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Optimizing Visual Performance for Sport

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Keywords

• Visual performance evaluation • Refractive options • Sport filters • Carotenoids • Sports vision training • Component skill training • Naturalistic training

Key points

- To optimize visual performance in an athlete, a reliable and ecologically valid evaluation of relevant visual performance abilities should be performed.
- Optimal refractive compensation is predicated on a careful evaluation of refraction, with consideration for sport demands and method of refractive compensation.
- Filters and nutritional guidance can benefit the athlete by reducing glare disability, and enhancing photostress recovery and contrast sensitivity.
- Sports vision training programs can enhance vision and visual performance factors through component skill and naturalistic training options.

INTRODUCTION

In the world of sports, pursuit of optimal performance is pervasive. Most of the focus is on development of requisite physical abilities, such as strength, speed, agility, and endurance. The other major focus is on skill development for specific sport applications, often requiring significant repetition with feedback about optimal biomechanics. Depending on the sport, athletes also may work on the psychological issues that can impede or enhance performance. The role of visual performance factors in sports has received a fair amount of attention over the years; however, many athletes still have limited access to evaluation and enhancement approaches.

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Vision and visual processing are recognized as important components for successful athletic performance. Former football coach Blanton Collier is credited with the quote, "The eyes lead the body." This quote, along with many others, highlights the importance of vision in guiding performance. The process of optimizing vision and visual processing skills begins with a reliable evaluation of those factors that are identified as valuable for relevant sport tasks. Because the visual demands critical to success in sports can vary tremendously, a thorough visual task analysis should be conducted for each sport and sport position. An effective visual performance evaluation helps to identify what visual factors would provide the most benefit from enhancement.

The most common options considered for optimizing visual performance include refractive compensation, filters, nutrition, and sports vision training (SVT). The goal of these interventions is to remediate any vision conditions, such as refractive error, and to enhance the athlete's visual performance factors that may be less developed than those of their peers. SVT approaches often isolate visual factors to allow repetitive practice with increasing levels of demand and integration, so that sport performance has the potential to benefit from better vision and visual processing.

With advancements in digital and virtual reality (VR) technologies in recent years, there has been a surge of innovation in instrumentation to evaluate and train visual performance factors for sports. Because these technological innovations are relatively new, there often is limited research available to determine the validity and efficacy of these tools. Although this article is not a critical review of the evidence-based research in this area, a summary of the existing published research is provided to support the effectiveness of the instruments discussed. Ultimately, the goal is to help the athlete to see their sport better; and there are several key aspects to consider for achieving that goal.

ASSESSMENT OPTIONS

The professional literature is rich with studies that demonstrate that high-achieving athletes perform better than nonathletes or lower-performing athletes on various measures of visual, perceptual, cognitive, and motor abilities. Two separate meta-analyses of the sports expertise literature have concluded that higher-achieving athletes are better able to detect perceptual cues, make more efficient eye movements, and perform better on measures of processing speed and attention compared with less accomplished athletes or nonathletes [1,2].

Development of visual and cognitive expertise depends on the demands of the sports experience of each athlete because these demands can be quite variable across the vast array of sports. For example, stereopsis is an important vision factor for performance in many sports but may have limited relevance for shooting sports in which the athlete sights monocularly. Furthermore, stereopsis is commonly assessed at a near distance but the stereopsis demands in most sporting situations are at relatively far distances. This example highlights the importance of a careful visual task analysis of the sport demands, and need for potential modification of the assessment to better simulate the visual demands important for specific sports applications.

The vision and perceptual skills often identified as important for sports include static and dynamic visual acuities, contrast sensitivity, stereopsis, accommodative-vergence facility, span of perception, multiple object tracking, central eye-hand reaction speed, and peripheral eye-hand response speed [3]. Some aspects of these visual skills are assessed as part of a routine vision examination; however, many are not evaluated for various reasons. For many of these vision skills, there is little or no standardization of assessment procedures, and some of the instrumentation used in research studies may be outdated, if available at all.

