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Sports Vision

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CONTENTS

Introduction 1

Background 1

Prediction: the Core of Sports Vision 2

How to Hit a Fastball 2

The Vision Pyramid 3

Visual Acuity in Sports 4
- Refractive Surgery for Athletes 6

Contrast Sensitivity in Sports 7

Stereopsis and Binocular Vision in Sports 8

Visual Mechanics: the Eye and the Brain Together 9
- Hand–Eye Reaction 9
- Hand–Eye Coordination 9
- The Quiet Eye 10

Conclusion 11

Clinicians' Corner 12

Suggested Reading 15

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LEARNING OBJECTIVES

Upon completion of this module, the reader should be able to:

1. Give 2 examples that illustrate athletes' use of the visual system to predict the next event
2. Describe the sports vision pyramid and the visual abilities that build upon each other to allow maximal sporting performance
3. List selected pros and cons of refractive surgery for athletes
4. Define "the quiet eye" in terms of its direct applicability to sporting performance

Introduction

Vision is a variable and selective sense, and not all visual needs are the same. These factors especially come into play when considering sports vision, an increasing field of interest for many ophthalmologists. For some patients, 20/20 vision, once deemed "normal," is being redefined by "what the patient needs" in order to pursue a variety of vocational and recreational interests.

When applied to sports vision, the visual needs of a baseball player are very different from the visual needs of a boxer. To properly help such patients, one needs to expand his or her approach to vision and not only consider visual acuity, but also functions such as contrast sensitivity, stereopsis, visual fields, and even how visual information is processed centrally and cognitively. Addressing each of these visual functions individually and in whole will help optimize visual abilities for patients and athletes. A focus on sports vision simply requires a change in approach rather than a reliance on new, and often unproven, testing and training techniques. The principles used in sports vision have application far beyond helping athletes perform at their best. They can be applied to every pediatric and adult patient in one's practice.

This module focuses on the visual functions necessary for sporting success. Other important topics of ocular sports injury, prevention, and treatment are beyond the scope of this review.

Background

The discipline of sports vision is thought to be rooted in antiquity. Prior to organized sports as we know them today, the best athletes were in fact the best soldiers. Early historical reports around 800 BC describe the "physical capacity and citizenship" of soldiers in Sparta. Over the intervening centuries, the ability to make accurate and precise physical assessments of function has improved, culminating in the first publications in the field of sports vision in the early part of the twentieth century.

Hunting has always been both a required human task as well as a sport for many. The ability to hunt in extreme arctic conditions was considered by Daland in 1917 when he reported a facemask device, with thin slits, which both protected arctic hunters from snow blindness and acted as a pinhole to improve visual acuity. One of the first laboratory-based reports of the visual abilities in sports was performed at Columbia University in the 1920s. This study was an attempt to understand, and explain, how Babe Ruth was able to bat as well as he did. The psychologists reported that Ruth's eyes were 12% faster and 90% more efficient than those of an average person. Although somewhat vague, these data begin to describe the difference in visual function between elite athletes and the general population.

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Over the past few decades, the number of publications in the field of sports vision has steadily risen. Although most of these reports are in the nonophthalmic literature, one early report was published in 1996 describing the visual function of professional baseball players (Laby et al). The authors found a statistically significant difference in visual acuity, contrast sensitivity, and stereopsis between professional baseball players and the general population as well as between major and minor league players. Subsequent to this report, the same authors published their findings with regard to several other sports at the Olympic level. They noted that the mean visual acuity, contrast sensitivity, and stereoacuity of these athletes differed greatly based upon their sport. Participants in sports that require excellent visual acuity but not stereopsis (eg, archery) differed from athletes in sports that do not require "supranormal" visual function for success (eg, boxing, track and field), which differed from athletes who require both excellent visual acuity and stereopsis (eg, softball, soccer).

There have been many publications during the past decade in the field of sports vision. Although many have contributed to the sports vision knowledge base, other studies have been poorly designed or controlled, or have jumped to "interventions" without first establishing the normal baseline level of function they are training to improve. As reviewed below, it is critical to establish norms for each particular sport prior to creating corrective training protocols. In addition, extra training or improvement of a visual ability to a state beyond the norm is not justified or necessary, unless a direct relationship between that visual function and the on-field performance can be statistically demonstrated.

Prediction: the Core of Sports Vision

On a global scale, the role of the visual system is to provide information that is used to predict the next event. Whether one is driving a car down the road or typing on a keyboard, vision is used to provide information about the task and to help plan for the next action.

The role of vision in sports is similar. Although a person can control the vertical, horizontal, and depth axes, the axis of time cannot be controlled. The visual system, through the ability to predict the next event (and thus interact with the axis of time), allows a person to achieve a given sporting task, whether that is hitting an oncoming baseball or blocking a shot on goal. Intuitively, one would "predict" that any loss of visual function would affect the ability to predict the next event and decrease performance in any sport in which that visual function was critical. For example, an archer who suddenly loses stereoscopic depth perception may not suffer any decrease in performance, while a Ping-Pong player or a baseball player likely would note a decrease in sports performance with the loss of stereopsis.

Some examples of prediction in sports are a golfer as she predicts how a ball will roll toward the cup on an uneven green; a hockey player as he predicts the motion of the opposing player as they both approach the moving puck; a football player as he strives to catch a pass thrown by the quarterback; and, finally, a baseball player as he predicts where the ball will be as it crosses the plate based on its initial trajectory and spin.

How to Hit a Fastball

Consider the process of batting and the role of vision in hitting a 90 mph fastball—an action often termed the most difficult task in all of sports. Given that the batter must hit a 3-inch-diameter ball moving at 90 mph or faster, from a starting point 60+ feet away with a piece of wood only 2.25+ inches in diameter, it is amazing that anyone could hit a baseball at all, let alone 30% of the time (giving them a very respectable 0.300 batting average). It takes a mere 400 ms for a baseball to travel the 60.5-foot distance from the pitcher's mound to home plate. That doesn't take into account that most pitchers are tall, have long arms, and can reduce that 60.5-foot distance by 10% to 15% as they take their stride from the mound and release the ball.

One can think of hitting a baseball as a 3-step process: looking, acting, and making contact (Figure 1). The first step is the most visually critical. It involves looking at the pitcher as the wind-up begins, watching the ball as it is released, and following it for the initial 250 ms. During this step, the batter must assess the pitch (based on the pitcher's arm position, the way the pitcher holds the ball in relation to the seams of the ball, and the spin of the ball as it travels toward home plate) and then use that information to predict where and when the ball will cross the plate. Only after making that visually based decision can the batter begin the physical process of the swing and hopefully slam the ball.

Visual information received after the initial 250 ms is useless, as it cannot be processed centrally and transferred to the muscles of the arms, a requirement for beginning the bat's movement toward the ball as it crosses home plate. Any swing that is too early or late by a fraction of a second will result in a foul or missed ball, and any swing that makes contact with the ball in the wrong location will likely result in a foul ball, ground-out, or a fly-out.

