports-related facial injuries, *Clin Sports Med 16:*543, 1997.
30. Bahr R, Maehlum S: Clinical guide to sports injuries, Champaign, IL, 2004, Human Kinetics.
31. Capao-Filipe JA: Soccer (football) ocular injuries: an important eye health problem, *Br J Ophthalmol 88:*159, 2004.
32. Vinger PF, Capao-Filipe JA: The mechanism and prevention of soccer eye injuries, *Br J Ophthalmol 88:*167, 2004.
33. NCAA Guideline 4b: Eye safety in sports. NCAA Committee on Competitive Safeguards and Medical Aspects of Sports, 2001. http://www.ncaa.org/library/sports_sciences/sports_med_handbook/2006-07/2006-07_sports_medicine_handbook.pdf. Accessed May 1, 2007.
34. Eagling EM, Roper-Hall MJ: *Eye injuries*: *an illustrated guide*, Philadelphia, 1986, J.B. Lippincott.
35. Arnheim DD, Prentice WE: *Principles of athletic training,* ed 10, Boston, 2000, McGraw Hill.
36. Stilger VG, Alt JM, Robinson TW: Traumatic hyphema in an intercollegiate baseball player: a case report, *J Athl Train 34:*25, 1999.
37. Reid DC: *Sports injury assessment and rehabilitation*, New York, 1992, Churchill Livingstone.
38. Capao-Filipe JA, Rocha-Sousa A, Falcao-Reis F, et al: Modern sports eye injuries, *Br J Ophthalmol 87:*1336, 2003.
39. Vinger PF: The incidence of eye injuries in sports. In Vinger PF, editor: *Ocular sports injuries*, Boston, 1981, Little, Brown, pp 21-46.
40. Vinger PF: Sports eye injuries: a preventable disease, *Am Acad Ophthalmol 88:*108, 1981.

41. Diamond GR, Quinn GE, Pashby TJ, et al: Ophthalmologic injuries, *Clin Sports Med 1:*469, 1982.
42. Diamond GR, Quinn GE, Pashby TJ, et al: Ophthalmologic injuries, *Prim Care 11:*161, 1984.
43. Gregory PT: Sussex Eye Hospital sports injuries, *Br J Ophthalmol 70:*748, 1986.
44. Grove D: Study: eye injuries in varsity sports, *Phys Sportsmed 15:*64, 1987.
45. Jones NP: Eye injuries in sport: an increasing problem, *Br J Sports Med 21:*168, 1987.
46. MacEwen CJ: Sport associated eye injury: a casualty department survey, *Br J Ophthalmol 71:*701, 1987.
47. Jones NP: One year of severe eye injuries in sport, *Eye 2:*484, 1988.
48. LaRoche GR, McIntyre L, Shertzer RM: Epidemiology of severe eye injuries in childhood, *Ophthalmology 95:*1603, 1988.
49. Jones NP: Eye injury in sport, *Sports Med 7:*163, 1989.
50. Pashby TJ: Eye injuries in Canadian sports and recreational activities, *Can J Ophthalmol 27:* 226, 1992.
51. Zagelbaum BM, Tostanoski JR, Kerner DJ, et al: Urban eye trauma: a one-year prospective study, *Ophthalmology 100:*851, 1993.
52. Orlando RG: Soccer-related eye injuries in children and adolescents, *Phys Sportsmed 16:*103, 1988.
53. Capoferri C, Martorina M, Menga M, et al: Eye injuries from traditional sports in Aosta Valley, *Ophthalmologica 208:*15, 1994.
54. Fong LP: Sports-related eye injuries, *Med J Aust 160:*743, 1994.
55. Fong LP: Eye injuries in Victoria, Australia, *Med J Aust 162:*64, 1995.
56. Pardhan S, Shacklock P, Weatherill J: Sport-related ocular trauma: a survey of the presentation of eye injuries to a casualty clinic and the use of protective eye-wear, *Eye 9(pt 6 suppl):*50, 1995.
57. Zagelbaum BM, Starkey C, Hersh PS, et al: The National Basketball Association eye injury study, *Arch Ophthalmol 113:*749, 1995.
58. Napier SM, Baker, RS, Sanford DG, et al: Eye injuries in athletics and recreation, *Surv Ophthalmol 41:*229, 1996.
59. Orlando RG, Doty JH: Ocular sports trauma: a private practice study, *J Am Optom Assoc 67:*77, 1996.
60. Capao Filipe JA, Barros H, Castro-Correia J: Sports-related ocular injuries: a three-year follow-up study, *Ophthalmology 104:*313, 1997.
61. Barr A, Baines PS, Desai P, et al: Ocular sports injuries: the current picture, *Br J Sports Med 34:*456, 2000.
62. Vinger PF: A practical guide for sports eye protection, *Phys Sportsmed 28:*49, 2000.
63. Vinger PF: Understanding eye trauma through computer modeling, *Arch Ophthalmol 123:*833, 2005.
64. Jones NP: Eye injuries in sport. In Loran DFC, MacEwen CJ, editors: *Sports vision*, Oxford, 1995, Butterworth-Heinemann.
65. Vinger PF: The eye and sports medicine. In Tasman W, Jaeger EA, editors: *Duane's clinical ophthalmology*, Philadelphia, 1985, JB Lippincott.
66. Pizzarello LD, Haik BG, editors: *Sports ophthalmology*, Springfield, IL, 1999, Charles C. Thomas.
67. Pane A, Simcock P: *Practical ophthalmology*: *a survival guide for doctors and optometrists*, Edinburgh, 2005, Elsevier Churchill Livingston, pp 106-127.
68. Fingeret M: The initial evaluation of ocular trauma in sports, *J Am Optom Assoc 51:*687, 1980.
69. Heiberger MH, Madonna RJ, Nehmad L: *Emergency care in the optometric setting*, New York, 2004, McGraw-Hill, pp 81-116.
70. Benson WE, Shakin J, Sarin LK: Blunt trauma. In Tasman W, Jaeger EA, editors: *Duane's clinical ophthalmology*, Philadelphia, 1983, JB Lippincott.
71. Consumer Product Safety Commission: *National Electronic Injury Surveillance System (NEISS) online*, http://www.cpsc.gov/library/neiss.html, accessed June 15, 2006.
72. Jones NP, Tullo AB: Severe eye injuries in cricket, *Br J Sports Med 20:*178, 1986.

73. Aburn N: Eye injuries in indoor cricket at Wellington Hospital: a survey January 1987 to June 1989, *NZ Med J 103:*454, 1990.
74. Vinger PF, Duma SM, Crandall J: Baseball hardness as a risk factor for eye injuries, *Arch Ophthalmol 117:*354, 1999.
75. Abrams JH: Sports related ocular trauma, *Athl Therapy Today 1:*31, 1996.
76. Marton K, Wilson D, McKeag D: Ocular trauma in college varsity sports, *Med Sci Sports Exerc 19:*S53, 1987.
77. Witherspoon CD, Kuhn F, Morris R, et al: Epidemiology of general and sports eye injuries, *Ophthalmol Clin North Am 12:*333, 1999.
78. Zagelbaum BM, Starkey C, Hersh PS, et al: The National Basketball Association eye injury study, *Arch Ophthalmol 113:*749, 1995.
79. Doggart JH: The impact of boxing on the visual apparatus, *Arch Ophthalmol 54:*161, 1955.
80. Palmer E, Lieberman TW, Burns S: Contusion angle deformity in prizefighters, *Arch Ophthalmol 94:*225, 1976.
81. Maguire JI, Benson WE: Retinal injury and detachment in boxers, *JAMA 255:*2451, 1986.
82. Giovinazzo VJ, Yannuzzi LA, Sorenson JA, et al: The ocular complications of boxing, *Ophthalmology 94:*587, 1987.
83. Smith DJ: Ocular injuries in boxing, *Int Ophthalmol Clin 28:*242, 1988.
84. Enzenauer RW, Mauldin WM: Boxing-related ocular injuries in the United States Army, 1980 to 1985, *South Med J 82:*547, 1989.
85. Leach A, McGalliard J, Dwyer MH, et al: Ocular injuries from boxing, *Br Med J 304:*839, 1992.
86. McLeod D: Ocular injuries from boxing, *Br Med J 304:*197, 1992.
87. Whiteson A: Ocular injuries from boxing, *Br Med J 304:*574, 1992.
88. Wedrich A, Velikay M, Binder S, et al: Ocular findings in asymptomatic amateur boxers, *Retina 13:*114, 1993.
89. Vadala G, Mollo M, Roberto S, et al: Boxing and the eyes: morphological aspects of the ocular system in boxers, *Eur J Ophthalmol 7:*174, 1997.
90. Hazar M, Beyleroglu M, Subasi M, et al: Ophthalmological findings in elite amateur Turkish boxers, *Br J Sports Med 36:*428, 2002.
91. Bianco M, Vaiano AS, Colella F, et al: Ocular complications of boxing, *Br J Sports Med 39:*70, 2005.
92. Bartholomew RS, MacDonald M: Fish-hook injuries of the eye, *Br J Ophthalmol 64:*531, 1980.
93. Grand GM, Lobes LA: Technique for removing a fishhook from the posterior segment of the eye, *Arch Ophthalmol 98:*152, 1980.
94. Mandelcorn MS, Crichton A: Fish-hook removal from vitreous and retina, *Arch Ophthalmol 107:*493, 1989.
95. Aiello LP, Iwamoto M, Guyer DR: Penetrating ocular fish-hook injuries, *Ophthalmology 99:*862, 1992.
96. Aiello LP, Iwamoto M, Taylor HR: Perforating ocular fish-hook injuries, *Arch Ophthalmol 110:*1316, 1992.
97. Yuksel N, Elibol O, Caglar Y: Penetrating corneal fish-hook injury, *Ophthalmologica 208:*112, 1994.
98. Alfaro DV 3d, Jablon EP, Rodriguez FM, et al: Fishing-related ocular trauma, *Am J Ophthalmol 139:*488, 2005.
99. Tanton JH, Elliott DC: Fishing-spear injury of the orbit, *Am J Ophthalmol 64:*973, 1967.
100. Heinrichs EH, Willcockson JR: Catastrophic eye injury in a football player, *Physician sportsmed 10:*71, 1982.
101. Sherwood DJ: Eye injuries to football players, *N Engl J Med 320:*742, 1989.
102. Millar GT: Golfing eye injuries, *Am J Ophthalmol 64:*741, 1967.

103. Portis JM, Vassallo SA, Albert DM: Ocular sports injuries: a review of cases on file in the Massachusetts Eye and Ear Infirmary pathology laboratory, *Int Ophthalmol Clin 21:*1, 1981.
104. Mieler WF, Nanda SK, Wolf MD, et al: Golf-related ocular injuries, *Arch Ophthalmol 113:*1410, 1995.
105. Burnstine MA, Elner VM: Golf-related ocular injuries, *Am J Ophthalmol 121:*437, 1996.
106. Pollack JS, Mieler WF, Mittra RA: Golf-related ocular injuries, *Curr Opin Ophthalmol 8:*15, 1997.
107. Jayasundera T, Vote B, Joondeph B: Golf-related ocular injuries, *Clin Exp Ophthalmol 31:*110, 2003.
108. Weitgasser U, Wackernagel W, Oetsch K: Visual outcome and ocular survival after sports ocular trauma in playing golf, *J Trauma 56:*648, 2004.
109. Devenyi RG, Pashby RC, Pashby J: The hockey eye safety program, *Ophthalmol Clin North Am 12:*359, 1999.
110. Pashby TJ, Pashby RC, Chisholm LD, et al: Eye injuries on Canadian hockey, *Can Med Assoc J 113:*663, 1975.
111. Vinger PF: Ocular injuries in hockey. Arch Ophthalmol *94:*74, 1976.
112. Pashby TJ: Eye injuries in Canadian hockey. Phase II, *Can Med Assoc J 117:*677, 1977.
113. Pashby TJ: Eye injuries in Canadian amateur hockey, *Am J Sports Med 7:*254, 1979.
114. Pashby TJ: Eye injuries in Canadian hockey. Phase III, *Can Med Assoc J 121:*643, 1979.
115. Pashby TJ: Ocular injuries in hockey, *Int Ophthalmol Clin 28:*228, 1988.
116. Benson B, Meeuwisse W: Ice hockey injuries. In Maffulli N, Caine DJ, editors: *Epidemiology of pediatric sports injuries*: *team sports*, *Med Sport Sci 49:*86, 2005.
117. Lapidus CS, Nelson LB, Jeffers JB, et al: Eye injuries in lacrosse: women need their vision less than men? *J Trauma 32:*555, 1992.
118. Livingston LA, Forbes SL: Eye injuries in women's lacrosse: strict rule enforcement and mandatory eyewear required, *J Trauma 40:*144, 1996.
119. Webster DA, Bayliss GV, Spadaro JA: Head and face injuries in scholastic women's lacrosse with and without eyewear, *Med Sci Sports Exerc 31:*938, 1999.
120. Waicus KM, Smith BW: Eye injuries in women's lacrosse players, *Clin J Sport Med 12:*24, 2002.
121. Mantz SO, Nibbelink G: Injuries in intercollegiate women's lacrosse, *Am J Sports Med 32:*608, 2004.
122. Singh I, Khanna PK, Srivastava MC, et al: Acute mountain sickness, *N Engl J Med 280:*175, 1969.
123. Frayser R, Houston CS, Gray GW, et al: Retinal hemorrhage at high altitude, *N Engl J Med 282:*1183, 1970.
124. Kobrick JL, Appleton B: Effect of extended hypoxia on visual performance and retinal vascular state, *J Appl Physiol 31:*357, 1971.
125. Rennie D, Morrisey J: Retinal changes in Himalayan climbers, *Arch Ophthalmol 93:*395, 1975.
126. Wiedman M: High altitude retinal hemorrhage, *Arch Ophthalmol 93:*401, 1975.
127. Clarke C, Duff J: Mountain sickness, retinal haemorrhages, and acclimatisation on Mount Everest in 1975, *Br Med J 2:*495, 1976.
128. McFadden DM, Houston CM, Sutton JR, et al: High-altitude retinopathy, *JAMA 245:*581, 1981.
129. Butler FK, Harris DJ, Reynolds RD: Altitude retinopathy on Mount Everest, 1989, *Ophthalmology 99:*739, 1992.
130. Shults WT, Swan KC: High altitude retinopathy in mountain climbers, *Arch Ophthalmol 93:*404, 1975.
131. Classe JG: Prescribing for noncontact sports, *Optom Clin 3:*111, 1993.
132. Easterbrook M: Ocular injuries in racquet sports, *Int Ophthalmol Clin 28:*232, 1988.
133. Ingram DV, Lewkonia I: Ocular hazards of playing squash rackets, *Br J Ophthalmol 57:*434, 1973.
134. Chandran S: Ocular hazards of playing badminton, *Br J Ophthalmol 58:*757, 1974.
135. Jones WL: Ocular manifestations of blunt racquetball injury, *Optom Monthly 69:*968, 1978.
136. Easterbrook M: Eye injuries in squash: a preventable disease, *Can Med Assoc 118:*303, 1978.

137. Barrell GV, Cooper PJ, Elkington AR, et al: Squash ball to eye ball: the liklihood of squash players incurring an eye injury, *Br Med J (Clin Res Ed) 283:*893, 1981.
138. Genovese MT, Lenzo NP, Lim RK, et al: Eye injuries among pennant squash players and their attitudes towards protective eyewear, *Med J Aust 153:*655, 1990.
139. Loran D: Eye injuries in squash, *Optician*, *204:*18, 1992.
140. Holdeman NR: Courting disaster*:* racquetball injury triggers hyphema, *Rev Optom 130:*83, 1993.
141. Knorr HL, Jonas JB: Retinal detachments by squash ball accidents, *Am J Ophthalmol 122:*260, 1996.
142. McWhae J: Badminton-related eye injuries [letter], *Can J Ophthalmol 25:*170, 1990.
143. Becker GD: Barotrauma resulting from scuba diving*:* an otolaryngological perspective, *Phys Sportsmed 13:*112, 1985.
144. Melamed Y, Shupak A, Bitterman H: Medical problems associated with underwater diving, *N Engl J Med 326:*30, 1992.
145. Andenmatten R, Piguet B, Klainguti G: Orbital hemorrhage induced by barotrauma, *Am J Ophthalmol 118:*536, 1994.
146. Kirby BS: In deep water: scuba diving mishap causes ocular barotrauma, *Rev Optom 131:*113, 1994.
147. Butler FK: Diving and hyperbaric ophthalmology, *Surv Ophthalmol 39:*347, 1995.
148. Carkeet A: Mask barotrauma leading to sub-conjunctival haemorrhage in a scuba diver, *Clin Exp Optom 78:*18, 1995.
149. Hoelting C, Egan DJ, Bennett ES: The use of contact lenses in swimming and scuba diving, *Can J Optom 46:*12, 1984.
150. Josephson JE, Caffery BE: Contact lens considerations in surface and subsurface aqueous environments, *Optom Vis Sci 68:*2, 1991.
151. Jurkus J, Colarusso MA: To see or not to see: a swimmer's dilemma, *Contact Lens Spect 11:*44, 1996.
152. Burke MJ, Sanitato JJ, Vinger PF, et al: Soccerball-induced eye injuries, *JAMA 249:*2682, 1983.
153. Horn EP, McDonald HR, Johnson RN, et al: Soccer ball-related retinal injuries: a report of 13 cases, *Retina 20:*604, 2000.
154. Capao-Filipe JA, Fernandes VL, Barros H, et al: Soccer-related ocular injuries, *Arch Ophthalmol 121:*687, 2003.
155. Renneker M: Medical aspects of surfing, *Phys Sportsmed 15:*96, 1987.
156. Easterbrook M, Pashby TJ: Eye injuries associated with war games, *Can Med Assoc J 133:*415, 1985.
157. Randall KA: War games: a new sport that can cause eye casualties, *Sightsaving 54:*2, 1985.
158. Ryan EH, Lissner G: Eye injuries during "war games," *Arch Ophthalmol 104:*1435, 1986.
159. Tardif D, Little J, Mercier M, et al: Ocular trauma in war games, *Phys Sportsmed 14:*90, 1986.
160. Martin PL, Magolian JJ: Eye injury during "war games" despite the use of goggles, *Arch Ophthalmol 105:*321, 1987.
161. Easterbrook M, Pashby TJ: Ocular injuries and war games, *Int Ophthalmol Clin 28:*222, 1988.
162. Wellington DP, Johnstone MA, Hopkins RJ: Bull's-eye corneal lesion resulting from war game injury, *Arch Ophthalmol 107:*1727, 1989.
163. Hargrave S, Weakley D, Wilson C: Complications of ocular paintball injuries in children, *J Pediatr Ophthalmol Strabismus 37:*338, 2003.
164. Fineman MS: Ocular paintball injuries, *Curr Opin Ophthalmol 12:*186, 2001.
165. Iwamoto MA, Iliff NT: Management of orbital trauma. In Tasman W, Jaeger EA, editors: *Duane's clinical ophthalmology*, Philadelphia, 1993, JB Lippincott.
166. Kuhn F, Pieramici DJ: *Ocular trauma principles and practice*, New York, 2002, Thieme.
167. Courville CB: Coup-contrecoup mechanism of cranio-cerebral injuries, *Arch Surg 45:*19, 1942.
168. Courville CB: Forensic neuropathology, *J Forens Sci 7:*1, 1962.

169. Wolter JR: Coup-Contrecoup mechanism of ocular injuries, *Am J Ophthalmol 56:*785, 1963.
170. Baker SM, Hurwitz JJ: Management of orbital and ocular adnexal trauma, *Ophthalmol Clin North Am 12:*435, 1999.
171. Griffin JR, Erickson GB: Binocular vision problems. In Alexander KL, editor: *The Lippincott manual of primary eye care*, Philadelphia, 1995, JB Lippincott, pp 378-421.
172. Caloroso EE, Rouse MW: *Clinical management of strabismus*, Boston, 1993, Butterworth-Heinemann, pp 32-39.
173. Griffin JR, Grisham JD: *Binocular anomalies,* Amsterdam, 2002, Butterworth-Heinemann, pp 110-126.
174. von Noorden GK: *Burian-von Noorden's binocular vision and ocular motility. Theory and management of strabismus*, St Louis, 1985, Mosby–Year Book, pp 350-351.
175. Amos JF, editor: *Diagnosis and management in vision care*, Boston, 1987, Butterworth-Heinemann, pp 549-550.
176. Magoon EH: Botulin therapy in pediatric ophthalmology. In Smolin G, Friedlaender MH, editors: Pediatric ophthalmology, *Int Ophthalmol Clin 29:*30, 1989.
177. Scott AB, Magoon EH, McNeer KW, et al: Botulinum treatment of strabismus in children, *Trans Am Ophthalmol Soc 87:*174, 1989.
178. Metz HS, Mazow M: Botulinum toxin treatment of acute sixth and third nerve palsy, *Graefes Arch Clin Exp Ophthalmol 226:*141, 1988.
179. Lang W: Traumatic enophthalmos with retention of perfect acuity of vision, *Trans Ophthalmol Soc UK 9:*41, 1889.
180. Smith B, Regan WF: Blow-out fracture of the orbit: mechanism and correction of internal orbital fracture, *Am J Ophthalmol 44:*733, 1957.
181. Jones NP: Orbital blowout fractures in sport, *Br J Sports Med 28:*272, 1994.
182. Carter JH: Diagnosis of pupillary anomalies, *J Am Optom Assoc 50:*671, 1979.
183. Parris CM, Chandler JW: Corneal trauma. In Kaufman HE, Barron BA, McDonald MB, et al, editors: *The cornea*, New York, 1988, Churchill Livingstone, pp 619.
184. Kirkpatrick JNP, Hoh HB, Cook SD: No eye pad for corneal abrasion, *Eye 7:*468, 1993.
185. Weene LE: Recurrent corneal erosion after trauma: a statistical study, *Ann Ophthalmol 17:*521, 1983.
186. Kenyon KR: Recurrent corneal erosion: pathogenesis and therapy, *Int Ophthalmol Clin 19:*169, 1979.
187. McLean EN, MacRae SM, Rich LF: Recurrent erosion: treatment by anterior stromal puncture, *Ophthalmology 93:*784, 1986.
188. Rubinfeld RS, Laibson PR, Cohen EJ, et al: Anterior stromal puncture for recurrent erosion: further experience and new instrumentation, *Ophthal Surg 21:*318, 1990.
189. Dausch D, Landesz M, Klein R, et al: Phototherapeutic keratectomy in recurrent corneal epithelial erosion, *Refract Corneal Surg 9:*419, 1993.
190. John ME, Van der Karr MA, Noblitt RL, et al: Excimer laser phototherapeutic keratectomy for treatment of recurrent corneal erosion, *J Cataract Refract Surg 20:*179, 1994.
191. Fountain TR, de la Cruz Z, Green WR, et al: Reassembly of corneal epithelial adhesion structures after excimer keratectomy in humans, *Arch Ophthalmol 112:*967, 1994.
192. Slingsby JG, Forstot SL: Effect of blunt trauma on corneal endothelium, *Arch Ophthalmol 99:*1041, 1981.
193. Cherry PMH: Rupture of the globe, *Arch Ophthalmol 88:*498, 1972.
194. Cherry PMH: Indirect traumatic rupture of the globe, *Arch Ophthalmol 96:*252, 1978.
195. Crouch ER, Williams PB: Trauma: ruptures and bleeding. In Tasman W, Jaeger EA, editors: *Duane's clinical ophthalmology*, Philadelphia, 1983, JB Lippincott.
196. Reppucci VS, Movshovich A: Current concepts in the treatment of traumatic injury to the posterior segment, *Ophthalmol Clin North Am 12:*465, 1999.

197. Rakusin W: Traumatic hyphema, *Am J Ophthalmol 74:*284, 1972.
198. Read JE, Goldberg MF: Comparison of medical treatment for traumatic hyphema, *Trans Am Acad Ophthalmol Otolaryngol 78:*799, 1974.
199. Blanton FM: Anterior chamber angle recession and secondary glaucoma: a study of the after effects of traumatic hyphemas, *Arch Ophthalmol 72:*39, 1964.
200. Milauskas AT, Fueger GF: Serious ocular complications associated with blowout fractures of the orbit, *Am J Ophthalmol 62:*670, 1966.
201. Haynes WL, Johnson AT, Alward WLM: Effects of jogging exercise on patients with pigmentary dispersion syndrome and pigmentary glaucoma, *Ophthalmology 99:*1096, 1992.
202. Goldberg MF: The diagnosis and treatment of secondary glaucoma after hyphema in sickle cell patients, *Am J Ophthalmol 87:*43, 1979.
203. Michaelson PE, Pfaffenbach D: Retinal arterial occlusion following ocular trauma in youths with sickle-trait hemoglobinopathy, *Am J Ophthalmol 74:*494, 1972.
204. Sorr EM, Goldberg RE: Traumatic central artery occlusion with sickle cell trait, *Am J Ophthalmol 80:*648, 1975.
205. Wax MB, Ridley ME, Magargal LE: Reversal of retinal and optic disc ischemia in a patient with sickle cell trait and glaucoma secondary to traumatic hyphema, *Ophthalmology 89:*845, 1982.
206. Hamill MB: Current concepts in the treatment of traumatic injury to the anterior segment, *Ophthalmol Clin North Am 12:*457, 1999.
207. Crouch ER, Frenkel M: Aminocaproic acid in the treatment of traumatic hyphema, *Am J Ophthalmol 81:*355, 1976.
208. Darr JL, Passmore JW: Management of traumatic hyphema: a review of 109 cases, *Am J Ophthalmol 63:*134, 1967.
209. Crouch ER: Traumatic hyphema, *J Pediatr Ophthalmol Strabismus 23:*95, 1986.
210. Kennedy RH, Brubaker RF: Traumatic hyphema in a defined population, *Am J Ophthamol 106:*123, 1988.
211. Sneed S, Weingeist T: Suprachoroidal dislocation of a posterior chamber intraocular lens, *Am J Ophthalmol 109:*731, 1990.
212. Lam D, Chua J, Kwok A: Combined surgery for severe eye trauma with extensive iridodialysis, posterior lens dislocation, and intractable glaucoma, *J Cataract Refract Surg 25:*285, 1999.
213. Netland K, Martinez J, LaCour OR, et al: Traumatic anterior lens dislocation: a case report, *J Emerg Med 17:*637, 1999.
214. Shingleton BJ, Hersh PS, Kenyon KR, editors: *Eye trauma*, St Louis, 1991, Mosby–Year Book.
215. Berlin R: Zur sogenannten commotio retinae, *Klin Monatsbl Augenheilkd 1:*42, 1873.
216. Cogan DG: Pseudoretinitis pigmentosa, *Arch Ophthalmol 81:*45, 1969.
217. Crouch ER, Apple DJ: Posttraumatic migration of retinal pigment epithelial melanin, *Am J Ophthalmol 78:*251, 1974.
218. Bastek JV, Foos RY, Heckenlively J: Traumatic pigmentary retinopathy, *Am J Ophthalmol 92:*621, 1981.
219. Friberg TR: Traumatic retinal pigment epithelial edema, *Am J Ophthalmol 88:*18, 1979.
220. Gass JDM: *Stereoscopic atlas of macular diseases*: *diagnosis and treatment*, ed 4, St Louis, 1997, Mosby–Year Book.
221. Kuhn F, Morris R, Mester V, et al: Internal limiting membrane removal for traumatic macular holes, *Ophthalmic Surg Lasers 32:*308, 2001.
222. Yanagiya N, Akiba J, Takahashi M, et al: Clinical characteristics of traumatic macular holes, *Jpn J Ophthalmol 40:*544, 1996.
223. Kelly NE, Wendel RT: Vitreous surgery for idiopathic macular holes: results of a pilot study, *Arch Ophthalmol 109:*654, 1991.

224. Rubin JS, Glaser BM, Thompson JT, et al: Vitrectomy, fluid-gas exchange and transforming growth factor-beta-2 for the treatment of traumatic macular holes, *Ophthalmology 102:*1840, 1995.
225. de Bustros S: Vitreous surgery for traumatic macular hole, *Retina 12:*451, 1996.
226. Ciulla TA, Topping TM: Surgical treatment of a macular hole secondary to accidental laser burn, *Arch Ophthalmol 115:*929, 1997.
227. Garcia-Arumi J, Corcostegui B, Cavero L, et al: The role of vitreoretinal surgery in the treatment of posttraumatic macular hole, *Retina 17:*372, 1997.
228. Madreperla SA, Benetz BA: Formation and treatment of a traumatic macular hole, *Arch Ophthalmol 115:*1210, 1997.
229. Margherio AR, Margherio RR, Hartzer M, et al: Plasmin enzyme-assisted vitrectomy in traumatic pediatric macular holes, *Ophthalmology 105:*1617, 1998.
230. Sheidow TG, Gonder JR: Macular hole secondary to retrobulbar needle perforation, *Retina 18:*178, 1998.
231. Amari F, Ogino N, Matsumura M, et al: Vitreous surgery for traumatic macular holes, *Retina 19:*410, 1999.
232. Chow DR, Williams GA, Trese MT, et al: Successful closure of traumatic macular holes, *Retina 19:*405, 1999.
233. Goffstein R, Burton TC: Differentiating traumatic from nontraumatic retinal detachment, *Ophthalmology 89:*361, 1982.
234. Weidenthal DT, Schepens CL: Peripheral fundus changes associated with ocular contusion, *Am J Ophthalmol 62:*465, 1966.
235. Tasman W: Peripheral retinal changes following blunt trauma, *Trans Am Ophthalmol Soc 70:*190, 1972.
236. McLeod D: Ocular injuries from boxing: what about prophylactic laser coagulation of boxers' retinas? *Br Med J 304:*197, 1992.
237. Steinsaper KD, Goldberg RA: Traumatic optic neuropathy, *Surv Ophthalmol 38:*487, 1994.
238. Frenkel REP, Spoor TC: Diagnosis and management of traumatic optic neuropathies, *Adv Ophthalmic Plast Reconstr Surg 6:*71, 1987.
239. Sanborn GE, Gonder JR, Goldberg RE, et al: Evulsion of the optic nerve: a clinicopathological study, *Can J Ophthalmol 19:*10, 1984.
240. Steinsaper KD, Goldberg RA: *Traumatic optic neuropathy*, ed 5, Baltimore, 1998, Lippincott, Williams & Wilkins, p 5.
241. Park JH, Frenkel M, Dobbie JG, et al: Evulsion of the optic nerve, *Am J Ophthalmol 72:*969, 1971.
242. Chow AY, Goldberg MF, Frenkel M: Evulsion of the optic nerve in association with basketball injuries, *Ann Ophthalmol 16:*35, 1984.
243. Rosenberg PN, Stasior OB: Optic nerve evulsion and transection, *Adv Ophthalmic Plast Reconstr Surg 6:*63, 1987.
244. Wolin MJ, Lavin PJM: Spontaneous visual recovery from traumatic optic neuropathy after blunt head injury, *Am J Ophthalmol 109:*430, 1990.
245. Fuller B, Gitter K: Traumatic choroidal rupture with late serous detachment of the macula, *Arch Ophthalmol 89:*354, 1973.
246. Smith RE, Kelley JS, Harbin TS: Late macular complications of choroidal ruptures, *Am J Ophthalmol 77:*650, 1974.
247. Hilton GF: Late serosanguineous detachment of the macula after traumatic choroidal rupture, *Am J Ophthalmol 79:*997, 1975.
248. Saar I, Raniel J, Neumann E: Recurrent corneal oedema following late migration of intraocular glass, *Br J Ophthalmol 75:*188, 1991.
249. Ralph RA: Chemical burns of the eye. In Tasman W, Jaeger EA, editors: *Duane's clinical ophthalmology*, Philadelphia, 1983, JB Lippincott.

8

Enhancement of Visual Skills in Sports

CHAPTER OUTLINE

Areas of Visual Performance Enhancement for Sports
Overview of Vision Enhancement Training
- Training Hierarchy for Procedures
- Athlete/Patient Selection
- Delivery of Visual Performance Enhancement Training
- Expectations of Visual Performance Enhancement Training

Vision Skill Remediation and Enhancement
- Visual Sensitivity: Acuity and Contrast Sensitivity
  - Lens Sensitivity
  - Howard-Dolman Sensitivity
  - Prism Sensitivity
  - Haidinger Brush Fixation
  - Blur Interpretation Activities
- Dynamic Visual Acuity
  - Rotators with Disks and Charts
  - Wayne Tachistoscope Rotator Activities
  - Pitchback with Ball and Letters
- Accommodation and Vergence Facility
  - Distance Rock
  - Lens Rock
  - Prism Rock
- Eye Movements
  - Pursuit Eye Movements
  - Saccadic Eye Movements
- Speed and Accuracy of Depth Perception
  - Brock String
  - Howard-Dolman Training
  - Simulated Depth Activities
  - Fixation Disparity
  - Spatial Localization
- Speed of Recognition
  - Tachistoscopic Training
  - Stroboscopic Training
- Visual-Motor Reaction/Response (Eye-Hand, Eye-Foot, Eye-Body Coordination)
  - Electronic Devices
  - Visual-Motor Reaction/Response Games
- Peripheral Vision
  - Wayne Peripheral Awareness Trainer
  - Spatial Localization Techniques
  - Split Attention Activities
  - Juggling
  - Yardstick Saccades
- Coincidence-Anticipation Skills
  - Bassin Anticipation Timer/Wayne Speed-trac
  - Stroboscopic Training

Summary

Significant interest exists regarding improving sports performance by using training procedures to enhance vision because visual skills are readily identified as a critical element to most sports performance. Chapter 4 provides support for the contention that athletes typically have better visual abilities than nonathletes and that top athletes benefit from visual abilities that often are superior to lower level athletes. Visual performance enhancement training has similar goals of transferring improvements in function to athletic performance as do other

areas of performance training, such as strength training, conditioning, speed and agility training, nutritional regimens, and sports psychology.[1] The relevant questions are whether visual abilities can indeed be trained and whether any improvements in visual skills transfer to improved sports performance by the athlete.

Many of the visual attributes identified as important in sports are amenable to training. This chapter presents visual performance enhancement procedures for each of the visual skill areas, including any relevant laboratory and clinical research regarding skill improvement for these visual skills. Although few studies have attempted to demonstrate the transfer of visual skill improvement to actual sport performance, isolating one area of intervention as solely responsible for any changes in performance is quite difficult. Many of the reports in the literature are anecdotal, and many studies have significant flaws in the research design that preclude a definitive result. The incomplete information regarding the efficacy of visual performance enhancement training clearly illuminates the need for more conclusive evidence.

AREAS OF VISUAL PERFORMANCE ENHANCEMENT FOR SPORTS

Visual performance enhancement training procedures can be selected to accomplish the following potential goals of training:

1. Remediation of vision inefficiencies that may have a negative impact on performance consistency.
2. Enhancement of vision skills deemed critical to optimal sports task performance.
3. Enhancement of visual information processing skills to facilitate rapid utilization of critical visual information.
4. Enhancement of visuomotor proficiency, when indicated, for sports task performance.
5. Enhancement of cognitive functions that are critical for visual decision making during competition.[2]

To determine the appropriate goals for an individual athlete, a thorough case history and sports vision evaluation must be completed. As discussed in Chapters 2 and 4, the sports vision practitioner must identify the vision factors essential to performance of the tasks critical for success in the sport and evaluate the quality of those skills in the most appropriate, accurate, and repeatable manner. A vision skill performance profile is recommended to communicate the relative strengths and weaknesses demonstrated by the athlete on the sports vision evaluation, as described in Chapter 5. The vision skill performance profile can be used to develop readily measurable, specific goals for the vision enhancement program to determine skill improvement. These goals should be consistent with the information processing model of skilled motor performance discussed in Chapter 3, and each training procedure should be scrutinized to determine any impact on the three central processing mechanisms: the perceptual mechanism, the decision mechanism, and the effector mechanism (see Fig. 3-1).

The athlete with identified visual deficiencies should logically expect improvement in affected aspects of sports performance if those deficient skills are improved to average performance levels. A review of the literature in 1988 concluded that, "it is evident from the research presented that there is sufficient scientific support for the efficacy of vision therapy in modifying and improving oculomotor, accommodative, and binocular system disorders, as measured by standardized clinical and laboratory testing methods, in the majority of

patients of all ages for whom it is properly undertaken and employed."[3] This conclusion was further supported by Ciuffreda in 2002.[4] Therefore vision therapy designed to remediate vision deficits is an essential element in the comprehensive vision care of an athlete, and a successful result should improve the function of the perceptual mechanism.

The athlete who possesses average, or even above-average, vision skills presents a compelling and controversial challenge. Can the vision skills of this athlete be enhanced above the current level, and would this perceptual mechanism skill enhancement result in demonstrable improvements in sports task performance? A recent review of the literature concluded that most normal visual functions can be improved by specific training paradigms, although thousands of trials may be required to demonstrate enhancement.[5] Several studies have reported positive effects of vision training programs on sports-specific tasks,[6-9] and some have not found improvement in performance.[10-12] The differences in study results are speculated to be caused by varying athlete skill levels (novice versus expert subjects) and the use of general versus specific vision training programs. In addition, research design factors in all these studies weakened the results and conclusions, indicating the need for further study in this area of sports vision.

Many vision enhancement training programs attempt to improve overall processing of visual information. Ultimately, the goal of the training procedures is to improve the speed and efficiency of the decision mechanism. This mechanism requires the athlete to know where crucial visual information exists, be able to direct attention to those crucial elements, select the best information from all that is available, organize and interpret the information in the most appropriate manner based on experience and memory of similar situations and information, and select the most accurate response with consideration of an anticipated action plan. Many studies have demonstrated that experienced athletes develop an organization of common sport situations into a knowledge architecture that offers many advantages, including the ability to process larger quantities of information in a short amount of time and the possibility of priming the perceptual and effector mechanisms for subsequent information.[13-19]

Many sports require the translation of visual information into motor responses. For example, a tennis player must identify the anticipated trajectory of the opponent's serve when the ball is struck and initiate the appropriate motor sequence to respond to that serve. Training procedures that provide feedback regarding eye-hand, eye-foot, balance, and/or eye-body responses may assist the athlete in developing improved speed, efficiency, and automaticity of visuomotor response. This type of motor learning is thought to be the result of improved synaptic efficiency,[20] and performance feedback is considered a critical element of enhancing performance of the perceptual and effector mechanisms.[20,21]

The ability to modulate attention appropriately, and often split attention among multiple stimuli,[22] is another valuable function of the decision mechanism in the information processing model. Many vision enhancement training procedures provide the opportunity for feedback to the athlete to facilitate development and control of visual attention. In addition, as expertise is developed in a sport, the complex knowledge structures acquired facilitate expanded and enhanced use of mental imagery strategies. Mental rehearsal is the act of constructing mental images of an event, commonly used by elite athletes in preparation for performance.[22-26] Studies have demonstrated that mental imagery may share the same types of neural processes as visual perception, which has significant implications in sports.[27] Sport psychologists, and some sports vision practitioners, use methods designed to improve

the mental imagery capacity and use by athletes,[27-30] although only anecdotal evidence supports the validity of this approach.

Many goals are possible for a vision enhancement training program; some are hierarchical and necessitate a sequential strategy for use of specific procedures. The information processing model detailed in Chapter 3 can provide a framework for understanding the connection between the specific procedures and visual performance factors and ultimately to sports performance.

OVERVIEW OF VISION ENHANCEMENT TRAINING

Once a visual performance profile has been completed and specific training goals have been established, specialized training procedures can be selected to accomplish those goals. Many idiosyncratic approaches to the selection of training procedures are available, from generalized programs administered to every athlete to precise, diagnosis-specific and task-specific individualized programs that are largely unique to the exact needs of each athlete. Each sports vision practitioner develops the approach that best suits his or her mode of practice; however, universal guidelines exist for visual performance enhancement training that should be heeded.