It is helpful to classify the areas of assessment to better understand how the factors affect performance. The Welford Processing Model [4] is useful for understanding how the critical sporting action output results from the successful execution of lower-level processes (Fig. 1). Using this model, the following is an example of classifying assessments into the relevant mechanism:

Perceptual mechanism
- Visual acuity
- Contrast sensitivity
- Dynamic visual acuity
- Ocular alignment
- Stereopsis
- Accommodative function
- Vergence function
- Oculomotor function
- Peripheral vision

Decision mechanism
- Speed or span of recognition
- Visual attention or visualization
- Multiple object tracking

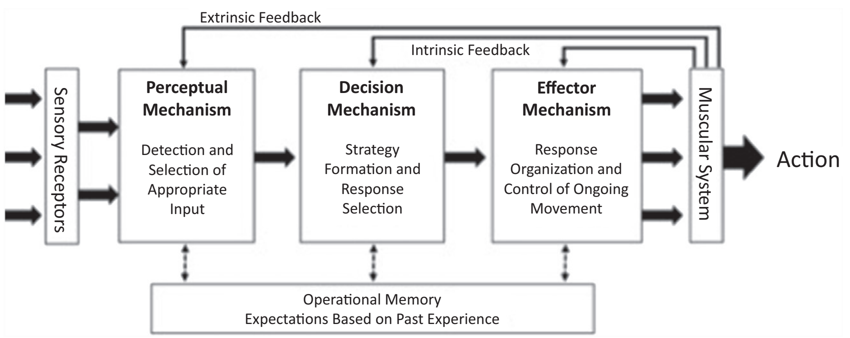

Fig. 1. A modified information processing model of skilled performance first proposed by Welford. (*Adapted from* Welford AT. The measurement of sensory-motor performance: survey and reappraisal of twelve years progress. Ergonomics 1960;3:192; with permission.)

Effector mechanism

- Visual motor reaction speed (eye-hand, eye-foot)
- Vision and balance
- Peripheral vision response speed
- Coincidence-anticipation.

Recently, several companies have developed digitized instruments that measure various aspects of visual performance that are important in most sports. Notably, these computer-based systems allow an individual athlete performance to be compared with a database of other athlete performances. Computerized assessment and training devices, such as the Senaptec Sensory Station (Beaverton, OR, http://senaptec.com), Sports Vision Performance from M&S (Niles, IL, http://www.mstech-eyes.com/products/category/sports-vision-performance), RightEye (Bethesda, MD, https://www.righteye.com/tests-therapies/vision-performance), and Vizual Edge Performance Trainer (http://vizualedge.com) have been developed to measure a broad set of visual, cognitive and sensorimotor skills.

Limited research evidence exists regarding the reliability or validity of some of these systems; however, many of these systems use standard psychophysical protocols, so it is reasonable to expect reliability of the measurements. The Senaptec Sensory Station is a successor to the Sensory Station device originally developed by Nike Inc (Beaverton, OR). Research with the Nike version of this instrument has demonstrated that certain assessments in the battery are reliable, cross-validated measures that can be used to investigate sensorimotor abilities in relation to performance in sports [5,6]. Recently published studies using RightEye have demonstrated good reliability of the dynamic visual acuity tests, and reliability and validity of the fine depth perception test [7,8]. In addition, stereoacuity performance was found to be significantly better in a sample of elite athletes compared with nonathletes [8].

A recent study of professional baseball players found that the sensorimotor abilities measured with the Sensory Station are significant predictors of on-base percentage, walk rate, and strikeout rate [9]. Furthermore, worse performance on the Sensory Station has been associated with an increased likelihood of sustaining head impacts during practices and games for US collegiate football players [10], indicating a link between collision avoidance and visual-motor skills. This suggests that these assessments might be useful in proactively assessing concussion risk, as well as potentially measuring recovery of visual performance abilities following a concussive episode.

Of significant value with these computer-based systems is that a standardized battery of tests can be administered and assessed for comparison to a database of athletes. The comparative analysis provides information about performance across the visual performance measures to identify areas of strength and potential disadvantage. This type of analysis can provide valuable information to an athlete about what interventions and training procedures would benefit them the most.

REFRACTIVE OPTIONS

Athletes require an evaluation to determine if they may benefit from a refractive prescription, or to determine if their current prescription is providing optimal visual performance for their specific sport demands. A task analysis of the sport will assist in determining how important visual acuity and contrast sensitivity is for successful performance. 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. In contrast, a sprinter in track may not require correction of small refractive errors. Ultimately, the subjective refraction should continue until the best visual acuity is reached because the athlete may be capable of seeing 20/10 or better.

The author uses the following prescribing guidelines for athletes to assist in determining when refractive compensation should be considered (Table 1).