This analysis brings to light several of the visual functions critical to success in batting. First is visual acuity. In order to identify the pitch as early in its trajectory as possible, the batter must possess the ability to identify the seams of the ball and the fingers of the pitcher from a distance of over 60 feet, in a fraction of a second. This is far from the office evaluation of visual acuity in which

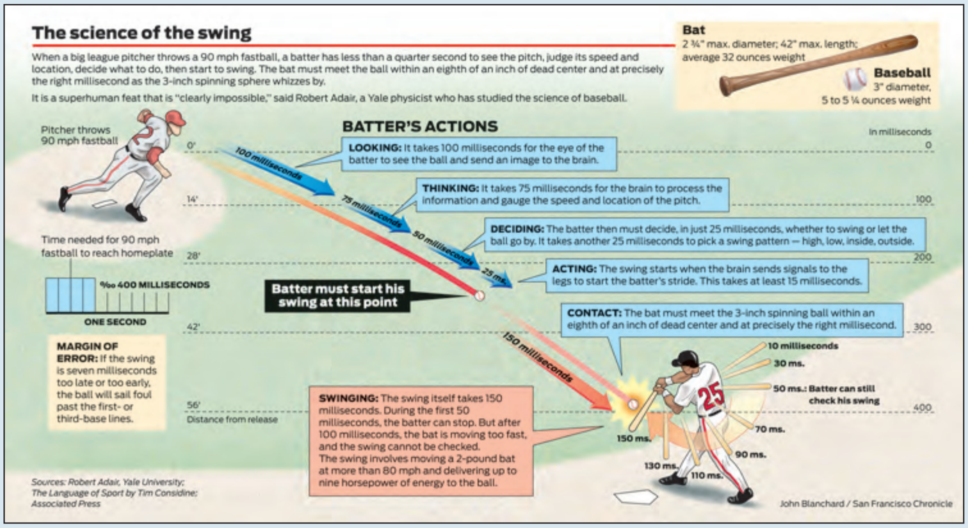


Figure 1 The science of the swing: a detailed analysis of the actions and timing required to successfully hit a 90 mph fastball thrown by a pitcher 60.5 feet from the batter. Note that the batter has less than 250 ms to identify the pitch, determine where it will cross the plate, and decide if he will attempt to hit the ball. (John Blanchard/San Francisco Chronicle/Polaris)

patients have an essentially unlimited amount of time to detect a Snellen letter with 100% contrast.

Contrast sensitivity is equally important. Imagine the difficulty in identifying the spin of the ball when the seams of the ball (red) are spinning on a scuffed, dirty ball that is colored and spotted with (red) clay and silt. Now consider what happens at night when there are shadows and areas of uneven lighting, or during the afternoon when the sun is shining toward the batter, creating significant glare. The ability to detect a target against a background (contrast sensitivity) is critical to determining which pitch is being thrown and how it will cross home plate.

Note that although the old adage of "keeping your eye on the ball" may work initially, as batters face pitchers of increasing skill, the ball travels faster than the ocular pursuit capability and the maximum saccadic velocity of the human visual system. Additionally, any information that is received during the final stages of the ball's flight cannot have an effect on the bat's position since there is simply not enough time to allow the neuromuscular system to react at that point.

In evaluating elite batters, it becomes clear that their visual system is aimed at a point dozens of feet in front of the plate as they make contact with the ball (Figure 2). In short, once they gather the visual information during the initial trajectory of the pitch, there is no need or reason to move the eyes or attempt to obtain additional information in order to succeed in batting.

Figure 2 A batter during the final moments of his swing. Note that as the ball strikes the bat, the batter's gaze is many feet ahead of the bat, near the point in the ball's path where he decided to swing the bat. (Aspen Photo/Shutterstock.com)

The Vision Pyramid

The paradigm of the pyramid serves to help organize and stratify the role of vision in sports (Figure 3). The pyramid, one of the oldest and most stable architectural structures known, is only as strong as its base: the stronger the base, the taller the pyramid. Additionally, the top of the pyramid depends on every layer; if one layer is weak, the pyramid will fall.

The role of vision in sports is similar. If one considers the base of the vision pyramid to be comprised of monocular visual functions such as visual acuity and contrast sensitivity, it becomes clear that the next level, binocular visual functions, can only be as strong as each monocular visual ability. Likewise, with strong monocular and binocular visual abilities, the athlete is afforded the most accurate and useful information upon which to make critical decisions (the next level of the pyramid: visually based decision making), such as to whether to swing or not swing at a pitch, where to kick the ball or

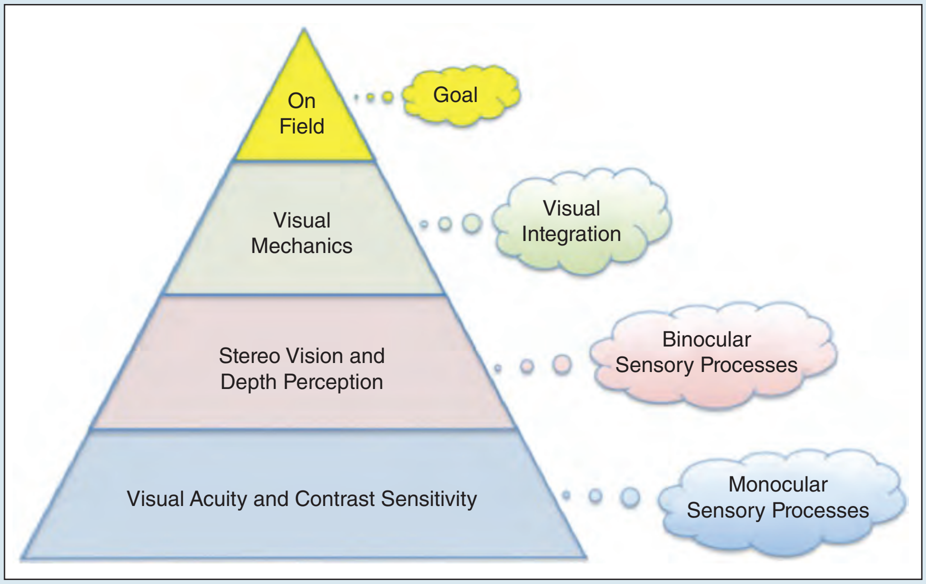


Figure 3 The vision pyramid: the visual abilities required for success in sports. Monocular visual abilities form the base of the pyramid. Binocular visual abilities form the pyramid's mid-section. Visual mechanics representing the integration of visual abilities and central processing skills form the penultimate level. Maximizing each level leads to optimal on-field performance. (Reproduced, with permission, from Laby DM, et al. The role of sports vision in eye care today. *Eye Contact Lens*. 2011;37:127–130.)

shoot the puck toward the goal, or how to block an oncoming shot as a goal keeper. Only when each of these levels is optimized for a given sport will athletes be able to perform at their best. Any defect in any level of this pyramid will likely affect the ultimate apex of successful on-field performance.

Visual Acuity in Sports

Two related monocular visual abilities form the base of the vision pyramid: visual acuity and contrast sensitivity. Visual acuity, or the ability to resolve detail, is critical to performance in any sport that requires it. It is important to understand the sport in question, and determine what visual acuity requirements are essential to allow for maximal performance. The literature over the past decade has increased regarding the visual acuity found in athletes in different sports at various levels of participation.