Training Hierarchy for Procedures

The development of a visual performance enhancement training program requires the practitioner to establish a series of procedures designed to improve, and progressively challenge, the visual skill(s) targeted for enhancement. The most important requirement of selecting training procedures is that the activity being performed must directly relate to specific task demands of the sport. The athlete will rarely invest the requisite effort needed for vision skill enhancement if the purpose of the procedure is not understood and correlated with sport performance.

Basic skill development procedures should be performed before challenging the athlete with more multifaceted demands. The visual skill targeted for enhancement should initially be isolated to allow the athlete to become aware of the visual response. With awareness of a visual response, strategies to improve the quality of the visual response should be discussed and practiced. An additional benefit of visual response awareness is the salutary effect on locus of attention; athletes can develop better control over modulation of attention during performance. Once a high quality of visual response is consistently demonstrated, the athlete should be pushed to increase the speed of the response while maintaining quality. The actual visual demands of the sport tasks should be considered when prescribing the training procedures; most visual demands encountered in sports occur well beyond arms' length and in nonprimary gaze positions. Therefore many sports vision training procedures are designed to have viewing distances greater than 3 m, and gaze position is adjusted to match the ergonomic demands of the sport. For example, training activities for a volleyball player would be modified to have the targets presented at far and in upgaze positions to simulate the demands frequently encountered in volleyball.

The ultimate goal of the training program is to achieve an effortless, reflexive level of performance excellence in the targeted visual response ability—a level sometimes referred to as *automaticity of response*.[31-33] The amount of attention that an individual must devote to accomplishing a task is a key variable in determining how automatic the response process is.

A high level of automaticity allows the athlete to allocate attentional resources from visual performance factors to other critical aspects of performance. Many methods are used in an effort to build automaticity of visual responses in a training program, most of which attempt to simulate the sport tasks ergonomically and divert attention to additional tasks.

Many sports require the athlete to process visual information that is in motion and/or while the athlete is in motion. Training procedures that may initially be performed under static conditions therefore can be altered to add dynamic elements, such as incorporating movement of the target or athlete during performance. Automaticity of a visual skill response is often encouraged by modifying the training procedure from a paradigm of skill isolation to integration of additional visual skill demands. For example, the athlete attempts to fuse a projected vectogram that produces a relative base-in vergence demand at 5 m after the introduction of minus lenses. Incorporating additional sensory demands is also common while performing a training procedure to match the ergonomic demands encountered in the sport situation more closely and build automaticity of the visual response. Common sensory integration demands include the addition of balance activities, auditory processing tasks, and increasing levels of cognitive processing and distractions. These sensory integration demands serve to increase the stress experienced by the athlete and require the reallocation of attentional resources. Specific examples of all these automaticity variables are presented throughout this chapter.

The ultimate goal of visual performance enhancement training is to transfer visual skill improvements to the field of play. The practitioner should discuss strategies to facilitate skill transfer with the athlete. Many of the approaches discussed for increasing automaticity of visual performance skills also provide a means of assisting transfer. For example, when an athlete can perform a visual task at a superior level despite many sensory integration demands, distractions, and stress loaded onto the activity, the more likely the athlete's visual system will continue to perform at an optimal level during high-stress moments of competition and despite significant physical fatigue. Athletes, athletic trainers, coaches, and other ancillary personnel can be invaluable resources for assisting in the development of on-field modifications to training procedures, thereby providing additional support for the transfer of skill improvements.

Athlete/Patient Selection

A visual performance enhancement training program provides the athlete with the conditions and opportunity for improvement of critical visual skills; the equipment or activities themselves do not cause the changes in performance. A baseball player can spend many hours in batting practice to develop the requisite skills for success, but if proper coaching is not available the athlete may simply reinforce inefficient or ineffective skills. Similarly, an innovative new bicycle does not allow an athlete such as Lance Armstrong to win the Tour de France; the effective use of that bicycle, unflagging motivation, and many other intangibles culminate in success. Therefore athletes should be thoroughly counseled regarding the commitment required for a successful outcome from a visual performance enhancement training program. A typical program will require frequent training sessions and many hours of quality practice to enhance visual performance successfully, and the athlete needs to fully understand the nature of this commitment. If the practitioner is not convinced that the athlete possesses the essential resources of motivation, time, and support for success with a

visual performance enhancement training program, the athlete should seek other approaches for enhancing sports performance.

Similar to most physical and psychological enhancement programs, the more quality effort the athlete invests in the program, the greater the potential impact on sports performance. The athlete must have the motivation to devote sufficient time and energy into developing the targeted visual skills to achieve a successful outcome. A dedicated support network (e.g., coaches, parents, teammates, family, friends) is an invaluable asset for sustaining the motivation of an athlete throughout the course of the enhancement program. Members of the support network can also serve as training partners for the athlete when practicing visual performance activities between training sessions. One of the best methods of generating motivation is excellent education regarding the connection between visual skill performance and sport performance. For example, the better the golfer understands how reduced depth judgment ability affects putting performance, the better the motivation will be to improve that visual skill. This also applies to the athlete's support network because coaches and teammates can provide valuable performance feedback and reinforcement of proper skills during practice and competition.

Specific training goals should be established before initiating an enhancement program, and measurable outcomes are desirable in determining program success. Training goals must be as task specific as possible. For example, rather than the point guard in basketball setting a goal of being a better playmaker, establish a goal of improving her ability to process more peripheral visual information when bringing the ball up the court. These specific sports goals should be matched with goals of improving the requisite and measurable visual performance skills necessary for success. Once the specific goals have been determined, more global competitive aspirations can be recognized to assist in motivating the athlete. For example, the basketball player may wish to be the starting point guard on her team, garner a college scholarship, or be drafted by a professional team. No matter what level of competition the athlete is in, visual performance goals can be established to provide a potentially critical competitive edge for peak performance.

Delivery of Visual Performance Enhancement Training

Many approaches can be used for the delivery of sports vision training. Most practitioners use one-on-one training sessions to assess the athletes' current visual skill performance and push the demand level of those skills to a higher level. These sessions are typically conducted by the eye care practitioner or a trained assistant. Others develop training programs to be delivered to a team or group of athletes simultaneously, although this approach reduces the ability to adjust the training program to each athlete's individual visual performance needs. Once the threshold of performance ability is determined during a training session, activities are customarily prescribed to allow the athlete to practice at that high demand level until the next session. A regular schedule of progress evaluations should be established to assess subjective changes in sports performance periodically, as well as changes in objective visual performance skills. These progress evaluations serve to reinforce training goals, maintain athlete motivation, and determine when specific goals have been achieved.

When a visual performance enhancement training program is recommended to an athlete, an estimated treatment time should be determined. The practitioner and the athlete can then agree on the appropriate frequency of one-on-one training sessions, the length of time for each session, and the location for the sessions. Depending on the intensity of the

training program and the availability of the athlete, training sessions may occur two to three times per week or every 2 to 3 weeks. Each training session usually lasts at least 30 minutes and may be scheduled for up to 90 minutes if needed. The practitioner typically delivers the training program at his or her office, where equipment and supplies are located; however, receiving the training at the athlete's training facility may be more convenient for the athlete. A candid discussion of the advantages and disadvantages of the available location options should occur and an agreeable solution reached before initiating the training program. Prescribed out-of-office training activities typically require an average of 30 minutes each day of dedicated practice and should be integrated with any existing training programs (e.g., weight training, speed training, skills practice) if possible. The incorporation of visual skills training with other training programs can help with compliance and transfer of skill improvements to sports performance. The athlete should understand that the quality and frequency of out-of-office practice are what produce the greatest impact on skill development and that the athlete should not assume that the one-on-one training sessions alone will improve performance.

Expectations of Visual Performance Enhancement Training

As previously mentioned, specific training goals should be established before initiating an enhancement program, and training goals should be as task specific as possible. If these goals are reasonable and the potential outcomes of the training program are clear, the athlete is more likely to have a realistic expectation of the benefits of committing to the training program. If the athlete has unrealistically high expectations or the practitioner makes unrealistic promises, disappointing results are inevitable. The practitioner and athlete should acknowledge that the training program is designed to improve only one aspect of sports performance. Even though vision may be a critical factor for successful sports performance, many other aspects may hinder performance. If the practitioner makes unrealistic promises and is not successful in achieving those goals, the program will not be perceived as successful by the athlete and his or her support network. If the athlete perceives that visual performance enhancement training is unsuccessful, that perception will be difficult for the practitioner to overcome when it is communicated to others in the sporting community. The old adage that it is better to underpromise and overdeliver is particularly relevant when setting goals and promising outcomes from enhancement programs.

VISION SKILL REMEDIATION AND ENHANCEMENT

Many practitioners have contributed suggestions and ideas for visual performance enhancement procedures over the years to the collective community of sports vision practitioners. The origins of each procedure or modifications of a procedure are often hard to identify, making proper credit difficult. The following suggested procedures have been culled from publications, lectures, and professional interactions, which makes identification of individual sources even more difficult. Although the following procedures do not represent all training procedures that have been developed, they have all been found to be effective by the author in clinical practice.

Visual Sensitivity: Acuity and Contrast Sensitivity

The primary goal of training is to improve the athlete's ability to discriminate subtle detail in the sport environment. Many examples in sports exist in which an athlete must judge

finely detailed information to determine the most appropriate response. For example, the more sensitive a golfer is to the subtle contours of the green, the better his or her judgment will be of the optimal putt trajectory. This example of putting includes resolution of the details of the green, as well as any muted contrast changes induced by the surface contours and variations in the grass. Several procedures encourage interpretation of blurred images, which may also help extract detailed information from a rapidly moving object.

Ample evidence shows that the ability to resolve detail can be enhanced with practice, both for foveal detail[34-44] and parafoveal information.[45-51] Most of the studies have involved blur interpretation in subjects with myopia; however, most studies did not find a change in refractive status from the training.[34,44,52-54] Contrast sensitivity function has also been shown to be amenable to enhancement with practice,[40-42] as has vernier acuity.[51,55,56]

Lens Sensitivity

This procedure introduces lenses of varying powers that the athlete must classify while viewing a distant target. This procedure is performed monocularly to eliminate the interaction with the vergence system, and the choice of fixation targets should relate to the task demands of the sport. For example, having a golfer fixate a golf ball positioned 3 to 6 m away rather than a chart of letters is preferable to simulate the visual task demands of golf. The athlete is asked to distinguish how the lens affected his or her view of the target. The athlete is encouraged to notice induced changes in size, location, and clarity of the target. Improved sensitivity to lens-induced changes of spatial information is theorized to have a salutary impact on depth discrimination because these monocular cues to depth are abundant in many sports tasks (e.g., catching a fly ball in baseball). An athlete may also notice a difference in the amount of effort required to achieve clarity with minus lenses, and this additional information should provide enough cues to discriminate a –0.25 D difference in lens powers. To promote improved sensitivity to retinal image size without the feedback from the accommodative system, iseikonic lenses can be substituted. Iseikonic lenses allow comparison of small changes in image size without changing the focusing demand for the target. Ultimately, sensitivity to 0.12 D and 0.5% magnification or minification changes should be the goal for sports requiring detail discrimination or precise depth judgments. Targets can also be presented in the athlete's periphery to stimulate improved sensitivity to peripheral discrimination, which may be valuable in sports such as downhill skiing.

As discussed in Chapter 3, the perception of motion in depth is partially produced by a changing retinal image size information system that operates relatively independently of the changing retinal disparity system.[57-59] Human beings possess cortical neurons that are selectively sensitive to changing image size, and these "looming" detectors provide a significant amount of information for judging time to contact even under monocular viewing conditions.[60,61] Binocular viewing has been shown to offer advantages in catching or hitting a ball[62-64]; however, monocular catching ability can be trained to similar skill levels as binocular viewing.[65] For sports that require an athlete to make rapid depth judgments of approaching objects (e.g., a tennis ball), sensitivity to subtle changes in image size may provide a valuable advantage.

Howard-Dolman Sensitivity

A Howard-Dolman apparatus can be used to enhance sensitivity to monocular cues to depth. A traditional Howard-Dolman device is a modification of the apparatus designed to measure the empirical longitudinal horopter and uses two rods of equal size and color to be

viewed in primary gaze position through an aperture in a rectangular box of a homogeneous color (see Fig. 4-4).[66-68] The athlete makes depth judgments concerning the apparent location of the two rods under monocular viewing conditions instead of the traditional binocular method. This procedure can be further modified for sports purposes by substituting two identical balls or objects, such as golf balls, tennis balls, or shooting clays.[1] The initial goal of training is to refine the athlete's sensitivity to subtle monocular cues to depth. The athlete is then obligated to make the depth judgments in progressively shorter periods (tachistoscopic presentation).

Prism Sensitivity

Low amounts of prism are used to increase visual sensitivity to target movement in a similar manner as lens sensitivity. A prism is introduced monocularly, with a random orientation of the prism base, while the athlete views a fixation target such as a golf ball, soccer ball, or shooting target. The initial goal for the athlete is to detect the direction of the target movement induced by the prism. As the athlete becomes more accurate in identifying spatial shifts stimulated with very small amounts of prism (e.g., 0.5^{Δ} to 1^{Δ}), the athlete is encouraged to make those fine judgments in progressively shorter time intervals.

Haidinger Brush Fixation

In sports that require steadiness of fixation, such as target shooting, the visual biofeedback provided by the entoptic phenomenon of a Haidinger brush can be valuable. The perception of the Haidinger brush is generated by variable absorption of plane-polarized light by Henle's fiber layer of the macular retina.[69] The athlete learns to maintain accurate and steady fixation of the Haidinger brush and achieves a proper state of concentration, reducing the tendency for fixation to drift off target. Di Russo et al[70] demonstrated that elite shooters possess better fixational ability than do novice shooters and can maintain accuracy of fixation despite the presence of distractions.[70] A macula integrity tester-trainer is a commercially available device that produces the entopic phenomenon; many slides are available that contain various fixation targets (Fig. 8-1). The athlete should become aware of the feeling required for the proper concentration needed to maintain accurate and steady fixation to reproduce that level of concentration during sport practice and competition. As the accuracy and steadiness of fixation improves, distractions should be introduced during Haidinger brush training to simulate competition conditions and build automaticity of concentration and fixation.

Blur Interpretation Activities

Many studies have successfully demonstrated the ability to improve the threshold visual acuity level in subjects after a course of training.[34-43] The procedures used to improve acuity generally involve the reduction of target size or clarity to a level that is barely subthreshold for the subject, and then guessing is encouraged as the targets are changed. Ample feedback is provided with each guess until the accuracy of target discrimination improves to a satisfactory level, at which time the target size or clarity is further reduced to a subthreshold level. When using this paradigm with athletes, the ability to discriminate subtle details from blurred or minuscule targets is enhanced. In sports that require rapid discrimination, such as batting in baseball, tachistoscopic presentation of stimuli is introduced as each level of performance is mastered.

Many targets and methods for reducing image clarity can be used to enhance the sensitivity of visual discrimination (Box 8-1). Random sequences of letters and numbers can be printed from a computer by using progressively smaller font sizes, and those targets can be

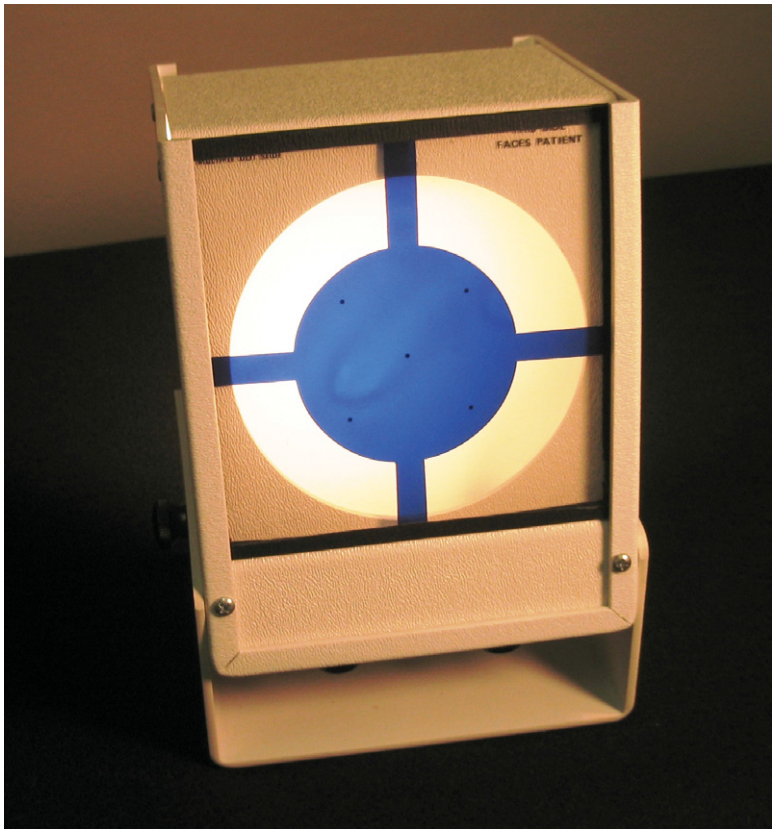


Figure 8-1. The macula integrity tester-trainer with fixation slide.

held at increasing distances from the athlete as he or she attempts to discriminate the targets. The targets can be further degraded by having the subject view through filters that decrease the amount of visible light transmission or by reducing the light levels on the targets, thereby increasing the demand on contrast sensitivity to discriminate the targets. The athlete can also wear lenses that induce blur, such as lenses that overplus the athlete or lenses with

BOX 8-1 VISUAL DISCRIMINATION DEMANDS

Threshold acuity targets or distance
Bangerter foils
Degraded optics (e.g., stippled lenses)
Lenses with excessive plus power
Lenses with excessive minus power (minification)
Iseikonic lenses
Dark filters
Reduced light levels



Figure 8-2. Bangerter foils to reduce vision through a patient's spectacles.

degraded optics (e.g., stippled lenses). Bangerter foils can also be used to provide a graded reduction in acuity through the lenses (Fig. 8-2). These same acuity-degrading lenses can be worn during practice sessions of the athlete's sport (e.g., during putting practice in golf), and the athlete can experience the perceived enhancement of visual discrimination when the lenses are removed. The safety of the athlete must be preserved during this activity, especially when a risk to the athlete is present, such as during batting practice in baseball. As described with the other visual sensitivity training activities, tachistoscopic presentation of stimuli is an important step for enhancing the speed of visual discrimination.

As previously discussed, incorporating additional sensory demands while performing these visual sensitivity training procedures is essential to match the ergonomic demands encountered in the sport situation more closely and build automaticity of the visual response. Many of these procedures allow the practitioner to include the addition of balance activities, auditory processing tasks, and increased levels of cognitive processing and distractions to increase the stress experienced by the athlete (Box 8-2). Balance activities typically entail the use of balance boards (Fig. 8-3) or walking rails (Fig. 8-4). The training effect from

BOX 8-2 SENSORY INTEGRATION BURDENS

Balance board
Walking rail
Auditory "noise" stress
Auditory integration (e.g., metronome)
Cognitive challenges (questions)
Peripheral vision processing
(e.g., beanbags)

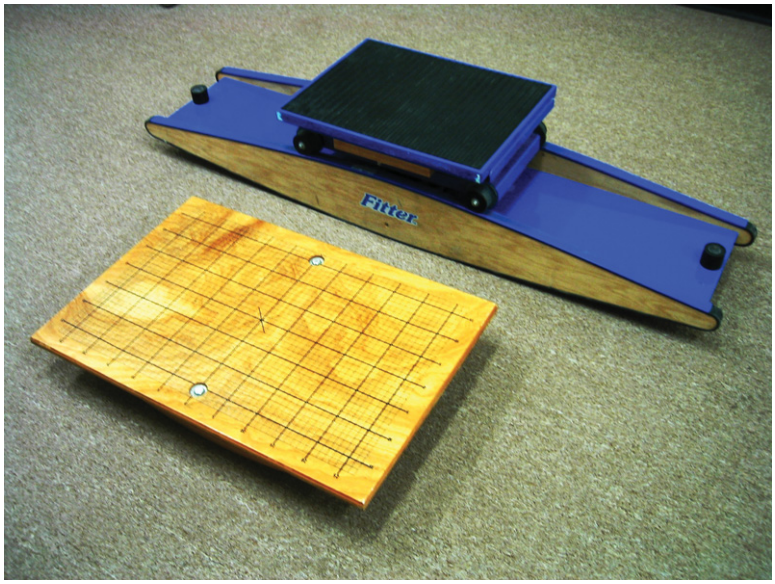


Figure 8-3. Two types of commercially available balance boards.



Figure 8-4. An adjustable walking rail.

these types of procedures has been shown to transfer to stimuli not used during training[37-39,43] and to improvements in contrast sensitivity function.[40-42] Evidence also exists that the training effect is produced at a level beyond the retina because the training effect has been shown to transfer to an untrained eye.[37,44]

Dynamic Visual Acuity

Many sports require the athlete to discriminate visual information that is moving, such as judging the speed and trajectory of a tennis serve. Traditional static visual acuity training may not fully address the visual demands encountered in some types of sports. Athlete attributes that can affect dynamic visual acuity include the resolving power of the retina (visual sensitivity), peripheral awareness, oculomotor abilities (pursuit and saccadic eye movements), and psychological functions that affect interpretation of visual information.[71-95] Dynamic visual acuity has been shown to be improvable with training,[96,97] with the training effect being most evident for the most challenging stimuli and tasks used in the studies.[97] Enhancement training for dynamic visual acuity frequently is recommended for athletes.[1,5,98-104] However, the nature of the training varies tremendously, and few instruments are available to generate the necessary targets. Some practitioners recommend using targets that move toward the athlete,[98] and some advocate for rotational targets.[1,98] Incorporation of a tachistoscopic presentation of the moving stimuli is valuable in sports for which the athlete must quickly fixate critical visual information and discriminate vital details, as in judging the trail contours when mountain biking.

Rotators with Disks and Charts

Target size is selected at a level that is at threshold for the athlete, and the target is placed on a rotating disk (see Fig. 4-1) and rotated at a speed that is too fast for the athlete to discriminate the target. Many targets can be used to enhance the sensitivity of visual discrimination while the targets are in motion. The athlete is encouraged to guess what the target is as the speed is slowly reduced to the point where accurate discrimination is achieved. Ample feedback is provided with each guess until the accuracy of target discrimination improves to a satisfactory level, at which time the target size is further reduced to a new threshold level. When using this modified paradigm of method of limits, the ability to discriminate subtle details from rapidly moving targets is enhanced. This approach is meaningful in sports in which the movement of the target is mainly predictable (e.g., a baseball pitch); however, it may have a limited benefit in unpredictable sports (e.g., downhill skiing). Additional visual discrimination demands and sensory integration burdens can be added to this task, as previously described with blur interpretation activities.

Wayne Tachistoscope Rotator Activities

The Wayne Tachistoscope Rotator Scanner (www.wayneengineering.com) is composed of two prisms that can be rotated in front of a Perceptamatic tachistoscope lens (Fig. 8-5). The speed at which each prism rotates can be adjusted between 20 and 240 rpm, allowing a projected image to move in a variety of directions. A variety of slide reels are available with images of numbers, arrows, patterns, and sports images (e.g., football, baseball pitches). These images can be presented for durations between 1 second and 0.01 second, facilitating the training of short-exposure dynamic visual acuity.

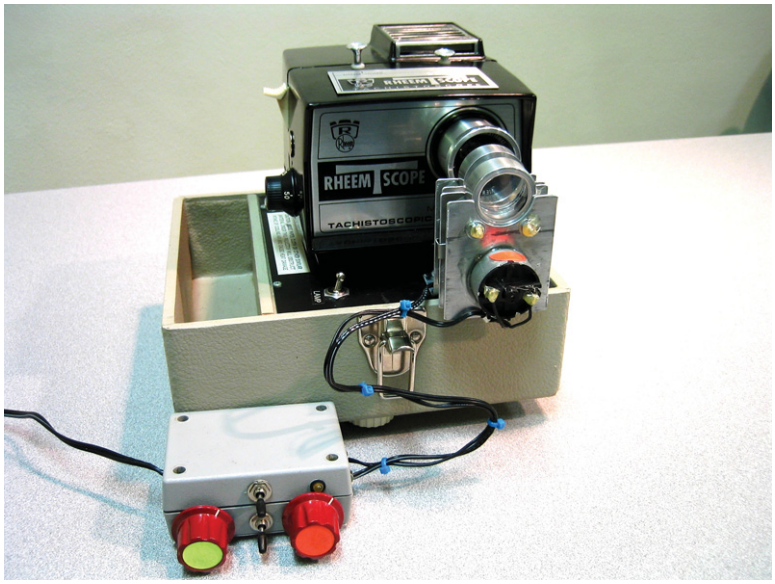


Figure 8-5. The Wayne Tachistoscope Rotator Scanner.

The athlete is placed at a distance from the images that approximates a threshold visual acuity demand and is then shown the area where the projected image will appear. With an auditory cue, the image is presented for a predetermined exposure time while the image is moving in a direction determined by the rotation of the prisms. The athlete must locate and fixate the moving image and maintain fixation with a pursuit eye movement during the exposure of the image to resolve the detail in the slide. Additional visual discrimination demands and sensory integration burdens can be added to this task, as previously described with blur interpretation activities. Furthermore, asking the athlete to respond to the target stimuli with an appropriate motor response is often beneficial. For example, with a slide of a tennis serve, the athlete is instructed to move into a backhand or forehand return position in response to the anticipated trajectory of the serve.

The use of ergonomically appropriate targets is preferred; however, few sport-specific images are available. Real-time video images presented tachistoscopically would produce a better simulation of the dynamic visual acuity demands encountered in a sport; however, considerable resources are required to develop a library of appropriate footage from the athlete's visual perspective.

Pitchback with Ball and Letters

A rubber baseball with letter stickers placed randomly around the ball is used for the pitch-back procedure (Fig. 8-6). The athlete throws the ball into a pitchback net and attempts to locate and fixate one of the letters on the ball during the return flight. As the athlete's ability to discriminate the letters improves, the ball is thrown faster into the net; more spin can be induced by the athlete during the throw. To add a level of unpredictability to the task, the ball can be thrown by another person, thereby requiring the athlete to rapidly judge the speed and trajectory of the ball during flight. Once the athlete can demonstrate consistently



Figure 8-6. A rubber baseball with letter stickers in front of a pitchback.

accurate ability on this task, additional visual discrimination demands and sensory integration burdens can be added. If a pitchback is not available, the athlete can either have someone throw the ball back, bounce the ball against a wall, or throw the ball high in the air to simulate the sport demands.

Accommodation and Vergence Facility

Accommodative and vergence facility training procedures aspire to improve the ability to rapidly adjust focus and eye alignment for the variety of fixation distances encountered in sports. Two principal methods are used to change accommodative and vergence demands: the use of lenses or prisms to alter the accommodative and vergence demands at a fixed distance; the use of charts or targets at different distances, with fixation being rapidly alternated between the targets. When lenses are introduced the accommodative system must adjust ciliary muscle tonus to regain image clarity; however, the vergence system must remain aligned with the plane of the target to prevent diplopia. This separation of accommodation and vergence is a common method to train relative accommodative facility binocularly at near in patients with asthenopia during near work.[105-107] However, it is not generally representative of the visual task demands experienced in sports. Charts or targets placed at different distances allow the accommodative and vergence responses to remain paired. Therefore procedures that use targets at a variety of different distances may be more appropriate for enhancing the strength and flexibility of focusing and eye alignment in athletes. If a student athlete has symptoms of asthenopia during near work, the more traditional use of lenses and prisms may be warranted to alleviate those symptoms.

Distance Rock

Charts with random letters (Fig. 8-7) are placed at a relatively far distance from the athlete, usually more than 10 feet, and at a near distance, usually within 50 cm. The athlete stands as



Figure 8-7. Hart's revised vision chart.

far away from the distant chart as possible while still being able to read the letters. The athlete should start by holding the near chart with reduced images at arm's length and slowly move it closer until the letters are too blurred to recognize. The athlete should take 2 to 3 seconds to try to clear the letters before adjusting the chart to a slightly farther distance, where the letters can again be cleared. The task requires the athlete to then clear and call out successive letters on each chart alternately as rapidly as possible, making sure to achieve maximal visual clarity with each fixation. This procedure initially can be performed monocularly to equalize accommodative facility in each eye individually, and the choice of viewing distance and positions of gaze should be based on the task demands of the sport. Once the athlete can demonstrate consistently accurate precision and speed on this task, additional visual discrimination demands and sensory integration burdens can be added. The use of a metronome is a particularly effective method for enhancing auditory-visual integration, and increasing the pace of the metronome can generate performance stress similar to athletic competition. When adding a metronome to this procedure, the athlete is challenged to call out a letter on each successive chart correctly with the beat from the metronome.

Lens Rock

A chart with random letters or words (e.g., reduced Hart chart, accommodative rock cards) is placed at a near distance, usually 40 cm. Lenses of various powers are placed in front of the athlete's eyes, and the athlete is instructed to make the letters or words clear again as rapidly as possible. The athlete should be able to feel the difference between when accommodation is stimulated and when accommodation is relaxed. Monocular lens sorting is a useful procedure

for developing awareness of accommodative effort. Lens sorting requires the athlete to organize a variety of loose lenses into a sequence based on power. For example, a series of minus lenses is provided ranging from −0.50 D to −4.00 D in 0.50 D steps. The athlete is instructed to clear a designated target through each lens; based on the apparent changes in image size and the accompanying feeling of accommodative effort, the athlete arranges the lenses from the weakest to the strongest power. A typical goal is sensitivity to differences of 0.25 D.

Lens rock procedures are usually performed monocularly at first, and binocular lens rock procedures are introduced once an acceptable level of performance is achieved monocularly. Lens flippers of various powers are used for binocular training; one side of the flippers contains minus lenses and the other side has plus lenses. Once the athlete can demonstrate consistently accurate precision and speed on this procedure, additional visual discrimination demands and sensory integration burdens can be added.

The goal of lens rock training is to increase the speed and accuracy of the accommodative response induced by the lenses. Although remedial vision therapy for accommodative dysfunctions emphasizes development of the ability to clear relatively large lens powers rapidly (e.g., +2.50/−2.50 D), this may not offer a significant advantage for an athlete during sports performance. As previously mentioned with lens sensitivity procedures, sensitivity to subtle changes in image size may provide a valuable advantage through enhanced sensitivity to monocular cues to depth. Therefore awareness of image size changes with brisk accommodative changes may yield supplementary performance benefits above the traditional goal of extending the range of accommodation.

Prism Rock

Prism sensitivity should be performed before initiating training with prism rock procedures to ensure that the athlete can accurately identify spatial shifts stimulated with very small amounts of prism (e.g., 0.5^{Δ} to 1^{Δ}). Prism flippers of various powers are used for vergence facility training; one side of the flippers contains base-out prisms, and the other side has base-in prisms. A threshold acuity target is placed at an appropriate distance based on the task demands of the sport. One side of the prism flippers is placed in front of the athlete's eyes, and the athlete is instructed to make the target single and clear again as rapidly as possible. The athlete should be able to feel the difference between a positive and negative fusional vergence demand. Once the athlete can demonstrate consistently accurate precision and speed on this procedure, additional visual discrimination demands and sensory integration burdens can be added.

The goal of prism rock training is to increase the speed and accuracy of the vergence response induced by the prisms. Although remedial vision therapy for vergence anomalies emphasizes development of ability to rapidly fuse relatively large prism powers (e.g., 10^{Δ} base out/10^{Δ} base in), this may not offer a significant advantage for an athlete during sports performance. Similar to lens rock procedures, awareness of image size changes and apparent spatial localization shifts induced with brisk vergence changes may yield supplementary performance benefits beyond the traditional goal of extending the range of fusional vergence. The athlete is encouraged to localize the perceived location of the target through each prism power to provide feedback regarding spatial judgments.

Eye Movements

The ability to maintain fixation of a rapidly moving object is frequently a critical aspect for allowing visual processing of crucial information in sports. The ability to change fixation

from one location to another rapidly and accurately is also an essential aspect of many sports tasks. In nondynamic sports such as precision target shooting, the ability to maintain steady fixation is a vital aspect of successful performance. Many training procedures have been developed to provide feedback regarding performance accuracy and speed of eye movements. Most of these procedures applied to athletes are modified therapy procedures originally designed to improve deficient eye movements in children, and the primary goal for these procedures is to improve eye movement efficiency for reading-type tasks.[105-107] The Haidinger brush fixation activity previously described can be used to enhance control of fixation steadiness by providing direct visual feedback. A task analysis of the specific eye movement demands involved in an athlete's sport gives the practitioner essential insight that can be used to modify therapy procedures to target specific sport-related eye movement skill development.

Poor eye movement control is difficult to find in a successful athlete; this deficiency is more commonly found in the emerging youth athlete who is attempting to acquire performance skills. These young athletes are more apt to yield significant benefits from training procedures directed at improving eye movement efficiency. For the more seasoned athlete, the goal is often enhancement of performance capacity during high-stress situations in which accurate and rapid eye movement control is a critical factor. Ultimately the goal of enhancement training is to improve automaticity of eye movement performance[31-33] so that minimal attention is required for skilled performance. The work of Hebb[108] and others[109-111] supports the concept that development of visual performance skills should be elevated to a level that requires minimal attention so that attention can be selectively distributed to other crucial aspects of performance. Eye movement training must involve additional sensory integration burdens and cognitive processing demands to elevate the athlete's automaticity of accurate eye movement control and ability to modulate attention during performance.

Pursuit Eye Movements

The Marsden ball is commonly used to provide feedback regarding pursuit eye movement accuracy. The Marsden ball is a soft baseball with random letters placed around the sphere that is suspended from the ceiling with a string that allows it to swing in various trajectories (Fig. 8-8). The athlete is challenged to maintain fixation on specific letters on the ball while it is swung in various patterns. The exercise typically begins with the ball swinging on a plane perpendicular to the athlete's line of sight so that the relative depth of the ball does not change while it is swinging. The athlete is encouraged to maintain a steady head position with instructions to follow the ball only with his or her eyes. When performance becomes smooth and efficient, the ball is swung in elliptical trajectories that induce changes in relative depth throughout the course the ball travels.

The athlete should be given verbal feedback regarding the accuracy of smooth pursuit eye movement performance during this activity so that he or she becomes aware when pursuit eye movements break down into saccades. A visual afterimage can be used to improve the feedback for the athlete when he or she has difficulty elevating awareness of pursuit eye movement accuracy. An afterimage can be generated with a masked camera flash or similar commercially available device (Fig. 8-9). The athlete is asked to fixate a central spot monocularly on the flash unit held with the light portion oriented vertically approximately 25 cm from the eyes, and the light is flashed. The athlete should then see a vertical streak of light wherever fixation is directed so that fixation accuracy can be monitored while pursuing the

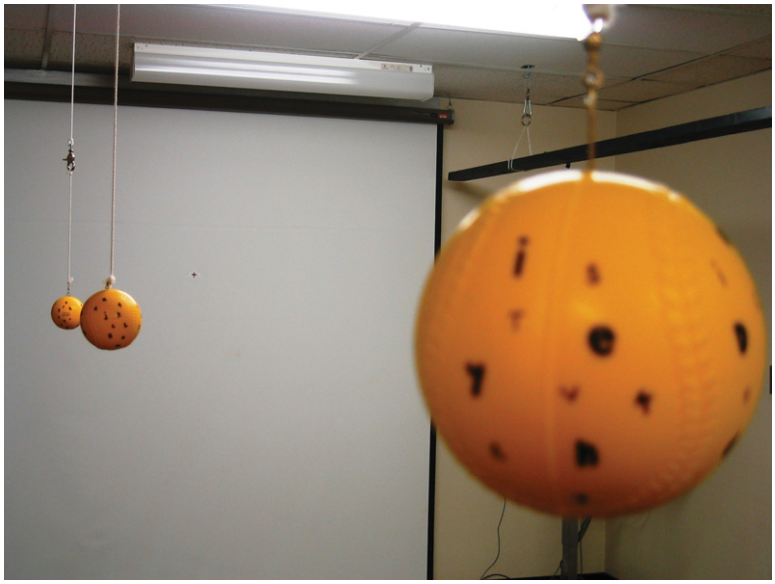


Figure 8-8. Marsden balls suspended from the ceiling.



Figure 8-9. The Wayne afterimage flash.

Marsden ball. If the athlete is having difficulty seeing the afterimage, rapid blinking and dimming the room lights should enhance the appearance of the image.

Once the athlete has achieved accurate pursuit eye movement performance with the Marsden ball, sensory integration activities are incorporated. A motor response is commonly added to the task by asking the athlete to locate and point at letters on the ball as an index finger pokes the letter on the ball hard enough to make it swing in an arc away from the athlete. Each time the ball swings back toward the athlete, he or she is instructed to locate and track a different letter until he or she can alternately poke it with the right or left index finger. Another motor element that can be added to the Marsden ball procedure is to have the athlete hold a stringless racquet (tennis, squash, racquetball) under the ball while it is swinging. The athlete is further instructed to raise the racquet on command and encircle, or hoop, the swinging ball without touching either the ball or the string.

Because many sports require the athlete to track a moving object or person while maintaining balance, adding a balance demand to the Marsden ball activity is particularly beneficial. The athlete is instructed to stand on a balance board and achieve steady balance while fixating a motionless Marsden ball. Once the athlete has attained steady balance, the ball is swung while the athlete attempts to maintain balance and fixation with smooth pursuit eye movements. Pursuit eye movements will induce vestibular responses that the athlete must override to maintain steady balance. The athlete can be further challenged with the elliptical trajectories and motor response activities previously described. In addition, if the athlete competes in a sport that requires awareness of peripheral information while processing central visual information, the trainer can randomly toss beanbags at the athlete from a peripheral location that the athlete must either catch or block during performance.

Saccadic Eye Movements

Charts with random letters (see Fig. 8-7) are placed at a relatively far distance from the athlete, usually 10 feet or more. The task requires the athlete to find and call out successive letters on the chart as rapidly as possible, making sure to achieve visual clarity with each fixation. The athlete is instructed to call out the first letter and last letter of each row (O, E, Y, X, and so on) until the bottom of the chart is reached. With successful execution of this task, the athlete is instructed to call out the second letter and the next-to-last letter of each row, the third letter and the third-from-the-last letter of each row, or other challenging saccade patterns. Multiple charts can also be used, with fixations moving in either a predetermined sequence between charts or at the command of the trainer. Accuracy of saccadic performance can be monitored through observation by the trainer and verbal feedback provided to the athlete regarding any overshooting or undershooting of saccadic eye movements. Further visual feedback can be provided with a visual afterimage, as previously described. The goal is smooth, quick performance with each pattern of saccadic eye movements.

Once the athlete can demonstrate consistently accurate precision and speed on this task, additional visual discrimination demands and sensory integration burdens can be added. The use of a metronome is a particularly effective method for enhancing auditory-visual integration, and increasing the pace of the metronome can generate performance stress similar to athletic competition. When adding a metronome to this procedure, the athlete is challenged to correctly call out a letter on each successive chart with the beat from the metronome. Polarizing filters also can be worn to increase the contrast demand of the task,

or lenses with degraded optics can be worn to simultaneously enhance blur interpretation. Because many sports require the athlete to make rapid saccadic eye movements while maintaining balance, adding a balance demand to this activity is particularly beneficial. The athlete is instructed to stand on a balance board and maintain steady balance while performing the saccadic task. In addition, if the athlete competes in a sport that requires awareness of peripheral information while processing central visual information, the trainer can randomly toss beanbags at the athlete from a peripheral location that the athlete must either catch or block during performance.