Myopia

Any patient with myopia of −0.25 D or more should be counseled on the possible benefits of refractive compensation, although correction of less than −0.50 D has limited availability in contact lenses (CLs).

Astigmatism

Astigmatism has a similar effect on visual resolution as myopia does, 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.

Hyperopia

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. Judicious refractive compensation may reduce the accommodative effort needed for the athlete to achieve optimal image clarity.

Table 1
Guidelines for refractive compensation in athletes

Refractive status	Consider prescribing
Myopia	−0.25 D or more
Hyperopia	+1.00 D or more
Astigmatism	0.50 D or more[a]
Anisometropia	0.50 D or more[b]

[a]Against the rule (ATR) and oblique astigmatism are more detrimental than with the rule (WTR).
[b]Consider meridional effects with asymmetric astigmatism.

From Erickson GB. Sports vision: vision care for the enhancement of sports performance. St Louis (MO): Elsevier; 2007. p. 96; with permission.

Anisometropia

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. Additionally, the effects of meridional anisometropia should be considered in athletes with asymmetric astigmatism. Balancing the image quality through refractive compensation will enhance sensory fusion and improve the quality of spatial localization judgments.

The athlete makes the decision whether to experiment with a prescription; however, these guidelines can be useful to help initiate a discussion. Ultimately, the preference is to achieve optimal visual acuity and contrast sensitivity.

Contact lenses versus spectacles

Spectacles are not commonly recommended for use in sport. The main concern is that most eyewear does not offer the impact resistance necessary to protect the wearer from the possible hazards encountered in many such activities. The American National Standards Institute performance standards for dress and industrial strength (safety) eyewear are not applicable in most sports. The American Society for Testing of Materials (ASTM) has developed performance standards for eye and head protection in many sports [3]. The ASTM performance standards are established for protective eyewear in each sport individually, and the forces potentially encountered in a sport are used to determine appropriate testing parameters.

Even if the athlete selects appropriate protective eyewear, the potential effects from optical aberrations of the lenses should be considered. Monochromatic lens aberrations can degrade the optical image transmitted through the off-center portions of the lens and distortion can decrease the useful field of view through a lens. The reduction in the useful field of view can have a detrimental impact on performance in sports. For example, a right-handed tennis player viewing the ball toss during a serve looks through the left field portions of the spectacle lenses, and the image can be significantly altered in large refractive errors because of these aberrations.

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. CLs eliminate the induced prismatic effects evident with most spectacle lenses. The potential visual field impediment created by eyewear frames also is eliminated with CLs, 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 CLs [11]. CLs are an excellent option in highly dynamic sports because no frame can be dislodged, and no problem with lens fogging occurs. Although CL comfort 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 CLs to the method of choice for refractive compensation for most athletes.

Despite some of the potential disadvantages of spectacles, there are advantages that lead many shooters and archers to prefer spectacles to CLs. The main advantage is 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. 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.

Contact lens options

Due to better comfort and stability, soft CLs are typically preferred to rigid gas permeable lenses for use in sports. The main considerations for hydrogel lenses are the material composition, water content, diameter, and thickness. In general, lenses with a higher water content tend to dehydrate faster than low to medium water-content lenses. Therefore, thicker low to medium water-content lenses or silicone hydrogel lenses should be used for athletes who have dehydration problems [12].

Additionally, it has been suggested that the significantly increased oxygen permeability with silicone hydrogel lenses contributes to improved comfort and decreased symptoms of dryness. High water-content lens materials or silicone hydrogel lenses may be needed for prolonged lens wear situations, in which oxygen transmission is a crucial factor. Larger-diameter lenses are also recommended for better stability and hydration.

Most athletes benefit from single-use lenses: from the weekend athlete, who seeks the comfort of a disposable lens, to the professional athlete who prefers immaculately clean and fresh lenses before starting a competition, and a quick replacement of lenses at any time during competition. Single-use CLs can be particularly useful for water sports; however, concerns regarding lens loss and risk for infection still need to be addressed.

Orthokeratology is another option to reduce myopia and astigmatism with specially designed rigid lenses. A potential disadvantage of initiating orthokeratology for an athlete is the increased presence of higher-order aberrations and spherical aberration that may occur [13,14]. The increase of higher-order aberrations may cause a reduction in low-contrast visual acuity during the daytime, and this reduction is exacerbated with larger pupil sizes.