In the early study describing the visual acuity of professional baseball players (Laby et al, 1996), the average visual acuity was approximately 20/12.5, with 77% being 20/15 or better. The range was wide, from 20/8.9 to 20/100. There was a trend suggesting that the major league players had superior visual acuity when compared to the minor league cohort (Figure 4).

Several years later, the same authors studied 8 different sports as part of their work leading up to the 2008 Olympic Games. The best visual acuity was found in archers and softball players, while the worst visual acuity was noted in boxers and track and field athletes (Figure 5). It is unclear whether this level of visual acuity in boxers was due to repeated blunt facial and ocular trauma or simply was not critical to boxing performance. Table 1 shows specific mean, median, and standard deviations for visual acuities for each sport as published by Laby et al. These can serve as a guide when evaluating and correcting vision to the level needed for the athletes' respective sport. For many sports, there is no published data regarding the necessary level of visual acuity, or even the average visual acuity found at the elite levels.

The most common technique used by athletes to correct abnormalities in visual acuity is contact lenses and, to a lesser extent, refractive lenses (glasses) and refractive surgery. In order to properly correct athletes, one must perform a careful refractive evaluation and ensure that the visual acuity chart is able to display targets of 20/10 or smaller. Very commonly, correction of small refractive errors that would otherwise not make a significant difference to nonathletes appears to be very helpful in further improving the visual acuity of elite-level athletes. Paying particular attention to small astigmatic refractive errors and accurate determination of the precise axis of astigmatism is important in order to provide athletes with maximum correction of their reduced visual acuity.

Daily wear disposable contact lenses are the most common choice for refractive error correction by athletes. Depending on the playing conditions (eg, indoor vs outdoor, dry vs humid environment, daytime vs nighttime competition), several athletes change their lenses throughout the day.

Due to the risk of corneal damage resulting from over-wear as well as from other complicating factors, it is best to monitor the athletes closely to be sure they use the contact lenses as prescribed, change them regularly, and return for the required follow-up visits. Just as a

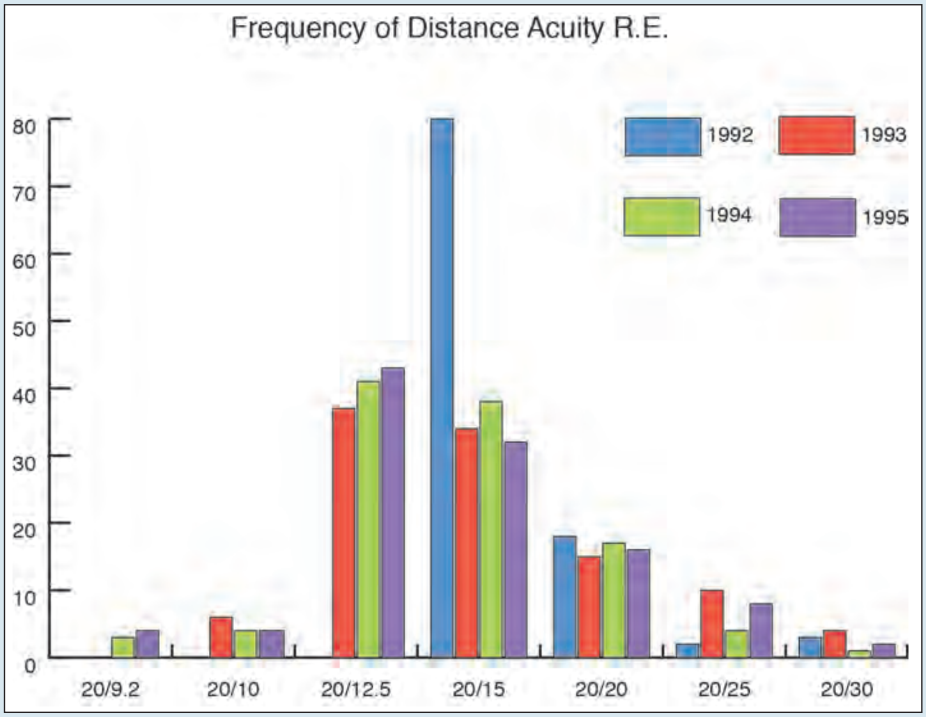


Figure 4 Frequency of professional baseball players (right eye only) achieving each level of visual acuity. Note that in 1992, the maximal visual acuity tested was 20/15, which 81% of the eyes achieved. (Reprinted, with permission, from the *American Journal of Ophthalmology*. Laby DM, et al. The visual function of professional baseball players. *Am J Ophthalmol*. 1992;122:476–485.)

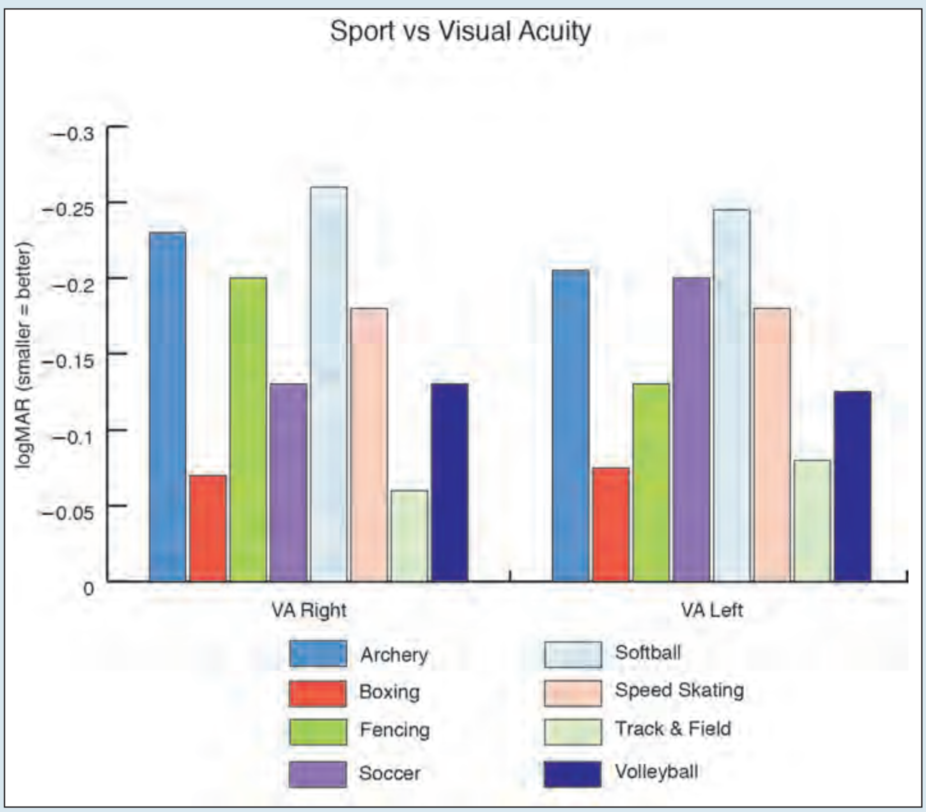


Figure 5 Mean visual acuity by Olympic sport. Note the wide range of visual acuity, with the archers and softball players having the best visual acuity and the boxers and track and field athletes having the worst visual acuity. (Reproduced, with permission, from Laby D, et al. The visual function of Olympic-level athletes—an initial report. *Eye Contact Lens*. 2011;37:116–122.)