A chart with arrows pointing in random directions can be substituted for a letter chart (Fig. 8-10). The arrow chart provides a method for adding a motor performance feature to the saccadic eye movement tasks. For example, the athlete can be instructed to move his or her feet in the direction of the arrow being named (right, forward, and so forth) or move a balance board in the direction indicated by each arrow. This sensory integration activity can also be performed with the athlete's hands or while the athlete is holding a racquet, bat, or hockey stick, for example. Computer programs also are available for saccadic eye movement training with an arrow stimulus in a random orientation presented in a random location of the computer screen that the athlete must respond to as quickly as possible by moving a joystick (or arrow key) in the same direction as the arrow. This is also an excellent activity to add cognitive challenges to the task demand. The athlete can be instructed either to answer questions that are asked at random intervals during performance or ignore the distracting chatter in the background.

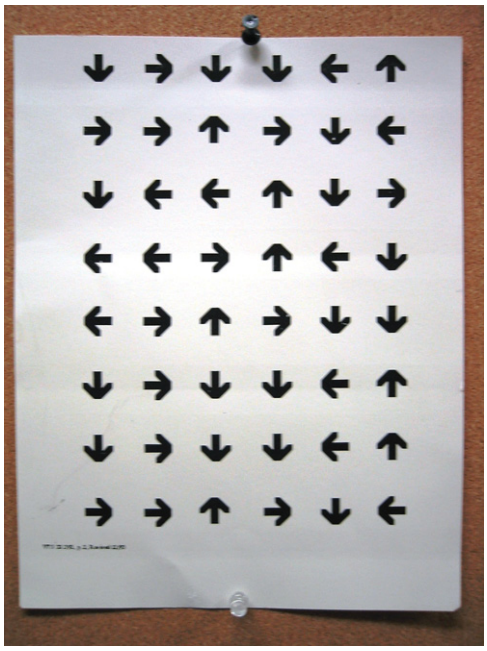


Figure 8-10. A modified Kirschner arrows chart.

For team sports, still photos can be projected of competitors in various positions who must be rapidly identified before the next photo is displayed. This requires the athlete to perform a searching saccadic eye movement task ergonomically similar to the task demands of the sport.

Speed and Accuracy of Depth Perception

Many sport tasks require judgments of depth and spatial localization. In sports such as golf, precise localization is a critical factor in the short game, but the golfer is not required to make depth judgments rapidly. In contrast, spatial localization in American football can tolerate less precision, yet the athlete is required to make depth judgments very quickly. The amount of innervation exerted by each of the six extraocular muscles in each eye to align on a target or object provides some of the information necessary to judge depth, and significant heterophorias should be treated by traditional methods applied to nonathletes.[4,105-107] Strength and flexibility in vergence function should provide better stability of depth information to the athlete, particularly when the athlete must deal with excessive fatigue and psychological stress. However, speculation exists that narrower vergence ranges may relate to more precise spatial judgment ability.[2] Most visual performance enhancement training programs include procedures that provide feedback regarding depth judgments, and many include feedback from changing vergence demands to stimulate sensitivity to alterations in relative depth.

Brock String

The Brock string is a long white string of different colored beads (Fig. 8-11). One end of the string is held against the tip of the patient's nose, and the other end can be either held by the

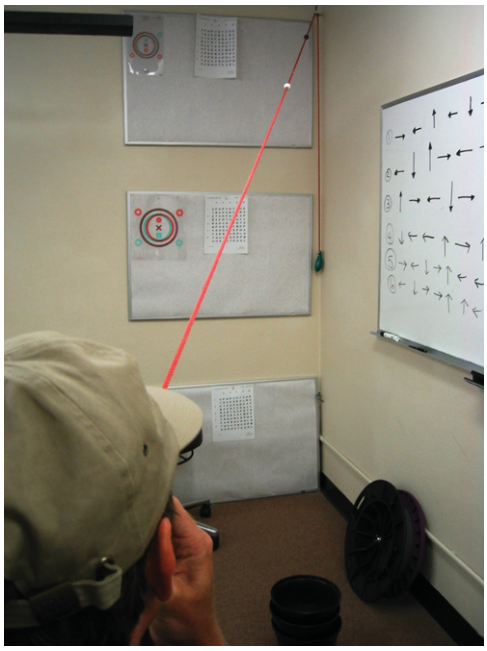


Figure 8-11. A long Brock string exercise being performed in the upgaze position.

trainer or tied to an object (e.g., a doorknob). The beads typically are placed in primary gaze position at near, intermediate, and far distances from the athlete. The athlete is instructed to look at a bead and report what is seen. Two strings should be seen in front of the bead and two strings seen emerging from behind the bead, with the strings forming an **X** at the bead. If the **X** appears to cross in front of or behind the bead, this represents an eso or exo fixation disparity, respectively. However, if the fixated bead is located beyond approximately 2 m, most patients will see the strings crossing in front of the bead because of the relative enlargement of Panum's fusional area. If diplopic images of the string are not seen behind or in front of the bead, the athlete is likely cortically suppressing the information from one eye. The athlete should be instructed to blink his or her eyes rapidly to break the suppression, or red/green filters may be worn to monitor any suppression more effectively.

The primary goal of the Brock string procedure is to provide visual feedback on the location of the visual axes when viewing an object. With practice, the athlete can learn to align the visual axes with the object, theoretically enhancing the precision of spatial localization provided by the extraocular muscles. The string can be moved from primary gaze position to other positions that simulate the task demands of the sport, such as viewing in baseball batting stance or golf putting stance. The athlete is assigned to practice alternately jumping from the far bead to the middle bead and then to the near bead. During practice, the athlete should be aware of the **X** pattern of the strings, and where it crosses, when fusing each bead so that quick, accurate alignment is reinforced. The athlete should be encouraged to become sensitive to the mental state that accompanies successful performance to facilitate transfer to the playing field.

Once the athlete can demonstrate consistently accurate precision and speed on this task, additional visual discrimination demands and sensory integration burdens can be added. Lenses and prisms can be introduced to add visual skill demands to the task. Because many sports require the athlete to shift eye alignment rapidly while maintaining balance, the addition of a balance demand to this activity is particularly beneficial. The athlete is instructed to stand on a balance board and maintain steady balance while performing the Brock string task. This is also an excellent activity to add cognitive challenges to the task demand.

Howard-Dolman Training

A Howard-Dolman apparatus can be used to enhance sensitivity to binocular cues to depth. As previously described for monocular cues to depth, a traditional Howard-Dolman device uses two rods of equal size and color to be viewed in primary gaze position (see Fig. 4-4).[66-68] The athlete makes depth judgments concerning the apparent location of the two rods under binocular viewing conditions in "real" space rather than simulated depth. This procedure can be further modified for sports purposes by substituting two identical balls or objects, such as golf balls, tennis balls, or shooting clays.[1] The initial goal of training is to refine the athlete's sensitivity to subtle cues to depth, and the athlete is subsequently obligated to make the depth judgments in progressively shorter time periods (tachistoscopic presentation). The athlete can also move from primary gaze position to other positions that simulate the task demands of the sport, such as viewing in baseball batting stance or golf putting stance.

Simulated Depth Activities

Many therapy procedures are commonly used to treat anomalies of binocular vision with either polarizing or colored filters to simulate stereopsis. Vectograms are targets with oppositely

polarized portions that allow the athlete to see some portions with the right eye and some with the left eye when wearing polarizing filters with crossed axes. Tranaglyphs are examples of anaglyphic targets that use red and green targets to simulate depth when red/green filters are worn. Both systems provide feedback concerning suppression, although polarizing filters provide a closer approximation of natural conditions because no chromatic interval is induced by the filters.

Vectograms and tranaglyphs are typically used at near viewing distances to increase positive and negative fusional vergence ranges (Fig. 8-12).[4,105-107] For athletes, training depth perception at far distances is often more appropriate, and large vergence ranges may offer a benefit only if the athlete has a significant heterophoria at far. The goal of visual performance enhancement training is development of accuracy of depth localization with vectogram or tranaglyph targets projected onto an appropriate screen. Tranaglyph targets can be projected onto a white screen; however, vectograms require a silverized screen to preserve the polarization. A small amount of positive fusional vergence demand is created by separating the target so that the target seen by the right eye is to the left of the target seen by the left eye. The common perception induced by a relative base-out demand is for the image to appear slightly smaller and closer in toward the observer; conversely, a relative base-in demand will produce the perception of the image becoming slightly larger and farther out (away) from the observer. These spatial perception effects are referred to as *SILO* (***s***maller ***i***n, ***l***arger ***o***ut). The SILO perception in the example described should cause the image to appear closer to the athlete than the screen, and the image should seem slightly smaller. If the athlete can fuse the image without suppression, he or she is asked to report the exact location of the target. The trainer can wave a hand or meter stick to help the athlete report the apparent plane of the target image; typically the trainer starts by waving his or her hand at the plane of the screen

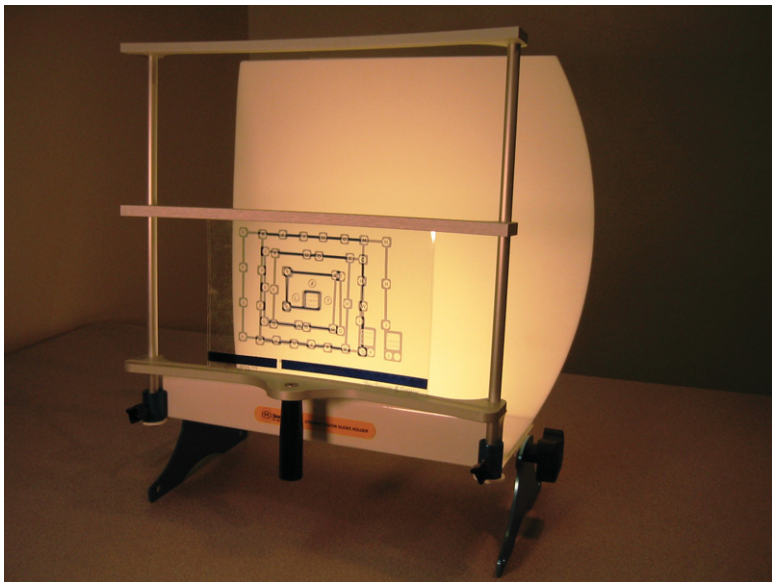


Figure 8-12. A spirangle variable vectogram on a VTE Dynamic Fusion Slides Holder.

and slowly moves toward the athlete. This training enhances the sensitivity of extraocular muscle information for the discrimination of relative depth judgments.

Once the athlete becomes proficient at making depth localization judgments with the targets, speed of stereopsis is enhanced. The athlete is first asked to localize a target with a moderate demand to positive fusional vergence and then close his or her eyes. While the athlete's eyes are closed, the positive fusional vergence demand is either increased or decreased a small amount. The athlete is then instructed to look again and determine whether the target is at the same relative location, slightly closer, or slightly farther away. In this manner the athlete becomes more sensitive to small changes in spatial localization and receives feedback regarding rapid depth judgments.

Once the athlete can demonstrate consistently accurate precision and speed on this task, additional sensory integration burdens can be added. A balance board or mini-trampoline can be added to this procedure to add proprioceptive challenges for the athlete and help build performance automaticity. The mini-trampoline is used in a manner similar to that previously described for the balance board. The athlete is instructed to maintain steady balance while rhythmically jumping on the mini-trampoline and performing the vectogram or tranaglyph task. The athlete can also move from primary gaze position to other positions that simulate the task demands of the sport, such as viewing in baseball batting stance or golf putting stance.

Fixation Disparity

Precise and stable eye alignment (measured as fixation disparity) has been suggested to be crucial in sports that require precise spatial localization.[1] Training targets that give the athlete visual feedback regarding eye alignment are readily available in many anaglyphic and polarized vision therapy activities used to improve vergence function, as previously described for simulated depth activities. For example, most vectograms have an "R" seen by the right eye directly above an "L" seen by the left eye. The vertical alignment of these letters indicates the status of horizontal fixation disparity. Other targets can be easily modified to provide alignment feedback, such as drawing nonius line markings inside the circles on the lifesaver card (Fig. 8-13). These targets typically include a fusional vergence demand in addition to feedback regarding fixation disparity; however, it may not be necessary to enhance vergence ranges in some athletes. Dr. Bradley Coffey designed the targets with no vergence demand in Figure 8-14 by using cross-polarizing filters and hand-drawn nonius lines.

The initial goal of training is to refine the athlete's ability to maintain steady, stable alignment of the targets and develop the feeling of steady alignment. Once the athlete can easily achieve and maintain target alignment, the athlete is compelled to achieve alignment in progressively shorter time periods—preferably attaining alignment instantaneously. The athlete should also move from primary gaze position to other positions that simulate the task demands of the sport, such as viewing in baseball batting stance or golf putting stance. Additional visual discrimination demands and sensory integration burdens can be added to further build automaticity of stable and precise eye alignment.

Spatial Localization

Spatial localization tasks in "real" space may provide a useful bridge between simulated depth activities and the actual demands of sports performance. In addition, mental imagery has been suggested to be a powerful tool for enhancing physical performance.[1] Studies have

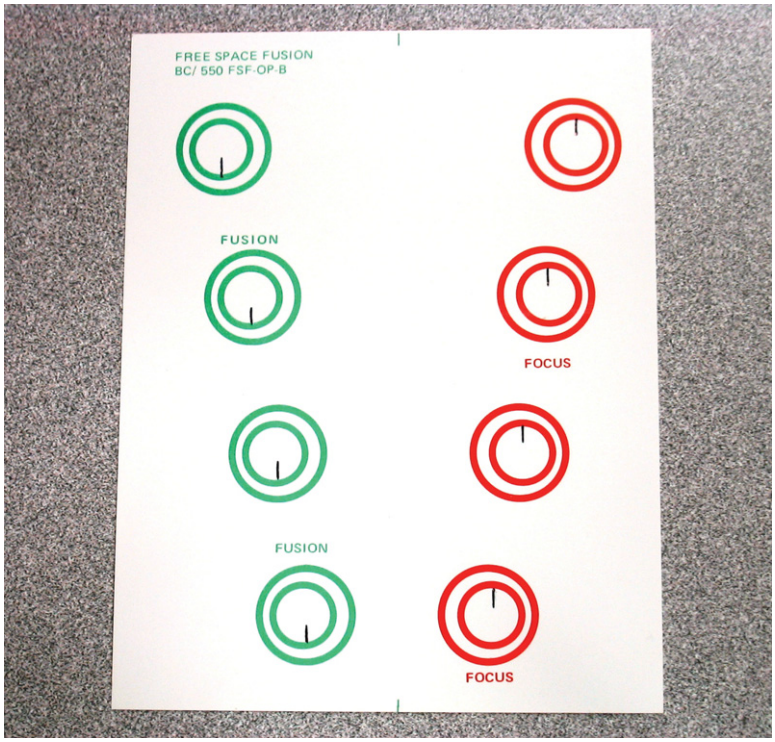


Figure 8-13. Nonius line markings on the lifesaver card for feedback regarding fixation disparity.

suggested that mental imagery may share the same types of neural processes as visual perception, which may have significant implications for depth judgments in sports.[112]

Coffey and Reichow[1] presented a visual performance enhancement training activity combining real space depth judgments with mental imagery calibrations. The athlete is positioned in front of an array of targets (e.g., varying sized papers, coffee cans) spaced at varying distances and visual directions. The athlete develops an internal calibration of

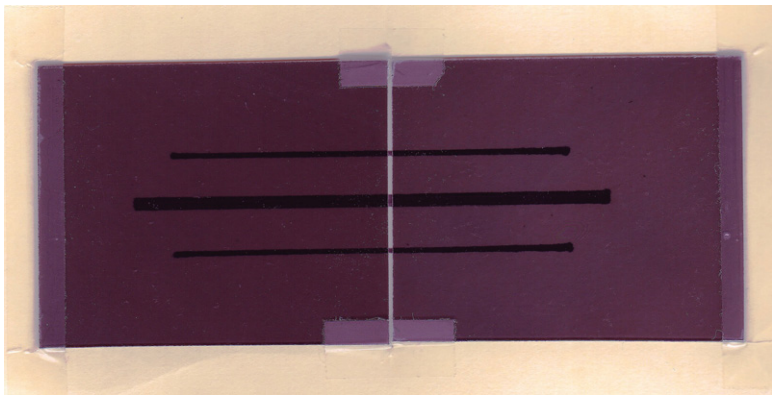


Figure 8-14. Fixation disparity targets with no vergence demand using cross-polarizing filters and hand-drawn nonius lines; designed by Coffey.

distance estimation by tossing beanbags at the targets and noting error tendencies. The targets are then rearranged at different distances and directions, and the athlete is instructed to construct a mental image of each target location. Before tossing the beanbags to each new target location, the athlete is instructed to close his or her eyes, recall as vividly as possible the exact position of the target, and then toss the beanbag at the target with the eyes still closed (Fig. 8-15). After each toss, feedback is provided to the athlete regarding performance accuracy. Once the athlete has achieved an appropriate level of performance accuracy, he or she is required to create a mental image of multiple targets and toss beanbags at all the targets before being allowed to access the visual feedback of performance accuracy. The practitioner may also wish to have the athlete perform this procedure monocularly to improve the use of monocular cues to depth. Although many variables can influence performance, this procedure may be particularly beneficial for sports in which the athlete's view of critical information is often interrupted by other participants or objects (e.g., basketball, soccer, hockey).

Speed of Recognition

The ability to process visual information rapidly has been considered an essential element for success in fast-action sports. Athletes must analyze available temporal and spatial information during sports situations relatively quickly to make accurate decisions concerning performance responses. Most visual performance enhancement training programs that include activities designed to improve speed of recognition also attempt to increase the quantity of information that the athlete can process.

Tachistoscopic Training

Tachistoscopes have been used for many years to enhance the ability to process visual information rapidly (Fig. 8-16). Typically the athlete is instructed to recall a sequence of numbers



Figure 8-15. A visual performance enhancement training activity combining real space depth judgments with mental imagery calibrations; created by Coffey and Reichow.



Figure 8-16. Dual tachistoscope projection system with control module.

that has been flashed for a very short period (e.g., 0.02 second). However, the use of numeric stimuli may confound the assessment and enhancement of speed of recognition in athletes. As previously discussed for training dynamic visual acuity, target parameters that more closely simulate the visual information processed in sport situations may provide a more effective approach to improving visual information processing speed for athletes. Sport-specific images or stop-action video offers the athlete a more direct benefit to sports performance and should enhance transfer of skill development to the playing field.

The addition of a motor response to the presented stimuli is useful to approximate the completion of the motor reaction process. For example, the athlete may be instructed to move his or her feet (or racquet, hockey stick, glove) in the direction of an arrow stimulus placed in a random location on the training slide. This type of activity can also be performed with flash cards or computer programs at home by the athlete. If video footage is used, the athlete can complete the anticipated motor response to the video action that was stopped, and feedback is provided concerning the accuracy of the predicted action. For example, video footage of a baseball pitch can be stopped at a designated time interval (e.g., 0.1 second) after release of the pitch, and the batter responds with a swing (or no swing) corresponding to the anticipated trajectory of the pitch.

Stroboscopic Training

A strobe light (Fig. 8-17) or stroboscopic filters provide another method for the development of visual information processing speed.[33] A strobe light in a darkened room reduces the availability of visual information to the brief periods when the strobe light illuminates the room.

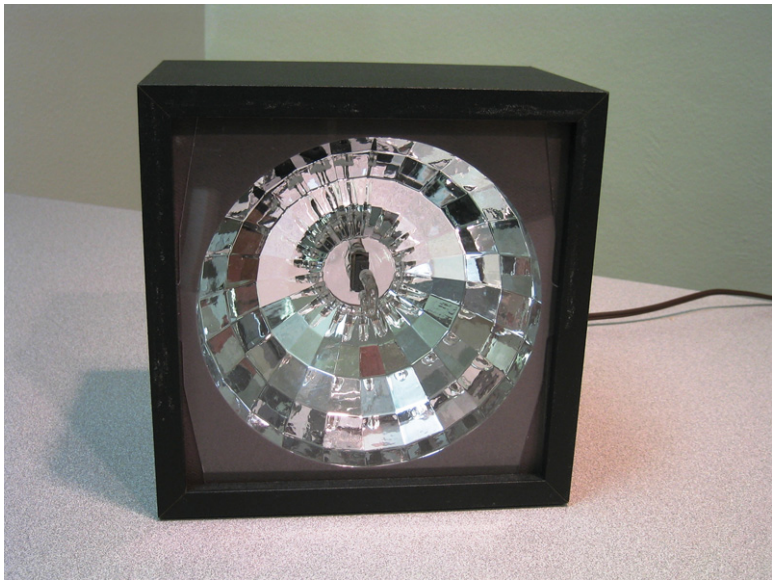


Figure 8-17. A stobe light.

The faster the flash rate of the strobe light, the greater the amount of information available to the athlete. Ultimately the athlete is encouraged to maintain performance of an activity with progressively less visual information as the flash rate on the strobe light is reduced.

Typically the athlete is engaged in a motor performance task, such as the pitchback activity previously described. The athlete throws a ball or beanbag into a pitchback net and attempts to catch it on the return flight. As the athlete's ability to catch improves, the ball or beanbag is thrown faster into the net, and more spin can be induced by the athlete during the throw. To add a level of unpredictability to the task, the ball can be thrown by another person, thereby requiring the athlete to rapidly judge the speed and trajectory of the ball during flight. The flash rate of the strobe light is gradually reduced so that the athlete must perform with less and less visual information.

The pitchback activity can be replaced with motor tasks that match the demands of the sport. For example, catching for baseball, softball, or football; service returns for tennis, racquetball, table tennis, or volleyball; or simulated game play for team sports such as basketball, softball, football, and volleyball. The practitioner must be careful to protect the athletes from injury when conducting strobe activities (e.g., use a batting cage with a machine rather than a real pitching/batting setup for stroboscopic batting). A product called Strobespecs by Maximum Performance previously provided battery-powered liquid crystal strobe filters in an eyewear frame. This device was excellent for providing strobe demands to actual sport performance because the athlete could wear the Strobespecs on the playing field during practice. This product will again be commercially available in the near future as Nike Strobe (http://www.nike.com), and the design will be modified to include a digital display of the flash rate (Fig. 8-18).



Figure 8-18. A prototype of the modified Strobespecs, now called Nike Strobe.

Visual-Motor Reaction/Response (Eye-Hand, Eye-Foot, Eye-Body Coordination)

Many sport situations require the athlete to make a motor response to visual information, and the speed of visual and neuromuscular processing is often a valuable attribute for an athlete. The visual system is responsible for providing critical information regarding response characteristics of the athlete's hands, feet, and body position. Many programs designed to improve athletic performance in reactive sports include activities designed to enhance visual-motor reaction time, and it is a frequent element of visual performance enhancement training programs.

The enhancement of visual-motor reaction and response speed has two main goals. The primary goal is to reduce the time that elapses between the initiation of a visual stimulus and the commencement of an appropriate motor response to the stimulus. This part of the reaction time process involves the speed of visual information processing (perceptual mechanism) and the decision mechanism to instigate the effector mechanism accurately. In the parlance of the sports world, this ability is often referred to as *quickness*. An athlete with superior quickness is able to react earlier to visual information than are other athletes. The second goal is to reduce the time required for the neuromuscular system to send the information to the muscles that need to be stimulated to make the appropriate motor response. This part of the reaction time process involves the speed of the effector mechanism and is often referred to as *pure speed*. An athlete with superior speed is faster at the required motor performance once the effector mechanism has been engaged. For example, a soccer goalkeeper with superior quickness will have a faster step toward a goal shot, and a goalkeeper with superior speed will cover the distance to intercept the goal shot faster. The combination of exceptional quickness and speed offers the best potential for success.

Electronic Devices

Several instruments have been created to evaluate and improve visual-motor reaction and response speed. The Wayne Saccadic Fixator (www.wayneengineering.com; see Fig. 4-6), Eyespan, Acuvision, Dynavision (www.dynavision2000.com), SVT (www.sportsvision.com.au),

and Activision are examples of such instruments, although the Wayne Saccadic Fixator, Dynavision 2000, and SVT are the only ones currently available for purchase. The instruments are similar in that they each consist of a two-dimensional panel with an array of lighted buttons. The athlete is required to press a randomly lit button as rapidly as possible with one hand; another button is then lit in a random position on the instrument and the reaction time reflex cycle is repeated for an established period.

Typically the athlete repeats a specific training program on the instrument in an attempt to improve his or her score. The practitioner provides the athlete feedback concerning performance behaviors, specifically regarding eye positioning and the use of central and peripheral vision. The athlete is encouraged to develop central and peripheral vision performance strategies consistent with the task demands of his or her sport. As performance improves, the speed of the training program is often increased to keep the athlete working at the threshold of ability. The program designed by Dr. Jack Gardner for "eye/hand athletics" on the Wayne Saccadic Fixator is an excellent program for gradually ramping up the stimulus speed until performance breaks down, then continuously adjusting the program speed to keep the athlete working within the zone of maximal ability. Additional sensory integration burdens (e.g., balance board) can be added to further build automaticity of visual-motor reaction and response speed.

Visual-Motor Reaction/Response Games

Many games require rapid motor responses to visual stimuli for success. For example, table tennis compels the athlete to perform extremely quick eye-hand responses, which should have a salutary effect on eye-hand responses in other sports applications. Even some video games can provide an environment for development of eye-hand response speed, although the nature of the motor response (e.g., thumbs) may not engage the gross motor neuromuscular system required in most sports. The pitchback stroboscopic activities described previously also provide an excellent environment for increasing visual-motor reaction and response speed.

Peripheral Vision

The processing of information from the peripheral visual fields is a practically universal beneficial element to successful sports performance, whether the task is to monitor teammates and opponents or maintain steady balance. Peripheral vision is critical to generate accurate saccadic eye movements and guide searching eye movements in most sports. The goal of visual performance enhancement training for peripheral vision is to enhance visual field awareness and responsiveness, often while simultaneously processing central visual information, and typically is not directed to extending the size of the visual fields.

Wayne Peripheral Awareness Trainer

The Peripheral Awareness Trainer (www.wayneengineering.com) has a central circular module that contains a central fixation light and has eight clear rods extending from it with red light-emitting diodes (LEDs) at each end (see Fig. 4-10). The athlete holds a joystick, fixates centrally, and moves the joystick in the direction of an LED when it is perceived by the peripheral visual field. This system is discussed in Chapter 4 for assessment of peripheral response speed, and it is often discussed to enhance peripheral awareness in athletes. The program provides the athlete some useful feedback regarding peripheral awareness, but it is

a beginning-level activity. Additional sensory integration burdens can be added to further build automaticity of peripheral awareness.

Spatial Localization Techniques

In sports such as trap or skeet shooting and gymnastics, precise peripheral localization is crucial to success. Some procedures have been developed that provide feedback regarding peripheral localization accuracy. The devices discussed to enhance visual-motor reaction require peripheral visual processing to locate each button as it is illuminated. These procedures can be modified to require precise peripheral localization by having the athlete fixate a central spot on the instrument panel. The athlete is instructed to point at the randomly illuminated button on the panel rapidly with a finger while maintaining central fixation, and to hold his or her finger on the spot where the finger touches the panel. The athlete is then allowed to look at his or her finger to see the accuracy of the localization. The process is repeated to build rapid accuracy of peripheral localization. Additional sensory integration burdens can be added to further build automaticity.

Coffey and Reichow[1] described a similar training procedure with a tachistoscope projector and a laser pointer. The athlete faces a screen with a central fixation spot and holds a laser pointer. A slide with a dot located in a random position is flashed tachistoscopically (e.g., 0.05 second), and the athlete is instructed to point the laser pointer at the position on the screen where the dot was seen. Feedback is provided by illuminating the slide so that the athlete can see the accuracy of his or her peripheral localization. As the athlete improves peripheral localization accuracy, the exposure time of the slide is reduced.

Split Attention Activities

Many sports demand that the athlete process central and peripheral information simultaneously, placing an almost insurmountable burden on the attention mechanism. When an athlete has developed superior visual performance skills, adding procedures that compel the athlete to split attention between central and peripheral information can be a powerful method of building automaticity. For example, the athlete is placed so that he or she centrally fixates a Hart chart and sees the Wayne Saccadic Fixator in the peripheral field of vision (Fig. 8-19). The athlete is instructed to perform a saccadic eye movement task with the Hart chart while simultaneously hitting the buttons of the Wayne Saccadic Fixator as they are randomly lit in one of the visual-motor reaction programs. Additional sensory integration burdens can be added to further build automaticity.

Juggling

The act of juggling requires heightened peripheral awareness and excellent hand reaction and response speed. For athletes who cannot successfully juggle three objects (balls), learning the skill demands significant attention to improving peripheral awareness with hand coordination. Several Web sites have specific instructions for learning how to juggle (e.g., http://www.jugglinginstructions.com), and these can be used to complement the instructions that the practitioner provides. Once the skill of three-ball juggling is mastered, additional sensory integration burdens can be added.

For team sports, the whole team can compete in daily juggling competitions in which everyone begins juggling simultaneously to determine who can continue the longest. As the athletes master juggling technique, movement can be added to the competition. The team

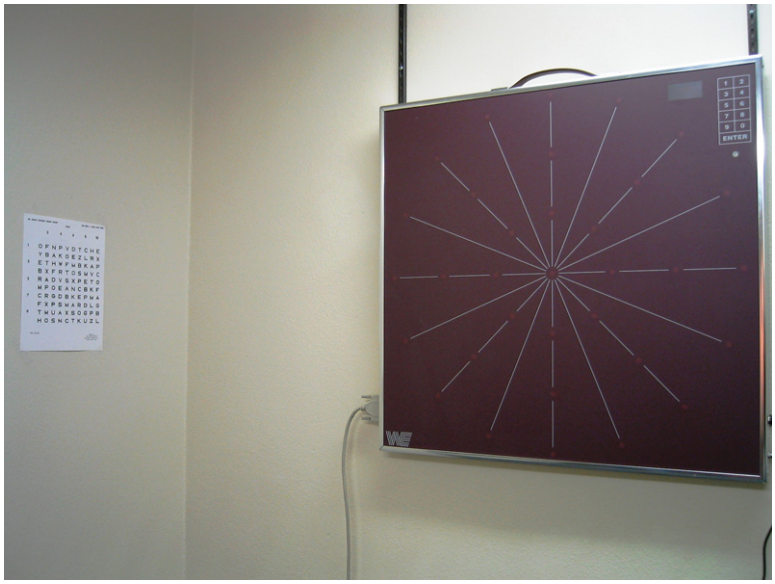


Figure 8-19. A Hart chart is fixated with the Wayne Saccadic Fixator in the peripheral field of vision to split attention between central and peripheral information to build automaticity.

members are allowed to move around and bump into each other in an attempt to induce a teammate to drop a ball. This movement significantly increases the load on peripheral awareness while introducing split attention and foot reaction/response demands to the activity. To further challenge the anticipation skills of the athletes, the room can be darkened and a strobe light used to add a speed-of-recognition demand to the activity. Performance of this level of activity helps the athlete develop better control of visual attention during stressful motor performance, which should help transfer the improvements to the field of play.

Yardstick Saccades

Yardstick saccades were described by Martin[113] to develop head control during saccadic eye movements. The procedure was explained with a yardstick; however, a meter stick is substituted in this description. The athlete is centered approximately 50 cm from the center of a meter stick (at the 50-cm mark) in primary gaze position. The task is for the athlete to fixate the 50-cm mark and locate the next higher mark (51 cm) by using peripheral awareness. The athlete completes an accurate saccade to that mark and makes a return saccade to the center point. This process is repeated for the next lower mark (49 cm). If performed smoothly and successfully, the athlete uses peripheral awareness to locate the mark two steps away (52 cm and 48 cm) and repeats the steps described previously. This process is continued until the athlete can no longer locate the next centimeter mark with his or her peripheral vision. Further visual feedback can be provided with a visual afterimage, as previously described. This task initially is performed with the meter stick placed horizontally; however, the orientation can be adjusted to simulate the sport demands and enhance more superior and inferior aspects of peripheral vision. The goal is smooth, quick, and accurate saccadic eye movements with an expanded awareness of the peripheral visual fields.

Once the athlete can demonstrate consistently accurate precision and speed on this task, additional sensory integration burdens can be added. The use of a metronome is a particularly effective method for enhancing auditory-visual integration, and increasing the pace of the metronome can generate performance stress similar to athletic competition. When adding a metronome to this procedure, the athlete is challenged to saccade to each successive centimeter mark accurately with the beat from the metronome. The athlete must develop awareness of the attentional conditions that enhance peripheral awareness to apply this mental state to sport performance.

Coincidence-Anticipation Skills

Many fast-action sports involve reaction and responses to visual information approaching the athlete. For example, a tennis player must determine when and where an opponent's serve will arrive on his or her side of the court and anticipate this location early enough to initiate the proper motor response. Predictive visual information concerning the space-time behavior of critical factors in fast-action sports can provide a significant advantage in determining and executing the most appropriate motor responses.[114-124] Therefore many visual performance enhancement training programs include activities designed to heighten coincidence anticipation skills. The goals for this area of enhancement are to improve the accuracy and consistency of visual-motor anticipation timing.

Bassin Anticipation Timer/Wayne Speed-trac

The Bassin Anticipation Timer (www.lafayetteinstrument.com) and Wayne Speed-trac (www.wayneengineering.com) are instruments most often used to assess coincidence anticipation. As described in Chapter 4, each instrument consists of a track of LED lights that make a "runway" of various lengths (see Fig. 4-8). The LEDs are illuminated sequentially down the runway in rapid succession to simulate the apparent motion of the stimulus lights traveling at velocities of 1 to 500 mph. The task requires the athlete to anticipate when the target light will be illuminated as the LEDs are sequentially illuminated along the *z*-axis approaching the athlete and to make a motor response that coincides with the illumination of the target light. The velocity of the stimulus lights can be calibrated to simulate the action speeds encountered in the athlete's sport, in effect simulating the stimulus parameters experienced by the athlete (e.g., the pitch speeds in baseball batting). Visual and verbal feedback is provided to the athlete concerning each performance so that the athlete can begin to internally calibrate coincidence-anticipation accuracy. Many athletes report improved visual concentration during sport performance after training with these instruments.

Stroboscopic Training

A strobe light or stroboscopic filters provide another method for development of coincidence-anticipation skills in addition to improving visual information processing speed. The emphasis is placed on motor responses to approaching objects, such as that described in the pitchback activity.

SUMMARY

The development of visual performance enhancement procedures is limited only by individual or collective creativity. The sports vision practitioner should perform a visual task analysis for each sports team or athlete for whom these services are designed. The relevant

and critical visual skills initially should be isolated for performance enhancement. Visual skill integration and sensory integration demands are gradually introduced to challenge the athlete and build automaticity of performance. The practitioner, the athlete, and the athlete's support network should develop strategies to assist in the transfer of enhanced visual performance to the playing field by incorporating vision performance aspects into sport skill practice and mental preparations for competition. A home-based program of visual skill procedures should be prescribed at the conclusion of visual performance enhancement therapy to provide the athlete a structure for maintaining skill development and for continuing performance improvements. Although many of the reports in the literature supporting sports vision training are anecdotal or significant flaws in the research designs preclude a definitive result, a logical relation exists between visual performance and sports performance. Ample evidence exists that visual skill performance can be enhanced with well-designed procedures; therefore enhancement of visual skill performance should provide the athlete an additional advantage when preparing for competition.

ACKNOWLEDGMENT

The author recognizes and acknowledges the influence of Drs. Bradley Coffey and Alan W. Reichow for much of the information contained in this chapter.

REFERENCES

1. Coffey B, Reichow AW: Visual performance enhancement in sports optometry. In Loran DFC, MacEwen CJ, editors: *Sports vision*, Oxford, 1995, Butterworth-Heinemann, pp 158-77.
2. Coffey B, Reichow AW: Optometric evaluation of the elite athlete, *Probl Optom 2:*32, 1990.
3. Cohen AH: The efficacy of optometric vision therapy, *J Am Optom Assoc 59:*95, 1988.
4. Ciuffreda KJ: The scientific basis for and efficacy of optometric vision therapy in nonstrabismic accommodative and vergence disorders, *Optometry 73:*735, 2002.
5. Ciuffreda KJ, Wang B: Vision training and sports. In Hung GK, Pallis JM, editors: *Biomedical engineering principles in sports*, New York, 2004, Kluwer Academic/Plenum, pp 407-433.
6. West KL, Bressan ES: The effect of a general versus specific visual skills training program on accuracy in judging length-of-ball in cricket, *Int J Sport Vis 3:*41, 1996.
7. Quevedo-i-Junyent L, Sole-i-Forto J: Visual training program applied to precision shooting, *Ophthalmol Physiol Opt 15:*519, 1995.
8. McLeod B: Effects of eyerobics visual skills training on selected performance measures of female varsity soccer players, *Percept Mot Skills 72:*863, 1991.
9. Kofsky M: Sports vision visual training and experimental program with Australian Institute of Sport basketball players, *Aust J Optom 6:*15, 1988.
10. Abernethy B, Wood JM: Do generalized visual training programmes for sport really work? An experimental investigation, *J Sports Sci 19:*203, 2001.
11. Quevedo L, Sole J, Palmi J, et al: Experimental study of visual training effects in shooting initiation, *Clin Exp Optom 82:*23, 1999.
12. Wood JM, Abernethy B: An assessment of the efficacy of sports vision training programs, *Optom Vis Sci 74:*646, 1997.
13. Allard F, Starkes JL: Perception in sport: volleyball, *J Sport Psychol 2:*22, 1980.
14. Allard F, Graham S, Paarsalu ME: Perception in sport: basketball, *J Sport Psychol 2:*14, 1980.

15. Starkes JL, Deakin J: Perception in sport: a cognitive approach to skilled performance. In Straub WF, Williams JM, editors: *Cognitive sport psychology*, Lansing, NY, 1984, Sport Science, pp 115-128.
16. Allard F, Burnett N: Skill in sport, *Can J Psychol 39:*294, 1985.
17. Helsen W, Pauwels JM: The use of a simulator in the evaluation and training of tactical skills in football. In Reilly T, Lees A, Davids K, et al, editors: *Science and football*, London, 1987, E&FN Spon, pp 493-497.
18. Starkes JL: Skill in field hockey: the nature of the cognitive advantage, *J Sport Psychol 9:*146, 1987.
19. Garland DJ, Barry JR: Sports expertise: the cognitive advantage, *Percept Mot Skills 70:*1299, 1990.
20. Lisberger SG: The neural basis for learning of simple motor skills, *Science 242:*728, 1988.
21. Gottlieb GL, Corcos DM, Jaric S, et al: Practice improves even the simplest movements, *Exp Brain Res 73:*436, 1988.
22. Bjurwell C: Perceptual-motor behavior in sport: the double reaction, *Percept Mot Skills 72:*137, 1991.
23. Mahoney M, Avener J: Psychology of the elite athlete: an exploratory study, *Cog Ther Res 1:*135, 1977.
24. Meyers AW, Cooke CJ, Cullen J, et al: Psychological aspects of athletic competitors: a replication across sports, *Cog Ther Res 3:*361, 1979.
25. Greenspan MJ, Feltz DL: Psychological interventions with athletes in competitive situations: a review, *Sport Psychologist 3:*219, 1989.
26. Davis H: Cognitive style and nonsport imagery in elite ice hockey performance, *Percept Mot Skills 71:*795, 1990.
27. Finke RA: Mental imagery and the visual system, *Sci Am 254:*88, 1986.
28. Harris DV, Harris BL: *The athlete's guide to sports psychology*: *mental skills for physical people*, New York, 1984, Leisure Press.
29. Heil J: Imagery for sport: theory, research, and practice. In Straub WF, Williams JM, editors: *Cognitive sport psychology*, Lansing, NY, 1984, Sport Science Associates, pp 245-252.
30. Suinn RN: Imagery and sports. In Straub WF, Williams JM, editors: *Cognitive sport psychology*, Lansing, NY, 1984, Sport Science Associates, pp 253-271.
31. Birnbaum MH: Automaticity in fusional vergence therapy, *J Am Optom Assoc 66:*471, 1995.
32. Groffman S: Consideration of individual characteristics and learning theory in vision therapy. In Press LJ, editor: *Applied concepts in vision therapy*, St Louis, 1997, Mosby, pp 51-52.
33. Leslie S: Sports vision therapy. In Press LJ, editor: *Applied concepts in vision therapy*, St Louis, 1997, Mosby.
34. Woods AC: Report from the Wilmer Institute on the results obtained in the treatment of myopia by visual training, *Trans Am Acad Ophthalmol Otolaryngol 49:*37, 1945.
35. Ewalt HW: The Baltimore myopia control project, *J Am Optom Assoc 17:*167, 1946.
36. Rowe AJ: Orthoptic training to improve the visual acuity of a myope, *J Am Optom Assoc 18:*494, 1947.
37. Epstein LH, Greenwald DJ, Hennon D, et al: Monocular fading and feedback training, *Behav Mod 5:*171, 1981.
38. Gil KM, Collins FL: Behavioral training for myopia: generalization of effects, *Behav Res Ther 21:*269, 1983.
39. Collins FL, Pbert LA, Gil KM: The effects of behavioral training for improving visual acuity in emmetropic and myopic volunteers, *Behav Med Abst 5:*142, 1984.
40. Gil KM, Collins FL, Odom JV: The effects of behavioral vision training on multiple aspects of visual functioning in myopic adults, *J Behav Med 9:*373, 1986.
41. De Valois KK: Spatial frequency adaptation can enhance contrast sensitivity, *Vision Res 17:*1057, 1977.
42. Adini Y, Sagi D, Tsodyks M: Context-enabled learning in the human visual system, *Nature 415:*790, 2002.
43. Ricci JA, Collins FL: Visual acuity improvement following fading and feedback training. III: effects on acuity for stimuli in the natural environment, *Behav Res Ther 26:*475, 1988.