Laser refractive surgery

For an athlete with significant refractive error, laser refractive surgery is an appealing prospect for eliminating the need for spectacles or CLs. First, the athlete must be a good candidate for success before proceeding with any refractive surgery procedure. All athletes considering refractive surgery should receive comprehensive counseling regarding the potential visual and ocular effects of the procedure, and expectations of better vision after the procedure should be tempered. A recent meta-analysis comparing postoperative visual performance outcomes of the various forms of laser refractive surgery found that, although there is an increased presence of higher-order aberrations and reduction in contrast sensitivity with these procedures, no statistically significant difference exists in outcomes [15]. A study of batting statistics in major league baseball players who had refractive surgery found no difference in offensive performance following laser refractive surgery [16]. The other issue to address is the potentially increased vulnerability in the event of ocular trauma. All athletes in sports with a risk of trauma to the face who have had refractive surgery should be encouraged to use appropriate protective eyewear during training and competition.

The good news is that most athletes who have had refractive surgery are very happy with the outcome. Although there are some cautionary tales, improvements in the procedures used have resulted in better visual outcomes, fewer negative effects, and reduced risk of corneal trauma postsurgery.

FILTER OPTIONS

Athletes who participate in outdoor sports are exposed to illuminance ranges from 1000 to 10,000 foot-lamberts [17], which saturates the retina and produces direct glare and surface glare that ultimately reduces visual clarity and contrast sensitivity. Dark filters aid in recovery of contrast sensitivity and dark adaptation after photoreceptor saturation. The ability of filters to reduce glare and improve contrast may enhance the ability to discern crucial details and judge depth in bright outdoor sport conditions.

Sun eyewear for sport can provide protection from harmful ultraviolet radiation while enhancing performance. When determining optimal filters for a sport, consideration should be given to both the quantity and type of light that is filtered. The amount of visible light transmission can help reduce overall glare and improve comfort. The spectral transmission properties can enrich specific colors, or mute colors, to enhance the visibility of specific details that are important in a sport. For example, a red-range filter can enhance the visibility of the red seam on a baseball. The transmittance characteristics for each filter are based on the tint colors used, the amount of tint used, and the lens material used. The following are some general filter recommendations that can be used as a guide.

Neutral gray

Neutral gray tints absorb all wavelengths of the visible light spectrum approximately equally; therefore, the natural appearance of colors is preserved. Those participating in snow sports and golf often favor these tints.

Yellow-brown range

Attenuation of the shorter wavelength light (blue) decreases the chromatic aberration between the longer red wavelengths and the transmitted midrange 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. Yellow filters have been shown to improve depth perception, contour recognition, and reaction times [3]. Many athletes appreciate the improvement in contrast and brightening effect with yellow-range tints, especially in low-light conditions such as twilight (dawn and dusk), fog, and heavy cloud cover. Yellow and brown tints are popular with shooting and snow sport athletes. Mountaineers use yellow tints in whiteout conditions to enhance the contrast of environmental features. A yellow-range tint also 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 [18,19].

Brown range filters also selectively absorb the blue portion of the visible light spectrum, thereby inducing some of the same effects of a yellow tint, most notably darkening the blue sky and enhancing the appearance of an object against the sky.

Green range

These tints allow green information to be enhanced and other colors to be relatively muted. Green tints may be preferred in golf, tennis, and woodland shooting. 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.

Red range

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

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. Some sports sun eyewear appears to have blue-tinted lenses; however, the metallic or iridescent coatings on the lens surface create this impression.

Polarized filters

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. These filters are potentially beneficial for fishing, water sports, driving, and cycling (especially useful for wet surfaces).

There always is an element of personal preference when assessing filter options, and some athletes may prefer filters that do not seem to be the best match for the specific sport demands. Information about filter options should be provided to help guide selection; however, it is ultimately the athlete's decision.

NUTRITION OPTIONS

There has been intense focus recently on the role of nutrients on age-related changes to ocular tissues. There has also been significant research into the effects of nutrients on visual performance in young, healthy people. Lutein (L) and zeaxanthin (Z) are plant-derived carotenoids that are found to be concentrated in the eye and brain. L and Z are concentrated within the inner layers of the fovea, specifically at the Henle fiber layer, and act as a filter for light [20,21].

The macular pigments have peak absorbance for short-wavelength light (400–500 nm), and filters light before it reaches the cone photoreceptors. The peak energy of both blue haze and sky light is 460 nm, which coincides with the peak absorbance of the macular pigments (similar to yellow-tinted filters) [22].