Table 1. Mean, Median, and SDs for All Olympic-Level Athletes Tested

SPORT		VA RIGHT[a]	VA LEFT	CONTOUR[b]	RANDOM DOT	LETTER CONTRAST[c]	CS1_5	CS3	CS18	CS1_5G	CS6G
All sports	Mean	–0.146	–0.151	41.500	36.759	0.859	0.499	0.405	1.689	0.625	0.539
	SD	0.227	0.205	38.079	35.060	1.361	0.328	0.064	2.363	0.481	0.666
	Median	–0.200	–0.200	27.000	18.000	0.400	0.400	0.400	0.800	0.400	0.400
Archery	Mean	–0.235	–0.204	61.769	46.000	0.892	0.554	0.400	1.385	0.492	0.400
	SD	0.113	0.118	41.799	33.013	0.851	0.555	0.000	2.164	0.240	0.000
	Median	–0.200	–0.200	71.000	45.000	0.400	0.400	0.400	0.400	0.400	0.400
Boxing	Mean	–0.070	–0.075	48.300	43.800	0.840	0.480	0.400	3.780	0.680	0.600
	SD	0.221	0.153	38.939	41.638	0.638	0.169	0.000	4.760	0.464	0.632
	Median	–0.175	–0.075	36.000	27.000	0.400	0.400	0.400	1.200	0.400	0.400
Fencing	Mean	–0.200	–0.133	29.833	22.333	0.933	0.400	0.400	1.333	0.800	0.400
	SD	0.148	0.204	38.483	24.905	0.413	0.000	0.000	1.354	0.669	0.000
	Median	–0.225	–0.150	13.500	9.000	1.200	0.400	0.400	1.000	0.400	0.400
Soccer	Mean	–0.130	–0.198	32.880	33.640	0.560	0.480	0.400	1.472	0.736	0.432
	SD	0.185	0.143	35.935	31.909	0.365	0.400	0.000	1.982	0.525	0.160
	Median	–0.150	–0.200	9.000	27.000	0.400	0.400	0.400	0.400	0.400	0.400
Softball	Mean	–0.259	–0.244	32.118	26.882	0.494	0.400	0.400	0.659	0.518	0.659
	SD	0.109	0.143	27.051	31.980	0.388	0.000	0.000	0.720	0.274	1.067
	Median	–0.300	–0.250	27.000	9.000	0.400	0.400	0.400	0.400	0.400	0.400
Speed skating	Mean	–0.182	–0.181	31.484	29.645	1.026	0.555	0.400	1.277	0.503	0.748
	SD	0.164	0.159	32.019	30.539	2.617	0.353	0.000	1.157	0.292	1.140
	Median	–0.200	–0.200	18.000	9.000	0.400	0.400	0.400	0.800	0.400	0.400
Track and field	Mean	–0.060	–0.078	48.029	47.000	0.976	0.541	0.400	2.347	0.553	0.435
	SD	0.277	0.298	42.323	42.166	0.940	0.325	0.000	3.073	0.418	0.206
	Median	–0.075	–0.125	27.000	27.000	0.400	0.400	0.400	1.400	0.400	0.400
Volleyball	Mean	–0.131	–0.121	52.667	35.810	0.857	0.457	0.438	1.581	0.895	0.438
	SD	0.342	0.205	41.747	33.664	0.888	0.262	0.175	1.839	0.779	0.175
	Median	–0.200	–0.150	45.000	27.000	0.400	0.400	0.400	0.800	0.400	0.400

SD = standard deviation; VA = visual acuity.

[a]VA values are expressed in logMAR units.

[b]Stereoacuity values are expressed in arc seconds.

[c]Contrast sensitivity is expressed in percent contrast. (Reproduced, with permission, from Laby D, et al. The visual function of Olympic athletes—an initial report. *Eye Contact Lens.* 2011;37:116–122.)

small refractive correction can significantly improve visual acuity and associated athletic performance, a small corneal scar can have a profound effect on visual acuity and sporting performance.

REFRACTIVE SURGERY FOR ATHLETES

Possibly the most controversial topic in sports vision is the case for and against laser refractive surgery, both LASIK and surface ablation. Following the success of laser refractive surgery in the general population, it is only natural that many athletes have elected to undergo this procedure as well. The controversies of refractive surgery in athletes are long-standing and polarizing. See the sidebar for further discussion.

A mention of higher order optical aberrations is in order. In contrast to previous reports that such aberrations may be beneficial to fighter pilots, a 2010 report (Kirschen et al.) did not show any clinically significant differences in higher order optical aberrations between professional baseball players and the general population. Although there was a statistically significant difference in trefoil between these populations, the magnitude was so small as to not contribute to real-world function. Thus, it appeared to the authors that the visual system of professional baseball players was a low order aberration limited system, making determination of simple refractive errors all the more critical to their sporting performance.

Laser Refractive Surgery for Athletes

PROPONENTS OF LASER REFRACTIVE surgery for athletes support its use because glasses may be broken, contact lenses may become torn or lost, and the quality of vision may suffer during a critical moment in competition. They note that in some sports, glasses and contact lenses are not allowed (eg, ultimate fighting) or there may be an increased risk of infection if contact lenses are worn (eg, swimming).

Opponents point out the well-accepted inherent risks of the surgery, including infection, scarring, loss of best-corrected vision, loss of contrast sensitivity, increased glare, dry eye, and an increase in unhelpful higher order aberrations. The visual demands of sporting competition may accentuate the performance effects of these complications. For example, increased sensitivity to glare can be devastating to athletes who perform in bright sunlight or under bright artificial lighting.

Most refractive surgeons would agree that it is uncommon to obtain a 20/10 or even 20/12 postoperative visual acuity in a refractive surgical procedure, even in an eye that was able to be corrected with contact lenses to that level preoperatively. Thus, in sports, where visual acuity and contrast sensitivity are critical to performance (eg, sports with fast moving, small targets, such as baseball and hockey), the decrease in vision resulting from the procedure compared to the best-corrected vision with contact lenses or glasses may result in a decrease in on-field performance.

Laby et al (2005) found no statistically significant increase in batting performance for players who had undergone laser refractive surgery. They concluded that the risk of damage to visual function outweighed any gain, and there was no gain reported in this study. Thus, they concluded that there was no benefit from the procedure for professional baseball players. Considered another way, since there was no statistically significant decrease in batting performance either, in cases in which there is significant giant papillary conjunctivitis (GPC), poor compliance with contact lens use, or other mitigating circumstance, laser refractive surgery, despite the above risks, may be of benefit in those patients.

The decision to undergo laser refractive surgery is an individual one and should be made after considering the visual requirements of the athlete's chosen sport. One should also consider the convenience and safety of the surgery in athletes who are remiss about caring for their contact lenses and may suffer from GPC or recurrent infectious keratitis.