44. Bailliet R, Clay A, Blood K: The training of visual acuity in myopia, *J Am Optom Assoc 53:*719, 1982.
45. Low FN: The peripheral visual acuity of 100 subjects, *Am J Physiol 140:*83, 1943.
46. Low FN: Some characteristics of peripheral visual performance, *Am J Physiol 146:*573, 1946.
47. Low FN: Peripheral visual acuity, *Arch Ophthalmol 45:*80, 1951.
48. Saugstad L, Lie I: Training of peripheral visual acuity, *Scan J Psychol 5:*218, 1964.
49. Johnson CA, Leibowitz HW: Practice effects for visual resolution in the periphery, *Percept Psychophys 25:*439, 1979.
50. Collins FL, Epstein LH, Hannay HJ: A component analysis of an operant training program for improving visual acuity in myopic students, *Behav Ther 12:*692, 1981.
51. Beard BL, Levi DM, Reich LN: Perceptual learning in parafoveal vision, *Vision Res 35:*1679, 1995.
52. Hildreth HR, Meinberg WH, Milder B, et al: The effect of visual training on existing myopia, *Am J Ophthalmol 30:*1563, 1947.
53. Marg E: Flashes of clear vision and negative accommodation with reference to the Bates method of visual training, *Am J Optom Arch Am Acad Optom 24:*167, 1952.
54. Gallaway M, Pearl SM, Winkelstein AM, et al: Biofeedback training of visual acuity and myopia: a pilot study, *Am J Optom Physiol Optics 64:*62, 1987.
55. McKee SP, Westheimer G: Improvement in vernier acuity with practice, *Percept Psychophys 24:*258, 1978.
56. Fahle M, Edelman S: Long-term learning in vernier acuity: effects of stimulus orientation, range and of feedback, *Vision Res 33:*397, 1993.
57. Regan D, Beverly KI, Cyander M: The visual perception of motion in depth, *Sci Am 241:*136, 1979.
58. Regan D, Beverley KI: Illusory motion in depth: aftereffect of adaptation to changing size, *Vis Res 18:*209, 1978.
59. Beverley KI, Regan D: Separable aftereffects of changing-size and motion-in-depth: different neural mechanisms? *Vis Res 19:*727, 1979.
60. Regan D, Beverley KI: Looming detectors in the human visual pathway, *Vis Res 18:*415, 1978.
61. Regan D, Cyander M: Neurons in area 18 cat visual cortex selectively sensitive to changing size: non-linear interactions between responses to two edges, *Vis Res 19:*699, 1979.
62. McLeod P, McLaughlin C, Nimmo-Smith I: Information encapsulation and automaticity: evidence from the visual control of finely timed actions. In *Attention and performance XI*, Hillsdale, NJ, 1985, Erlbaum, pp 391-400.
63. Judge SJ, Bradford CM: Adaptation to telestereoscopic viewing measured by one-handed ball-catching performance, *Perception 17:*783, 1988.
64. von Hofsten C, Rosengren K, Pick HL, et al: The role of binocular information in ball catching, *J Mot Behav 24:*329, 1992.
65. Savelsbergh GJP, Whiting HTA: The acquisition of catching under monocular and binocular conditions, *J Mot Behav 24:*320, 1992.
66. Ogle KN: *Researches in binocular vision*, New York, 1964, Hafner.
67. Cline D, Hoffstetter HW, Griffin JR: *Dictionary of visual science*, ed 3, Radnor, PA, 1980, Chilton, p 641.
68. Griffin JR, Grisham JD: *Binocular anomalies. Diagnosis and vision therapy*, Amsterdam, 2002, Butterworth-Heinemann, pp 59-62.
69. Hart WM: Entoptic imagery. In Moses RA, Hart WM, editors: *Adler's physiology of the eye*, St Louis, 1987, Mosby–Year Book, pp 383-384.
70. Di Russo F, Pitzalis S, Spinelli D: Fixation stability and saccadic latency in elite shooters, *Vision Res 43:*1837, 2003.
71. Blackburn RH: Perception of movement, *Am J Optom 14:*365, 1937.

72. Graham CH, Cook C: Visual acuity as a function of intensity and exposure time, *Am J Psychol 49:*654, 1937.
73. Ludvigh EJ: The gradient of retinal illumination and its practical significance, *Am J Ophthalmol 20:*260, 1937.
74. Langmuir I: The speed of the deer fly, *Science 87:*233, 1938.
75. Ludvigh E: Extrafoveal visual acuity as measured with Snellen test-letters, *Am J Ophthalmol 24:*303, 1941.
76. Ludvigh E: Visibility of the deer fly in flight, *Science 105:*176, 1947.
77. Ludvigh E: The visibility of moving objects, *Science 108:*63, 1948.
78. Ludvigh EJ: Visual acuity while one of viewing a moving object, *Arch Ophthalmol 42:*14, 1949.
79. Westheimer G: Eye movement responses to a horizontally moving visual stimulus, *AMA Arch Ophthalmol 52:*932, 1954.
80. Hulbert SF, Burg A, Knoll HA, et al: A preliminary study of dynamic visual acuity and its effects in motorist's vision, *J Am Optom Assoc 29:*359, 1958.
81. Ludvigh EJ, Miller JW: Study of visual acuity during the ocular pursuit of moving test objects. I. Introduction, *J Opt Soc Am 48:*799, 1958.
82. Miller JW: Study of visual acuity during the ocular pursuit of moving test objects. II. Effects of direction of movement, relative movement, and illumination, *J Opt Soc Am 48:*803, 1958.
83. Burg A, Hulbert SF: Dynamic visual acuity and other measures of vision, *Percept Mot Skills 9:*334, 1959.
84. Burg A, Hulbert S: Dynamic visual acuity as related to age, sex and static acuity, *J Appl Psych 45:*111, 1961.
85. Miller JW, Ludvigh E: The effect of relative motion on visual acuity, *Service Ophthalmol 7:*83, 1962.
86. Weissman S, Freeburne CM: Relationship between static and dynamic visual acuity, *J Exp Psychol 69:*141, 1965.
87. Burg A: Visual acuity as measured by dynamic and static tests: a comparative evaluation, *J Appl Psychol 50:*460, 1966.
88. Kirshner AJ: Dynamic acuity a quantitative measure of eye movements, *J Am Optom Assoc 38:*460, 1967.
89. Barmack NH: Dynamic visual acuity as an index of eye movement control, *Vis Res 10:*1377, 1970.
90. Brown B: Resolution thresholds for moving targets at the fovea and in the peripheral retina, *Vision Res 12:*293, 1972.
91. Brown B: Dynamic visual acuity, eye movements and peripheral acuity for moving targets, *Vis Res 12:*305, 1972.
92. Brown B: The effect of target contrast variation on dynamic visual acuity and eye movement, *Vis Res 12:*1213, 1972.
93. Hoffman LG, Rouse M, Ryan JB: Dynamic visual acuity: a review, *J Am Optom Assoc 52:*883, 1981.
94. Westheimer G: Eye movement responses to a horizontally moving visual stimulus, *AMA Arch Ophthalmol 52:*932, 1954.
95. Heck H, Jendrusch G, Wenzel V: The significance of dynamic visual acuity as a performance-influencing parameter in tennis, *Int J Sports Med 19:*S46, 1998.
96. Long GM, Rourke DA: Training effects on the resolution of moving targets-dynamic visual acuity, *Hum Fact 31:*443, 1989.
97. Long GM, Riggs CA: Training effects on dynamic visual acuity with free head viewing, *Perception 20:*363, 1991.
98. Seiderman A, Schneider S: *The athletic eye*: *improved sports performance through visual training*, New York, 1983. Hearst Books.
99. Reichow AW, Stern NS: Athlete and optometrist: performance oriented, *OEP Curriculum II 59:*35, 1986.

100. Revien L: *Eyerobics* [videotape], Great Neck, NY, 1987, Visual Skills.
101. Gregg JR: *Vision and sports*: *an introduction*, Stoneham, MA, 1987, Butterworth Publishers.
102. Sherman A: Sports vision testing and enhancement: implications for winter sports. In Casey M, Foster C, Hixson E, editors: *Winter sports medicine*, Philadelphia, 1990, F.A. Davis, pp 78-84.
103. Leslie S: Sports vision: therapy in motion. In Press LJ, editor: *Applied concepts in vision therapy,* St Louis, 1997, Mosby.
104. Wilson TA, Falkel J: *Sports vision training for better performance*, Champaign, IL, 2004, Human Kinetics.
105. Griffin JR, Grisham JD: *Binocular anomalies diagnosis and vision therapy*, Amsterdam, 2002, Butterworth-Heinemann.
106. Scheiman M, Wick B: *Clinical management of binocular vision*: *heterophoric, accommodative, and eye movement disorders*, Philadelphia, 2002, Lippincott Williams & Wilkins.
107. Press LJ: *Applied concepts in vision therapy,* St Louis, 1997, Mosby.
108. Hebb DO: *The organization of behavior*: *a neurophysiological theory*, New York, 1949, John Wiley & Sons.
109. Piaget J: Development and learning. In Ripple R, Rockcastle V, editors: *Piaget rediscovered*, Ithaca, NY, 1964, Cornell University.
110. Case R: *The mind's staircase*: *exploring the conceptual underpinnings of children's thought and knowledge*, Hillsdale, NJ, 1991, Erlbaum.
111. Peachey GT: Minimum attention model for understanding the development of efficient visual function, *J Behav Optom 2:*199, 1991.
112. Finke RA: Mental imagery and the visual system, *Sci Am 254:*88, 1986.
113. Martin WF: *An insight to sports featuring trapshooting and golf*, Seattle, 1984, SportsVision, pp 155-159.
114. Sharp RH, Whiting HTA: Information processing and eye-movement behavior in a ball catching skill, *J Human Mov Studies 1:*124, 1975.
115. Franks IM, Weicker D, Robertson DGE: The kinematics, movement phasing and timing of a skilled action in response to varying conditions of uncertainty, *Human Mov Sci 4:*91, 1985.
116. Bootsma RJ, van Wieringen PCW: Visual control of an attacking forehand drive. In Meijer OG, Roth K, editors: *Complex movement behavior*: *the motor-action controversy*. Amsterdam, 1988, North-Holland, pp 189-199.
117. Bootsma RJ: *The timing of rapid interceptive actions*: *perception-action coupling in the control and acquisition of skill*, Amsterdam, 1988, Free University Press.
118. Bootsma RJ: Accuracy of perceptual processes subserving different perception-action systems, *Q J Exp Psychol 41A:*489 1989.
119. Bootsma RJ, van Wieringen PCW: Timing an attacking forehand drive in table tennis, *J Exp Psychol Hum Percept Perform 16:*21, 1990.
120. Bootsma RJ: Predictive information and the control of action, *Int J Sport Psychol 22:*271, 1991.
121. Savelsbergh GJP, Whiting HTA, Bootsma RJ: "Grasping" tau, *J Exp Psychol Hum Percept Perform 17:*315, 1991.
122. Bootsma RJ, Peper CE: Predictive visual information sources for the regulation of action with special emphasis on catching and hitting. In: Proteau L, Elliott D, editors: *Vision and motor control*, Amsterdam, 1992, North-Holland, pp 285-314.
123. Bootsma RJ, Oudejans RRD: Visual information about time-to-collision between two objects, *J Exp Psychol Hum Percept Perform 19:*1041, 1993.
124. Siegel D: Response velocity, range of movement, and timing accuracy, *Percept Mot Skills 79:*216, 1994.

9

Peter Shaw-McMinn, OD

Sports Vision Practice Development

CHAPTER OUTLINE

- Internal Marketing
  - Brand Identity and Image
  - Theme
  - Niche
  - Practice Logo
  - Quality
  - Pricing
  - Selection
- Marketing Opportunities before the Patient Enters the Office
  - Telephone Hold Messages
  - Making the Appointment by Telephone
  - Web Site
  - "Welcome to the Office" Mailing
  - Practice Location
  - Parking Lot
  - Window Displays
- Marketing in the Reception Room
  - Office Design and Decor
  - Staff Appearance
  - Patient Education
  - Patient-Centered Office
  - Bathrooms
  - Music
- Communication During Patient History and Pretesting
  - Pretesting Room
  - Technician Review of History Form
  - Pretesting Scripts for the Technician
- The Doctor's Examination
  - The Human Bond before the Business Bond
  - Explaining the Value of the Examination Procedures
  - The Case Presentation
  - Communicating the Benefits in the Dispensary
  - Demonstrators, Displays, and Written Materials
  - Fee Slips and Receipts
  - Dispensary Decor
- External Marketing
  - Direct Mail
  - E-mail Bulletins
  - Newspaper Inserts
  - Newspaper Advertisements
  - Newspaper Columns
  - Public Relations
  - Refrigerator Magnets
  - Courses and Lectures
  - Referrals from Medical Practitioners
  - Contests
  - Community Activities
  - Special Invitations
  - Reputation
  - Word of Mouth

The key to sports vision practice development is getting the message out that you have something unique to offer. You have a story to tell, and you should communicate it in a consistent manner. This requires that internal marketing be in place before external marketing. External marketing brings new patients to the practice. If patients do not receive what was promised in the external marketing message, your practice will go downhill faster than if you did not market at all. Look at all the communication opportunities within the practice experience and make them consistent with your message. Marketing a sports vision practice is similar to marketing any vision practice, with the exception that you are promoting a particular niche in eye care. This chapter discusses developing a marketing plan to promote sports vision.

Table 9-1 shows a self-assessment exercise listing several communication opportunities available to a practice. Complete the exercise and use your responses to determine what to change within your practice to make it more sports vision friendly. The following paragraphs contain some suggestions relative to many marketing techniques.

INTERNAL MARKETING

Brand Identity and Image

When positioning your practice, consider what image to project. One way to look at image is that it represents your brand. What is your brand? What is special about you that will motivate patients (consumers) to choose you over the competition? This question is especially important to ask in highly competitive areas.

Patients have much more to do than think about eye care and eyewear. They are worried about paying their bills, fixing dinner, going to work, and keeping track of family members. The eye care provider is responsible for educating the public about what the practice has to offer. What do you have to offer?

The book *Eyecare Business: Marketing and Strategy* provides exercises to help develop your practice brand and image, which tell a story about you.[1] This story is what your patients will use when speaking about you. Their words are "word of mouth" marketing, which has always been the leading marketing technique for the health care industry. Trust and competence are so important in health care that most patients choose a provider on the basis of what trusted individuals say. What do you want your patients to say about you? What story should they tell?

Following is an example story: "We provide everything available in eye care to allow the athlete to perform at his or her highest level, whatever age or sport. Come to us and we will provide you the best visual acuity, eye protection, and program to improve visual skills, which will give you an advantage over the competition. Whether you are a weekend warrior or a professional athlete, new technology is available to give you the winner's edge. We are dedicated to providing you the tools to perform at your highest ability."

Before you decide on marketing techniques, think about your practice brand and practice story. Begin with this and develop a practice message. All communications should be consistent with this image and brand, or conflict will occur in the minds of your patients and prospective patients regarding who you are. Communication occurs during every interaction a consumer has with you and your practice. Orchestrating what occurs during these interactions results in your ideal image and brand. This image and brand should be expressed throughout the patient visit.

TABLE 9-1 **Marketing technique self-evaluation form**

Marketing Technique Self-Evaluation

Marketing Technique	Successful	Needs Improvement	Not Using but Want to	Not Appropriate
Marketing plan				
Survey				
Brand identity/image				
Name				
Theme				
Niche				
Logo				
Quality				
Pricing				
Selection				
Direct mail				
Demographics research				
Newspaper inserts				
Refrigerator magnets				
Newspaper advertisements				
Courses and lectures				
School educational programs				
Seminars				
Trunk shows				
Medical practitioner referrals				
Contests				
Scholarships and awards				
Community activities				
Public relations				
Clubs and associations				
Outside signs				
Reputation				
Word of mouth				
Availability of financing				
Hours of operation				
Days of operation				
Free consultations				
Speed				
Service				
Phone hold messages				
Smiles				
Welcome to the office				
Office brochure				

TABLE 9-1 cont'd

Biographical sketch				
Information packet				
Practice location				
Building appearance				
Parking lot				
Window displays				
Web site				
Office appearance				
Reception area design				
Color				
Decor				
Furniture				
Staff greeting				
Staff appearance				
Attire				
Attitude				
Attention				
Library				
Electronic bulletin board				
Videos				
Counter cards				
Product brochures				
Samples				
Demonstrators				
Business cards				
Advertising and publicity reprints				
Refreshments				
Treats				
Television				
Reading materials				
Miscellaneous				
Bathrooms				
Music				
History form				
History questions				
Posters				
Testimonials				
Diplomas, awards				
News articles				
Photos of celebrity patients				
Equipment				
Explanations of benefits				
Scripts for assistants				
Dispensing mats				
Examination room appearance				
Neatness				
Saying hello				

TABLE 9-1 cont'd

Explaining test procedures				
Human bonding				
Models				
Pictures				
Lenses				
Written materials				
Articles				
Books				
Prescription pad				
Saying goodbye				
Referral cards				
Examination summaries				
Dispensary design				
Sales training				
Lens packages				
Frame displays				
Merchandise displays				
Gift packages				
Fee slips/receipts				
Follow-up				
Phone calls				
Cards and letters				
Stationery				
Newsletters				
Special invitations				
Gifts				
Recall				
Tie-in with other professionals				
Team sponsorships				
Cooperative funding				
Radio advertisements/shows				
Television advertisements/shows				
Magazine advertisements/ articles				
Billboards				
E-mail bulletins				

Theme

One of the best ways to communicate your brand and story is through a practice theme. The theme, or slogan, is a phrase that describes what you stand for. This should be used on all your communications to give patients the message you want them to remember. The reader should be able to tell what your office emphasis is based on reading your theme. What do you think is emphasized in the following themes?

Correction, protection, and enhancement for athletics

Sports vision correction, protection, and enhancement

Sports vision for winners
Seeing your way to championships
The athlete's edge: super vision
SuperVision, SuperCaring
See better, play better
Everything for the sportsperson
Specializing in sports vision for all athletes
See like a pro athlete
See the best, be the best

If someone saw those words associated with you, would they perceive what you want them to perceive about you? If so, that is a theme for you.

Niche

Consider whether you are interested in a particular aspect of sports vision. Sports vision is already a niche within vision care, but you may want to emphasize LASIK, contact lenses, or visual performance enhancement training. You may want only to work with athletes at the college or professional level, or perhaps you prefer those younger than 18 years. In a highly competitive area, you may want to carve out a certain part of sports vision that is being underserved. Decide on your niche and make it part of your story.

Practice Logo

Your logo is a symbol representing what you stand for. Every time someone sees your logo, you want them to think about what you have to offer. Potential patients may not read your direct mail, but they will see your logo. If the logo is chosen properly, they will think "sports vision" when they see it (Fig. 9-1). The logo can be used several ways to promote your practice. In addition to having it on all your office communications, you can write a paragraph on why the logo was chosen and what it represents. This can be included in "Welcome to the Office" materials or your Web site. You can send an e-mail or letter explaining the new logo to existing patients. Many companies in the ophthalmic industry send out such a letter when changing their logos.

Quality

Although you may not think of quality of products and services as a marketing tactic, the quality of what you offer communicates something to your patients. The average household in the United States earns approximately $45,000 a year. Don't you think they should be spending a part of this on what you offer? Educate them about the benefits of high-quality products and services so that they can make an educated decision on how to spend their hard-earned money.

Pricing

Pricing goes along with quality. You can provide high-quality service and high-quality products at a high cost, but not at a low cost. If you do provide high-quality services and products at a low cost, you will not be in business long. An early strategy could be to provide the services and products at a reduced cost until you build a demand. You may even choose to give away services and products to opinion shapers within the community in the hope that they will spread the word and generate new patients. Keep in mind you cannot offer high-quality services and high-quality products at a low price for long. Only lessening either will allow you to lower the price.



Figure 9-1. Proper sports vision logos.

Each practitioner must establish fees for sports vision services that reflect the local health and fitness economy. The practice should determine appropriate fees for a comprehensive sports vision evaluation, visual performance enhancement training sessions, and consultation services. For individual athletes, the practitioner can use a fee-per-session approach or charge a global fee for a package of services.

When establishing a relationship with a team or club, the agreement can entail per-session fees or a retainer fee for needed services. The team or club management and doctor must agree on which method better suits the relationship. One advantage of a retainer for the

team and doctor is that the doctor does not need to justify the fee for each office visit or training session; that way the team has no concerns about the doctor making recommendations for care that are unnecessary simply to increase income from the team. The doctor should ascertain an appropriate retainer fee for the range and frequency of services that are likely to be provided and negotiate effectively with the team management.

Selection

Product selection is an area in which you can outperform the competition. Few general practices have a good choice of protective eyewear, lenses for athletes, and visual performance enhancement training services. Unfortunately, the patient population does not know this unless you tell them. Provide the best selection of services and products for the athlete and communicate this every chance you get. If the competition does not provide what you provide, they are not really competing. A good example of this is special spectacle designs for hunters and shooters.

Choose your practice brand identity, name, theme, niche, logo, quality, pricing, and selection and you will be ready to develop the internal marketing opportunities to send a consistent message to anyone coming to the practice setting. Remember to be consistent in all your communications and keep the practice brand promise you make to the patient.

MARKETING OPPORTUNITIES BEFORE THE PATIENT ENTERS THE OFFICE

Consumers form perceptions about businesses during every contact. Many perceptions are formed before the consumer has even entered the business premises. Your patients form opinions about you when they call for an appointment; visit your Web site; note the practice location, building appearance, and parking lot; and see the window displays. Use each of these opportunities to enhance the chance they perceive you in the manner you desire.

Telephone Hold Messages

No one likes being put on hold, but it is expected with busy practices. Use this opportunity to educate the caller about what you have to offer in the area of sports vision. Remember, consumers have more to worry about than eye care. Few know much about corneal refractive therapy (also known as *orthokeratology*), higher-order aberrations, or visual performance enhancement training to improve visual skills. State in your on-hold message that you can improve their ability to perform in sports.

Making the Appointment by Telephone

While making the appointment the receptionist can note the age of the caller and perhaps ask whether he or she plays sports, and alert him or her to new technology that may be of benefit. An example of new technology is a computerized training program by NeuroVision (www.neuro-vision.com) that claims to improve contrast sensitivity. As of October 2006 the program was undergoing clinical trials in the United States but is already approved by the Food and Drug Administration for treating amblyopia. Nearly all athletes could potentially benefit from this technology. After making the appointment, your receptionist could say, "Dr. _____ is using a new technology that can improve vision and give athletes an edge. He will let you know if NeuroVision is for you." This comment can generate enthusiasm for the upcoming visit, lessening the chance of a no-show and positioning your practice as current with new technologies.

Web Site

More consumers are evaluating service providers by visiting their Web sites. Many are even using Web sites to make appointments. Use your Web site to convey your message to prospective patients. You may want to refer to it in your external marketing for those who want more information. Provide links to companies whose products you sell, and be sure to include your theme and logo. You may want to provide a sports vision history form to be completed before patients come to the office. Sport-specific history questions can effectively communicate your expertise and educate the prospective patient about the range of services provided by your practice. You and your staff must follow up with the patient responses to sport-specific questions, however, to attain the potential practice benefits of this tool. Your Web site can generate enthusiasm, reducing the number of no-show patients and resulting in patients generating referrals.

"Welcome to the Office" Mailing

You can also mail information about your practice to new patients. This can take the form of an office brochure or an information packet consisting of a presentation folder with a "Welcome to the Office" letter, biographical sketches of staff and doctors, and product and service brochures. Although costly, professional mailings separate you from the competition. To be more successful than others, you must do what others do not, or will not, do. This welcome packet is a good example of providing more than the competition. If the patient uses e-mail, you can send the same information by e-mail at no cost except the time it takes to send it.

Practice Location

Where does the average consumer expect a sports vision practice to be located? Answer this question for your community, and you will send the correct message to potential patients. Good locations are sports training facilities; physical therapy and orthopedic surgery buildings; and facilities in proximity to athletic fields, stadiums, or gyms. All have the advantage of a location where athletes typically frequent. You may also be able to demonstrate the benefits of the products easier if you are near an athletic field, where you can demonstrate the difference or instruct patients on proper use of what you prescribed.

Often the patients of a physical therapist or sports physician become sports vision patients when the two practices share a reception room or are in the same building. Choose a location where others work with athletes. You can often share the cost of external marketing pieces with these other professionals.

Parking Lot

Sometimes the first perception a patient builds about an office is the parking, or lack thereof. The appearance of your parking lot sends a message to your patients. Ask yourself how you can make the parking lot consistent with your image as a sports vision specialist. Perhaps you can include a basketball hoop, with the basketball key painted on the lot; banners of local sports teams; or even a scoreboard giving scores of games.

Window Displays

Many practices have large windows near the entrance to the office. Patients and prospective patients walk by these windows before entering the practice or may wait for a ride near them.

In either case, use them to communicate that you are an expert on sports vision and have benefits to offer the athlete.

MARKETING IN THE RECEPTION ROOM

Your office space is one of the primary ways to communicate with your patients. Patients usually cannot tell whether you have the most up-to-date equipment and instruments, but they can tell whether your color scheme, carpeting, draperies, and decor are modern. Examine your office from the point of view of the consumer and consider what it says. Is the message consistent with your desired image and brand? A good way to ascertain whether you have modern colors and decor is to observe fast food restaurants. They typically redecorate as often as every 4 years to keep a fresh, modern appearance. Eyewear display vendors may offer expertise in office decor for free or at a reduced price. Their expertise often can result in a greater return on your investment in office design.

While waiting, patients look at everything in the reception area. They see every cobweb and outdated magazine. They notice how staff dress, how they move, and how they treat others. They hear every word said and how it is said. Therefore consider offering an experience that is enjoyable and educational. Use the reception area as a classroom and provide opportunities to learn about what you offer and how it can benefit them. Brainstorm everything you can include that fits your image and brand and is practical based on your office design.

Office Design and Decor

As a sports vision specialist, you may want to use the colors of the favorite professional teams in your area. Fans will appreciate the fact that you like the same teams they like. (Of course, this can lead to interesting banter from those who root for opposing teams.) You may want to decorate it like a sports store, sports department, or den. You can include pennants, sports memorabilia, and photographs, especially from thankful patients who are known in the community. Decor that includes photos of teams you have sponsored and trophies and plaques you or your patients have won are consistent with a sports-oriented practice.

Staff Appearance

Staff appearance communicates a message to your patients. What clothes convey that they work with sports vision? Surgical greens may imply work with eye injury, whereas sport shirts with your logo and theme may convey an athletic bent. Referee uniforms add a whimsical, fun atmosphere. Staff members who are fit send the message that you practice what you preach when it comes to being in the best shape possible to succeed.

Patient Education

Properly designed, the reception area can offer information on services and products for patients. Use every opportunity to educate them regarding the benefits derived from treatments. If you have not already sent a “welcome to the office” packet, hand the patient one when he or she arrives. Customize it to the sport or age of the patient and include information about the practice and the products and services that may be of benefit to the patient. Use libraries to impress them with what you know. Stock a bookcase with books on vision, including textbooks. Develop a system for loaning the books to patients if they ask to borrow them. Seeing the complexity of the textbooks will impress them with your knowledge.

Electronic bulletin boards can display game scores and highlight new technology and how it can benefit them. Have counter cards, brochures, posters, demonstrators, and advertisement and publicity reprints readily available to waiting patients so that they can learn more about eye care. Televisions and computer monitors can be used in the reception area to educate patients and prospective patients by playing videos, Eyemaginations or iPort (http://www.eyemaginations.com, or http://www.iportmedia.com), or televised games.

Patient-Centered Office

An experience that is enjoyable helps ensure that patients are more apt to return, especially families. If no distraction is available for children, they will resist coming to the office—either as a patient or brought by a parent who is a patient. Make a sports vision practice athlete centered. Provide video games for the young and maybe a separate glassed-in area for the children. Allow them to be seen by their parents playing with video games, plastic kitchens and workshops, or blocks. With the proper environment, children may be excited about coming to your practice.

How do you treat friends who come to your home? Typically you offer them a refreshment and snack. Providing the same in your office positions you as a friend to your patients, and people generally like doing business with friends. Make your patients comfortable and enhance your sports vision brand by providing sporting events on television sets, magazines with a sports theme such as *Sports Illustrated*, and the sports section from the newspaper.

Bathrooms

A bathroom typically is not thought of as a marketing technique, but the office's bathroom communicates something to your patients, which is what marketing is all about. A bathroom that is meticulously clean and patient friendly says something about your service. It says you pay attention to small details and understand the consumer's needs. If staff are careful about the bathroom, the staff likely are careful about vision care. Include make-up mirrors in the ladies' room along with hairspray, hand lotion, and tissues. Many patients will visit the bathroom to check their appearance after an eye examination. Some may want to fix their hair before returning to the office or going to their next errand. Give them the tools to do the job and include educational information on eye drops, sports-tinted contact lenses, and sports vision.

The men's room can be made more appealing by posting the sports page and having posters on the wall and information about sports vision. Remind them that you can relate to their needs. Provide information about sports vision to read.

Music

Music is always a difficult choice in any office because it is impossible to address the preferences of every patient. As a sports vision expert, you may be able to avoid this by broadcasting sports talk show stations or game commentaries, which would convey the message that you are all about sports, effectively separating you from other eye care professionals.

COMMUNICATION DURING PATIENT HISTORY AND PRETESTING

The next opportunity to communicate with your patient is during completion of the patient history form. The patient history form can be used to make the patient aware of needs he or she may not have realized when making the appointment. As Susan Stenson noted, "General medical care relies on the history, physical examination, and various hereditary, social,

environmental, occupational, and recreational considerations to generate prescriptions to help treat and/or prevent disease."[2] The history form can be used to gather information that you would otherwise not garner. For example, the history may reveal risk factors requiring someone active in outdoor sports to protect the eyes from sunlight. A patient may mention a type of recreation that puts him or her at risk for eye injury, such as racquetball. A sports vision practice should ask specific questions regarding sports activities. Does the patient play tennis, golf, baseball, racquetball, basketball, or other sports? How often? Does the patient wish he or she could see better when playing the sport? A checklist of all sports activities is useful for a sports vision history form. As previously mentioned, follow-up regarding the information the patient provides is crucial. For example, for a patient who indicates skeet shooting as a recreational pursuit, the examination and dispensing services should provide evaluation and recommendations specifically suited for this pursuit.

Many medications can cause mydriasis, which may decrease the depth of focus and increase the effect of higher-order aberrations on vision. A good history lets you give the proper counseling on the effect these medications may cause on vision during sports.

Pretesting Room

Often patients are seated in a pretesting room before tests are conducted by a technician. While in the room they will look around, as they do in the reception area. Posters, testimonials, diplomas, awards, news articles, and photos of special patients can be placed on the walls in this room. Highlighting well-known athletes can be strong support for your recommendations.

Counter cards, brochures, dispensing mats, and copies of office marketing materials can also be displayed. Use the pretesting room to educate patients about the services you offer.

Technician Review of History Form

A well-trained technician can review the history form and recognize treatment possibilities for the athlete. The technician can discuss opportunities with the athlete by saying, "I see from the history that you play racquetball. There are lenses that are light and less apt to break that can protect your eyes. Here is a brochure about the lenses and special frames made for racquetball players." Or the technician may say, "I see from your history form that you are taking allergy medications that may affect the way your pupils respond to sunlight. Combined with the time you spend playing golf outside, you should protect your eyes from the sun. Here is a brochure about sun eyewear specially designed for golf to give you better vision and protect your eyes from cataracts and macular degeneration. The doctor can discuss whether these lenses are appropriate for you."

Train your assistants how to look at the history form and match the history with probable treatment options. Give your staff materials to educate the patient on what you offer.

Pretesting Scripts for the Technician

The technician can further educate the patient about the value of examination procedures by explaining their value in relation to the patient's particular needs. For example, the technician may say, "I am now going to test your peripheral vision, which you use to detect the ball out of the corner of your eye when playing basketball," or "I am going to test your depth perception to make sure you can judge distances as well as possible as when you are playing baseball."

A well-trained technician can relate binocular vision, visual field, and color vision tests to sports and convey the message that you provide an excellent examination experience. "The doctor will use these test results and history information to deliver an eye examination designed to your specific needs."

THE DOCTOR'S EXAMINATION

After pretesting examination, the patient typically is led to a doctor's examination room and seated. The patient may review the brochures and educational materials obtained from the technician, then look around the examination room. Diplomas, awards, recognition, photos of eye conditions, posters, and other materials that convey the image of a sports vision specialist can also be hung on the walls of this room.

The Human Bond before the Business Bond

Marketing experts say the doctor must form the human bond before the business bond, and the human bond can be on any subject other than the business at hand. Sports vision fits in nicely for the amateur athlete who never considered speaking to the doctor about improved performance through better vision. A discussion about similar sports interests can lead to a relationship with the patient, enhancing the chances he or she will adhere to the prescribed treatment after the examination. When seen again the following year, a mention of "How's your golf game?" can immediately bond the patient to the doctor. Casual discussion about your experiences with sports can enhance your image as someone who understands the needs of the athlete patient.

Creating the human bond goes a long way in building trust between the doctor and patient. The human bond results in more loyalty, enthusiasm, and referrals.

Explaining the Value of the Examination Procedures

Eye care practitioners often incorrectly assume that patients know what is going on during the examination. Unless the procedure is explained, patients have no idea of the benefit. For example, retinoscopy has been performed for hundreds of years, yet few patients know the value of the procedure. A simple description such as, "I am shining a light off the back of your eye and focusing it up close where I am looking, so it will get blurry for you. This tells me what your eye needs without asking you any questions. Half the tests I do today don't require you to say anything. This is called objective testing. That way you do not have to worry about giving answers." This explanation dispels the worry of many patients that they will give the wrong response and get the wrong lenses. Given this explanation, the patient often marvels at the "new" examination procedures available today.

Link examination procedures to patients' particular sports needs whenever possible. Prepare them for prescribed treatments such as contact lenses, polarized sun lenses, visual performance enhancement training, and safety glasses. By talking throughout the examination, the time will be no longer and the patient will be much more involved in what is going on. Explained properly, the patient will not be surprised at the recommended treatment and may be eager to purchase it.

The Case Presentation

The case presentation is the doctor's chance to put everything together for the patient to understand. Studies show that a patient remembers 60% more if a visual aid is used during an explanation.[3]

Models, pictures, lenses, videotapes, written materials, samples, and demonstrations may be used to explain the patient's needs (based on history and examination) and the solutions to these needs. Often doctors are so caught up in data gathering that they do not spend enough time communicating what they can offer the patient. If anything, spend extra time on this part of the eye examination. Patients want explanations from their doctors.

An examination summary form can be used to summarize the findings and prescribed treatments (see Appendices C and D). This form can make the patient aware of everything involved in the examination and the complexity of vision care. Handing an examination summary form to a patient is a good example of doing something that other doctors do not, or will not, do. This act can help you stand out as special to your patients.

Recommendations by the doctor are often referred to as the "power of the white coat." Patients are more apt to spend money on products and services if the doctor discusses them with the patient and makes a strong recommendation or prescription. Offices that leave the explaining of lens features to the opticians have less compliance with the prescription. Use the power of your "white coat" to improve the lives of your patients.

After the examination, you may want to hand the patient a few referral cards. A referral card is a business card that says on the back, "The greatest compliment our patients can give is the referral of their friends and loved ones. Thank you for your trust." If you feel as if you bonded well with the patient, hand him or her a few cards and say, "If you know of family or friends who could benefit from my services, I'll be glad to see them." Some doctors say this is the single most important tool they have used to generate new patients.

Communicating the Benefits in the Dispensary

The patient typically is next escorted to the dispensary, where the recommendations are restated and demonstrated by the optician. Sales training is a benefit to the person in this position because he or she is required to "close the sale" and explain the fees. Sometimes objections must be overcome and the value of the prescribed product or service restated. Have your staff develop scripts to explain the benefits and overcome common concerns.

Demonstrators, Displays, and Written Materials

Demonstrators, displays, and written materials can be used to show the patient what to expect from the prescribed product or service. Lens packages are an excellent way to present fees and options without going through every lens option. Think of the "value meal" offered by fast food restaurants. This concept is a simple way to bundle all the options and present them to the consumer. The computer and auto industries have used bundling for many years. Presenting lens options as best, better, and good can help the optician explain what is ideal for the patient. Bundling may also be used to join products together with services such as contact lenses. What sports vision services and products can you bundle together and offer patients?

Fee Slips and Receipts

When presenting the bill, a fee slip or receipt should act as a marketing technique by including your logo, theme, and a list of available services and products. Show patients what you stand for and what you offer on the fee slip. Patients often do not realize the wide variety of services and products offered by eye care professionals. Their exposure to vision care may consist only of a general eye examination and a limited choice of lenses. Listing many of the

services and product choices on your receipt can help educate patients that there is more to eye care than simply a basic examination and glasses.

Dispensary Decor

The decor of the dispensing area should be consistent with the sports vision theme of the practice. Team memorabilia, colors, and sports themes can be reinforced. Modern decor is consistent in conveying that your practice is consistent with the latest technology. Merchandise displays can make observers aware of what is available to them.

EXTERNAL MARKETING

Once all the internal marketing techniques are aligned with your image, you are ready to develop external marketing to bring in new patients. If the internal marketing is not in place, you will not keep the promise made by your theme and story and thus lose patient trust sooner, leading to the demise of your business faster than if you did no marketing at all. A survey of top practices in Southern California showed that external marketing was not necessary once word of mouth and reputation were strong.[4] To get to that point, however, external marketing is required to get the "mouths" in and give them the message to spread. Box 9-1 shows several marketing techniques that can be used to bring in new patients.

External marketing techniques should depend on what has been most effective in the past; be most fun, easiest to do, and free or inexpensive; fill a present need; and be something of interest to someone on staff.