Visual effects

There is mounting evidence from placebo-controlled, double-blind trials that the density of the macular pigment has an effect on glare disability and discomfort, photostress recovery, and contrast enhancement. Less discomfort is reported from short-wavelength light in those with a higher concentration of macular pigment, as well as less glare disability [23,24]. Supplementation with L and Z has shown an improvement in glare disability that is proportional to the level of macular pigment increase [24–26]. The same trend can be seen with photostress recovery following exposure to bright light and with visual discomfort [25,26]. The ability to perform optimally under intense glare conditions may be improved by increasing macular pigment density.

Recent research has demonstrated a linear relationship between macular pigment density and contrast enhancement [27]. Because the macular pigments selectively filter short-wavelength light, it has been proposed that those with a higher density of macular pigments have an expanded visible range (approximately 30%) due to the preponderance of short wavelength light in the atmosphere [28]. Therefore, the ability to detect a target such as a baseball or tennis ball against a blue sky is enhanced with increasing macular pigment.

Neural effects

Although the presence of L and Z in the macula is well-recognized, these carotenoids also concentrate in the brain. Randomized, double-masked, placebo-controlled trials of young healthy subjects have shown that macular pigment density is linked to L and Z levels in the brain [29], and that the level present is related to functions such as cognition, reaction time, and temporal visual processing [30–32]. Neuroimaging to measure the relation of L and Z to brain structure in vivo has confirmed that L and Z influences white matter integrity, particularly in regions vulnerable to age-related decline [33]. L and Z are incorporated in cell membranes and axonal projections, which serve to enhance interneuronal and neural-glial communication [34]. Recently, supplementation with carotenoids has been shown to increase critical flicker frequency thresholds, visual motor reaction time, and temporal contrast sensitivity function compared with a placebo control group, improving processing speed by an average of 10% to 20% [31,32]. In dynamic, reactive situations, this may enhance the ability to evaluate critical visual information faster. For example, more rapid visual processing allows a baseball batter to process more visual information regarding the judgment of the speed and trajectory of a pitched ball.

Athlete recommendations

To help athletes achieve optimal visual performance, recommendations should include modifications to diet to increase intake of carotenoids, or supplementation with purified forms of L and Z. Placebo-controlled studies have found that macular pigment density can be increased an average of about 20% with supplementation [23,24]. Recent studies have used 20 mg of dietary Z in supplements for those who are young and healthy compared with lower concentrations for the aging population (the AREDS [Age-related Eye Disease Studies] 2 formula has only 2 mg of Z) [25,31,32]. For competitive athletes, care should be taken to recommend supplements that have been certified for content, including for substances banned in sports. Currently, the only available supplements that are formulated specifically for athletes are Eyepromise Vizual Edge products (www.eyepromise.com), which are certified by the National Science Foundation for sports. In addition to the visual performance improvements found with supplementation, evidence exists that L and Z have protective effects for the retina from photo-oxidative damage.

For those athletes who experience difficulties with glare, photostress, and contrast judgment, increasing macular pigment density offers a potential method to improve these functions by enriching natural physiology. Some athletes do not see a benefit from filter recommendations to help with glare disability, and filters can be cumbersome to change when moving between bright light and shadow. It may be that improvement in L and Z concentrations in the macula can provide enhanced visual function without the reduction in overall luminance that occurs with external filter use.

SPORTS VISION TRAINING

SVT programs operate under the logic that practice with demanding visual, perceptual, and sensorimotor tasks will improve vision, leading to quicker sensory processing, swifter and more accurate motor movements, and improved athletic performance while potentially reducing injury. There is a long history of SVT approaches that isolate component visual performance factors (eg, vergence, accommodation, pursuit, and saccadic eye movements), and repetition of these SVT activities is combined with increasing integration of other sensory and cognitive demands. Essentially, these programs modified traditional vision therapy procedures to better simulate the visual performance demands that may be encountered in sports.

There is limited and mixed support demonstrating that traditional analog SVT drills can improve sports-relevant vision, or manifests into better on-field performance [35]. However, isolating a single 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.