Contrast Sensitivity in Sports

As a broader measure of visual function, contrast sensitivity is an important monocular visual function often required for sporting success. In their published studies regarding the visual acuity of professional as well as Olympic-level athletes, Laby et al detailed the contrast sensitivity results for several sports at multiple different spatial frequencies, with and without concomitant glare interference. Baseball players and softball players possessed better contrast sensitivity at the 18 cycles per degree (cpd) level compared to athletes in other sports, specifically boxers and track and field athletes. All athletes appeared to have similar contrast sensitivity abilities at the lower spatial frequencies tested (1.5 and 3 cpd) (Figure 6). Interestingly, the authors reported no difference in contrast sensitivity results when comparing the major league players to the minor league players.

Contrast sensitivity can be improved by the use of tinted lenses. Although this most commonly is achieved through tinted eyeglass lenses, contact lenses can be tinted as well to achieve a similar effect. Perhaps the most commonly used tint is yellow, which has long been known to skiers for providing increased contrast on the snow surface, allowing for dips and elevations on the ski slope to be more easily identified.

Several years ago, tinted sports vision contact lenses were available in amber and green colors. The manufacturer suggested that the amber color was good for ball sports such as soccer and baseball, while the grey-green color was best for sports played in bright sunlight, such as golf and rugby (Figure 7). Unfortunately, the lenses were withdrawn from the market before significant research could be performed, either confirming or refuting their purported advantages. Although not commercially available, several independent laboratories are able to perform custom tinting of contact lenses, enabling athletes to wear a specific color that may improve contrast sensitivity in their particular sport.

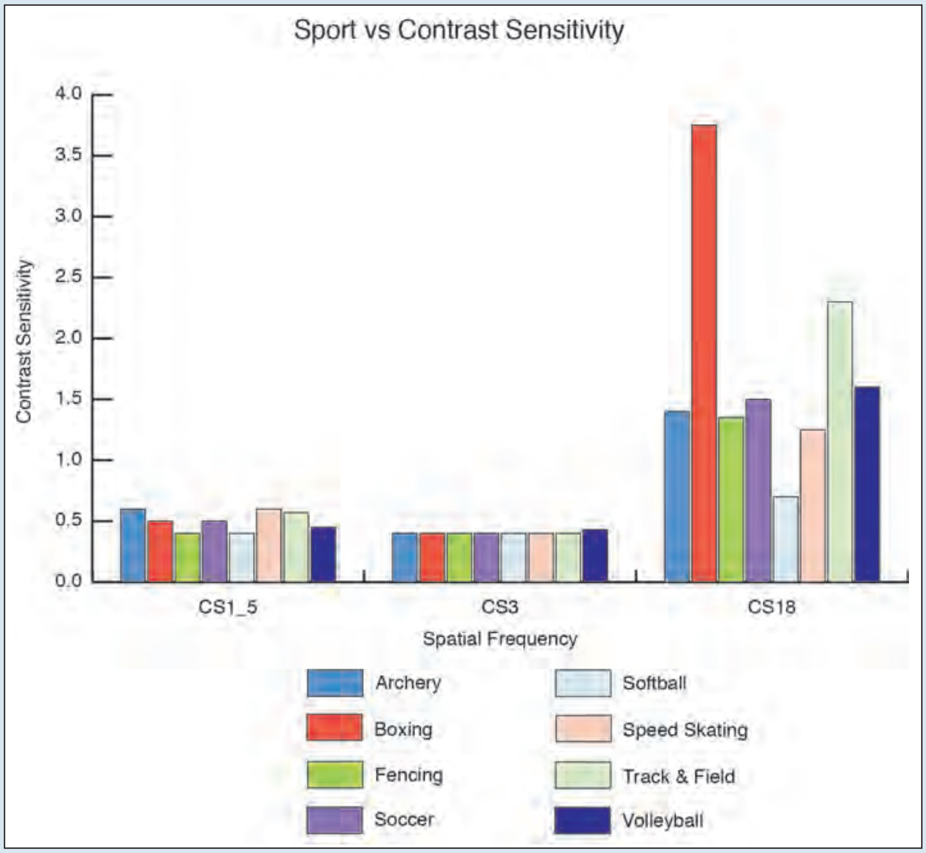


Figure 6 Contrast sensitivity by Olympic sport. At lower spatial frequencies there appears to be no difference between the athletes of different sports while at the 18-cpd level the softball players have the greatest sensitivity while the boxers have the least contrast sensitivity. (Reproduced, with permission, from Laby D, et al. The visual function of Olympic-level athletes—an initial report. *Eye Contact Lens*. 2011;37:116–122.)

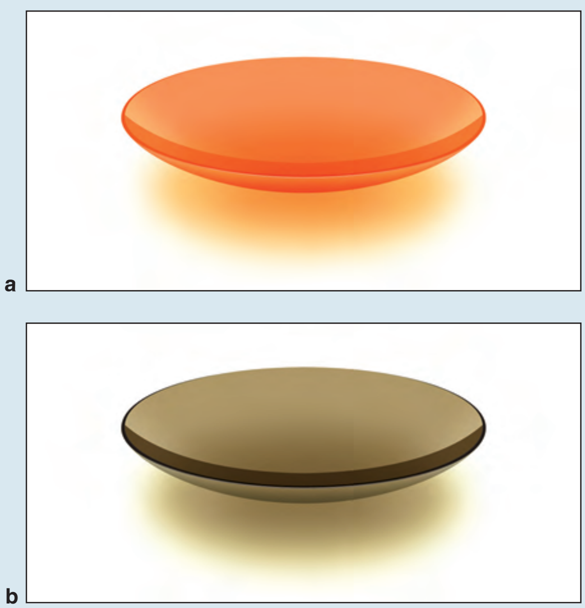


Figure 7 Tinted contact lenses for sports, with amber for fast-moving ball sports **(a)** and grey-green for sports played in bright sunlight **(b)**. This particular product is no longer commercially available, although custom lenses of many different tints can be obtained on an individual basis. (Courtesy of Bausch & Lomb.)

Stereopsis and Binocular Vision in Sports

Once the monocular functions of visual acuity and contrast sensitivity are optimized, attention is turned to the next level: the use of both eyes together for binocular vision. The sports vision literature contains several reports relating to the role of stereopsis in sports. In baseball, there is a significant difference between the stereoacuity of major league vs minor league players, and both groups have superior stereoacuity compared to the general population. At the Olympic level, a spread of stereoacuity abilities is also noted. In sports that do not depend on judgments of depth (eg, archery), one finds baseline stereoacuity. In Olympic athletes from other sports, such as softball and speed skating, stereoacuity is better than that measured in the general population and similar to that of professional baseball players. A similar trend was noted in youth baseball and softball players, with athletes having twice the depth detection ability as compared to nonathletes.

Table 1 lists the mean, median, and standard deviation of visual acuity, contour, and random dot stereopsis as well as contrast sensitivity with and without glare in Olympic-level athletes. This table can be used when working with athletes of these sports as a guide to normal levels of visual function common to elite athletes.

In a 2006 report, Nepalese football and cricket players were given a battery of vision tests, and 60% of the athletes tested had stereo acuity better than 40 seconds of arc. Compared to a 1991 report by Zanoni and Rosenbaum, mean contour stereo acuity in the general population they evaluated was found to be 41 seconds of arc. Thus, it appears that the football and cricket players in this study had slightly better stereo depth perception than the general population.