Direct Mail

Although no one seems to want to receive "junk" mail, direct mail still proves to be the leading method by which people learn about products and services.[5] Nearly all eye care practitioners attempt direct mailings at some point. Many professionals scoff at using direct mail, citing the irritation of junk mail. However, the author remembers a friend who complained about receiving junk mail. The friend was driving both his and the author's family to a ski area and mentioned that he had just gotten new tires on his vehicle. He went on to say he bought the new all-weather tires made by a national manufacturer. When the

BOX 9-1 MARKETING TO ESTABLISHED AND NEW PATIENTS

- Direct mail
- Research demographics
- E-mail
- Newspaper inserts
- Refrigerator magnets
- Newspaper advertisements
- Courses and lectures
- School educational programs
- Seminars
- Trunk shows
- Referrals from medical practitioners
- Contests
- Scholarships and awards
- Community activities
- Public relations
- Club and association memberships
- Outside signs
- Reputation
- Word of mouth

author inquired where he heard about them, he said he received an ad in the mail from the local tire store. The author stared at him without saying anything. The friend grinned and replied, "Well I really don't read junk mail, but I did need all-weather tires for driving my kids to the mountains! I would have gotten them anyway."

Often the strength of direct mail is simply reminding recipients that they can benefit from certain services or products. In a hectic world, direct mail can remind them that eye care is important. Your name, logo, and theme on a direct mail piece can suggest they receive that care from you.

Many professionals send out direct mail pieces only once and lament how the effort did not result in any additional sales. Common mistakes such as omission of a phone number or address, misspellings, and postal errors regarding bulk rates can defeat even the best direct mail intentions.

A successful direct mail campaign includes at least four direct mailings a year. Each should result in an increased response. Ideally, the fourth mailing will provide the greatest success. Marketing experts state that people must hear a message at least three times before they respond to it. For example, it takes 27 opportunities to notice a sign nine times, and nine times to pay attention to the message three times. Direct mailings work better than signs because recipients must look at the piece to make the decision to throw it away. Eye care practitioners can expect a gross return on investment of 10 times from four direct mailings a year.

The success of direct mail also increases by targeting the proper population. As a sports vision specialist, target coaches, physical therapists, orthopedists, gyms, and any group associated with sports, such as little league baseball. Sending letters, newsletters, or postcards to targeted groups about what you offer costs little and can result in big returns for your practice.

E-mail Bulletins

If you have the e-mail addresses of important referral sources, you may want to communicate with them in that medium. Remember, a message can be deleted with the press of a button, but the reader will still be reminded you exist. You could ask recipients how they prefer to learn about new technologies that may help their athletes. Sending e-mails to former patients and those who inquire about the practice can also result in building the sports vision portion of your office.

Newspaper Inserts

Inserts are full-page advertisements in newspapers that are an inexpensive way to deliver information to the general community. The cost can be as low as $45 per 1000 papers, but prices vary depending on the size of the newspaper's circulation. Although the consumer may not read the entire flyer, again, he or she must look at it long enough to throw it away. It will remind consumers that you exist and may be timed perfectly to someone who has recognized the need for eye care services and products.

Another advantage of inserts is that the medium is separate from other newspaper information. An insert is much more noticeable than an advertisement tucked away on a page with several columns of news articles or other advertisements. The insert can also be reused in other forms of marketing, such as direct mail, posted flyers, or office information presented in the reception area or that of another health care provider.

Newspaper Advertisements

Many people like to learn about services available to them through their local newspaper. Local papers often do not have the technology to include newspaper inserts. In those cases, a well-placed advertisement, run on a regular basis, may convey to the community what you offer. Make sure your advertisements include all the benefits of your products and services. Often a combination of several small benefits inspires a potential patient to choose you rather than one particular benefit. Think of every possible benefit you can offer the athlete and list them in the advertisement along with your logo, theme, and contact information. Placing advertisements in the newspaper can also position you for free public relations exposure.

Newspaper Columns

If you prove to be adept at writing and enjoy it, offer to write a column for your local newspaper. Include samples of columns that may be useful to the paper to use when they have space to fill. Relationships with newspaper decision makers can offer many opportunities to get your name into print.

Public Relations

Ask the salesperson who handles your newspaper advertisements and inserts to introduce you to the sports or science editor of your newspaper. You can establish your credibility as an authority in eye care by providing information to him or her in the form of press releases and articles you have written supporting the releases. Follow the release with a phone call from your office manager and offer to be interviewed on pertinent topics.

Although eye care practitioners may be well versed on LASIK or new technologies, the sports or science editor may not. Be a resource that journalists can trust to clarify information they may have heard elsewhere. Offering complimentary eye examinations and sports vision evaluations to opinion shapers such as newspaper editors can demonstrate your ability to improve their standard of life.

Consider local radio stations, cable television stations, and magazines and other periodicals as an audience for public relations announcements.

Refrigerator Magnets

If you enjoy working with young people, refrigerator magnets are a must. No parent has enough refrigerator magnets to post all their children's school work and notices. An advantage of a refrigerator magnet is that it can put your name in front of prospective patients every day for a year or more. Design it like a mini-brochure, including your logo, theme, and contact information. Many offices send a calendar refrigerator magnet to encourage use.

Courses and Lectures

Personal contact is the second most powerful marketing tool according to surveys concerning optometry. Courses and lectures establish you as an authority in the field. Send out a letter from your office manager each year offering to give a specific lecture to service organizations and community associations. Athletic trainers are often very receptive to an in-service on the triage and management of sports eye injuries, presenting an excellent opportunity to build

a relationship. By seeing you in person, the prospective patient or referreal source will be more comfortable choosing you as a practitioner.

You can also hold lectures and workshops in your office. Even if few participants show up, the ones who do attend could be key referral sources. Advertising the lecture also provides opportunities for exposure.

Referrals from Medical Practitioners

Saying you have something to offer is simple, but getting trusted medical practitioners to say you have something to offer can be more effective in convincing a prospective patient to come to you. Market to prospective professional referral sources by sending them letters, brochures, and referral pads. Offer complimentary examinations and refer to them in return. Friendships with key medical practitioners can develop into strong referral sources. Often their staff can be even more effective in busy medical offices. Have your staff take them out to lunch and encourage referrals.

Contests

If your brand identity is someone who is fun, a lottery-style drawing could be effective. You can advertise the contest and receive free exposure from your local newspaper or radio station. Add those entering the contest to your mailing list. The prizes for a sports vision practice should be related to sports, such as sports sunglasses or goggles.

For elementary schools, a poster contest can be appropriate. For higher grades, an essay on the importance of vision in sports could be effective.

Community Activities

People like to buy from friends. The more involved you are with the community, the more friends you will make. Make sure they learn of your qualifications through patient education pieces. Offer to contribute time and money to their causes and build loyalty for supporting the community.

One important fact to remember, however, is to act like a professional. Some eye care practitioners build their practice through community activities, and others are unsuccessful. If you want the public to come to you as a doctor, you must fit their image of a doctor. Often this means certain expected behaviors. If you cannot act like a doctor (whatever that means for your community), do not try to build your practice through community involvement. You may be the life of the party, but that person may not be a doctor to whom others are willing to trust their eyes.

Consider building your practice by joining fraternity clubs, parent-teacher associations, booster clubs, alumni organizations, the YMCA or YWCA, or women's clubs.

Other marketing techniques that may build your practice include billboards, team sponsorships, radio advertisements, radio shows, television advertisements, television shows, magazine advertisements, and magazine articles. Sponsoring a local youth team puts your logo and name on their uniforms, reminding everyone that vision is an important part of sports and that you are there to help athletes. Advertising on a stadium or arena billboard or in a team media guide associates you with high-achieving athletes and bonds you with the fans. If you are the eye care provider for high-achieving athletes, you may be perceived as better than other eye doctors. Some offices pay professional teams more than $100,000 to advertise that they are the eye doctors for the team. If you have a large practice, this level of sponsorship may be beneficial.

Special Invitations

Your marketing plan should include as many opportunities as possible to give prospective patients an excuse to come to the office and learn about you and what you offer. Invitations can take the form of an open house, patient appreciation day, community service day, or sports vision screening day. You can send out invitations to learn more about new frame releases, new sports vision contact lenses, sports-tinted contact lenses, disposable bifocals, LASIK, and new procedures and services.

Often you can partner with an optical or pharmaceutical company to provide cooperative funds to pay for the special event. They may send sales representatives to help with contact lens application and removal or frame experts.

Reputation

The ultimate goal of all external marketing is to build a desired reputation. Once the community learns to associate you and your office with desired characteristics, the patients will want to go nowhere else. Reputation is built by getting patients to your practice with a promise to provide what they want and then fulfilling this promise through the practice experience and internal marketing. Once a good reputation is achieved, the strongest marketing tool of all is available to you—word of mouth.

Word of Mouth

Consumers are better educated than ever before. They have grown skeptical through advertisements that promise one thing and provide another. Consumers have a greater number of products and services to spend their money on than at any other time in history. Trusting a friend or colleague to confirm what the prospective patient has learned through a Web site or marketing pieces is critical in choosing an eye care provider. For this reason, word of mouth continues to be the primary marketing technique to bring in patients. Always remember when designing patient communications that satisfied patients have the mouths; you are responsible for putting the words into them.

Use every communication opportunity available to place positive words in your patients' mouths. Restate what you stand for and retell your story. Once you have others telling your story and building your reputation, you have arrived. You are the sports vision expert!

REFERENCES

1. Moss GL, Shaw-McMinn PG: *Eyecare business marketing and strategy,* Boston, MA, 2001, Butterworth-Heinemann, pp 98-106, 11J.
2. Stenson S: Healthy site counseling, http://www.ustransitions.com/NR/rdonlyres/4045879B-C093-426D-9DFC-393BADFA6465/0/hscpaper.pdf. Accessed May 1, 2007.
3. Levinson JC: *Guerilla marketing attack,* Boston, MA, 1989, Houghton Mifflin, p 8.
4. Katzaroff J, Hopkins J, Shaw-McMinn PG: *A survey of marketing methods by private practitioners in Southern California* [thesis], 1997, Southern California College of Optometry student research papers, 97-28 to 97-39, Fullerton, CA.
5. Majority of adults prefer direct mail, says survey. http://www.directmag.com/news/marketing_majority_adults_prefer/. Accessed May 1, 2007.

A

Appendix A: Vision Evaluation Protocols for the 2006 AAU Junior Olympic Games

CONTENTS

Consent 242
History 243
Lensometry 245
Visual Acuity (Snellen) 248
Cover Test 249
Near Point of Convergence 251
Color Vision (Color Vision Testing Made Easy) 252
Color Vision (Ishihara Color Plates) 253
Randot Stereopsis 255
Pupils 256
Ocular Motilities 257
Pursuits/Saccades 258
Dominant Eye-Hand (WSVP Dominance Wand) 259
Dominant Eye-Hand 260
Autorefraction 261
External Health 263
Internal Health 265
Eye Movements: Ober II 266
Threshold Dynamic Visual Acuity 268
Acuvision 1000 Eye-Hand Coordination 269
Wayne Foot Speed 270
Wayne Saccadic Fixator 271
Wayne Saccadic Fixator (Hand Speed) 272
Wayne Saccadic Fixator (Balance Board) 273
Wayne Peripheral Awareness Tester (PAT) 274
Tachistoscope 275
Vectorvision Contrast Sensitivity 276
Howard Dolman Stereoacuity Test 278
Bassin Anticipation Timer 280
Wesson Fixation Disparity Card 281
Vision and Balance 282

(Reprinted with permission from the American Optometric Association, St. Louis, MO © 2006)
(From Beckerman S, Hitzeman S: Vision Evaluation Protocols for the 2006 AAU Junior Olympic Games)

CONSENT

For the consent to participate in a vision screening and research study
Read the following to the athlete:

I, the undersigned, give my permission for a sports vision screening to be performed on me by the members of the AOA Sports Vision Section Screening Team (AOA SVSST). In granting this permission, I release agents and representatives of the Junior Olympics and the AOA SVSST from any and all liability, which may arise from the screening examinations or tests. I realize that a screening should not be considered a complete examination and that responsibility for any recommended follow-up care is mine alone.

Having come to the AOA SVSST for this screening, I voluntarily consent to allow the information in my record (including test results, photographs, and other pertinent information) to be inspected (reviewed) and/or used for the purpose of research, student education, scientific studies, or other professional purposes. During my examination, the clinician or optometrist assigned to me will explain the benefits and risks of specific testing procedures to me. I understand that my name will remain confidential (will not be used) if the information in my record is reviewed.

Furthermore, I am aware that I may refuse to allow the use of my record, but that such refusal would in no way affect the level of care to which I am entitled.

Present the above information to the athlete and allow questions to be asked.

If the athlete agrees to the vision screening, have him or her sign in the appropriate location on the recording form. If the athlete is a minor, have his or her legal guardian sign the form.

HISTORY

It is important to get an accurate ocular and medical history to fully utilize the screening information. Ask the athlete the following questions about his or her ocular and medical health and sports involvement. Allow the athlete to ask questions and offer additional information and record the answers in the appropriate area on the recording form.

Demographic Information:

Patient initials:
Age (at time of screening):
Sport (record primary competitive sport):

1. Baseball
2. Basketball
3. Hockey
4. Football
5. Volleyball
6. Soccer
7. Track
8. Tennis
9. Swimming
10. Wrestling
11. Golf
12. Softball
13. Sailing
14. Gymnastics
15. Karate/Martial Arts
16. Surfing
17. Field Hockey
18. Power Lifting
19. Jump Aerobics
20. Water Polo
21. Other

Male/Female:

Competition Level (Record Highest Level Achieved):

1. Grade school
2. Junior high
3. High school
4. Junior college
5. College NCAA division 2/3
6. College NCAA division 1
7. Professional (minor league)
8. Professional (major league)
9. Recreational
10. Control

Prescription History

What was the date of your last eye exam in an eye doctor's office?
What is your eye doctor's name?
Do you wear corrective lenses?
If yes, do you wear them for sports?

Ask which of the following describe the athlete's current spectacles:

- None
- ASTM f803 Approved Eyewear (Prescriptive)
- Plano Polycarbonate Shield

- Standard Spectacle

If the athlete wears contact lenses, ask which of the following applies.

- Soft Sphere Daily Wear
- Soft Sphere Extended Wear
- Soft Disposables
- Soft Toric
- Rigid Gas Permeable

Ocular Symptoms

Ask the athlete whether he or she ever experiences or has been told he or she has any of the following symptoms:

- Difficulty seeing
- Reduced peripheral vision
- Sensitivity to lights
- Reduced performance as stress builds
- Lack of consistency of play
- Headaches
- Easily distracted from visual target
- Poor depth perception
- Difficulty following moving objects
- Blurred vision after close work

Ask the athlete whether he or she has any reason to believe he or she has an eye or vision problem.

Medical History

Ask the athlete to describe his or her current medical health and list any medications he or she is currently taking.

LENSOMETRY

Evaluates: The sphere, cylinder, and axis of the athlete's current optical prescription. Perform lensometry on the prescription that the athlete most often uses for sports activities.

Basic Components of a Lensometer: All lensometers have the same basic parts and features, although the designs vary. These components are:

1. Viewing telescope

This allows the image of the target mire formed by the unknown lens to be viewed. The telescope is focused for optical infinity; therefore the mire image will appear clear only if light emerging from the unknown lens into the telescope is parallel.

2. Eyepiece

The eyepiece is where the observer looks into the lensometer. This must be focused to make the internal reticule clear. The reticule is a black crosshair that in some models has a series of concentric circles and/or hash marks used to measure prism. The reticule must be in focus to obtain an accurate neutralization of unknown lenses.

3. Target (mires)

These are object lines inside the body of the lensometer, that are focused by turning the power wheel. They are two perpendicular sets of either two or three lines. The lines of one set are spaced closely together, and the lines of the other set are spaced more widely apart.

4. Power wheel

This is an external wheel that is rotated until the internal mire targets are clear. The sphere and cylinder components of the prescription are read off a scale on the power wheel when the mires are in focus.

5. Cylinder (axis) wheel

This is an external wheel that rotates the mires. It is calibrated in degrees to indicate the orientation of the minus cylinder axis of the lens when the mires are properly positioned.

6. Lens stage (table)

This is a horizontal platform that supports the lower edge of the glasses. It can be moved up or down to accommodate different frames.

7. Lens stop

The lens to be measured is placed against the lens stop. The area of the lens centered on the lens stop is the area measured.

8. Lens holder

This is a spring-loaded arm that holds the lens firmly against the lens stop when it is released.

9. Lens marker

This is a three-dot marking system used to mark a horizontal line across a lens. It is used to mark the optical center of the lens when the mire pattern is centered on the reticule.

10. Prism compensator

This device is used to compensate for the displacement of the mires from the center of the reticule. A scale on the compensator allows the prism magnitude and direction to be determined. The compensator is set on zero unless prism is being measured.

Preparing the Lensometer

1. Focus the eyepiece.

First, set the power wheel to zero. Next rotate the eyepiece completely out, counterclockwise, until the reticule is blurred. Then rotate the eyepiece slowly inward until the reticule is clear and distinct (Fig. 1).

2. Reset the prism compensator.

If the lensometer has a prism compensator, it must be reset to zero. When you look into the lensometer, if the mire patterns are not centered on the reticule then the prism compensator is not set at zero.

Neutralizing the Lenses

1. Always measure the right lens first.
2. Place the pair of glasses in the lensometer with the concave surface away from you (Fig. 2).
3. Center the lens by aligning the target in the center of the eyepiece reticule by moving the lens up, down, to the right, or to the left. Once the lens is centered move the stage so that it supports the bottom of the frame. Carefully release the lens holder so that the lens is held firmly in place.
4. Turn the power wheel to very high plus. Then slowly turn the power wheel toward the minus direction and rotate the axis wheel until the sphere mires (small narrow lines) come into sharp focus. If the cylinder mires (wider lines) come into focus first, rotate the axis wheel 90 degrees so that the sphere mires are in focus. If the sphere and cylinder mires come into focus at the same time the lens is spherical.
5. Now find the cylinder power. Do not move the axis wheel. The axis has already been determined. Continue turning the power wheel in the minus direction until the cylinder mires are clear. The difference between the new power reading shown on the power wheel and the original sphere power is the amount of minus cylinder power in the lens. Read the axis of the cylinder from the axis wheel (Fig. 3.).

Examples

1. Power wheel reading when the sphere mires are in focus = −1.00 D
Axis wheel reading when the sphere mires are in focus = 175 degrees
Power wheel reading when the cylinder mires are in focus = −3.00 D

$$Rx = -1.00\ -2.00 \times 175$$

2. Power wheel reading when the sphere mires are in focus = +2.00 D
Axis wheel reading when the sphere mires are in focus = 45 degrees
Power wheel reading when the cylinder mires are in focus = +0.50 D

$$Rx = +2.00\ -1.50 \times 045$$

Recording

1. Always record the sphere and cylinder power and the axis location as three digits. For example:

Correct	Incorrect
+1.00 −0.50 × 045	+1.00 −.50 × 45

2. If the lens is spherical, record "sph" or "DS." For example: −3.00 DS.

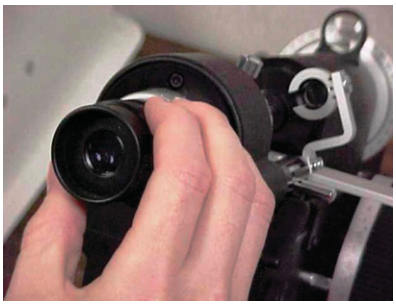


Figure 1



Figure 2

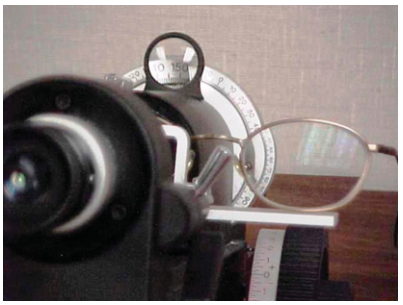


Figure 3

VISUAL ACUITY (SNELLEN)

Evaluates: The Snellen chart uses minimum separable angle techniques to determine visual acuity. The fraction result obtained is the reciprocal of minimum angle of resolution (this is based on 1 minute of arc).

Test Distance: 20 feet

Illumination: Standard illumination

Position: Standing relaxed

Critical Factors: Sequence for testing is OD followed by OS

Criterion: Crisp 20/20 (1 minute of arc) OD, OS

Instructional Set: "Please cover your left eye and read the row of letters above the red line. Then the smallest line below the red line you can with out squinting. Guess if you have to." Repeat this with the right eye covered.

Record: Record BVA (best visual acuity) as the smallest line where the patient gave more than half correct.

Standard Chart Answers:

200: E
100: F, P
70: T, O, Z
50: L, P, E, D
40: P, E, C, F, D
30: E, D, F, C, Z, P
25: F, E, L, O, P, Z, D
20: D, E, F, P, O, T, E, C
15: L, E, F, O, D, P, C, T
13: F, D, P, L, T, C, E, O
10: P, E, Z, O, L, C, F, T, D

COVER TEST

Evaluates: This test assesses the presence and magnitude of a phoria or a tropia (strabismus). If motor fusion is present (no strabismus) the cover test measures the demand put on the athlete's fusional vergence system.

Equipment: Occluder, Snellen chart, near point target, and a prism bar.

Setup: This test is done at both distance (20 feet) and near (16 inches). The athlete should wear his or her habitual prescription for the distance being tested. The room illumination should be full. For distance testing the target should be an isolated Snellen letter two lines above best visual acuity for the patient's poorer seeing eye (Fig. 1). For near testing the target should be an isolated near target letter (Fig. 2).

Instructions: Inform the athlete that this test measures the ability of his or her eyes to work as a team. Instruct the athlete to look at a particular detail of the target letter ("look at the tip of the A"). Tell the athlete to keep that detail clear throughout the entire test. It is very important that the athlete does not look around during this test.

Procedure:

1. First perform the unilateral cover test (UCT). This portion of the test determines whether a strabismus (tropia) is present. Begin the UCT with the occluder in the midline position (over the patient's nose). Cover the patient's right eye while observing the left eye. Repeat this several times, noting any movement of the left eye only. Then cover the patient's left eye while observing the right eye. Again, repeat this several times, noting any movement of the right eye only. Be sure to hold the occluder over the eye for 2 to 4 seconds to allow the deviating eye (if present) to regain fixation. Note the direction and magnitude of any movement. If no movement is present on this test the athlete does not have a strabismus. Perform the above procedure at both distance and near (Fig. 3).
2. Now perform the alternating cover test (ACT). This allows the determination of the presence of a phoria if a tropia has already been ruled out by performing the UCT. Alternately occlude the right and left eye for at least five cycles. Watch the eye that is uncovered as you move the occluder to the other eye. It is important to make sure the athlete is not binocular at any time. The occluder is in place over the eye for 2 to 4 seconds, but it should be moved quickly between the eyes to avoid binocularity. Note the direction of the movement of the eye as it is uncovered to determine the type of deviation present.
   a. If the eye moves in when uncovered = exo deviation (the eye was out)
   b. If the eye moves out when uncovered = eso deviation (the eye was in)
   c. If the eye moves down when uncovered = hyperdeviation (eye was up)
   d. If the eye moves up when uncovered = hypodeviation (eye was down)

   Also perform the ACT at both distance and near (Fig. 4).
3. To determine the magnitude of the deviation, hold the appropriate base prism over one eye and perform the alternating cover test.
   BO prism for eso
   BI prism for exo
   BD prism for hyper
   BU prism for hypo

Begin with low amounts of prism and increase the amount of prism and repeat alternate occlusion until no motion is seen. The magnitude of the deviation is determined when no motion is noted (Fig. 5).

Recording:

Phorias: Record the magnitude and direction of the deviation.

Tropias: Record the type of deviation, laterality (unilateral or alternating), magnitude of the deviation (in prism diopters), frequency of the deviation (constant or intermittent), and the direction. The prime sign (′) indicates a near deviation.

P = phoria
T = tropia = strabismus
E = eso deviation
X = exo deviation

Examples: 2 XP = 2 prism diopters of exophoria at distance
10 EP′ = 10 prism diopters of esophoria at near
5 CLET = 5 prism diopters constant left esotropia at distance
30 IAXT′ = 30 prism diopters intermittent alternating exotropia at near

Referral Criteria:

Any strabismus that is present.
A phoria greater than 2 exo or 2 eso at distance.
A phoria greater than 6 exo or 2 eso at near.

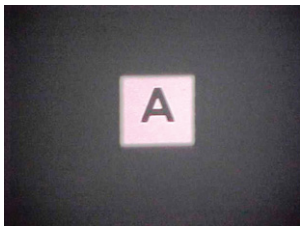


Figure 1

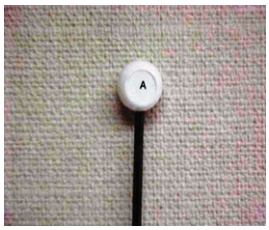


Figure 2


Figure 3


Figure 4


Figure 5

NEAR POINT OF CONVERGENCE

Evaluates: The ability of the eyes to converge while maintaining fusion.

Equipment: Near point target, PD ruler.

Setup: The athlete can either sit or stand and should be wearing his or her habitual prescription. The near target should be fully illuminated. Hold the PD ruler with the zero mark at the eye's center of rotation (Fig. 1).

Instructions: Instruct the athlete to look at the near target. Tell the athlete that you are going to be bringing the target in toward his or her nose. Instruct the athlete to report whether the target becomes blurry or splits into two targets. Tell the athlete to maintain fixation on the target at all times.

Procedure:

1. Start with the fixation target slightly below the athlete's eye level at 50 cm.
2. Bring the target slowly up the midline toward the nose. If the patient reports two targets or if the examiner notices an eye turn, note the distance from the eye. This is the break point.
3. Now bring the target back toward yourself until the patients reports that the target is now one or until you witness the eyes regaining bifixation (Fig. 2). This is the recovery point.

Recording: Record the break point and recovery point in centimeters. Also note whether diplopia was reported or whether the examiner saw an eye deviation. If the athlete maintains bifixation all the way to his or her nose, record "TN" (to nose).

Example: 5/8 (broke at 5 cm and recovered at 8 cm)

Referral Criteria: Any break or recovery greater than 12/15 cm.

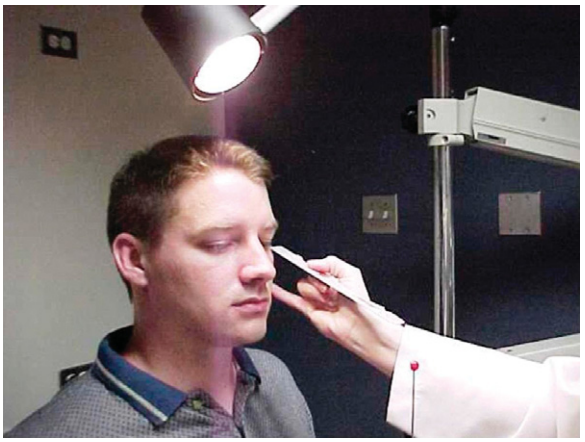


Figure 1

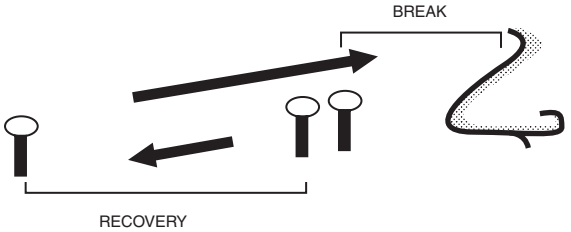


Figure 2

COLOR VISION (COLOR VISION TESTING MADE EASY)

Evaluates: To detect the presence of any red-green color deficits.
Test Distance: 75 cm (30 inches)
Illumination: True daylight illuminant (TDI), standard illumination "C"
Position: Sitting or standing
Critical Factors: Binocular testing
Criterion: If the athlete was able to identify 8 of 9 plates, the test is complete. If the athlete identified the sample plate but scored less than 8, present all 9 plates a second time.
Instructional Set:
Part 1: "Please tell me if you see a circle (or ball) on these cards." Present the first card to the binocular athlete and allow 3 seconds per plate. If the athlete fails the first attempt, repeat the test.
Part 2: "Please tell me what object you see on each of these cards. Do you see a dog, boat, balloon, or nothing?"
Recording: Record the number of correct responses attempted out of nine (X/9) by the trial number. Do not include the demonstration card in this number. Classify any color deficiency.

Standard Chart Answers: Part 1

Card No.	Normal Color Vision	Deficient Color Vision	Normal Color Vision	Deficient Color Vision
1	+	+	+	+
2	+	Nothing	+	Nothing
3	+	+	+	+
4	+	Nothing	+	Nothing
5	+	+	+	+
6	+	Nothing	+	Nothing
7	+	Nothing	+	Nothing
8	+	Nothing	+	Nothing
9	+	Nothing	+	Nothing

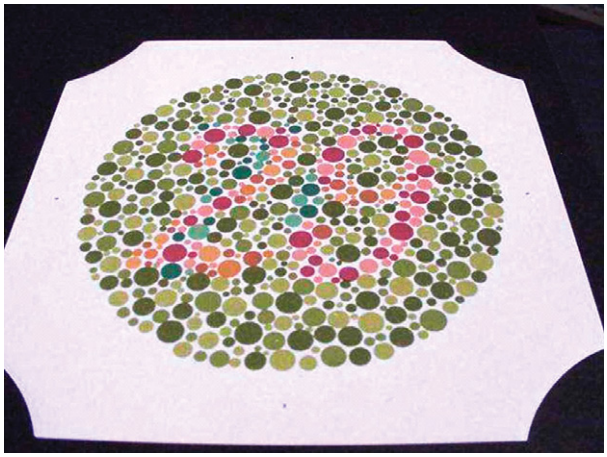
Standard Chart Answers: Part 2

	Normal Color Vision	Deficient Color Vision
A	Boat	Nothing
B	Balloon	Nothing
C	Dog	Nothing

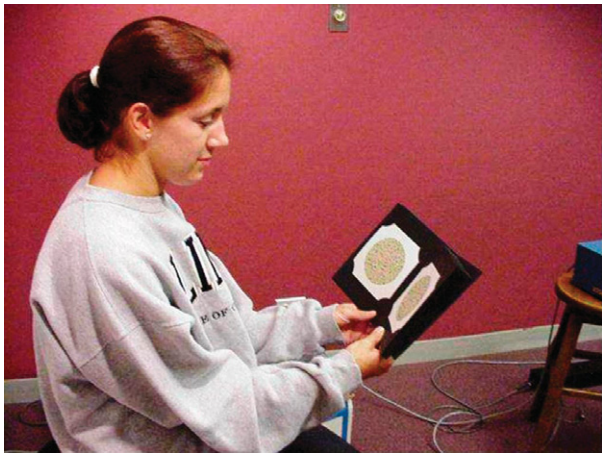
If patient responds "car," then diagnose as malingering.

COLOR VISION (ISHIHARA COLOR PLATES)

Evaluates: Presence of any deficits in sensitivity to various wavelengths of light.
Test Distance: 50 cm
Illumination: True daylight illuminant (TDI) or standard illuminant type "C"
Position: Sitting or standing
Critical Factors: Binocular testing
Criterion: The athlete is not allowed to miss any plates binocularly. If any plates are missed, retest monocularly. The first plate is for demonstration and should not be missed by anyone, or the athlete may be malingering. For plates 1 to 15, only show every other plate (1, 3, 5, etc...), then show plates 16 and 17.
Instructional Set: "Look at the plates and tell me what the dots form."
Recording: Record the number of correct responses (X/10) per response attempted. Classify person as red-green deficiency, protan, deutan, or total color deficiency.



Example of color plate.



Example of proper testing position.

Answers for Ishihara Color Plates (Normative and Color-Deficient Responses)

Plate	Normal Person	Person with Red-Green Deficiencies				Person with Total Color Blindness
1	12	12				12
2	8	3				X
3	29	70				X
4	5	2				X
5	3	5				X
6	15	17				X
7	74	21				X
8	6	X				X
9	45	X				X
10	5	X				X
11	7	X				X
12	16	X				X
13	73	X				X
14	X	5				X
15	X	45				X
		Protan		Deutan		
		Strong	Mild	Strong	Mild	
16	26	6	(2) 6	2	2 (6)	
17	42	2	(4) 2	4	4 (2)	

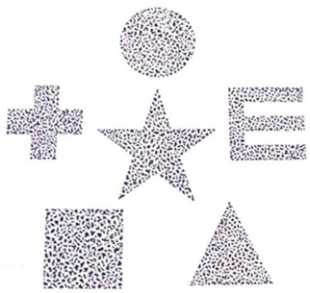
RANDOT STEREOPSIS

Evaluates: Near sensitivity to binocular disparity depth information presented vectographically.
Test Distance: Exactly 40 cm
Illumination: Normal room lighting
Position: Sitting or standing
Critical Factors: Must test the forms located in the six boxes on the right side of book first. All six boxes must be correctly identified before the test is continued. Then test the circles; there must be no head tilting or turning of the book. Time limit of 5 seconds per line for response. Test at **exactly** 40 cm. **Note:** Many patients have difficulty at #6; please encourage guessing until #10.
Criterion: 6/6 on forms and 7/10 circles without hesitation
Norms: 8.71 ± 1.94
Instructional Set: Have the athlete wear cross-polarized filters over habitual prescription. Present the example figures shown below and on the cover of the book and have the athlete identify those figures in the six boxes on the right side of the book by asking, "What shapes do you see hidden in each of these panels?" If all figures are seen, present the rows of circles on the left. "Tell me which of the circles, left, middle, or right, appears to be floating slightly above the other circles." Ask this question for all 10 rows of stimuli.
Record: Record the number of figures identified correctly. The first incorrect response on the circles will be considered the limit of disparity except when the patient identifies two consecutive finer stimuli correctly.

Answer Key

Scoring Key	Section of Arc at 16 Inches
1 → L	400
2 → R	200
3 → L	140
4 → M	100
5 → R	70
6 → M	50
7 → L	40
8 → R	30
9 → M	25
10 → R	20

Example of stereo forms.





Example of proper testing position.

PUPILS

Evaluates: Direct, consensual, and afferent pupillary responses.

Equipment: Fixation target with low accommodative demand, transilluminator.

Setup: The athlete is standing with his or her eyes directed at a fixation target 20 feet across the room.

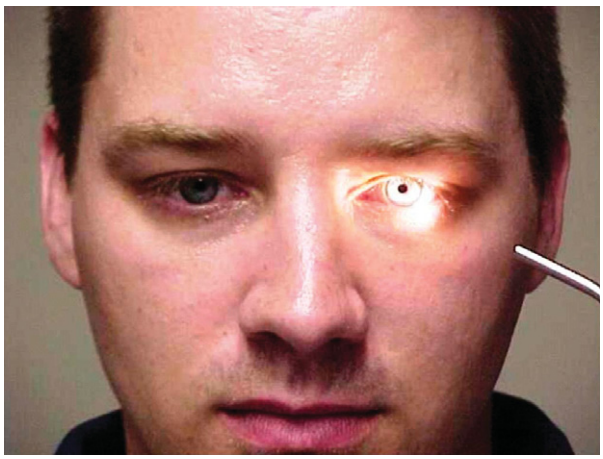
Instructions: Explain to the athlete that you are assessing how well his or her eyes react to light. Instruct the athlete to keep fixation on the distant target while you shine the transilluminator in his or her eyes.

Procedure:

1. Shine the light into the right eye without interfering with the athlete's visual axis and observe the size of the pupil and the speed of the constriction for three cycles. This is the direct response of the right eye.
2. Continue to shine the light in the right eye while observing the pupil of the left eye for three cycles. This is the consensual response of the left eye.
3. Shine the light into the left eye and observe the direct response of the left eye for three cycles and the consensual response of the right eye for three cycles.
4. Check the athlete's pupils for an afferent pupillary defect (APD) by moving the light alternately between both eyes rapidly while sustaining a period of 4 seconds per eye. Observe the responses of the eyes as the light moves to each of them. Be sure to indicate for each eye whether constriction occurs (normal) or whether an initial dilation occurs (abnormal) as the light shines on the eye.

Recording: Record the relative appearance of the pupils (pupils equal, round [PER]), if the pupils were responsive to light (RL), and whether an APD is present or not (±APD). Be sure to record any difference in size or shape between the two pupils.

Referral Criteria: Any abnormal response, including diminished light response, presence of an APD, or differences between size and shape.



Pupils.

OCULAR MOTILITIES

Evaluates: The athlete's ability to perform conjugate eye movements.

Equipment: Transilluminator.

Setup: The athlete should stand facing the examiner 50 cm away. The room illumination should be full and the athlete should remove his or her habitual prescription.

Instructions: Tell the athlete that you are testing the ability of his or her eyes to move in different directions. The athlete should be instructed to keep the head still and follow the light with his or her eyes (Fig. 1). Instruct the athlete to report whether he or she feels pain or has double vision at any time during the test.

Procedure: Beginning in primary gaze, move the penlight into the cardinal positions indicated in the physiological "H" pattern (Fig. 2). Be sure to move the penlight to the athlete's extreme limits of gaze. Throughout the procedure, observe the smoothness of movement, the accuracy of following the penlight, and the extent of eye movement. At the extreme limits of a healthy person's gaze it is normal to observe a low-amplitude nystagmus, termed end-point nystagmus.

Recording: If the athlete follows the penlight smoothly and accurately in all positions, record FROM (full range of motion). Record the presence of any pain, diplopia, or restriction in the position that it occurred.

Referral Criteria: The presence of any oculomotor restriction.



Figure 1

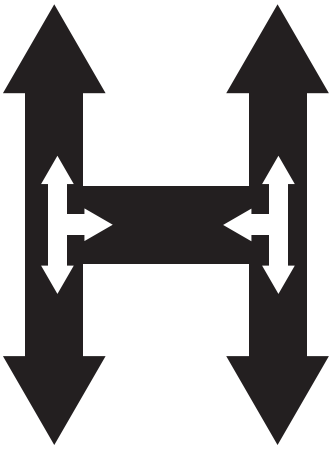


Figure 2

PURSUITS/SACCADES

Evaluates: The quality of the athlete's pursuits and saccades.

Equipment: Two near targets of different colors.

Setup: The athlete should stand facing the examiner 50 cm away. Room illumination should be full and the athlete should wear his or her habitual sports prescription.

Instructions:

Pursuits: Tell the athlete that you are testing his or her ability to follow a moving near target. Instruct the athlete to look at the target and follow it wherever it goes only using his or her eyes and without moving the head.

Saccades: Tell the athlete you are assessing his or her ability to change fixation from one target to another. Instruct the athlete to look at one near target and look at the other target as quickly and accurately as possible when you call the color of the second target.

If any head movement occurs during either test, instruct the athlete to try to hold the head still and move only the eyes. If the athlete is unable to resist head movement, grade him or her as a 1 on that section.

Procedure:

Pursuits: Use one near target and move it left to right, right to left, up and down, down and up, and then in a circular pattern. Be sure to maintain the 50 cm working distance and not to exceed a pattern greater than the circumference of the athlete's face (Fig. 1).

Saccades: Use both near targets held at a distance of 10 cm apart. Direct fixation from one target to the other for a total of five cycles. Be careful not to get into a predictable rhythm (Fig. 2).

Recording: Record According to the Following Scales:

Pursuits	4+	Smooth and accurate
	3+	One fixation loss
	2+	Two fixation losses (fail)
	1+	More than two fixation losses or any head movements (fail)
Saccades	4+	Smooth and accurate
	3+	Some slight undershooting
	2+	Gross undershooting or overshooting or increased latency (fail)
	1+	Inability to do task or greatly increased latency, any head movements

Referral Criteria: A score of 2+ or 1+ on either test.