SVT approaches have been advanced greatly by training programs that use information about the structure and function of the visual system combined with recent innovations in perceptual learning paradigms to engender more specific and robust learning. There are many examples of dramatic improvements in visual abilities from appropriately structured tasks, showing that practice leads to substantial gains in sensitivity that can last for months or years [36]. Most importantly, this research has shown that perceptual learning benefits can transfer to new contexts that have not been trained for [37]. Furthermore, VR simulations that can recreate and augment sporting contexts to promote certain sports-specific visual-cognitive abilities have also enhanced SVT approaches.

The following section is a review of recent digital visual training instruments based on principles of perceptual learning that have shown promising evidence for improving vision and sporting performance. More detailed information can be found in a recently published review paper [35].

Component skill training

Visual acuity and contrast sensitivity

A recent innovation in visual component training is called Ultimeyes (Calabasas, CA, https://ultimeyesvision.com). This video application incorporates diverse-stimuli, adaptive near-threshold training with learning-optimized flickering stimuli and multisensory feedback in a digital training program designed to improve foundational aspects of visual sensitivity. In a series of studies, this training application has demonstrated improvements in visual acuity and contrast sensitivity in both nonathletes [38] and athletes [39], as well as improved batting performance in collegiate baseball players [39].

Multiple object tracking

The CogniSense NeuroTracker (https://neurotracker.net) is an example of a perceptual-cognitive training program. The training platform entails an immersive 3-dimensional multiple object tracking program to increase cognitive load. There is ample research with the NeuroTracker system involving groups of healthy young adults [40], healthy older adults [41,42], and athletes across several sports and skill levels. NeuroTracker performance has been correlated with actual game performance in professional basketball players [43] and demonstrated that training with this program can selectively transfer to improved small-sided game performance in university-level soccer players [44]. The use of multiple object tracking has also been incorporated into NeuroTrainer (https://neurotrainer.com/), in which athletes are given a series of dual tasks that simultaneously challenge attention and peripheral vision.

Visual-motor reaction

Visual-motor reaction training is a common aspect of component SVT because many sport situations require an athlete to quickly make motor responses to visual information. Several instruments have been created to evaluate and improve visual-motor reaction speed, including the Wayne Saccadic Fixator (www.wayneengineering.com), Dynavision D2 (West Chester, OH, www.dynavisioninternational.com), Vision Coach (www.visioncoachtrainer.com), SVT (www.sportsvision.com.au), Batak (Horley, Surrey, UK, www.batak.com), Sanet Vision Integrator (Gold Canyon, AZ, www.svivision.com), and FITLIGHT Trainer (Aurora, ON, Canada, www.fitlighttraining.com). These instruments each consist of a 2-dimensional panel or setup with an array of illuminated buttons. The athlete is required to press a randomly lit button as rapidly as possible with 1 hand, then another button is lit in a random position on the instrument and the reaction-time reflex cycle is repeated for an established period. FITLIGHT is unique in that it uses wireless light-emitting diode (LED)-powered light units that are controlled by a computer tablet and can be flexibly placed at distances up to 50 yards from the controller rather than embedded in a fixed board as is customary in the other devices.

Previous research with these tools has varied considerably in the scope and intent of the studies. Multiple peer-reviewed studies have been done on some devices, whereas others have undergone little or no research. Several studies have used the Dynavision tools in SVT programs that include additional SVT procedures, and demonstrated improvements in batting averages, slugging percentage, and on-base percentage in baseball [45]. In a study with a similar SVT program design, concussion incidences during 4 years of collegiate football were reduced relative to the 4 years before the implementation of the training programs (1.4 vs 9.2 concussions per 100 player season) [46].

The visual-motor reaction instruments discussed in this section are most often used to train eye-hand reaction; however, there are some instruments that provide a method to train eye-foot response. The Quick Board (www.thequickboard.com/) and FITLIGHT offer training options for foot speed. Training with the Quick Board has demonstrated significant improvements in foot speed, choice reaction, and change-of-direction in moderately active adults [47].

Sports vision training systems

In addition to visual performance assessments, a variety of computerized training programs are also available on the Senaptec Sensory Station (http://senaptec.com) and Vizual Edge Performance Trainer (http://vizualedge.com). Currently, there is limited research on using these systems for training and more definitive studies are needed to determine their efficacy and applicability to sport.

Naturalistic and virtual reality training

Actual sports practice is typically viewed as the most naturalistic method for developing the necessary skills for success; however, practices have the potential for injury to the athlete. Over the past several years, digital technologies have been developed to allow SVT approaches to be used during natural training activities and in VR simulations that can recreate sport scenarios to promote sports-specific visual-cognitive abilities.