Although it is possible to improve stereoacuity in some patients through training, this is a seldom-used intervention in sports vision. However, if an athlete has abnormal stereoacuity, a search for a pathologic cause is initiated. A thorough review of the athlete's past ocular history is obtained, especially noting any strabismus, amblyopia, or other abnormality that may affect binocular vision. A comprehensive motility examination, searching for any tropia or heterophoria, is also performed. Efforts are made to correct any abnormalities before initiating a stereoacuity training protocol.

Visual Mechanics: the Eye and the Brain Together

Following the maximization of the monocular and binocular visual functions, the next level of the visual pyramid emphasizes the brain's use of the visual information to perform a motor task. In the final analysis, it is the accuracy in space, as well as time, of the motor task that leads to superior performance in sports.

There are many measures of this function, including hand–eye coordination, reaction time, and the ability to concentrate simultaneously on the central visual field as well as the peripheral visual field. Below, several of the more common and likely important vision-dependent functions in sports vision are described. Perhaps the most intuitively relevant integrated function between the eyes and the body in sports involves hand–eye reaction and hand–eye coordination time. The ability to drive the upper extremities based on a visual event is critical in almost every type of sporting event.

HAND–EYE REACTION

In general, hand–eye reaction time is measured in 2 basic ways, although many variations exist. The *simple reaction time* is measured by the subject's ability to press a button based on the presence of a visual cue. For example, every time a light illuminates, the subject must press it as soon as possible. The second type of reaction time is termed a *recognition reaction time*. In this scenario, the subject only presses the button when a specific target is shown (eg, a green light) and refrains from pressing if other targets are shown (eg, a red light). Universally, the recognition reaction time is slower than the simple reaction time, owing to the cognitive processing of the visual cue that must occur before the decision to move the extremity to press the button. These measures are often useful in measuring an athlete's quickness or ability to react to changing visual information during a sporting event.

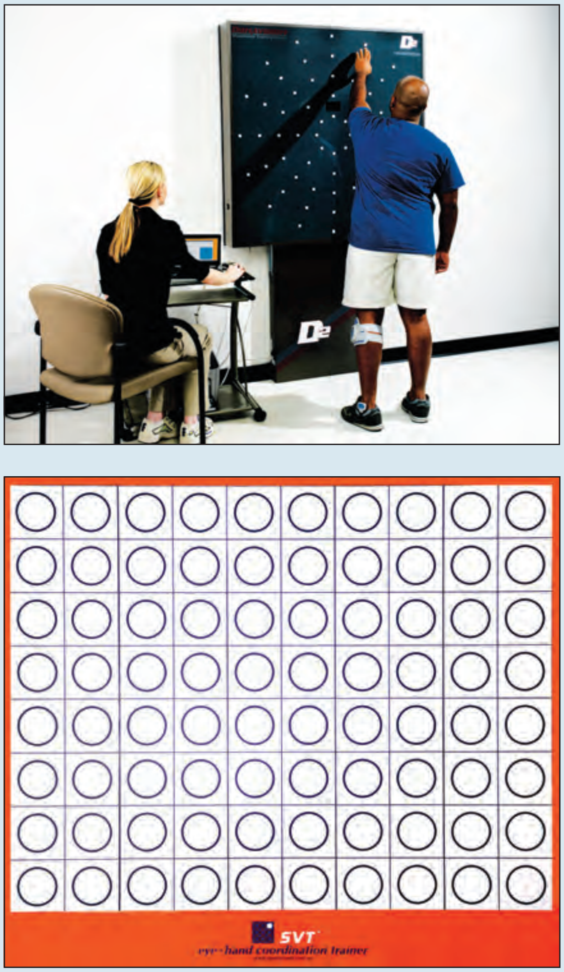
HAND–EYE COORDINATION

The reaction time tests are episodic in nature and are measured in a quantitative fashion, with a score generated for each target presentation. A more appropriate test of a subject's ability to integrate visual information with a motor action over time is the *hand–eye coordination test*. Again, there are many variations of this test, and different manufacturers promote several testing systems. Although each has different terminology, they all follow the same premise of the subject reacting to a visual stimulus with a motor action. Some systems are able to display 2 sets of stimuli—one centrally and another in the peripheral visual field. The central target is designed to force the subject to maintain central fixation and cognitive engagement in a task, while simultaneously being aware of the target presentation in the periphery, and initiating the appropriate motor action. Scoring for these tests is based on what has been termed a *proactive* score and a *reactive* score (Figure 8).

The proactive test of hand–eye coordination is similar to the simple reaction time test described above, except that instead of a single light turning on, any one of a matrix of lights may light up. The subject must detect that a light has lit, as well as accurately determine its position in the matrix in order to effectively press it with one of the hands. The amount of time between the light turning on and the light being pressed is recorded. Typically a set of 20 lights is presented and the total time to press all 20 lights is recorded. The next light is not presented to the subject until the previous light has been pressed, leading on occasion to some lengthy scores if the subject has a visual field defect or lack of attention (visual agnosia) for a portion of their visual field. A score of 11.22 seconds for the set (0.561 seconds per light) is average for the general population, with athletes scoring 9.12 seconds on average (0.456 seconds per light) for the same set of 20 randomly presented lights.

The reactive test of hand–eye coordination is based on the proactive test, but in this case the light stays lit for a specified amount of time and the subject must press the light before it turns off. In the proactive test, the subject determines when the next light will illuminate based on their pressing the previous light.

In the reactive test, the computer determines when to turn the light on and off, and the subject must keep up with the rate of the computer testing system. Scores are recorded as a percentage of the lights pressed while they are lit, at a given lamp duration time. Longer periods of light duration lead to higher percentages, and



a

b

Figure 8 The Dynavision D2 **(a)** and the Sports Vision Trainer (SVT) **(b)** systems. Both systems test proactive and reactive hand eye coordination, and can be used for both diagnostic testing as well as training. A button lights (on the D2), or the central area circled in black lights up (SVT), prompting the subject to press the light as soon as possible. Each system has additional features and variations. (Part **a** courtesy of Dynavision International LLC; Part **b** courtesy of Sports Vision Pty Ltd.)

shorter illumination times lead to lower percentages of successful strikes. A series of illumination times are used, often ranging from 0.8 seconds to 0.2 seconds, with the percentage of correct responses recorded for each level. The data is plotted as a cumulative distribution function on an ogive curve (a type of cumulative function curve where the total percentage of successful strikes is plotted on the ordinate and illumination time is plotted on the abscissa). The illumination duration times required to provide a 50% and 80% success rate are recorded as the scores for the subject's reactive hand–eye coordination. Typical reactive scores are around 0.4 seconds for 50% and 0.6 seconds for an 80% success rate. This test can be made even more difficult by adding a *recognition* component, asking the subject to only press a green light that illuminates, and avoid pressing any red lights that may illuminate.

THE QUIET EYE

Another higher-level visual function that has direct applicability to sporting performance has been termed the *quiet eye* by Dr. Joan Vickers of the University of Calgary. The quiet eye refers to the period just prior to completion of a specific sporting task. Sporting tasks in which this is applicable range from a golfer about to strike the ball during a putt, or a basketball player about to make a free throw (Figure 9). Both of these tasks, as well as many others, require the subject to fix on a target and engage the arms to interact with an object directed at the target. Dr. Vickers has found, and others have confirmed, that it is critical to maintain steady fixation for a period of time before and after the target has been engaged to increase the chances for a successful outcome.