Figure 1

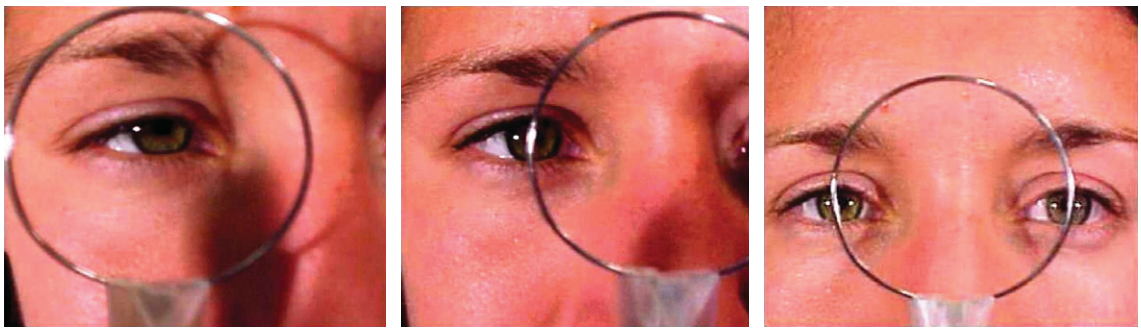


Figure 2

DOMINANT EYE-HAND (WISCONSIN SPORTS VISION PROJECT [WSVP] DOMINANCE WAND)

Evaluates: To determine the dominant eye and hand.
Test Distance: The examiner is 10 feet from the athlete.
Illumination: Standard illumination
Position: Standing relaxed
Critical Factors: The athlete is to hold the handle of the WSVP dominance wand with both hands and arms extended in the midline of the body a few feet below primary gaze. The examiner points to his or her dominant eye and instructs the athlete to slowly raise the arms in the midline and capture the eye within the circle.
Instructional Set: "Hold the wand between both hands at the center of your body. Look at the eye I am pointing to with both eyes open. Bring the wand up and look at my eye through the hole."
Record: Record whether the patient is left or right handed. Circle the dominant eye and record strong, mild/moderate preference, or central or cyclopean tendency, or alternate/undetermined preference. Refer to diagram at station.

Strong. Mild/moderate. Cyclopean.



Note: Alternating nonestablished athletes will appear as mild/moderate with both eyes (eye dominance may switch from one to the other).

DOMINANT EYE-HAND

Evaluates: To determine the dominant eye
Test Distance: An isolated 20/40 letter is placed 6 to 15 feet from the athlete.
Illumination: Standard room
Position: Standard relaxed
Critical Factors: Ensure the athlete is looking through the circle aperture and not moving it once the task is understood. The athlete's body needs to be centered with the target.
Instructional Set: "Look at the target across the room with both eyes open. While holding the circle aperture, bring it up and center the distant object in the circle." The examiner is to cover up the right eye and ask, "Can you still see the object through the circle?" Cover the left eye and ask if the object is still seen.
Recording: The dominant eye sees the object while the other eye is covered. Record OD dominant or OS dominant. Record whether patient is right or left handed.

AUTOREFRACTION

Evaluates: The refractive error objectively with the use of an automated instrument. Either a desktop or a handheld autorefractor can be used.

Desktop

Setup: Use standard room illumination. The athlete should be seated with his or her chin in the chin rest and forehead against the forehead rest. The athlete should remove his or her habitual prescription.

Procedure:

1. Turn the instrument on.
2. Adjust the chin rest and the instrument for the athlete. Position the instrument to allow for measuring the right eye first (Fig. 1).
3. Instruct the athlete to fixate on a specified target.
4. Look at the monitor to ensure proper alignment and fixation. Use the instrument's landmarks designated for proper alignment (Fig. 2).
5. Push the button that will begin the objective evaluation.
6. The instrument may voluntarily move to the left eye once it is finished testing the right eye. If not, manually adjust the instrument to test the left eye.
7. Press the print button to receive a readout of the indexes found (Fig. 3).

Handheld (Nikon Retinomax)

Setup: Use standard room illumination. The athlete should be seated comfortably with his or her eyes in primary gaze and habitual prescription removed. Focus the eyepiece for the examiner by rotating it until the text inside is clear. Release the forehead by pushing in gently. The rest will then release. The angle of the eyepiece can be adjusted according to both the examiner's and the athlete's height. The adjustments should allow the instrument to be held perpendicular to the athlete's line of sight.

Procedure:

1. Direct the athlete to look into the Retinomax. He or she should see a character riding a rocket to the moon. Ask the athlete to keep looking at this target throughout the testing.
2. Begin by testing the right eye. The instrument will assume the right eye is being tested first if it is set on automatic. Hold the instrument so that the line on the left side of the Retinomax lines up with the lateral canthus and the line on the top of the instrument is at mid-pupil. If the instrument is lined up correctly, the pupil should be centered when the examiner looks into the eyepiece (Fig. 4).
3. The examiner should move in and out until the circle of dots in the center of the eyepiece is focused clearly. Once this is accomplished, press the trigger on the handle and the instrument will automatically begin taking readings.
4. Before the examiner starts taking readings, "R0/L0" will be seen on the right in the eyepiece in the lower portion of the screen. This represents the number of readings taken on the right and left eyes. The instrument needs at least eight readings to average the information accurately. As the Retinomax takes reliable readings the number on the right side will increase up to eight. Once "R8/L0" is reached, the left eye is ready for testing. The "R0/L0" on the top of the screen takes keratometry readings. Do not be concerned with this information at this station.

5. The Retinomax will automatically respond to shift to the left eye. Just be sure that the examiner is centered in the middle of the pupil with the circle of dots focused clearly. The trigger does not need to be pressed again. Continue to take readings until the screen reads "R8/L8."
6. Aim the Retinomax toward the front of the printer at a distance of no more than 50 cm. Press the button located on the top of the Retinomax for 2 to 3 seconds until you hear a beep from the Retinomax and a responsive beep from the printer. The tones are slightly different so that you can distinguish them.
7. The printer will begin immediately after the beep. The reading with the asterisk is the averaged reading. Record this value as the autorefraction information on the screening form.



Figure 1



Figure 2



Figure 3



Figure 4

EXTERNAL HEALTH

Evaluates: External and anterior segment health of the eye.

Illumination: Dim

Position: Athlete is seated. If biomicroscope is available, have the athlete put his or her chin in the chin rest and have the forehead touching the upper bar.

Critical Factors: Steady fixation to a target point as directed by the examiner.

Criteria:

Lids: Look at the edges of the eyelids. Observe for signs of inflammation, discharge, and crusting or debris on the eyelids. If crusting debris is found, the athlete may have blepharitis.

Conjunctiva: The peripheral conjunctiva should appear smooth. Note the presence of papillae (a vessel is located in the center) or follicles (a raised bump without a central vessel). If the papillae are very large, GPC may be present. Common disorders of the bulbar conjunctiva include *Pinguecula* and *Pterygia;* these should be noted if the athlete has either or both conditions. Also note whether the athlete has any injection (graded on a 1+ to 4+ scale).

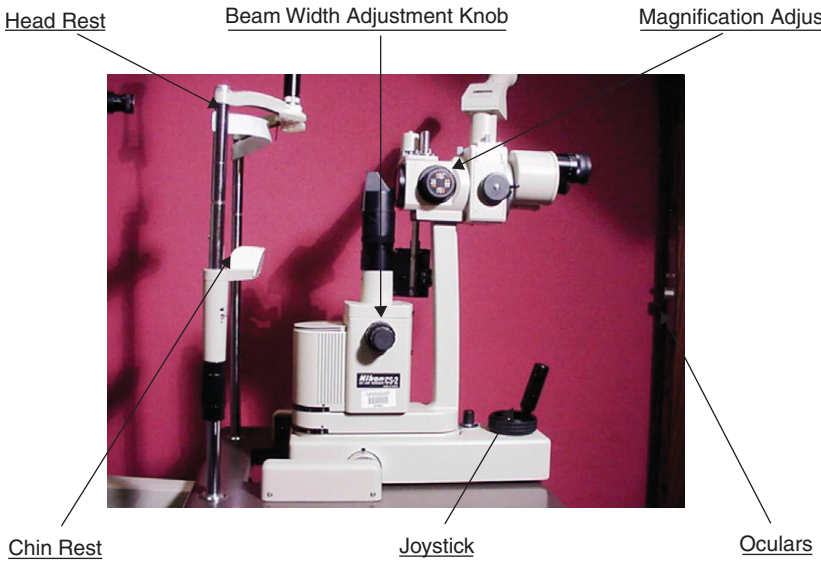
Cornea: Scan the cornea for any scarring, note location and level within the cornea layer if a scar is found. Infiltrates (made up of polymorphonuclear leukocytes) should also be noted.

Anterior chamber: Look for signs of cell and flare (both are graded on a 1+ to 4+ scale, with 1+ being trace and 4+ dense). The depth of the chamber angle is measured by comparing the depth of the anterior chamber with the corneal thickness at the limbus.

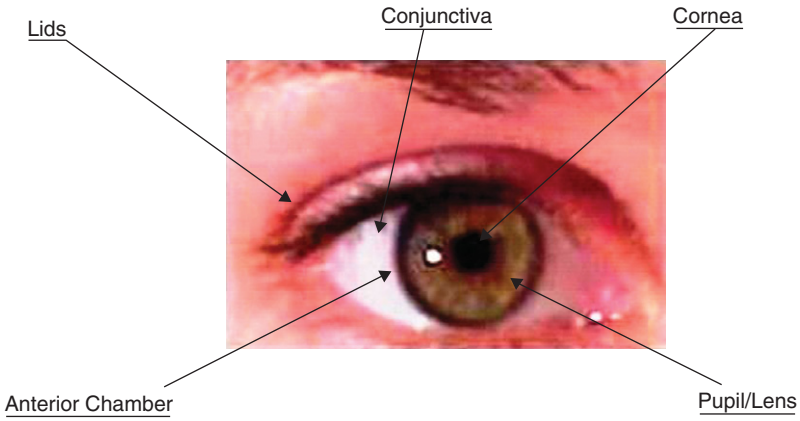
Lens: Look for any opacifications and note location: anterior or posterior subcapsular, cortex, or nucleus.

Instructional Set: "This procedure evaluates the health of the front or the eye. Place your chin on the rest and forehead against the bar. Try to keep your head still and hold your eyes on whatever target I direct you to."

Record: Record status of lids, conjunctiva, cornea, anterior chamber, and lens.



Slit lamp (biomicroscope).



External eye.

INTERNAL HEALTH

Evaluates: The health of the internal structures of the eyes.
Equipment: A direct ophthalmoscope, a distant target.
Setup: The athlete should be seated and the target should be set up at 20 feet. The room illumination should be dim to encourage dilation of the pupils.
Instructions: Tell the athlete that you are evaluating the health of the back of his or her eye. Instruct the athlete to look at the distance target and continue to look in the direction of the target if you get in the way.
Procedure:

1. Hold the ophthalmoscope with your right hand, placing it over your right eye to examine the athlete's right eye. Position yourself at approximately 15 degrees off the axis of the athlete's eye to allow the athlete to continue to fixate on the distance target (Fig. 1).
2. Dial in +8.00 D to +10.00 D in the ophthalmoscope to investigate the iris of the athlete.
3. Slowly reduce the power in the ophthalmoscope (less plus/more minus) to focus on the vitreous. Monitor the vitreous for clarity.
4. Continue to reduce plus to focus on the fundus. Look for the red reflex.
5. Evaluate the optic nerve head, including the disc margin, rim tissue (contour and color), and the cup/disc size and depth.
6. Evaluate the adjacent posterior pole, including the macular area and the surrounding vasculature. Note the following: color and clarity of the macular area, presence of a foveal reflex, and the artery/vein (A/V) ratio.

Recording: Record the cup/disc ratio, the A/V ratio, and the macular status.
Referral Criteria: Refer if any abnormal findings are found.



Figure 1

EYE MOVEMENTS: OBER II

Evaluates: Fixation status, saccadic speed and accuracy, and the quality of pursuits at distance. Test I evaluates the ability to point the eyes accurately. Test II measures how quickly the eyes move from point to point, and Test III evaluates the ability to track a moving object.

Setup:

1. Turn on the computer and click on the "Visa 4.3" icon. Click on the first icon on the Visa home page tool bar. Go to "Input Subject & Test Data." Enter the name, class (enter "JO"), test (enter "v"), sex, and date of birth of the athlete. Click on "measure" and prepare to do "Fixation Maintenance."
2. The athlete should be standing at a 5-foot test distance, and the room illumination should be standard. The athlete must be at eye level with the targets. The goggles must be properly adjusted and calibrated to the athlete's pupillary distance (Fig. 1).

Instructions and Procedure:

Test I, Fixation Maintenance: Instruct the athlete to look at the center "O" target without moving his or her eyes or head until you say to do so. Allow *at least* 25 seconds (four screens) to pass before telling the athlete to stop or move his or her eyes. Press the "enter" key (or click on "OK") to begin the test. Click on "stop" to end the test. The software will take you to the next test.

Test II, Motilities—Lateral Saccades: Tell the athlete to move his or her eyes back and forth between the two X's as fast as he or she can. The two X's should be separated by 50 cm. Stress accuracy and speed during this procedure, avoiding head movements. Test this for *at least* 25 seconds, beginning and ending the procedure the same as for Test I.

Test III, Tracking: Instruct the athlete to again alternate fixations between each X for 5 to 10 seconds. Begin and end this procedure as before.

At the end of these three procedures you will be asked whether the measurement is OK or whether you need a retest. Click on "OK" and you will receive a Visual Skills Profile containing the data. If data are not available (only zeros), you will need to repeat the procedure, but you should expect to see zeros in the tracking portion of the results.

Record fixations (under Fixation Maintenance) as "fixation loss/10 sec." Record excursions (under Motilities) as the "saccadic speed/15 sec." Select the eye (right or left) with the best test results (the lower the number, the better the result). The "tracking" data are not used.

(Note: After every five subjects, exit the extra subject windows by clicking on the X on the superior right side of the subject windows. Failure to limit the number of open windows will significantly slow down the computer.)

Pursuits: Note: The pursuit section is not routinely done at the Junior Olympics.

Return to the Visagraph 4.3 toolbar and click on "new" (File menu). Enter the same data as before in the "Input Subject & Test Data" box (it may already be entered from the initial Tests II, III, and I) except enter the word "Pursuits" in the comment section. Click on "measure" to begin the next test.

Test I, Fixation Maintenance: This test is used for pursuit fixation loss. The athlete views the swinging ball from a distance of 4 feet. Instruct the athlete to fixate on one letter or the black line (switch to another letter if the ball rotates) during the horizontal ball swing, a total lateral swing of approximately 50 to 55 cm. The athlete should view the ball for approximately 25 seconds. Begin and end the test as before.

Test II, Motility: This part of the procedure is necessary only for calculation purposes. Instruct the patient to alternate fixation between each X for 5 to 10 seconds before ending the test.

Test III, Tracking: This part of the procedure is necessary only for calculation purposes. Follow the identical instructions as for the previous test II.

At the end of these three procedures you will be asked if the measurement is OK or if you need a retest. Click on "OK," which will provide a Visual Skills Profile containing the data. If only zeros are present, you will need to repeat the procedure.

Record "Pursuit Fixation Losses/10 sec" as the fixation data under the Fixation Maintenance section (lowest for either right or left eye). The other data are ignored for this test. Close this page when completed and return to the Visagraph 4.3 toolbar.

	Age <7 Years	Age 7-11 Years	Age 12-15 Years	Age 16-25 Years	Age >25 Years
Fixation loss of 10 sec	10 ± 7	8 ± 6	7 ± 5	6 ± 4	4 ± 3
Saccadic speed of 15 sec	17 ± 8	20 ± 7	24 ± 8	28 ± 8	29 ± 6
Pursuit fixation loss of 10 sec	26 ± 7	24 ± 6	21 ± 6	17 ± 6	15 ± 6

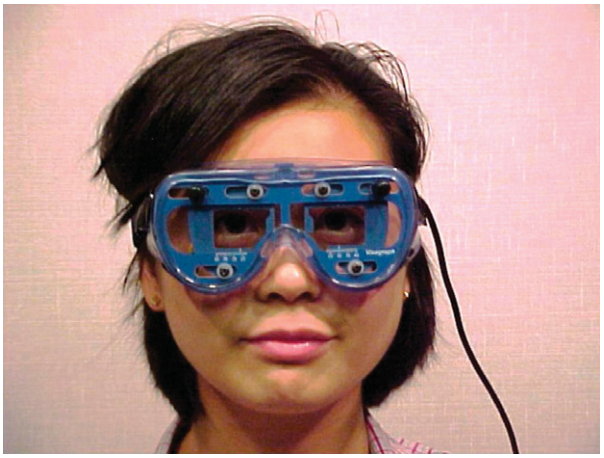


Figure 1

THRESHOLD DYNAMIC VISUAL ACUITY

Evaluates: The subject's ability to resolve a 20/40 Snellen letter while it is in motion.

Testing distance: 10 feet

Illumination: Standard room illumination

Positioning: The athlete should be standing with feet comfortably apart. Testing is done binocularly with the athlete's habitual distance prescription.

Standard Parameters:

- Track size: 980 pixels × 40 pixels
- Stimulus (letter) size: 9 mm (30 pixels, or 20/40 equivalent)
- Stimulus color: black
- Target color: white
- Speed: 10
- Stimulus exposure time: 200 msec

Instructions and Procedure: From the computer desktop, click on the "Dynamic Acuity" icon. Click on "run session." The program defaults to standard test parameters. Give the patient instructions and press any key to begin the test. The test ends automatically and records scores on the screen.

Instruction Set: "Watch the center of the screen. When I start the test, you will see a white ball going back and forth on the screen. Follow the ball with your eyes, and when you see a letter flashed on the ball, call out the letter that you see. The target may speed up or slow down during testing. Continue to follow the target until I tell you to stop."

Responses and Recording:

1. When the athlete calls out a letter, press the space bar on the keyboard. Enter the letter that the athlete called out. Press enter to run next trial.
2. The software will stop automatically when a threshold is reached. Record the mean, median, and standard deviation dynamic acuity scores displayed on the screen.
3. To abort a trial, press F2.

ACUVISION 1000 EYE-HAND COORDINATION

Evaluates: The ability to direct the hand to a target visually in an efficient manner.

Test Distance: The athlete is 30 inches from the front of the instrument. The center green target light of the instrument should be at eye level.

Illumination: Medium room illumination. Faceplate illumination ranges from 0.65 ft-c at the center to 2.50 ft-c at the peripheral portions of the faceplate.

Positioning: The athlete should be standing, centered equidistant from the right to left edge of the instrument. The athlete should wear appropriate athletic footwear.

Testing Sessions:

Speed = 7/Mode = FF120/Fixation = Off/Brita = 9/Map = Ne/Sound 9

For ages younger than 7 years, use the following parameters:

Speed = 7/Mode = rF60/Fixation = Off/Brite = 9/Map = Ne/Sound 9

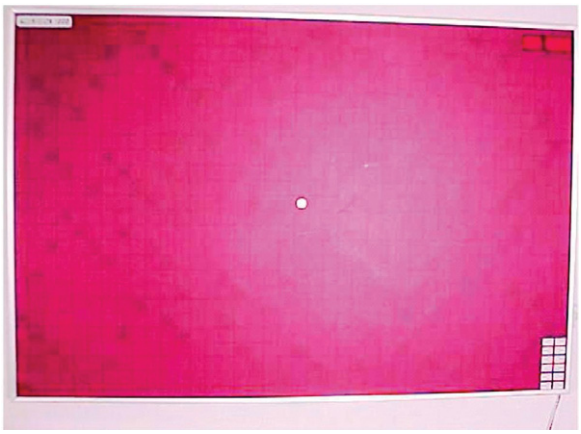
Instructional Set: "This device assesses your ability to use your eyes to guide hand movements in space. While you are watching the board, red lights will appear in your peripheral vision. With the fingertips of either hand, attempt to press the red lights as they appear. There will be a total of 120 test lights (ages younger than 7 years will see 60 lights). The light will move to the next location after approximately 1 second if you do not press it. If you correctly press a light, it will immediately appear at another location. Try to find the lights with yours eyes as fast as you can, but try not to move your head."

Criterion: During each trial, monitor the presence or absence of head movement and body movement. Rate this on a scale of 0 to 4, with 4 being excessive movement of the head or body.

Junior Olympics 1997

	Grade School	Junior High	High School	Control/Coach	Entire Population
Acu#	30 ±17	52 ± 12	67 ± 13	55 ± 28	53 ± 22
Acu-Late	29 ± 12	35 ± 8	25 ± 11	34 ± 24	27 ± 12
Acu-Time	95 ± 12	88 ± 5	82 ± 7	80 ± 2	87 ± 11

For each trial, record the number of correct hits, the number of late responses, and the time used to complete the trial. Print out a hard copy of the distribution of points after the trial.



Acuvision 1000. Speed/mode/fixation/brite/map/sound buttons.

WAYNE FOOT SPEED

Evaluates: Perceptual reaction time and motor foot speed.
Test Distance: 7 feet
Illumination: Standard room (approximately 7 ft-c)
Position: Athlete stands with left foot on the center footplate, knees bent in a ready position.
Critical Factors: Do not allow athlete to put pressure on left footplate until instructional set is completed. Footplates are secured horizontally and separated by 7 feet on a hard surface. Push "Enter-9-99-Enter" to program the test.
Criterion:

Junior Olympics 1997

	Grade School	Junior High	High School	Control/Coach	Entire Population
Foot speed	0.66 ± 0.6	0.49 ± 0.18	0.48 ± 0.19	0.55 ± 0.39	0.54 ± 0.29
Release foot speed	1.5 ± 0.6	1.2 ± 0.6	1.2 ± 0.3	1.6 ± 0.9	1.3 ± 0.5

Instructional Set: "This test evaluates reaction time and foot speed. When you place your weight on the center footplate, a green light will illuminate on the board in front of you. After approximately 3 seconds a beep will sound and a red light will appear on the board at the 12, 3, 6, or 9 o'clock position. If a light appears at 12 o'clock, move to the front footplate as fast as you can. If the light appears at 3 o'clock, move to the right; at 6 o'clock, move behind you; or at 9 o'clock, move to the left. As soon as you hear the beep and see the light change, move as fast as you can and touch the other footplate with your right foot. You will do this three times."
Record: Record the release time first, followed by foot speed. Two numbers will flash; the foot speed number is followed by a period. Record the direction of movement by checking a box on the score sheet for each of the trials. Enter the trials for each position in the computer.
Reprogram Codes:
1 → 13
2→ 0
3→ 0
4→ 3
5→ 4
6→ 0

WAYNE SACCADIC FIXATOR

Evaluates: Visual motor response to visual stimuli based on a precise, visually guided motor response (finger pressing a lighted target). Measures eye-hand coordination.
Test Distance: 30 inches
Illumination: 20 ft-c incident on the instrument in a dimly lit room
Position: Center of instrument should be at eye level. Athlete should be able to reach the top and bottom of instrument without changing the test distance (Fig. 1).
Critical Factors: Illumination and the test distance are critical. Testing is conducted by using one finger of the dominant hand. Both subtests 1 and 2 run for 30 seconds. Demonstrate the task by allowing the athlete to press 5 lights correctly, then restart the test by touching the green light.
Subtest 1 (proaction): Enter; 9, 1, Enter
Subtest 2 (reaction): Enter; 9, 21, Enter
Criterion:
Proaction: Mean, 42; standard deviation, 5
Reaction: Mean, 27; standard deviation, 4
Speed: Mean, 94; standard deviation, 13
Instructional Set: "This instrument measures eye-hand coordination and hand speed. For the first test, touch the lighted circles with either hand. As soon as you touch one, another circle will light up in another random position. Touch as many circles as you can in 30 seconds."
"The second test is similar to the first except the light may not wait for you. If you do not get it in time, the light will move to a new location, so keep trying to touch it. The faster you go, the faster the lights will start moving. Try to get as many as you can in 30 seconds."
Recording:
Subtest 1: Record number of buttons touched (from display)
Subtest 2: Record number of buttons touched and presentation speed. Hit #3 to access presentation speed.

Program Codes

Proaction	Reaction
1 → 1	1 → 14
2 → 30	2 → 30
3 → 0	3 → 57
4 → 3	4 → 3
5 → 1	5 → 1
6 → 0	6 → 0
7 → 0	7 → 0
8 → 0	8 → 0
9 → 0	9 → 0

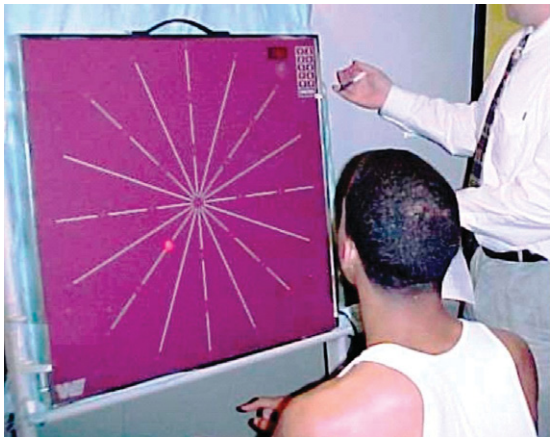


Figure 1. Wayne Saccadic fixator.

WAYNE SACCADIC FIXATOR (HAND SPEED)

Evaluates: Visual motor response to visual stimuli based on a precise, visually guided motor response (finger pressing a lighted target). Also measures eye-hand coordination and hand speed.

Test Distance: At comfort of the athlete

Illumination: Critical at 40 to 70 cd/m^2 incident on the instrument in a dim room

Position: Center of instrument at eye level. Athlete should be able to reach 3 o'clock and 9 o'clock positions of instrument without changing the test distance.

Critical Factors: Illumination and the test distance are critical. The athlete looks at one point or follows the stimulus; the athlete may use only one hand but any finger.

Subtest 3 (hand speed): Enter; 9, 18, Enter

Criterion: hand speed: 0.28 ± 0.07

Instructional Set: "This instrument measures eye-hand coordination and hand speed. You can use all your fingertips of any one hand. I want you to touch this button (9 o'clock), then touch this button (3 o'clock). Do this only one time." Record speed. "Do it again." Record speed. "One last time. Now try to do it faster." Record again.

Recording: Record all three trials. Circle the best one and enter it into the computer.

Program Codes:

1 → 11
2 → 0
3 → 3600
4→ 4
5 → 1
6 → 0
7 → 0
8 → 0
9 → 0

WAYNE SACCADIC FIXATOR (BALANCE BOARD)

Evaluates: Visually directed balance
Test Distance: 7 feet
Illumination: Standard room
Position: Standing on balance board facing the Wayne PAT
Critical Factors: Good balance to start procedures, stable position. Allow the athlete to move the board in the various directions to get a feel of the balance shifts required.
Enter; 9, 26, Enter
Criterion: To be determined
Instructional Set: "This instrument measures visually directed balance. While you balance on the board, a light will appear at the 12, 3, 6, or 9 o'clock positions. If it appears at the 12 o'clock position, tilt the board forward; 3 o'clock, tilt right; 6 o'clock, tilt back; and 9 o'clock, tilt left. Be very careful not to go in the wrong direction because any wrong move will lose all your points. The task will continue for 30 seconds."
Record: Record the number attained after 30 seconds.
Program Codes:

1→ 11
2→ 0
3→ 0
4→ 3
5→ 1
6→ 121
7→ 0
8→ 0
9→ 0

WAYNE PERIPHERAL AWARENESS TESTER (PAT)

Evaluates: Visual motor response time (by lever press) to peripheral stimuli in eight visual field locations.

Test Distance: 30 inches

Illumination: 3 to 5 ft-c

Position: Standing relaxed with center of Wayne PAT (Fig. 1) at the athlete's eye level. Alignment is especially critical with athletes whose spectacle prescription might restrict their visual field.

Critical Factors: All PAT screening should be performed in accordance with PAT diagnostic testing protocols. The instrument should be mounted against a neutral, light-colored background. The patient must continuously fixate on the red center light of the unit during the testing procedure.

Enter; 9, 125, Enter

Criterion: Criteria <0.6 seconds per location.

Instructional Set: "This instrument measures peripheral vision. Always keep your eyes on this center red light. When you see a light at any one of the edges, move the joystick quickly in the direction of that light and release it. One of the lights will turn on every 2 to 4 seconds."

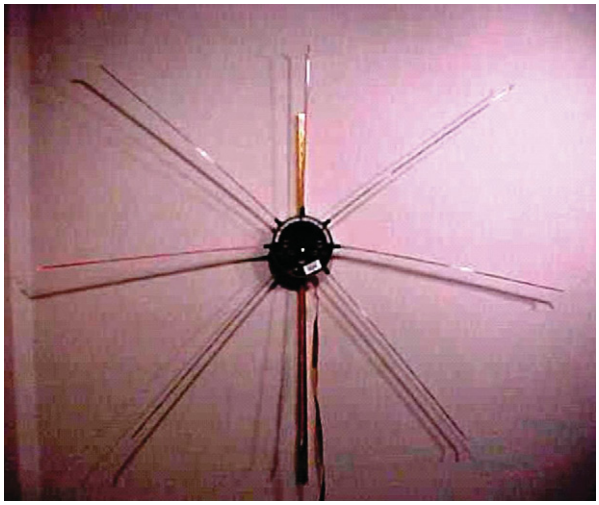


Figure 1

TACHISTOSCOPE

Evaluates: Speed and span of recognition.
Test Distance: Athlete is 10 feet from the screen.
Illumination: 35 ft-c
Position: Standing comfortably
Critical Factors: Numbers must be 3.5 cm high (20/80 acuity). There are six numbers per set, and each set is shown at 0.05 seconds.
Criterion:

Junior Olympics 1997

Grade School	Junior High	High School	Control/Coach	Entire Population
9 ± 4	12 ± 3	13 ± 3	13 ± 2	12 ± 4

Instructional Set: "On the wall between the two stickers there will appear a set of numbers such as these." Push the external shutter to show six numbers (Fig. 1). "They will appear this fast." Push shutter initiate to show how fast they will appear. "Look between the two stickers, remember the numbers in order, and recite them back to me." Each athlete has three trials (18 total numbers).
Record: Number correct out of 18 (three trials).
Scoring: Athlete allowed one transposition per slide. For example, the numbers appear as 123456 and the subject recites 123465. The number correct is 5 out of 6 because 4 were correct plus 1 point for transposition.

Answers

	Set 1	Set 2	Set 3	Set 4	Set 5
Demo	360842	842907	728053	264073	739201
1	254698	302658	394625	628149	583902
2	628407	620174	873142	802476	831927
3	602391	905281	984527	219684	730159

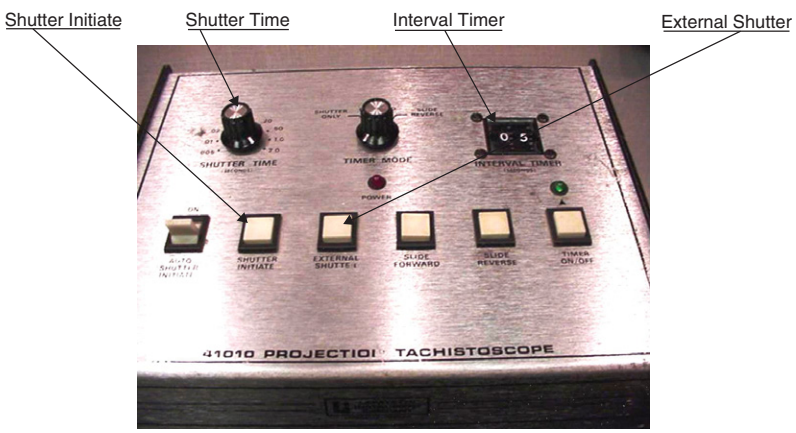


Figure 1. Tachistoscope control panel.

VECTORVISION CONTRAST SENSITIVITY

Evaluates: Visual contrast sensitivity; visual discrimination ability.
Test Distance: 12.5 feet
Illumination: Test is backlit with an internal light source.
Position: Standing relaxed
Critical Factors: Test only OD, OS

Spatial Frequency Examples for Various Testing Distances in Cycles/Degree

	Row A	Row B	Row C	Row D
8 feet	3	6	12	18
10 feet	3.75	7.5	15	22.5
12.5 feet	**4.7**	**9.4**	**18.75**	**28.1**

Criterion:

Junior Olympics 1997

	Grade School	Junior High	High School	Control/Coaches	Entire Population
CSFOD1	6 ± 2	6 ± 1	6 ± 1	6 ± 2	6 ± 2
CSFOD2	6 ± 2	6 ± 2	6 ± 2	6 ± 2	6 ± 2
CSFOD3	6 ± 2	6 ± 2	6 ± 2	5 ± 6	6 ± 2
CSFOD4	6 ± 2	6 ± 2	6 ± 2		6 ± 2

Instructional Set: "On each panel are two rows of circles; for each pair one of the circles will contain some lines. For each pair, tell me whether the top or bottom contains the lines. Some of the lines will be faint; try to guess if you are unsure."

Record: Record the number of grids correctly called in each of the four plates on the Vectorvision chart (Figs. 1 and 2).

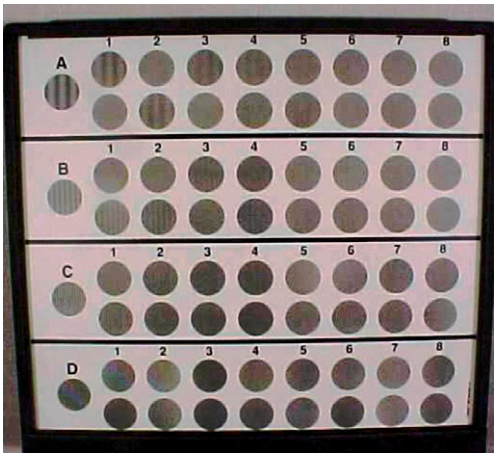


Figure 1

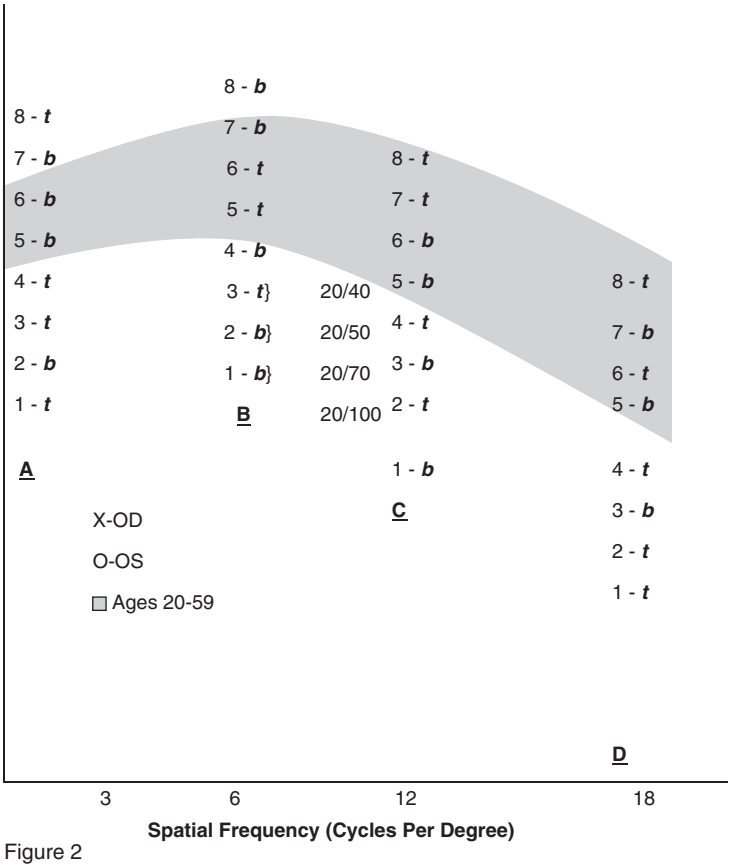


Figure 2

HOWARD DOLMAN STEREOACUITY TEST

Evaluates: Stereoacuity or depth perception at distance.

Test Distance: The athlete is 6 m from the zero point of the scale on top of the apparatus to the athlete's eye.

Illumination: Normal room

Positioning: The athlete should be seated in front and level with the apparatus. The athlete should be wearing appropriate sports vision correction. Be sure the athlete cannot see the guide tracks on top and bottom of the inside of the box. Adjust chair accordingly.

Testing Sessions: Four trials should be done for each rod separation in front and behind. Trials are done at 9, 6, 4, 2, and 1 cm separation. Four trials are performed at each separation distance: two trials with the right rod in front and two trials with the left rod in front. Start with the largest separation first. Only move to the next shorter separation if the athlete correctly identifies the movable rod in front of or behind the stationary rod in three of the four trials. When moving the rod in front or behind, stand in front of the box. Stereoacuity is recorded as the last trial that was correctly identified three of four times. The athlete should be given only approximately 3 to 5 seconds for each response, and he or she should not move the head during the test. After 3 seconds, urge the patient to answer. If the subject does not answer, then consider that a fail for that trial. Do not inform the patient of the number of trials or the number of times the left or right rod is in front. Do not pause between testing of different separations. Do not test those with strabismus or amblyopia.

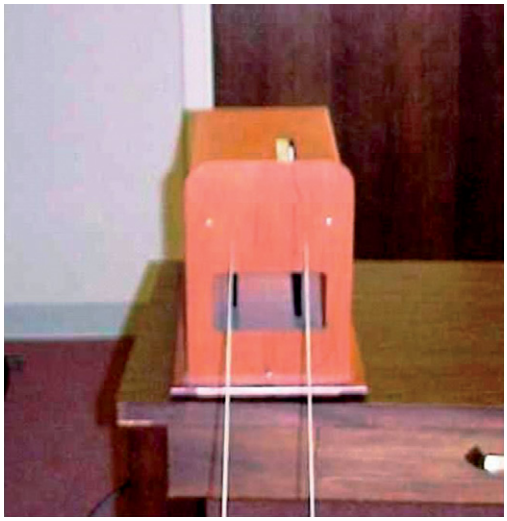
Instructional Sets: "This device helps measure your distance depth perception. There are two rods in the box in front of you. When you see the rods, immediately tell me which one is in front; either left or right."

Test Results:

Separation Distance	Stereoacuity
9 cm	30.94″
6 cm	20.63″
4 cm	13.75″
2 cm	6.88″
1 cm	approximately 3.44″

Record:

Separation Distance	Presentation: Rod in Front
9 cm	R, L, L, R
6 cm	L, R, L, R
4 cm	L, L, R, R
2 cm	R, L, R, L
1 cm	R, L, L, R



BASSIN ANTICIPATION TIMER

Evaluates: Visual anticipation skills; the ability to anticipate the arrival of the lights at the end of the track.

Test Distance: 3 feet away from the end of the track

Illumination: 6 to 7 lumen (dim room)

Protocol: The athlete demonstration is conducted with a speed at 10 mph. Do one trial at this speed. When the athlete understands the task, increase the speed to 50 mph. Record the results of the next three trials.

Record: When the light is reacted to before it arrives, record with a plus sign. If reacted to late, record with a minus.

Position: Standing relaxed with track perpendicular to shoulders (Fig. 1)

Critical Factors: Athlete understands to stop the light when it arrives at the last position.

Criterion: Computer average + sign for early/– sign for late (Fig. 2)

Instructional Set: "The row of lights represent a target approaching you. Stop the light exactly at the end of the track by pushing the handheld trigger. I will let you practice on the slow balls so you will learn how it works, then we will speed it up."

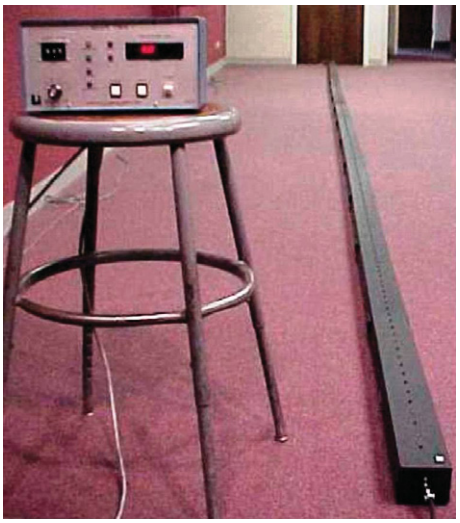


Figure 1



Figure 2

WESSON FIXATION DISPARITY CARD

Evaluates: Phoric posture.