Using putting as an example, the golfer must address the ball, line up the shot, and swing the putter precisely to strike the ball in a specific location to maximize the chance that it will roll into the cup. If the golfer moves fixation to the cup immediately after the ball is struck, there is a lower success rate than if the golfer maintains fixation on the spot where the putter hit the ball for a longer period, after the ball is on its way toward the cup.

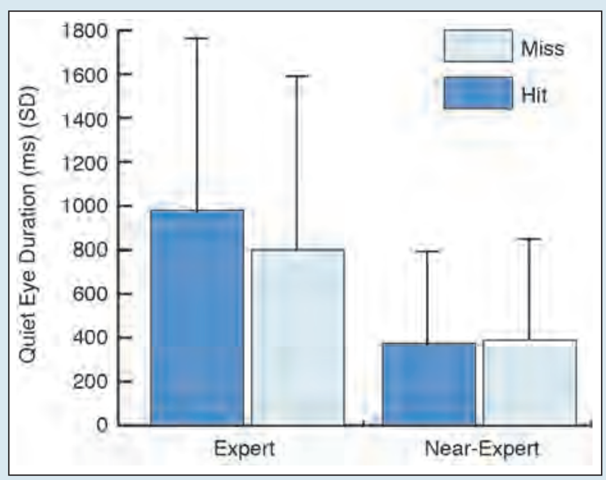


Figure 9 Quiet eye in basketball. The mean quiet eye duration of expert and near expert basketball players. Note the longer quiet eye duration in both the hit vs. miss (successful free throws) as well as expert vs. near-expert basketball players. (Vickers JN. Visual control when aiming at a far target. *J Exp Psychol Hum Percept Perform*. 1996; 22:342–354. Reprinted with permission from the American Psychological Association.)

The reasoning for this requires a review of the neurologic process leading up to a voluntary saccade. If the golfer makes a saccadic eye movement, changing the fixation of the eyes from the stationary ball immediately after the ball is struck, the frontal eye fields of the prefrontal cortex will initiate planning the motor movement about 200 to 250 ms before the movement actually occurs (saccadic latency). This effective loss of central concentration appears to have a detrimental effect on the golfer's ability to strike the ball ideally, leading to a greater rate of failure. If the golfer refrains from changing fixation for a period of several hundred milliseconds after the ball has been struck, the golfer is more likely to hit the ball ideally, leading to a greater success rate in sinking the putt.

A growing body of literature suggests that practice and targeted training can improve these higher visual skills. In addition, several reports suggest that these improved skills transfer onto the athletic field in better on-field performance as well.

Conclusion

The emerging field of sports vision integrates all aspects of eye care and represents nearly ultimate function of the human visual system. Keeping in mind that sports vision is only one aspect of the broader field of performance vision, by understanding visual function and visual motor integration, the ophthalmologist can help patients attain the visual performance necessary to accomplish the tasks they wish to pursue, whether they are athletes or not. By challenging the common paradigm that 20/20 vision is sufficient for all patients, especially those who require sports vision, one can intervene in a variety of ways to improve the basic monocular and binocular visual functions as well as the integrated eye–body capabilities.

To better understand the scientific foundations of sports vision, several teaching hospitals are beginning to pursue or have established new sports vision programs, including the Wills Eye Hospital, the University of Cincinnati, Duke University, the Mayo Clinic, and Boston Children's Hospital/Harvard Medical School. These academic programs will support sports vision scientists in their efforts to use rigorous scientific methods to challenge assumptions and develop and test new hypotheses related to sports vision. The result will enhance the precision of sports vision science and broaden its acceptance, thus making it available to more patients in need.

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Clinicians' Corner

Clinicians' Corner provides additional viewpoints on the subject covered in this issue of *Focal Points.* Consultants have been invited by the Editorial Review Board to respond to questions posed by the Academy's Practicing Ophthalmologists Advisory Committee for Education. While the advisory committee reviews the modules, consultants respond without reading the module or one another's response. *–Ed.*

1. Have you seen patients with sports vision problems related to defects in color vision?

>>>Dr. Kim and Dr. Legault: We have not encountered any patients with color vision defects that created problems with sports vision. Color vision defects can potentially affect an athlete's performance, depending on the severity. An athlete with a red-green color deficiency may have a difficult time distinguishing the difference between red and green jerseys, and therefore potentially turn over the ball to the opposing team in a game such as basketball. The same athlete would struggle identifying a red cricket ball on the green grass. For the vision evaluation protocols for the 2006 AAU Junior Olympic games, Ishihara color plates were used to test all of the participants. We have started including Ishihara plates in the annual screening of the Duke men's basketball team.

>>>Dr. Kozarsky: I do not recall any specific performance issues in high-level athletes related to defective color vision. In another "performance vision" population, professional pilots, we are required to test color vision during every flight physical exam. For pilots, color vision defects may cause difficulty on specific tasks such as interpretation of color light signals, but most color vision deficient pilots function flawlessly in all other regards.

2. Please discuss the most common sports vision problems you encounter in practice.

>>>Dr. Kim and Dr. Legault: The most common sports vision problem for our practice is refractive error. The athletes are playing at the collegiate level, so typically they have been wearing glasses or contact lenses for years. Occasionally we find significant uncorrected refractive error. Data from the eye screenings of our Duke men's basketball team over a 10-year period showed a 23% prevalence of contact lens use. Because the majority of athletes with refractive error rely solely on contact lenses, it is paramount to teach proper contact lens use and hygiene to help avoid problems like corneal ulcers and dry eyes. Some of our athletes have been switched to daily disposable contact lenses and others have sought out refractive surgery.

The most common injuries we have treated in our collegiate athletes include corneal abrasions, conjunctival lacerations, hyphema, and traumatic iritis occurring from blunt trauma in practice or in games. Because of the severity of some of these injuries, we have stressed the importance of protective eyewear, especially with stick sports like lacrosse and field hockey.

>>>Dr. Kozarsky: By far, the most common issue among young athletes is refractive error. The young athlete is frequently seen at a time that myopia is still progressive. Staying current with the refractive error of the young athlete is an important requirement for those entrusted with their vision care. Especially for myopic baseball position players who must play at night as well as during the day, full myopic correction or slight overcorrection is required.

The vast majority of young athletes with refractive error utilize soft contact lens correction, so that refractive and lens care regimen is a frequent concern. A small percentage of athletes utilizing contact lens correction are marginally contact lens tolerant so that lens materials and care products must be optimized to assure continuing contact lens use. I have treated a number of professional athletes with contact lens–related keratitis causing temporary disability. The optimization of contact lens material and care regimen is a major preventative parameter in keeping players with refractive errors "on the field." Contact lens expertise is a requirement for taking care of athletes.

Laser vision correction is an option for many athletes with stable refractive error and difficulty with contact lens use. One should reserve this modality for players who have achieved a stable refractive error so that increasing myopia and the need for enhancement can be avoided. One must be prepared to treat very small residual refractive errors with contact lens or laser correction and often with the goal of slight hyperopia.

Unfortunately, traumatic eye injuries are not uncommon among athletes and especially common in basketball and boxing. Baseball-related blunt eye trauma is more unusual but often severe. Pterygium and seasonal allergic conjunctivitis are frequent issues among professional baseball players for which preventative measures must be applied.

3. Is it possible for a patient with high myopia to become a successful professional athlete in baseball and other sports, or are the visual demands just too great for this to be feasible?

>>>Dr. Kim and Dr. Legault: According to the National Collegiate Athletic Association, the governing body of college athletics, the probability of competing at a professional level beyond high school is very slim—less than 1%. The competitiveness to achieve at such a high level requires perfect eyesight in conjunction with many other traits; however, is still possible to become a professional athlete with high myopia.

Tiger Woods had high myopia prior to refractive surgery and still became the best golfer in the world. Lebron James, the best player in basketball, also had LASIK surgery to treat refractive error. The visual demands required in baseball outweigh other sports, and these can be addressed with contact lenses to help an athlete succeed at a high level in this sport. Despite an uncorrected visual acuity of 20/500, Mark McGuire was able to play professional baseball and become one of the greatest home run hitters of all time with the use of contact lenses. An interesting study to support the presumption that glasses can hinder athletic performance showed that young (8 to 11 years of age) myopic children who were randomized to wear glasses versus contact lenses showed a greater athletic competence with contact lenses.

>>>Dr. Kozarsky: Yes, it is indeed possible for a contact lens or LASIK-corrected myopic athlete to perform successfully as a position player in major league baseball. It is surprising how many major league baseball players wear contact lenses or have had LASIK. With hitting in baseball and competitive shooting as examples of the most visually demanding sports, I have seen excellent performance at the highest levels in highly myopic individuals corrected with contact lens or LASIK.

4. Are higher order aberrations (HOAs) created by LASIK less probable with custom photorefractive keratectomy (PRK) ablations?

>>>Dr. Kim and Dr. Legault: HOAs can increase after any refractive surgical procedure. Krueger and colleagues showed that HOAs were related to the magnitude of correction; however, these aberrations did not affect visual performance. Wavefront-guided (custom) PRK has been shown to create fewer HOAs. At our facility, we use wavefront-guided and wavefront-optimized ablations with both PRK and LASIK in an attempt to minimize the degree of HOA in all of our patients.

>>>Dr. Kozarsky: I do not think that LASIK creates significantly more aberration than PRK when using the same excimer ablation treatment. In trying to minimize postoperative positive spherical aberration (night myopia) in athletes as well as nonathlete patients, a custom treatment or wavefront-optimized ablation should be utilized. The optical zone should be increased for large pupil size if the residual stromal thickness is adequate with the increased ablation depth. If there is marginal residual stromal thickness with an aggressive myopia treatment, PRK should be considered rather than LASIK. At least 3 months of recovery is needed before the athletes are visually competitive after PRK. LASIK has the advantage of a much faster recovery, and especially if a femtosecond flap is used, a flap lift enhancement is possible years after the initial procedure.

5. Are there thresholds for myopia or increased axial length that would preclude an athlete from pursuing a career in boxing, due to the higher risk of retinal tear and detachment?

>>>Dr. Kim and Dr. Legault: Boxing results in the most damage to the eye of any sport. The World Boxing organization does not allow anyone with more than five diopters of myopia to participate in the sport while the European Boxing Union uses four diopters as the threshold. Interestingly, one of the most prominent U.S. boxers, Sugar Ray Leonard, suffered a retinal detachment, underwent surgery, and then resumed his boxing career successfully by winning several championships.

>>>Dr. Kozarsky: Thirty years ago, Sugar Ray Leonard suffered a retinal detachment that was successfully repaired, bringing a lot of attention to the ocular dangers of boxing. With his retina surgeon's permission, he returned to boxing after his retinal detachment repair. It is thought that boxing eye injuries are more related to thumb contact than the larger part of the glove. "Thumb-less" boxing gloves are available and many state commissions favor such gloves. I don't think that axial myopia is an absolute contraindication to professional boxing. One might expect resistance from a young boxer with a promising career and no other career path to refrain from boxing because of a theoretical risk.

6. How would an ophthalmologist learn more or receive additional training to begin offering sports vision testing and training services for individual, school, university, or professional team athletes?

>>>Dr. Kim and Dr. Legault: Although there is no formal sports vision training program available at this time, we recommend networking with other ophthalmologists interested in sports vision. The current sports vision screening guidelines for the AAU junior Olympics are only available by becoming a member of the American Optometric Association Sports Vision Section, and the 1997–98 and 2006 guidelines have been published. At Duke, we created our own eye screening guidelines that included standardized measurements of visual acuity, pupil size and reaction, stereopsis, color vision as well as a slit lamp and fundus examination. Based on these results, some of the athletes are sent for further testing that may include manifest and cycloplegic refraction and automated visual field testing.

For sports vision training, an ophthalmologist has to decide on which technology to purchase. It is still controversial whether vision training actually improves athletic performance. We have had the opportunity to trial and demo several technologies, including Dynavision (dynavisioninternational.com), NikeSPARQ Vapor Strobe glasses, and FitLight (http://www.fitlight.ca).

Despite the utilization, popularity, and purported benefits of these technologies, we are not aware of any prospective, peer-reviewed published studies that have objectively evaluated the value of these vision-training programs.

>>>Dr. Kozarsky: That is an interesting question. An interest in the specific sport is a prerequisite. Most college and professional sports require preseason eye exams so that volunteering to work with the existing ophthalmologist is a good starting point. Our postgraduate fellows with an interest in professional sports have the opportunity to "shadow" sports vision ophthalmologists and participate in preventative screening of professional athletes as well as the in-season care of the players. This is an important credential for those who might want to include a sports vision component to their practice.

7. How are newer eye-tracking technologies being used to study the higher level visual functions and motor responses required in complex sport-related activities, such as baseball, basketball, golf, and Olympic sports?

>>>Dr. Kim and Dr. Legault: The newer eye-tracking technologies are using video eye trackers and sensors to improve the understanding of visual functions and motor responses. Using the latest technology, a recent study showed that college baseball players maintain gaze close to the ball throughout the pitch while varying movement amplitudes. The FitLight system now incorporates the eye-tracking technology that allows monitoring of the eye movements throughout the test. The new eye-tracking technology will provide additional objective data for vision training and may prove beneficial for future research in sports vision.

>>>Dr. Kozarsky: With advances in sensor and processing technology, eye-tracking capability is much more widely available. It is a fascinating parameter in studying the performance of athletes. Whether tracking speed and visual strategies observed in the most successful athletes can be transferred by training to other athletes with improvement of performance is an interesting question. There is little doubt that performance on in vitro tracking tasks can be improved with practice, but whether this directly influences on-field performance has not been convincingly proven.

Determination of the results of visual training is difficult, given expected placebo effect and the proprietary interests of those who provide visual training. The highest-level athletes are physically gifted in many respects including their visual system. Without prompting, they generally read a Snellen eye chart twice as fast as nonathletes. Whether the visual capabilities of already accomplished athletes can be emulated or improved long after the visual development of early childhood is an important question, and the eventual answer will guide us in the importance of visual training.

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