Setup: The athlete should be standing with his or her head straight. The test should be performed at a near distance of 16 inches and a far distance of 10 feet. Standard room illumination should be used, and the athlete should wear vectographic glasses.

Procedure: Instruct the athlete to look at the card. Ask the athlete to watch the bottom arrow and notice whether the top arrow is to the right, left, or directly above the bottom arrow. Next have the athlete look at one of the horizontal arrows and notice whether the other horizontal arrow is above, below, or horizontally aligned with the arrow of fixation.

Recording: Record the associated phoria. Note that with standard vectographic glasses the top arrow to the right indicates eso posture and the top arrow to the left indicates exo posture. In addition, the right arrow higher indicates left hyperphoria.

Referral Criterion: Eso or exo greater than one or any vertical deviation (Fig. 1 and 2).

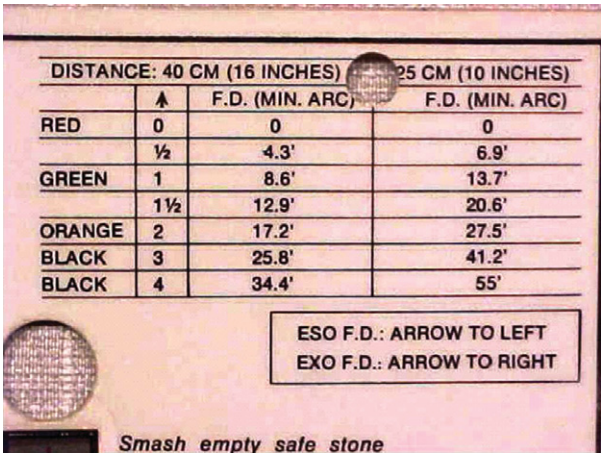
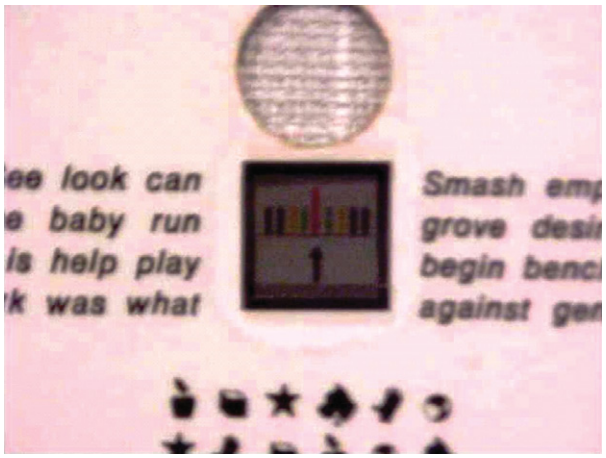


Figure 1


Figure 2

VISION AND BALANCE

Evaluates: Visual factors involved in maintaining gross motor balance under various conditions.

Setup: Standard room illumination is used and test distance is not applicable except for the eye movement sequence; a 40-cm distance should then be used. The athlete should remove his or her shoes and stand on the flat edge of a standard 4 × 4 (3 5/8″ × 3 5/8″ × 10 ft). The athlete should place feet heel to toe, parallel to the long dimension of the beam.

Critical Factors: The examiner should read and memorize the scaling definitions to avoid the need for reference during screening. Use different colored targets to test eyes.

Scaling Definitions:

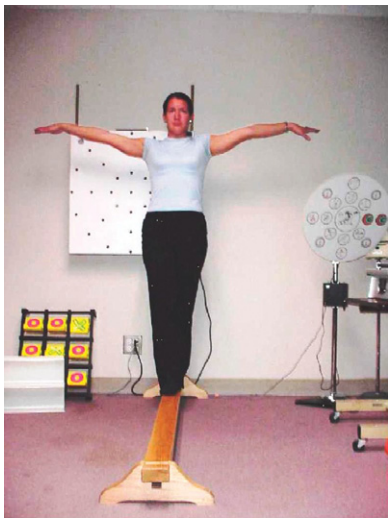
1. Highly stressed, tremendous body wavering and struggling. Obvious difficulty staying on the beam. Unable to stay on any longer than 2 to 3 seconds during tasks.
2. Stressed, with considerable struggling and wavering present; falls off the beam two or more times during the task.
3. Significant wavering but able to recover. Falls off the board no more than one time during a task. Excessive wavering and struggling (to the point where barely recovers) with no falls.
4. Slight noticeable lean with minimal wavering. No falls or near falls. Maintains a high level of stability during the majority of the task.
5. No wavering and no falls. Maintains a high level of stability throughout the task.

Instructional Set: The vision and balance testing consists of five subtests, each of which should be carefully scored in accordance with the criteria listed above.

1. "Stand heel to toe and maintain balance while looking straight ahead with arms at your side [demonstrate]. You may use whichever foot you prefer in the forward position." Score 10 seconds.
2. "Now close your eyes." Score for 10 seconds beginning the moment the athlete closes his or her eyes.
3. "Open your eyes. Follow this target (bead) with your eyes only. Do not use head movement." Use the following four eye movement probes:
4. Two slow Near Points of Convergence (NPCs) to nose (break and recovery) over a 15-second total. One slow NPC 6 inches from the patient's right to nose (break and recovery) over a period of 8 seconds and one slow NPC 6 inches from the patient's left to the nose (break and recovery) over a period of 8 seconds.
5. Rapid saccades between opposite cardinal points at a test distance of 40 cm with the beads separated by approximately 75 cm. Two times each point.
6. Rapid near-far saccades, 3 feet away to 6 inches away.
7. Smooth eye movements at a 40 cm target distance. Lateral pursuits 2 × 2 round trips full range, oblique pursuits two times each, vertical pursuits twice each, rotation once each.
8. Dynamic: eyes open. "Walk forward to the end of the beam and back using heel to toe. Try to keep your eyes pointed straight ahead."
9. Dynamic: eyes closed. "Walk forward to the end of the beam. I will tell you when you are at the end. Then reverse and stop."

Recording: Record the performance scale rating on each subtest.
Criterion: The athlete should score a grade 3 on all phases of the screening. The total score is related to computer averages.
Mean = 18
Standard deviation = 2
Scoring criteria: (low) 1 2 3 4 5 (high)
Example: An athlete shows good balance with slight wavering during the first test. When the patient closes his or her eyes, he or she has to use a toe touch to keep balanced but then shows steady balance for the remainder of the test. The athlete falls once when performing eye movements. The athlete uses two toe touches when walking with eyes open and wavers and struggles to keep balance when walking with eyes closed. The athlete also falls twice during the last test.
Record:
1. 5
2. 3
3. 3
4. 3
5. 2

Total = 16



B

Appendix B: Baseball Team Vision Screening

Date: _____

Name: _____ Date of birth: _____

Position: _____ Year in school: _____

Last eye exam: _____ Doctor's name: _____

Do you wear glasses? Yes _____ No _____

Do you wear contact lenses? Yes _____ No _____

If yes, what type of contact lenses (soft, hard, daily wear, overnight wear, etc.)? Be as specific as possible.

_____

Do you wear your glasses or contact lenses for baseball? _____

Do you have or have you had any of the following (circle all that apply):

Difficulty seeing	Reduced peripheral vision
Sensitivity to lights	Reduced performance as stress builds
Lack of consistency of play	Headaches
Easy distraction from visual targets	Reduced depth perception
Difficulty following moving objects	Blurred vision after close work

Do you ever feel that your vision compromises your athletic performance? Explain.

_____

Are you under a doctor's supervision for any medical conditions? If yes, what is the **condition** and what **medications** do you take for it?

_____

This testing is designed to screen for common visual problems; it does not replace a complete vision examination.

Refractive Error

Habitual Rx: OD:_____ OS: _____

Lensometer Rx: OD:_____ OS: _____

Autorefractor: No Rx: OD: _____ OS: _____

(Retinomax) Over Rx: OD: _____ OS: _____

Visual Acuity (Bailey-Lovie)

Distance: OD _____ OS _____ OU _____ (± .02/letter)

Cover Test

Primary position: Distance _____ Near _____

Batting position: Distance _____ Secondary: Near _____ _____ _____

_____ _____

_____ _____ _____

AcuVision (FF120, Speed 2): _____

Contrast Sensitivity

OD: A _____ B _____ C _____ D _____

OS: A _____ B _____ C _____ D _____

OU: A _____ B _____ C _____ D _____

Bassin (1.5 warning time)

	(Subj.) (Obj.)		(Subj.) (Obj.)	
5 mph:	(L)/(O)/(E)-(L)/(E)	_____	(L)/(O)/(E)-(L)/(E)	_____
	(L)/(O)/(E)-(L)/(E)	_____		
10 mph:	(L)/(O)/(E)-(L)/(E)	_____	(L)/(O)/(E)-(L)/(E)	_____
	(L)/(O)/(E)-(L)/(E)	_____		
20 mph:	(L)/(O)/(E)-(L)/(E)	_____	(L)/(O)/(E)-(L)/(E)	_____
	(L)/(O)/(E)-(L)/(E)	_____		
30 mph:	(L)/(O)/(E)-(L)/(E)	_____	(L)/(O)/(E)-(L)/(E)	_____
	(L)/(O)/(E)-(L)/(E)	_____		

Distance Rock

20/80 _____/60 seconds 20/25 _____/60 seconds

BVAT— Speed of Stereopsis

240″ + – _____sec 180″ + – _____sec 120″ + – _____sec

60″ + – _____sec 30″ + – _____sec 15″ + – _____sec

C

Appendix C: Sample Sports Vision Therapy Letter

DATE

NAME
ADDRESS

FILE/Date of Birth

Dear XX:

You were seen at XX for a sports vision evaluation on DATE.

History

The main concern was to evaluate your visual skills as a factor in your return to competitive skeet shooting. You had recently noticed momentary blur in the distance (worse in the morning) and some difficulty "locking on" when targets are coming from directly overhead.

Visual Acuity and Refractive Status

Entering visual acuities without spectacle lenses were:

OD 20/20– at far, 20/20 at near
OS 20/20– at far, 20/20 at near

You were found to have a low hyperopic (farsighted) astigmatic refractive error in your left eye.

Vision Efficiency Skills

Ocular motility (eye tracking): You were found to have adequate ability.

Accommodation (eye focusing): You were found to have adequate ability for your age.

Sensory and motor fusion (eye teaming): You were found to have adequate ability for normal vision needs; however, the instability in your fixation disparity (accuracy of eye teaming) and poor divergence skills in the distance may adversely affect your performance in skeet shooting.

Sports Vision Evaluation

Depth perception skills: You were found to have excellent ability and speed of responsiveness.

Dynamic visual acuity: You were found to have average ability; better performance is expected for skeet shooters.

Contrast sensitivity (glare adaptation): You were found to have adequate ability for a nonathlete; however, your ability was below the expected level for a skeet shooter on high spatial frequencies.

Visual motor reaction skills (eye-hand speed and accuracy; eye-foot speed): You were found to have adequate ability; however, this skill area is quite relevant for skeet shooting and can be improved.

Visual anticipation skills (timing of motor actions): You were found to be consistently early and less responsive to varying speeds than expected.

Assessment

You performed well on many of the vision efficiency and sports vision skills described above, with some difficulties in the areas of eye teaming skills, eye-hand speed and accuracy, anticipation responsiveness, dynamic visual acuity, and contrast sensitivity. The eye teaming deficiency directly affects spatial judgments when tracking an object; in your case, this can affect your spatial judgments and cause some inconsistency in shooting. Decreased performance of eye-hand accuracy can result in improper or slow weapon movement and adjustments in critical situations. This problem, combined with varying responsiveness with visual anticipation, can account for early and/or late shooting. Contrast sensitivity skills at high spatial frequencies allow you to make detailed judgments concerning small objects (e.g., skeet) under varying low-contrast situations, such as a cloudy day versus a clear day or changing backgrounds. Difficulties in this skill can lead to misjudgments of the skeet under the circumstances described. Difficulties in dynamic visual acuity affect your ability to discriminate detailed information from a rapidly moving object. In skeet shooting, this ability will impair an athlete's ability to see the rotation of the skeet and "lock on."

The difficulties described above would be insignificant to the average person; however, they can adversely affect visual performance in elite competition situations. Enhancement of these skills could eliminate any detrimental consequences to your return to competitive shooting.

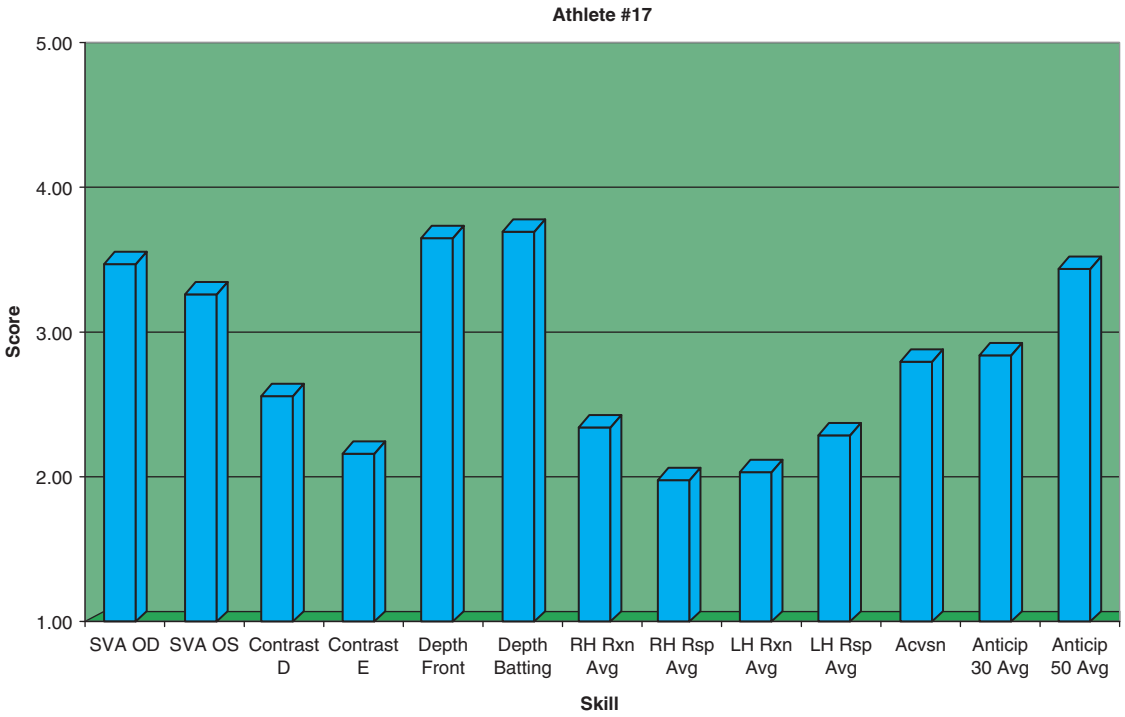
Recommendations

1. No lens correction of your left eye is recommended at this time; however, the possibility can be evaluated during your sports vision therapy program.
2. A program of sports vision therapy is recommended to improve the deficient visual skills noted above. The vision therapy program will consist of a 60-minute office visit each week combined with a prescribed home vision therapy program of approximately 15 to 20 minutes per day. The initial estimated treatment time is approximately 15 office visits.

If you have any questions or want more information about your vision care, please do not hesitate to contact me.

Sincerely,

Appendix D: Sample Athlete Profile with Brief Narrative



Athlete #17
Visual strengths:

- Good visual acuities
- Performed well on anticipation timing
- Good depth perception

Visual weaknesses:

- Slower hand reaction and response speeds for both left and right hand
- Contrast sensitivity slightly reduced compared with the team average

Recommendations:

- Performance tinted lenses or enhancement training may improve contrast judgment
- Eye-hand reaction/response training may be beneficial for fielding and batting

Index

A

AAU. *See* Amateur Athletic Union
Ablation
  procedures. *See* Laser ablation procedures
  zone, creation, 127
Acanthamoeba species, presence (concern), 124-125
Accommodation, vergence (separation), 57, 197
Accommodation facility, 197-199
Accommodative amplitudes, presence, 57
Accommodative demand, manipulation, 22
Accommodative facility
  evaluation, 57
  example, 17
Accommodative function, 56-57
Accommodative rock cards, 198
Accommodative system, feedback (absence), 190
ACT. *See* Alternating cover test
Activision, 213
Activity, visual characteristics, 9-15
Acuity, sensitivity, 189-195
Acute choroidal rupture scar, 171f
Acuvision, 212-213
AcuVision, setup method, 86
AcuVision 1000, performance (impact), 61
Acuvision 1000 eye-hand coordination, 269. *See also* Junior Olympics
  speed/mode/fixation/brite/map/sound buttons, 269f
Advanced cues, usage (assessment paradigm), 25
Aiming sports
  fixation, prolongation, 119
  peripheral vision, insignificance, 99
AK. *See* Astigmatic keratotomy
Alkali burn. *See* Corneal alkali burn
  cause, 150
Alpine skiing
  protective eyewear, usage, 108
  short duration requirement, 10b
Alternating cover test (ACT)
  distance/near testing, 250f
  performing, 249
Amateur Athletic Union (AAU) Junior Olympic Games
  American Optometric Association Sports Vision Section screening
    eye-hand reaction time station, 89f
    far stereopsis station, 89f
    Wayne Saccadic Fixator portable stand setup, 87f
Amateur Athletic Union (AAU) Junior Olympic Games—cont'd
  demographic information, 243
  lensometry, usage, 245-247
  male/female competition level, 243
  medical history, necessity, 244
  ocular symptoms, impact, 244
  prescription history, usage, 243-244
  vision evaluation protocols
    consent, 242
    history, 243-244
Amateur Athletic Union (AAU) Junior Olympics, 3
Ambient room lighting, level (impact), 66
American Academy of Ophthalmology, 101
American Academy of Pediatrics, 101
American College of Sports Medicine, 3
American National Standards Institute (ANSI)
  industry standard, 98
  Z80.1 standard, 98, 117
  Z87.1 standard, 98
American Optometric Association (AOA)
  emergency management protocol, development, 142-143
  recommendations, 112
  web site, 9
American Optometric Association (AOA), Sports Vision Section
  establishment, 3
  guidebooks, 46
  insights, offering, 9
  mission, 2
American Society for Testing Materials (ASTM), 101
  F513 standard, 104
  F659 standard, 108
  F803 standard, 101, 103
    recommendation, 104-105
    revision, 105
  F910 standard, design, 106
  F1587 standard, 104
  F1776 standard, 108
Anaglyphic vision therapy activities, 207
Angle recession, 167f
Anisometropia, impact. *See* Depth perception
ANSI. *See* American National Standards Institute
Anterior chamber, 264f
  blunt chamber, 166-168
  pooled blood, presence, 151f

Anterior mesodermal leaf, detachment, 166
Anterior nose, digital pressure, 148
Anterior segment surgery, convalescent periods (recommendations), 160t
Anticipation skills, challenge, 215
Antifog coatings, availability, 99
Antireflective coatings, value, 99
AOA. *See* American Optometric Association
AO Vectographic slide, usage, 53
Archery
  directional localization demands, 14b
  far distance demands, 13b
  nondynamic sport, 11b
  short duration requirement, 10b
Armstrong, Lance, 187
Artificial lighting, usage. *See* Sports
Artificial orbit, soccer ball impact, 150f
Ascent rate, impact, 158
Assessment
  procedures, recording method (inclusion), 86
  protocols, establishment, 87
Asthenopia, 56
  symptoms, 197
Astigmatic keratotomy (AK), 127
  combination. *See* Radial keratotomy
ASTM. *See* American Society for Testing Materials
Athletes. *See* Functionally monocular athletes
  case history, 46
  consultation, 2
  contact lenses
    counseling, 126
    issues, 126
  evaluation, 48
  eye-body coordination, evaluation, 62
  face circumference, pattern (limitation), 258f
  ocular health, evaluation, 124
  performance
    comparison ability, reduction, 87-88
    narrative, providing, 92
  prescriptions, 94
    references, 128-138
  profile sample, narrative (inclusion), 288-289
    recommendations, 289
  recognition abilities, speed (investigation), 59
  refractive compensation, guidelines, 96t
  screening, efficiency, 89
  selection, 187-188
  supplementary questions, 47
  support network, 217
  vision correction, usage, 52
  vision skills, evaluation, 3
  visual evaluation, 51-52
  visual information, processing ability, 25
Athletic excellence, pursuit, 2
Athletic performance, relation. *See* Depth perception
Athletic success, elements (understanding), 45-46
Attention
  distribution, 23-24
  modulation, ability, 185-186
Auditory-visual integration, enhancement, 198
Automaticity, level, 187
Autorefraction, 261-262. *See also* Desktop autorefraction; Handheld autorefraction
  alignment, landmarks (usage), 262f
  indexes, readout, 262f
Awareness. *See* Peripheral awareness

B

Badminton, ball/shuttlecock speeds (estimation), 106t
Bailey-Lovie logMAR charts, 47
Balance
  maintenance
    ability, 27
    factors, 27-28
  relationship. *See* Vision
  skills, investigation, 64
Balance boards. *See* Wayne Saccadic Fixator
  types, 194f
  usage, 203
Ball
  hitting/catching, success, 28
  inclusion. *See* Pitchback
Bangerter foils, usage. *See* Vision
Baseball
  contrast judgment demands requirements, 11b
  decision mechanism, usage, 31-32
  directional localization demands, 14b
  dynamic reactive sport, 16b
  dynamic sport, 11b
  effector mechanism, usage, 33
  eye injuries, 142
  eye protectors, recommendations, 103t
  far distance demands, 13b
  ocular injuries, 156-157
  perceptual mechanism, usage, 30-31
  protective eyewear, usage, 105-106
  sports-related eye (ocular) injuries, incidence, 105-106, 143
  sports vision evaluation, example, 17
  sustained performance, 10b
  team vision screening, form, 284-285
Baseball batting
  dominant eye, effect, 53
  information processing model, application, 30-32
  pitch speeds, 63
  short duration requirement, 10b
Basketball
  directional localization demands, 14b
  dynamic reactive sport, 16b
  dynamic sport, 11b
  eye injuries, 142
  eye protectors, recommendations, 103t
  far distance demands, 13b
  ocular injuries, 157
  open team sport, 27
  sports-related ocular injuries, incidence, 143
  sustained performance, 10b
Bassin Anticipation Timer
  availability, 64
  ceiling suspension, 63f
  criterion, 280f
  instructional set, 280

Bassin Anticipation Timer—cont'd
position, 280f
usage, 216
Bassin Anticipation Timer, usage, 63
Bathrooms, marketing technique, 232
Beach volleyball, 155
Beam width adjustment knob, 263f
Beanbags, tossing, 20
Berlin's edema, 170
Best-corrected visual acuity, level, 110
BETTS. *See* Birmingham Eye Trauma Terminology System
Bicycling, eye protectors (recommendations), 103t
Bifixation, regaining, 251f
Bifocal spectacle, measurement, 98
Billiards
directional localization demands, 14b
near distance demands, 13b
Binocular static visual acuity, assessment, 92
Binocular viewing conditions, real space, 205
Biomicroscope, 263f
Birmingham Eye Trauma Terminology System (BETTS), 156
Black eye, occurrence, 152
Blindness. *See* Cortical blindness
eye injuries, impact, 140
Blowout fracture
ethmoid sinus, fracture, 163
signs, 149
Blue-range tints, 115
Blunt trauma, 143-147, 161-172
inclusion. *See* Right orbital blowout fracture
pressure forces, 166
pressure patching, 166f
treatment, 145t
Blur interpretation activities, 191-195
Body
coordination. *See* Eye-body coordination
position/balance, 14
Bone structures, blunt trauma, 163-164
Bony discrepancy, 149
Bony orbit, 150
blunt trauma, 163
Boundaries, 12
Bowling, directional localization demands, 14b
Bowman's layer, injury, 165
Boxing
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
eye protectors, recommendations, 103t
near distance demands, 13b
ocular injuries, 157
sustained performance, 10b
Brand
identity/image, 223
theme, communication, 226-227
Broad-spectrum antibodies, prophylactic treatment, 172-173
Brock string, 204-205
exercise, upgaze position exercise, 204f
procedure, goal, 205
Brock String photometry, recommendation, 53
Bruising. *See* Mild bruising
Bungee jumping, 155
Burns, 147. *See also* Corneal alkali burn
treatment, 145t
Business bond, 234

C

Canadian Association of Optometrists, Sports Vision Section (formation), 3-4
Canadian Standards Association (CSA), 101
CAN3-Z262.2-M78 standard, 204
certifying logo, 102f
Carbon dioxide gas exchange, inhibition, 125
Cardiovascular stress, 15
Case history. *See* Athletes; Visual performance evaluation
importance, 46
Case presentation, 234-235
Cataracts, 112
Catching
success. *See* Ball
tasks, actual performance, 29
Central dominance, issues, 52
Central information, processing, 65-66
Central perceptual performance, improvement, 65-66
Central processing, peripheral processing (contrast), 15
Central retinal artery occlusion, 159
Changing-disparity/changing-size
relative effectiveness, 28
retinal information, 29
Charts, inclusion. *See* Rotators
Chemical burn
procedure, 147
rarity, 173
Chemical injuries, 173
Children, ocular morbidity, 140
Chin rest, 263f
Choroid
blunt trauma, 171
direct trauma, 171
Choroidal rupture scar. *See* Acute choroidal rupture scar; Old choroidal rupture scar
Chromatic aberration
reduction, 114
significance, 112-113
Ciliary body
blunt trauma, 167
risk, 167
tissues, damage, 168
Ciliary muscle tonus, adjustment, 57
Clear lens extractions, 127
Climbing, physical exertion, 158
Closed-head trauma, 172
Closed skill sports, 27
Coaches, consultation, 2
Coffey, Bradley, 207
Cognition (explanation), models (usage), 31-32
Cognitive functions, enhancement, 184
Cognitive processing, levels (increase), 193, 195
Cognitive stress, 15

Coincidence anticipation
assessment, 63
independence, 63-64
Coincidence-anticipation skills, 216-217
Color, characteristics, 12
chart answers, 252
Color-deficient response. *See* Ishihara color plates
Color plate. *See* Ishihara color plates
Color plate, example, 253f
Color testing, usefulness, 172
Color vision
Ishihara color plates, 253-254
testing, 252
position, example, 254f
Combative sports, performance (importance), 16-17
Committee on Sports Medicine and Fitness, recommendations, 141b
encouragement, 141
Commotio retinae, 169
Communication skills, importance, 84
Community activities, importance, 239
Compensation. *See* Refractive compensation
Competition
area, boundaries, 12
duration, 9-10
Competivision tinted lenses, 121
Complex interaction medication. *See* Effector mechanism
Computed tomography scan, usage, 172
Computer programs, availability, 91
Concussion, 142
Conductive keratoplasty, 127
Conjunctiva, 264f
Conjunctival injection, 173f
Conjunctival injury, blunt trauma, 164
Conjunctivitis, 152
Contact lenses, 118-126
athlete preference, 126
considerations. *See* Performance contact lenses
determination, 121-122
drying, wind (impact), 120
environmental conditions, impact, 120
eye infection, risk, 124-125
fit, 124
issues. *See* Athletes
oxygen transmission, necessity, 120
piggyback setup, 122-123
recommendations, 121-123
removal, 150
rigid lenses, suggestions, 123
services, specialization, 2
soft lenses, recommendations, 123
tinting, in-office systems (usage), 121
tissue damage, risk, 124-125
usage. *See* Performance-tinted contact lenses
impact, 15-16
value. *See* Plastic contact lenses
visual performance variables, 124
water sports, relationship, 124-125
Contests, usage, 239
Contrast
judgment
demands. *See* Sports
improvement, 114-115
levels, 10-11
sensitivity, 49-51, 189-195
demand, 192-193
example, 17, 18
Contrast sensitivity function (CSF), 22, 49
comparison, 50
measurement, 119
commercial systems, 50
test system, selection, 51
Contrecoup forces, 170
Contusion. *See* Periorbital contusion
Cornea, 264f
Corneal abrasion, 150, 166f
suspicion, 152-153
pressure patching to manage, 166f
Corneal alkali burn, 173f
Corneal changes, 125
Corneal epithelium, compromising, 173
Corneal healing, interference, 165
Corneal injuries, 150
blunt trauma, 165-166
management, 150
problem, 166
Corneal laceration (visual axis), 165f
self-sealing, absence, 165
Corneal layers, injuries, 166
Corneal pigmented arc formation, incidence (increase), 125
Corneal reshaping. *See* Orthokeratology
Coronal computed tomographic scan. *See* Right orbital blowout fracture
Cortical blindness, 159
Courses, personal contact, 237-238
Cover test, 249-250. *See also* Alternating cover test; Unilateral cover test
distance/near procedure, 250f
instructions, 249
procedure, 249
recording, 250
referral criteria, 250
CR39 lenses
availability, 116
impact. *See* Ocular trauma
Crepitus, 148
Crossed eye/hand dominance, advantages/disadvantages, 52-53
Cross-polarizing filters, usage, 207, 208f
Crystalline lens
blunt trauma, 168-169
dislocation, 154f
CSA. *See* Canadian Standards Association
CSF. *See* Contrast sensitivity function
CSV-1000E contrast sensitivity chart, 51f
Custom-fit scleral lenses (haptic lenses), 118
Cycling
contrast judgment demands requirements, 11b
directional localization demands, 14b

Cycling—cont'd
dynamic reactive sport, 16b
far distance demands, 13b
near distance demands, 13b
sustained performance, 10b
Cycloplegia, 166
Cycloplegics, usage, 165

D

Data spreadsheet programs, statistical calculations, 91
DCS. *See* Decompression sickness
Decision mechanisms, 24-26
speed/efficiency, improvement, 32
usage. *See* Baseball
Decompression sickness (DCS), 159
ocular manifestations, 159
Demands. *See* Directional localization; Far distance demands; Near distance; Visual attention demands; Visual discrimination demands
contrast. *See* Static task demands
sustaining, 9-10
Demonstrators, usage, 235
Depth
activities, simulation, 205-207
discrimination, 14
judgment, 191
evidence, 24
making, 204
usage, 22-23
localization judgments, proficiency, 207
motion perception, 190
simulation, 205
systems, motion, precision, 28
Depth perception, 54
abilities, athletic performance (relation), 54
anisometropia, impact, 96
example, 17, 18
speed/accuracy, 204-209
yellow filters, impact, 114
Descemet's membrane, damage, 166
Desktop autorefraction, 261
Detached retina, 152
Detail resolution, ability (enhancement), 190
Developmental Eye Movement Test, 58
Diplopia. *See* Double vision
Direct fixation, nonpredictable pattern (usage), 258f
Directional localization, 13-14
demands, 14b
Direct mail
campaign, success, 237
usage, 236-237
Disks, inclusion. *See* Rotators
Dispensary
benefits, communication, 235
decor, 236
Displays, usage, 235
Distance
demands. *See* Far distance demands; Near distance
fixation disparity characteristics, assessment, 53
near distance, contrast, 13
rock, 197-198
Distance target, fixation, 265f
Diving
closed skill sport, 27
directional localization demands, 14b
dynamic reactive sport, 16b
Doctor
examination. *See* Patients
human bond, importance, 234
Dominance, 52
issues. *See* Central dominance
phenomenon. *See* Ocular dominance
Dominant eye-hand, 260
Dominant eye-hand test, 259
cyclopean result, 259
midmoderate result, 259f
strong result, 259f
Double vision (diplopia), 151, 159
Drag racing, short duration requirement, 10b
Dry eye syndrome, 120
Dual tachistoscope projection system, control module (inclusion), 210f
DVA. *See* Dynamic visual acuity
Dynamic
contrast. *See* Nondynamic
term, definition, 10
Dynamic reactive sports, 16b
visual task analysis, 16-17
Dynamic sports
activities, nondynamic sports activities (contrast), 10
athlete, motion, 11b
Dynamic visual acuity (DVA), 48-49, 195-197. *See also* Threshold dynamic visual acuity
assessment, inVision package (usage), 50f
correlation, reduction. *See* Static visual acuity
enhancement training, 195
example, 17
human attributes, impact, 48
impact, 195
measurement systems, 49
parameters, research, 49
testing, Wayne Robot Rotator (visual acuity chart) usage, 49f
training, 210
visual task performance, relationship (determination), 22
Dynavision, 212-213
Dynavision 2000, availability, 61

E

Edematous compression, 170
Effector mechanism, 26-29
instigation, 212
responses, complex interaction mediation, 28-29
usage. *See* Baseball
Electromagnetic spectrum, 112f
Electronic devices, usage, 212-213
E-mail bulletins, usage, 237
Emphysema. *See* Subcutaneous emphysema
Environmental analysis. *See* Recreation; Sports
EOM. *See* Extraocular muscles
Epistaxis, 148

Ergonomically appropriate targets, usage, 196
Erythrocytes, sickling, 168
Ethmoid sinus, fracture. *See* Blowout fracture
Evaluation. *See* External evaluation; Internal evaluation
Examination. *See* Patients
  procedures
    explanation, 234
    linkage, 234
  summary form, usage, 235
Experts, visual search patterns, 23-24
External evaluation, 263-264
External eye, 264f
External marketing, 236-240
External rim fracture, 148-149
Extraocular muscles (EOM)
  abnormalities, 162
  action, isolation, 162
  diagnostic action fields, 162t
  entrapment, orbital fractures (impact), 162
  innervation, exertion, 204
  restrictions, 164
Extreme sports, 155
Eye-body coordination, 61-62, 212-213
  evaluation, 62
  Wayne Saccadic Fixator, availability, 62
Eyecare Business: Marketing and Strategy, 223
Eye care practitioner, resources, 128
Eye care providers, patient counseling, 111
Eye-care specialist, on-site sports medicine provider (communication), 174
Eye-foot coordination, 212-213
Eye-hand coordination, 61, 212-213. *See also* Acuvision 1000 eye-hand coordination
  evaluation, 61
  score, calculation (application), 91
Eye/hand/foot preference, 52-53
Eye-hand reaction time station. *See* Amateur Athletic Union Junior Olympic Games
Eye injuries. *See* Nontraumatic eye injuries/conditions
  age percentage, 140b
  comprehensive eye injury, usage, 155
  nontraditional sports, impact, 155
  occurrence, 140
  recognition, 147-155
  reports/national estimates. *See* Recreation; Sports
  risk, increase, 142
  signs, 143b
  sustaining, risk, 5
Eyelids, 264f
  blunt trauma, 161-162
  eversion, steps. *See* Upper eyelid
  margin, laceration, 153f
  superficial injury, 147
Eyemaginations, 232
Eye movements, 199-204. *See also* Pursuit eye movements; Saccadic eye movements
  efficiency, improvement, 200
  evidence, 24
  Ober II, usage, 266-267
  usage, 23-24
Eye protection, 46-47. *See also* Hockey; Paintball
  specifications, establishment, 108
  stick penetration test, necessity, 101
Eyes
  alignment
    accuracy/stability, 53
    precision, 53
  anterior chamber, blood (collection), 151
  blood, presence, 146
  bruising, 148
  conditions. *See* Nontraumatic eye injuries/conditions
  deviation, magnitude (determination), 249, 250f
  following. *See* Light
  globe, rupture, 151
  infection, risk. *See* Contact lenses
  measurement, 262f
  protectors. *See* Goggle-style sports eye protectors
    recommendations. *See* Sports
  rotation center, zero mark, 251f
  test. *See* Poorer seeing eye
  trauma, 149-150
Eyespan, 212-213
Eyewear. *See* Nonprotective sports eyewear; Protective eyewear
  fogging, problems, 110
  prescription. *See* Performance sun eyewear
  selection, 142
  usage. *See* Alpine skiing; Baseball; Ice hockey; Lacrosse; Paintball; Racquet sports; Soccer; Swimming; Water sports
    impact, 15-16
Eyewear products, benefit, 113

F

Face circumference, pattern (limitation). *See* Athletes
Face-form design (wrap design) sun eyewear, coverage (improvement), 117
Face protection. *See* Hockey; Paintball
Facial bone, fracture. *See* Nose
Facial fractures, 147
Facial injuries, recognition, 147-155
Far distance demands, 14b
Far stereopsis station. *See* Amateur Athletic Union Junior Olympic Games
Fast-action sports, factors, 216
Feedback, providing, 195, 214
Fee slips/receipts, marketing technique, 235-236
Fencing
  dynamic reactive sport, 16b
  eye protectors, recommendations, 103t
Field dependence/independence, 64-65
  example, 18
Field hockey, eye protectors (recommendations), 103t
Figure/ground characteristics, 12
Figure skating, short duration requirement, 10b
Filters. *See* Photochromic filters; Polarized filters; Purple-range filters
Filters, prescription, 112-119
Fishing, ocular injuries, 157
Fixation. *See* Distance target
  disparity, status, 207

Fixation. *See* Distance target—cont'd
loss, 267t. *See also* Pursuit fixation loss
nonpredictable pattern, usage. *See* Direct fixation
slide, inclusion. *See* Macula integrity tester-trainer
steadiness, requirement, 191
Fixation disparity, 207
feedback, 208f
influence, 53
targets, vergence demand (absence), 208f
Flat light conditions, 115
Fluorescein
leakage, 164
staining. *See also* Small inferior epithelial defect
stream, 165f
usage, 164
Fly ball, catching, 190
Fogging
factors, consideration. *See* Lenses
minimization, 117
prevention, 118f
problems. *See* Eyewear
Follow-up co-management. *See* Ocular injuries
Foot
coordination. *See* Eye-foot coordination
preference. *See* Eye/hand/foot preference
Football
contrast judgment demands requirements, 11b
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
eye protectors, recommendations, 103t
far distance demands, 13b
ocular injuries, 157
open team sport, 27
sustained performance, 10b
Foreign body sensation, complaint, 154
Foreign object
blunt trauma, 143, 146
treatment, 145t
Frontal bone fracture, 149
Frontal sinus
crepitus, 149
depression, 149
Full-contact martial arts, eye protectors (recommendations), 103t
Functionally monocular athletes, 110-111
Fundus examination. *See* Pupils

G

Ganzfield effect, production, 115
Gardner, Jack, 213
Gaze angles, 14
Glare, visible light (responsibility), 113
Glaucoma, development (risk), 167-168
Globe, compression (anterior-posterior direction), 161
Globe, rupture. *See* Eyes
potential, blunt trauma (impact), 128
Goggle designs, ventilation holes (usage), 109
Goggle-style sports eye protectors, 104f
Golf
ball, fixation, 190
Golf—cont'd
contours, interpretation, 20
contrast judgment demands requirements, 11b
directional localization demands, 14b
far distance demands, 13b
nondynamic sport, 11b
ocular injuries, 157-158
sports vision evaluation, example, 17-18
sustained performance, 10b
Gonioscopy studies, suggestions, 167
Gratings, usage, 50
Green-range tints, 115
advocacy. *See* Tennis
Grounding system. *See* Hyphema
Gymnastics
closed skill sport, 27
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
short duration requirement, 10b

H

Haidinger brush, perception, 191
Hand
coordination. *See* Eye-hand coordination
preference. *See* Eye/hand/foot preference
foot preference, relation, 52
speed. *See* Wayne Saccadic Fixator
Handball, ball design, 102-103
Hand-drawn nonius lines, usage, 207, 208f
Handheld autorefraction, 261-262
eyepiece, usage, 262f
Haptic lenses. *See* Custom-fit scleral lenses
Hart chart. *See* Reduced Hart chart
fixation, Wayne Saccadic Fixator (usage), 215f
Hart's revised vision chart, 198f
Haynes distance rock test, 56f
Head
blunt trauma, 161
position, impact, 53
rest, 263f
trauma, 147
Hemorrhage. *See* Orbital hemorrhage; Subconjunctival hemorrhage
resolution, 171
Henle's fiber layer, plane-polarized light (absorption), 191
Hess-Lancaster test, 162
Heterophoria, amounts, 22-23, 53
High-contrast conditions, acuity task (performing), 49-50
Higher-order aberrations, increase, 126
High-level athletes, vision examination (absence), 5-6
History
form, technician review, 233
pretesting communication. *See* Patients
Hockey
contrast judgment demands requirements, 11b
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b

Hockey—cont'd
face/eye protection, 107f
far distance demands, 13b
ocular injuries, 158
open team sport, 27
sustained performance, 10b
Hockey Equipment Certification Council (HECC), certifying logos, 102f
Howard-Dolman device, usage, 54. *See also* Real-space depth perception
Howard-Dolman sensitivity, 190-191
Howard Dolman Stereoacuity Test, 278-279
instructional sets, 278
testing sessions, 278
test results, 278t-279t
usage, illustration, 279f
Howard-Dolman training, 206
Human bond, importance. *See* Doctor
Hydrogel lenses (soft lenses)
choice, 118
combination. *See* Rigid lenses
goal, 123
recommendations. *See* Contact lenses
Hyperbaric oxygen, usage, 159
Hyphema, 151. *See also* Traumatic hyphema
clearance, 167
grading system, 168b

I

Ice hockey
eye protectors, recommendations, 103t
protective eyewear, usage, 104
ICRS. *See* Intracorneal ring segments
Idiocyclitis, 173
Imagery, relationship. *See* Visualization
Impact attenuation, improvement, 100
Impact-resistant lens material, suitability, 99
Induced prism, amount, 117
Information
providing, visual system (quality), 31
Information conversion, 26-27
Information processing, 213
cognitive style, 64
model. *See* Skilled performance; Sports application. *See* Baseball
perceptual mechanism, oculomotor function (aspect), 23
relationship. *See* Optometry
Injuries. *See* Corneal injuries; Eyelids; Eyes; Ocular injuries; Retinal injury
comprehensive case history, usage, 155
mechanisms, determination, 147
rate data, compilation, 156
risk, ophthalmic materials (impact), 46
In-office system, usage. *See* Contact lenses
Inspection time (IT), 59
Intelligence quotient (IQ), reduction, 60
Internal evaluation, 265
Internal marketing, 223-229. *See also* Sports vision practice development
Internal rim fracture, 148-149
Intracorneal ring segments (ICRS), 127
usage, 128
Intraocular infection, 172
Intrastromal corneal rings, implantation, 128
inVision package, usage. *See* Dynamic visual acuity
iPort, 232
Ipsilateral upper lip, hypesthesia/anesthesia, 149
Iris, displaced lens (contact), 169
Iris sphincter, rupture, 167f
Iris stroma, injury, 166-167
Iris tissues, damage, 168
Iritis, 166
Iseikonic lenses, substitution, 190
Ishihara color plates, 253
answers, 254
color-deficient responses, 254
normative responses, 254
usage. *See* Color vision
IT. *See* Inspection time

J

Juggling, 214-215
competitions, 214-215
skill. *See* Three-ball juggling
Junior Olympic Games
athletes, vision correction usage, 52
refractive error, incidence, 95
visual symptoms, incidence, 95
Junior Olympics (1997)
Acuvision 1000 eye-hand coordination, 269t
tachistoscope, 275t
Vectorvision Contrast Sensitivity, 276t
Wayne Foot Speed, 270t
Junk mail, problem/perception, 236-237

K

Kayaking
directional localization demands, 14b
dynamic reactive sport, 16b
Keratitis, 154
Keratopathy, 112
Keystone telebinocular, usage, 47
King-Devick Test, inappropriateness, 58
Kirschner arrows chart. *See* Modified Kirschner arrows chart
Korb lens, lens positioning, 123

L

Laceration, 152-153. *See also* Eyelids; Superficial laceration; Visual laceration
first-aid management, 152
Lacrosse
eye protectors, recommendations, 103t
ocular injuries, 158
protective eyewear, usage, 104-105
wire mesh protector. *See* Women's lacrosse
Lafayette Instruments, motor response time measurement devices (availability), 59-60
Landolt C optotypes, 47
Large-diameter lenses, usage, 124
Laser ablation procedures. *See* Refractive surgery

Laser in situe keratomileusis (LASIK), 127-128
emphasis, 227
Laser refractive surgery, post-surgery symptoms, 127-128
Laser subepithelial keratomileusis (LASEK), 127-128
Laser thermokeratoplasty, 127
Lectures, personal contact, 237-238
Lenseless eye guard, usage. *See* Racquet sports
Lenses, 264f. *See also* Contact lenses
breakage, protection, 108
coatings, 116-118
impact resistance properties, reduction, 99
dislocation, 153. *See also* Crystalline lens
fogging, factors (consideration), 99
neutralization. *See* Lensometer
rock, 198-199
sensitivity, 190
Lensometer
components, 245
lens, neutralization, 246
preparation, 246
recording, usage, 247
Lensometry, usage. *See* Amateur Athletic Union Junior Olympic Games
Lens rock training, goal, 199
Lens sorting, 199
Letters, inclusion. *See* Pitchback
Letter stickers, usage. *See* Pitchback
Liberty MAXX frame
straps, inclusion, 104f
temples, inclusion, 104f
Lid attachment design, lens positioning, 123
Lifesaver card, Nonius line markings, 208f
Light
eyes, following, 257f
intolerance. *See* Photophobia
movement. *See* Physiological H pattern
transmission characteristics, development, 114
Light-emitting diodes, (LEDs), 213
illumination, 216
tracking, 63
Lighting, variations, 15
Limbal relaxing incisions, 127
Localization. *See* Directional localization; Spatial localization
aspects, 14
Logos
examples, 228f
usage. *See* Practice logo
Low-contrast visual acuity, reduction, 126
Lower lacrimal canaliculi (tear duct), laceration, 153
Lower lid stye, 154f
Low-level motor effects, production, 67
Low-set segment setting, 97

M

Macula integrity tester-trainer
availability, 191
fixation slide, inclusion, 192f
Maddox Rod photometry, recommendation, 53
Maddox rod testing, 162
Magnification adjustment, 263f
Major League Baseball, pitch (analysis), 12
Marketing. *See* External marketing; Internal marketing; Niche marketing; Reception room
opportunities. *See* Sports vision practice development
techniques
decision, 223
self-evaluation form, 224f-226f
Marsden balls, ceiling suspension, 201f
Martial arts
alternative sport, 155
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
eye protectors, recommendations. *See* Full-contact martial arts
near distance demands, 13b
sustained performance, 10b
Medial orbital wall blowout fracture, 165f
Medical practitioners, referrals, 239
Mental imagery
calibrations, 208-209
combination. *See* Visual performance enhancement training
involvement, 67
strategies, 185-186
value, 67
Metallic coatings, usage, 116-117
Mid-peripheral cornea, thickening, 125
Mild bruising, 144f
Mild traumatic brain injury (MTBI), signs/symptoms, 142b
Mini-trampoline, usage, 207
Minus lenses, usage, 190
MOART. *See* Multi-Operational Apparatus for Reaction Time
Modified Kirschner arrows chart, 203f
Modified Strobespecs, prototype, 212f
Monocular athletes. *See* Functionally monocular athletes
Monocular diplopia, creation, 167
Motion, perception, 28. *See also* Depth
Motor performance task, involvement, 211
Motor racing
contrast judgment demands requirements, 11b
directional localization demands, 14k
dynamic reactive sport, 16b
dynamic sport, 11b
far distance demands, 13b
nondynamic sport, 11b
sustained performance, 10b
Motor response
accuracy, 23
addition, 210
time, 59-60
measurement devices, usage, 59
Motor sports, near distance demands, 13b
Motor tasks, performance, 67
Mountaineering
contrast judgment demands requirements, 11b
dynamic sport, 11b
far distance demands, 13b

Mountaineering—cont'd
sustained performance, 10b
visual information processing, sustaining ability, 9-10
Mountaineering, ocular injuries, 158
Moving object, tracking, 202
Moving target, visual acuity (reduction), 48
MTBI. *See* Mild traumatic brain injury
Multi-Operational Apparatus for Reaction Time (MOART), availability, 61
Muscles, diagnostic action fields. *See* Extraocular muscles
Music, impact, 232
Mydriasis, 166
Myopia
amount, 96
correction, 128

N

Narrative, inclusion. *See* Athletes
Nasal bones, mobility, 148
Nasal deformity, 148
Nasal fractures, 148
signs, 148
National Athletic Trainers' Association, 3
National Collegiate Athletic Association (NCAA), 3
eyewear recommendations, 150
legal requirements, 140
National Electronic Injury Surveillance System (NEISS)
creation, 156
data, summary. *See* Recreation; Sports
National Football League (NFL), retrospective study, 149
National Hockey League (NHL), eye injuries, 158
National Operating Committee on Standards for Athletic Equipment (NOCSAE), certifying logo, 102f
Natural lighting, usage. *See* Sports
NCAA. *See* National Collegiate Athletic Association
Near distance
contrast. *See* Distance
demands, 13b
Near point of convergence (NPC), 251
assessment, 55
Near testing, 250f
NEISS. *See* National Electronic Injury Surveillance System
Neural processes, sharing, 67
Neurologic mechanisms, filtering, 21
NeuroVision, computerized training program, 229
Neutral gray tints, 114
Newspaper
advertisements, usage, 238
columns, usage, 237
inserts, usage, 237
NFL. *See* National Football League
NHL. *See* National Hockey League
Niche marketing, 227
Nike golf tint, 116f
Nike Max Golf Tint, purple tint, 115
Nike MAXSIGHT contact lenses, 122f
tints, 121
Nike Vision Eye Shield, 105f
Nikon Retinomax
eyepiece, usage, 262f
usage, 261-262
NOCSAE. *See* National Operating Committee on Standards for Athletic Equipment
Nondynamic
dynamic, contrast, 10
term, definition, 10
Nondynamic precision sports, visual task analysis, 17-18
Nondynamic sports
activities, contrast. *See* Dynamic sports
athlete, stationarity, 11b
Nonius line markings. *See* Lifesaver card
Non-life threatening injuries, determination, 147
Nonprimary gaze directions, information, 119
Nonprotective sports eyewear, 98-99
Nonstatic task demands. *See* Sports
contrast. *See* Static task demands
definition, 9
Nontraumatic eye injuries/conditions, 154-155
Nordic skiing, sustained performance, 10b
Northeastern State University College of Optometry Oculomotor Test, 58
Nose, facial bone fracture, 148
NPC. *See* Near point of convergence
Number sequence, recall, 59
NXT lens material, usage, 98
Nylon sutures, interruption, 165f
Nystagmus, 159

O

Ober II, 266-267
instructions/procedures, 266-267
usage. *See* Eye movements
Object localization, accuracy, 23
Ocular alignment
example, 17, 18
improvement, 22
measurement, 53
Ocular damage, blunt trauma (mechanism), 161f
Ocular dominance, phenomenon, 52
Ocular emergencies, management. *See* Sports-related ocular emergencies
Ocular gaze, impact, 53
Ocular health evaluation. *See* Athletes
Ocular health status, 67
evaluation procedures, decision, 76
Ocular injuries
assessment/management, 140
clinical management, 155-173
follow-up co-management, 173-174
prevention, 141-142
references, 174-182
risk, minimization, 104-105
sideline management, 140-155
Ocular morbidity. *See* Children
Ocular motilities, 257
Ocular preference, role, 53
Ocular problems, 112
Oculars, 263f
alignment, 53-54

Ocular surface, coverage (improvement, 117
Ocular trauma (risk increase), CR39 lenses (impact), 103-104
Ocular vergence information, 29
Oculomotor function, 57-58
  aspect. *See* Information processing
    importance, 57-58
Oculomotor skills, performance, 55
Oculoplastic surgery, convalescent periods (recommendations), 160t
Office design/decor, 231
Office welcomes. *See* Welcome to the Office
Off-site screening, usefulness/portability, 86-87
Old choroidal rupture scar, 172f
One-eyed athletes, protective eyewear (usage), 110
Open eye guards, usage, 102-103
Open skill team sports
  advantages, 27-28
  field dependence, advantage, 64
Ophthalmic surgery, convalescent periods (recommendations), 160t
Optical devices, need (absence), 95
Optic nerve
  avulsion, 170
  blunt trauma, 170-171
Optic neuropathy, 159
Optometry, visual information processing (relationship), 32-33
Oral nonsteroidal antiinflammatory agents, usage, 165
Orbital blowout fracture
  blunt trauma, inclusion. *See* Right orbital blowout fracture
  result, percentage, 164
Orbital contents
  blunt trauma, 162
  compaction, 161
Orbital floor blowout fracture, mechanism, 148f
Orbital fractures, 148-149
Orbital hemorrhage, 152
Orbital wall blowout fracture. *See* Medial orbital wall blowout fracture
Orthokeratology (corneal reshaping), 125-126
  alternative, 126
  prolongation, 125-126
Outdoor low-light conditions, intensity, 114-115
Out-of-office practice, 189
Out-of-office testing, Wayne Saccadic Fixator (portable stand setup), 86f
Overnight orthokeratology, reverse geometry lens design (marketing), 125

P

Pacific University College of Optometry, elective course (providing), 4
Paintball
  eye/face protection, 108f
  eye protectors, recommendations, 103t
  nonsport recreational pursuits, 155
  ocular injuries, 161
  protective eyewear, usage, 108
PAL. *See* Progressive addition lens
Panum's fusional area, enlargement, 205
Paper-and-pencil tasks, response, 64-65
Parking lot, practice perception, 230
Park three-step test, 162
PAT. *See* Wayne Peripheral Awareness Trainer
Patient-centered office, 232
Patients
  doctor examination, 234-236
  education, 231-232
  history/pretesting, communication, 232-234
  marketing, 236b
  selection, 187-188
Peak performance
  contribution, visual factors, 85
  impediment, 20
PECC. *See* Protective Eyewear Certification Council
Penetrating trauma, 172-173
Perceived distance, changes, 53
Perceptamatic tachistoscope lens, rotation, 196-197
Perceptual mechanisms, 21-24
  information, receiving, 21
  responsibility, 30
  usage. *See* Baseball
Perforating injuries, 173
Performance
  accuracy, visual feedback, 209
  evaluation. *See* Visual performance evaluation
  feedback, 188
    minimum, 88
  improvement, 5
  information processing model. *See* Skilled performance; Sports
  profile, statistical analysis (graphic presentation), 92
  tints, 51
  vision factors, identification, 4, 45-46
Performance contact lenses, 118-120
Performance sun eyewear, prescription, 112-118
Performance-tinted contact lenses, usage, 121
Periorbital contusion, 152
Peripheral awareness, 65-66
Peripheral Awareness Tester. *See* Wayne Peripheral Awareness Trainer
Peripheral commotio retinae, 170f
Peripheral information, processing, 65-66
Peripheral perception performance (increase), physical ability (impact), 65-66
Peripheral processing, contrast. *See* Central processing
Peripheral retina, bucket handle appearance, 169
Peripheral vision, 213-216
  assessment, 65
  demand, 16
  evidence, 24
  usage, 24
Peripheral visual field
  constriction, 109-110
  information processing, 213
Personal contact, 237-238
Phakic intraocular lenses, 127
Photochromic filters, 116
Photochromic lenses, availability, 116
Photophobia (light intolerance), 150, 154

Photorefractive keratectomy (PRK), 127-128
Physical ability, impact. *See* Peripheral perception performance
Physical space, range (control), 12
Physiological H pattern, light movement, 257f
Piggyback setup. *See* Contact lenses
Pinguecula, 112
  risk, 160
Pistol shooters, presbyopia (impact), 97-98
Pitchback
  activity, replacement, 211
  ball/letters, inclusion, 196-197
  rubber baseball, letter stickers (usage), 197f
  stroboscopic activities, 213
Pitchers
  elbow, release point, 30
  skill, 32
Plane-polarized light, absorption. *See* Henle's fiber layer
Plano dress eyewear, 117
Plastic contact lenses, value, 118
Polarized filters, 115-116
Polarized vision therapy activities, 207
Polycarbonate lens material
  availability, 116
  usage, 98
Polymethylmethacrylate lenses
  impact, 159
  nitrogen inhibition, 125
Poorer seeing eye, test, 250f
Porta, Giovanni Battista della, 52
Positive Seidel test, demonstration, 165f
Posterior synechiae, prevention, 173
PPPE. *See* Preparticipation physical examination
Practice location, importance, 230
Practice logo, usage, 227
Practitioners, knowledge (depth), 8
Precipitation, factors (consideration), 99
Prentice's rule, approximation, 98-99
Preparticipation physical examination (PPPE), 140-141
Presbyopia
  challenge, 97
  impact. *See* Pistol shooters
  prescribing challenges, 96-97
Presbyopic athlete, viewing distances (consideration), 95
Pretesting room, 233
Pretesting scripts, usage, 233-234
Prevent Blindness America, estimates, 100
Pricing, importance. *See* Products/services
Prismatic effects, lens design (impact), 117
Prism flippers, placement, 199
Prism rock, 199
  training, goal, 199
Prism sensitivity, 191
PRK. *See* Photorefractive keratectomy
Products/services
  pricing, importance, 227-229
  quality, 227
  selection, 229
Professional negligence, claim, 111
Program codes. *See* Wayne Saccadic Fixator
Progress evaluations, schedule, 188
Progressive addition lens (PAL), prescription, 97
Projected vectogram, fusion, 187
Prosoft, teal-tinted contact lens, 121
Protective eyewear, 100-111
  clinicolegal issues, 111
  issues, 109-110
  usage, 149. *See also* Alpine skiing; Baseball; Ice hockey; Lacrosse; Paintball; Racquet sports; Soccer; Swimming; Water sports
    epidemiologic evidence, 142
Protective Eyewear Certification Council (PECC), 101
  certifying logo, 102f
Pterygia, 112
  risk, 160
Public relations, impact, 237
Pupillary distance, goggle adjustment/calibration, 266f
Pupillary reflex, testing (usefulness), 172
Pupillary responses, 162
Pupils, 264f
  dilation, fundus examination, 144f
  irregularity, 151
  testing, 256
    illustration, 256
Purple-range filters, 115
Pursuit eye movements, 200, 202
  accuracy, feedback, 200, 202
  performance, achievement, 202
  usage, 30-31
Pursuit fixation loss, 267t
Pursuits
  recording, scales basis, 258
  usage, 258

R

Racquetball, ball/shuttlecock speeds (estimation), 106t
Racquet sports
  ball/shuttlecock speeds, estimation, 106t
  contrast judgment demands requirements, 11b
  directional localization demands, 14b
  dynamic reactive sport, 16b
  dynamic sport, 11b
  eye protectors, recommendations, 103t
  F803 standard, usage, 109
  far distance demands, 13b
  lenseless eye guard, usage, 106f
  ocular injuries, 158-159
  protective eyewear, usage, 101-104
  sustained performance, 10b
Radial keratotomy (RK), 127
  AK, combination, 127
  procedure, commonness, 127
Randot steropsis, 255
  answer key, 255
  testing position, example, 255
Rapid-action sports, visual judgments (requirement), 56
Rapid saccadic movements, involvement, 119
Reaction time (RT). *See* Visual-motor reaction time
  measures, 27
  reflex
    cycle, repetition, 61
    measurement, 60

Real space depth judgments/mental imagery calibrations, combination. *See* Visual performance enhancement training
Real-space depth perception (assessment), Howard-Dolman device (usage), 55f
Real-space distance judgments, usage, 54
Reception room, marketing, 231-232
Recession injuries, 167-168
Recognition
  abilities, speed (investigation). *See* Athletes
  span, tachistoscopic procedures (usage), 59
  speed, 58-59, 209-211
Recompression therapy, 159
Recording forms, usage. *See* Sports vision screening
Recreation
  environmental analysis, 15-16
  eye injury reports
    national estimates, 100t
    NEISS data, summary, 156t
Red eye, sign, 152
Red lens testing, 162
Red-range tints, 115
Reduced Hart chart, 198
Red vision, report, 113
Referrrals. *See* Medical practitioners
Refraction. *See* Autorefraction
Refractive compensation, 95-98
  guidelines. *See* Athletes
    consideration, 96
Refractive correction, 46-47
Refractive status, 51-52
  amount, 51-52
  example, 17, 18
  letter, sample, 286
Refractive surgery, 126-128
  advantage, 95
  incisional methods, 127
  laser ablation procedures, 127-128
Refrigerator magnets, usefulness, 237
Relaxation, involvement, 64
Report letter, construction methods, 91
Reports, generation. *See* Sports vision; Sports vision screening
Reputation, importance, 239
Retina. *See* Detached retina
  hemorrhage, 151
  integrity, evaluation, 169
  ocular trauma, 169
Retinal image disparity, 53
  induction, 54
Retinal information. *See* Changing-disparity/changing-size
Retinal injury, 151
  blunt trauma, 169-170
Retinal tears/detachments, 170
Retinal vasculature changes, 158
Reverse geometry lens designs, 125
  marketing. *See* Overnight orthokeratology
RGP. *See* Rigid gas permeable
Right-hand golfer, segment offset, 97
Right orbital blowout fracture
  blunt trauma, inclusion, 144f
  coronal computed tomographic scan, 165f
Rigid gas permeable (RGP) lenses
  choice, 118
  consideration, 119
  fit, modification, 123
  larger lens diameters, usefulness, 123
Rigid lenses
  hydrogel lenses, combination, 122
  scleral lenses, comparison, 122
  suggestions. *See* Contact lenses
Rim fracture. *See* External rim fracture; Internal rim fracture
RK. *See* Radial keratotomy
Rod/frame test, 65f
Rotators, disks/charts (inclusion), 195
RT. *See* Reaction time
Rubber baseball, letter stickers (usage). *See* Pitchback
Ruth, Babe (sensory/motor gifts), 3

S

Saccades
  recording, scales basis, 258
  usage, 258
Saccadic eye movements, 202-204
  initiation, ability, 23
  training, 203
Saccadic speed, 267t
Sailing
  contrast judgment demands requirements, 11b
  directional localization demands, 14b
  far distance demands, 13b
  sustained performance, 10b
Scleral expansion, 127
Scleral injury, blunt trauma, 164
Scleral lenses, comparison. *See* Rigid lenses
Scleral rupture, 164
Screening. *See* Sports vision screening
  flow through, 88
  meeting time, usefulness, 89
  staff, training (thoroughness), 88
Scuba diving, ocular injuries, 159
Secondary glaucoma, incidence, 167-168
Seidel testing, 164
  performing, 172
Sensory demands, incorporation, 193, 195
Sensory information, processing, 21
Sensory integration
  activity, performance, 203
  burdens, 193b
Sensory receptors, usage, 21
Separation distance, stereoacuity (relationship), 278t, 279t
SH. *See* Subconjunctival hemorrhage
Shade, characteristics, 12
Shield-style protection, attachment, 101
Shooters, tint selection, 113f
Shooting sports
  directional localization demands, 14b
  far distance demands, 13b

Shooting sports—cont'd
near distance demands, 13b
nondynamic sport, 11b
short duration requirement, 10b
Short-wavelength light, transmission (reduction), 116
Shuttlecock diameter, 159
Sighting preference, tests, 52
Sighting sports, 53
SILO. *See* Smaller in, larger out
Single-vision intermediate distance prescription, usage, 97
Skating
contrast judgment demands requirements, 11b
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
far distance demands, 13b
Skeet shooting
contrast judgment demands requirements, 11b
dynamic reactive sport, 16b
sustained performance, 10b
Skiers, red-range tints (usage), 115
Ski goggles, performance tints, 51
Skiing. *See* Alpine skiing
contrast judgment demands requirements, 11b
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
far distance demands, 13b
short duration requirement, 10b
Skill development procedures. *See* Vision skill
Skilled performance, information processing model, 20f
Skill level, discrimination, 65
Slit lamp, 263f
Smaller in, larger out (SILO) perception, 206-207
Small inferior epithelial defect, fluorescein staining, 165f
Snellen chart
answers, 248
standard, 47
usage, 248
Snellen-type visual acuity measurements, 49-50
Soccer
ball
impact. *See* Artificial orbit
ocular trauma, responsibility, 159
contrast judgment demands requirements, 11b
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
eye protection, work item (WK1237), 109
eye protectors, recommendations, 103t
far distance demands, 13b
ocular injuries, 159
protective eyewear, usage, 109
sustained performance, 10b
Softball
batting, short duration requirement, 10b
contrast judgment demands requirements, 11b
directional localization demands, 14b
dynamic reactive sport, 16b
far distance demands, 13b
ocular injuries, 156-157
Softball—cont'd
sustained performance, 10b
Soft lenses. *See* Hydrogel lens
SoftPerm lens, availability, 122
Soft toric lenses, consideration, 119
Solar radiation/glare, optical protection, 2
Spatial frequency. *See* Vectorvision Contrast Sensitivity examples. *See* Testing distances
Spatial localization, 14, 207-209
techniques, 214
Spatial occlusion, usage, 15-16
Special invitations, marketing technique, 239
Special Olympics, 3
Special-purpose shooting prescription, usage, 98
Specialty lens, engineering (alternative), 123
Spectacle lenses, prismatic effects, 118
Spectacle prescriptions, recommendation (absence), 98
Speed, tachistoscopic procedures (usage), 59
Speed-of-recognition demand, addition, 215
Speed skating, short duration requirement, 10b
Spherical refractive errors, compensation, 119
Spirangle variable vectogram, usage. *See* VTE
Split attention
activities, 214
contrast, 15
usage, 215f
Sporting activities, participation, 1
Sports
artificial lighting, usage, 15
contrast judgment demands, 11b
environmental analysis, 15-16
eye injury, prevention/management, 2
eye injury reports
national estimates, 100t
NEISS data, summary, 156t
eye protectors. *See* Goggle-style sports eye protectors
recommendations, 103t
eyewear. *See* Nonprotective sports eyewear
interest, increase, 3
natural lighting, usage, 15
nonstatic visual demands, 9b
ocular injuries, 156-161. *See also* Ocular injuries
participation, risk, 140
protective eyewear, usage. *See* Racquet sports; Water sports
sustained performance demands, 10b
vision, role (debate), 1
visual characteristics, 9-15
visual information processing, 19
visual task analysis, 8. *See also* Dynamic reactive sports; Nondynamic precision sports
references, 18
Sports participation
conditions, evaluation, 47
habitual correction, 48
risk, 5
Sport-specific contact lenses, usage, 119-120
Sport-specific performance
details, follow-up, 47
envelope, pushing, 114
Sport-specific refractive prescription (benefit), 95-96

Sport-specific screenings, development, 65
Sport-specific visual information, processing, 58
Sports performance
  enhancement, factors, 19-20
  information processing model, 20-21
  sun eyewear, 116
Sports-related eye injuries
  incidence, 100
  occurrence/impact, 158-159
Sports-related ocular emergencies
  management, 142-143
  treatment, 145t
Sports-related ocular injuries
  incidence. *See* Baseball; Basketball
  number, 140
Sports-related perceptual information, structure/recall ability, 25
Sports-related visual abilities, assessment, 2
SportsSight contact lens technology, 121
Sports-specific tasks, 5
  vision training programs, impact, 185
Sports vision
  clinical model, overview, 4-5
  evaluation
    development, 67-68
    letter, sample, 287
    reports, generation, 90-93
  evaluation, example. *See* Baseball; Golf
  future, 5-6
  historical perspective, 2-4
  introduction, 1
  references, 6-7
  report strategies, 84
  screening/report strategies, references, 93
  specialist, 6
  term, association, 2
  terminology, overview, 2
  therapy letter, sample, 286-287
Sports Vision Guidebooks, 3
Sports vision practice development, 223
  internal marketing, 223-229
  marketing opportunities, 229-231
  references, 240
Sports vision screening
  5 Ws, 90
  conducting, 86-90
  development, 84-85
  equipment/supply list, 86-87
  evaluation procedures, selection, 65
  flow, 88-90
  protocols, 87-88
  recording forms, usage, 86
  reports, generation, 90-93
  staff training, 87-88
  strategies, 84
Sports Vision University, 4
Squash
  ball/shuttlecock speeds, estimation, 106t
  eye injury, risk, 110
  F803 standard, 109
Staff appearance, importance, 231
Static task demands
  definition, 9
  nonstatic task demands, contrast, 9
Static visual acuity (SVA), 47-48
  assessment. *See* Binocular static visual acuity
  DVA, correlation (reduction), 48
  example, 17
  measurement, 48
Station-to-station approach, efficiency, 88-89
Stenopeic slit masks, usage, 2
Step-off deformity, 149
Stereoacuity, relationship. *See* Separation distance
Stereo forms, examples, 255
Stereopsis. *See* Randot steropsis
Sterile eye solution, usage, 147
Stick penetration test, necessity. *See* Eye protection
Stimuli, tachistoscopic presentation, 191
Stimulus-response procedure, 27
Street hockey, eye protectors (recommendations), 103t
Stress, 15. *See also* Cardiovascular stress; Cognitive stress
Strobe light, 211f
Strobespecs, prototype. *See* Modified Strobespecs
Stroboscopic training, 210-211
  usage, 216-217
Stye, 154. *See also* Lower lid stye
Subconjunctival hemorrhage (SH), 152
  result, 164
Subcutaneous emphysema, 164f
Sun eyewear
  ventilation/nosepiece design, highlights, 118f
Sun eyewear, prescription. *See* Performance sun eyewear
Superficial injury. *See* Eyelids
Superficial laceration, 144f
Surfing
  contrast judgment demands requirements, 11b
  directional localization demands, 14b
  dynamic reactive sport, 16b
  dynamic sport, 11b
  far distance demands, 13b
Surgery. *See* Anterior segment surgery; Oculoplastic surgery; Refractive surgery; Vitreoretinal surgery
  convalescent periods, recommendations. *See* Ophthalmic surgery
Sustained performance demands. *See* Sports
SVA. *See* Static visual acuity
SVT, 212-213
  availability, 61
Swimming
  dynamic reactive sport, 16b
  eye injury, absence, 109
  ocular injuries, 160
  protective eyewear, usage, 109
Synchronized swimmers, goggles (absence), 125
Synchronooptical ability, assessment, 65
Synechiae formation, 168

T

Table tennis
  4^{Δ} base in, usage, 56
  10^{Δ} base out, usage, 56
  ball/shuttlecock speeds, estimation, 106t

Tachistoscope, 275. *See also* Junior Olympics
answers, 275t
control panel, 275f
instructional set, 275
projection system, control module (inclusion). *See* Dual tachistoscope projection system
Tachistoscopic procedures, usage. *See* Recognition span; Speed
Tachistoscopic training, 209-210
Target shooting, sighting sport, 53
Target size, 12
Teams
personnel, reports review (usefulness), 92
Teams, consultation, 2
Team sports, peripheral information (importance), 16
Tear duct. *See* Lower lacrimal canaliculi; Upper lacrimal canaliculi
Telebinocular devices, usage, 54
Telebinocular photometry, recommendation, 53
Telephone appointments, making, 229
Telephone hold messages, usage, 229
Tennis
green-range tints, advocacy, 115
Tennis, ball/shuttlecock speeds (estimation), 106t
Testing distances, spatial frequency examples, 276t
Texture, characteristics, 12
Theme, communication. *See* Brand
Three-ball juggling, skill, 214
Threshold dynamic visual acuity, 268
Thumb, force (transmission), 157
Tints. *See* Blue-range tints; Green-range tints; Neutral gray tints; Red-range tints; Yellow-brown range tints
selection. *See* Shooters
types, 114-115
Tissue damage, risk. *See* Contact lenses
Topical antibiotics, usage, 165
Topical cycloplegic agents, usage, 166-167
Tour de France, 187
Track/field events
closed skill sport, 27
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
eye protectors, recommendations, 103t
far distance demands, 13b
short duration requirement, 10b
Trainers, consultation, 2
Training. *See* Howard-Dolman training; Stroboscopic training; Tachistoscopic training
delivery. *See* Visual performance enhancement training
expectations. *See* Visual performance enhancement training
goals, 184
establishment, 189
hierarchy, 186-187
overview. *See* Vision
primary goal, 189-190
procedures. *See* Vision
evaluation procedures, 6
Tranaglyphs
task, performing, 207
usage, 206
Trap shooting
contrast judgment demands requirements, 11b
dynamic reactive sport, 16b
sustained performance, 10b
Trauma. *See* Blunt trauma; Eyes
Traumatic hyphema, 151
consequences, 168
Traumatic hyphema problems, 166
Traumatic macular holes, 169
Trivex lens material, usage, 98
Twilight transition hours, competition (necessity), 113

U

Ultraviolet (UV) attenuation standards, 117
Ultraviolet (UV) burns, 147
Ultraviolet (UV) radiation, ocular effect, 112
Unilateral cover test (UCT), 249
Upgaze position, exercise. *See* Brock string
Upper eyelid, eversion steps, 146f
Upper lacrimal canaliculi (tear duct), laceration, 153
U.S. Consumer Product Safety Commission, 156
report, 100
U.S. Olympic Committee, 3
Uvea, blunt trauma, 166-168

V

Vasculature problems, 158
Vectograms
task, performing, 207
usage, 206
Vectographic images, usage, 54
Vectorvision Contrast Sensitivity, 276-277. *See also* Junior Olympics
chart, plates, 277f
spatial frequency, 277f
Vector Vision contrast sensitivity test, 50-51
Vergence facility, 197-199
evaluation, 55-56
Vergence function, 54-56
Vergence range measurements, reports, 55
Vergence responses, 22-23
Vergence subsystem function, assessment (recommendation), 54
Vestibular responses, inducement, 202
Visible light, responsibility. *See* Glare
Vision
assessment, letter (sample), 287
balance, relationship, 64, 282-283
illustration, 283f
care practitioner, role, 4-5
chart. *See* Hart's revised vision chart
correction, 46-47
criterion, 283
efficiency skills, letter (sample), 286
enhancement training
overview, 186-189
program, goals, 186
evaluation, development. *See* Sports

Vision—cont'd
inefficiencies, remediation, 184
instructional set, 282
peripheral field, 215f
problems, 146
recording, 283
recovery, 171
reduction, Bangerter foils (usage), 193f
scaling definitions, 282
screening, reports, 84
training goals, establishment, 188
training procedures, goal, 185
training programs
goal, 186-187
impact, 5. *See also* Sports-specific tasks
usage. *See* Peripheral vision
Vision skill
development, procedures, 186
enhancement, 184
evaluation. *See* Athletes
first-hand knowledge, effectiveness, 89-90
investigation, 64
level, 185
recognition, 3
remediation/enhancement, 189-217
Vistech Contrast Test System, 50-51
Visual abilities, enhanced training, 2
Visual acuity, 248. *See also* Dynamic visual acuity; Static visual acuity
decrease, 151
complaint, 153
degradation, 48
letter, sample, 286
testing, usefulness, 172
Visual apparatus, functions, 21-22
Visual attention demands, 15
Visual Choice Reaction Time Apparatus, availability, 60
Visual coincidence anticipation, 62-64
example, 17
Visual deficiencies, identification, 184-185
Visual discrimination
demands, 192b
demands, addition, 202-203
enhancement, perception, 193
sensitivity, 191-192
sensory integration, addition, 202-203
tasks, suboptimal lighting (usage), 49-50
Visual elements, discussion, 1-2
Visual fields
blunt trauma, 172
defects, 159
Visual function, loss (determination), 110
Visual information
enhancement, 12
motor response, 60
translation, 185
processing skills, enhancement, 184
quality, receiving, 30
stability, improvement, 56
Visual information processing. *See* Sports
discussion, 19
Visual information processing—cont'd
references, 33-44
relationship. *see* Optometry
Visual input, quality, 29
Visualization
imagery, relationship, 66-67
value, 67
Visual-motor reaction/response, 212-213
enhancement, 212
games, 213
Visual-motor reaction time, 60-61
definition, 59
time elapse, 27
Visual motor reaction time, example, 17
Visual noise, distraction, 12
Visual performance, sustaining, 9-10
Visual performance enhancement
areas, 184-186
procedures, 6
Visual performance enhancement training
activity, real space depth judgments/mental imagery calibrations (combination), 209f
delivery, 188-189
expectations, 189
feedback, usage, 204
goal, 187
programs, 5
recommendation, 188-189
Visual performance evaluation, 45
case history, 46-47
references, 68-83
Visual performance variables. *See* Contact lenses
Visual resolution
evidence, 24
usage, 22
Visual response, quality, 186
Visual search patterns. *See* Experts
process, 24
Visual sensitivity, 189-195
increase, 191
Visual skills enhancement, 183
reference, 217-221
Visual space ranges, 12
Visual strengths, profile, 288
Visual system, quality, 31
Visual target, size, 12
Visual tasks
analysis, examples, 16-18
performance
relationship, determination. *See* Dynamic visual acuity
vision factors, identification, 45-46
Visual time, 12-13
Visual weaknesses, profile, 289
Visuomotor proficiency, enhancement, 184
Vitreoretinal surgery, convalescent periods (recommendations), 160t
Vitreous base avulsion, 169
Vitreous body, blunt trauma, 169
Volleyball. *See* Beach volleyball
contrast judgment demands requirements, 11b
directional localization demands, 14b

Volleyball—cont'd
dynamic reactive sport, 16b
dynamic sport, 11b
far distance demands, 13b
sustained performance, 10b
vonGraefe photometry, recommendation, 53
Vossius ring, result, 168
VTE, spirangle variable vectogram (usage), 206f

W

Walking rail, adjustability, 194f
Water polo
blunt trauma, risk, 160
contrast judgment demands requirements, 11b
directional localization demands, 14b
dynamic reactive sport, 16b
dynamic sport, 11b
eye protectors, recommendations, 103t
far distance demands, 13b
sustained performance, 10b
Water sports
eye injury, absence, 109
ocular injuries, 160
protective eyewear, usage, 109
relationship. *See* Contact lenses
Wayne afterimage flash, 201f
Wayne Electronic Balance Board
validity problem, 62
Wayne Saccadic Fixator, inclusion, 62f
Wayne Engineering, motor response time measurement devices (availability), 59-60
Wayne Foot Speed, 270. *See also* Junior Olympics
Wayne Peripheral Awareness Trainer (PAT), 66f
central circular module, usage, 66
illustration, 274f
instructional set, 274
position, 274
usage, 213-214
Wayne Robot Rotator, visual acuity chart (usage). *See* Dynamic visual acuity
Wayne Saccadic Fixator, 60f, 212-213
availability, 61. *See also* Eye-body coordination
balance board, 275
hand speed, 272
illustration, 271f
Wayne Saccadic Fixator—cont'd
instructional set, 271
motor RT program, usage, 59
performance, impact, 61
portable stand setup. *See* Amateur Athletic Union Junior Olympic Games; Out-of-office testing
program codes, 271t
recording, 271
setup method, 86
usage. *See* Hart chart
Wayne Speed-trac
availability, 64
usage, 216
Wayne Tachistoscope Rotator activities, 195-196
Wayne Tachistoscope Rotator Scanner, 195-196, 196f
Web sites, usage, 230
Welcome to the Office
mailings, usage, 230
packet, 231
Wesson Fixation Disparity Card, 281
eso/exo, vertical deviation, 281f
Window displays, usage, 230-231
Wisconsin Sports Vision Project (WSVP) Dominance Wand, usage, 259
With-the-rule astigmatism compensation, 96
Women's lacrosse, wire mesh protector, 107f
Word of mouth, usage, 239
Wrap lens design, usefulness, 99
Wrestling
directional localization demands, 14b
dynamic reactive sport, 16b
eye protectors, recommendations, 103t
near distance demands, 13b
Written materials, usage, 235
WSVP. *See* Wisconsin Sports Vision Project

Y

Yardstick saccades, 215-216
Yellow-brown range tints, 114-115
Yellow filters, impact. *See* Depth perception
Yellow-range tint, helpfulness, 115

Z

Zygomatic fractures, 149
force, direction/impact, 149