Stroboscopic training

Strobe lights or liquid crystal shutter eyewear can be used in natural practice situations to intermittently disrupt vision, thereby only allowing the athlete to see brief snapshots of the activity being performed. This provides a format for training under more challenging visual conditions than typically encountered, so that athletes learn to more effectively use the limited visual input.

The most common device used for stroboscopic athletic training has been the Nike Vapor Strobe (Nike Inc, Beaverton, OR) eyewear. However, it has been discontinued and now a similar new product is available from Senaptec (http://senaptec.com/products/senaptec-strobe; Fig. 2). Similar in design to the Nike and Senaptec eyewear, the Visionup Strobe glasses (Appreciate Co, Ltd, Kyoto, Japan; http://www.sportsvision.jp) and the MJ Impulse eyewear (http://mjmilitary.com) also allow control of the transition frequency and opaque-to-transparent ratio. These products all use battery-powered liquid crystal filtered lenses that alternate between transparent and opaque states. The Nike and Senaptec products are defined by a 100-millisecond fixed-duration transparent state with complete visibility and a variable-duration opaque state that can be changed through durations ranging from 25 to 900 milliseconds of visual occlusion. With all strobe training, the difficulty is increased by lengthening the duration of the opaque state.

Studies involving stroboscopic training suggest that it can enhance sensory and motor skills, with some evidence that these translate to on-field performance. Stroboscopic training has been shown to increase dynamic visual acuity (after 1 training session) and ball catching performance (over the course of the training) compared with training without a stroboscopic effect [48]. In a study with National Hockey League players, the strobe training group averaged an 18% improvement in on-ice skill performance from pretraining to posttraining, whereas the control group's performance did not improve [49]. Additionally, a preliminary study suggests that strobe training might be a useful tool for lower extremity (eg, anterior cruciate ligament [ACL]) injury

Fig. 2. Senaptec strobe. (*Courtesy of* Senaptec, Beaverton, OR.)

recovery [50]. The study establishes a link between dynamic movement mechanics, neurocognition, and visual processing, and provides evidence that neurocognitive and visual-motor training approaches during rehabilitation of ACL injury may further optimize treatment by mitigating postinjury movement dysfunction and reducing injury risk when returning to play.

Eye movement tracking

The advent of lightweight portable eye tracking technology has allowed for evaluation and feedback of eye movements in sporting activities that are carried out in natural settings. These systems typically consist of 2 cameras mounted on an eyeglass-type frame: 1 to monitor eye position and 1 to monitor the scene (point-of-view) with an external camera that is positioned to monitor motor performance characteristics. The data collected by the mobile eye tracker are then synchronized with elements of motor performance using software programs that can operate in real time.

Studies with such mobile eye trackers have typically found that experts have a lower number of fixations that occur for longer durations than do novices during the viewing of specific sport situations (this is referred to as the quiet eye), especially when the subjects are required to move while gaze behaviors are recorded [51,52]. Further, for expert performers, fixations are typically clustered on features that provide the most information about the task being viewed [53]. Abundant research supports quiet eye training in several sport applications, with many studies reporting benefits such as improved visuomotor behaviors and control of attention and anxiety under pressure that persists for days or weeks.

Several companies market complete mobile eye tracking systems for use with sport applications, such as SensoMotoric Instruments (www.smivision.com/en/gaze-and-eye-tracking-systems/applications/sports-professional-training-education.html), Tobii Pro (Falls Church, VA, www.tobiipro.com/fields-of-use/human-performance/), and Arrington Research (Scottsdale, AZ, www.arringtonresearch.com). There are also less expensive monitor-based systems; however, these platforms may not provide the same benefits as training in the natural sport environment.

Virtual reality training

Computerized simulations and VR platforms have been developed to simulate game action, and are a type of naturalistic sports training. Such simulation platforms allow for the design of complex training protocols that can mimic real-game activities, allowing athletes to gain mental repetitions. Three companies in particular, Eon Sports VR (http://eonsportsvr.com/), StriVR Labs (http://www.strivrlabs.com), and Axon Sports (http://www.axonsports.com/), have recently developed suites of digital training simulations that are marketed toward athletes, coaches, and trainers. In addition to these broad commercial platforms that have applications for many different sports, a growing number of products target specific individual sports. Importantly, these VR sport simulations are a new technology with relatively little supporting evidence at this time.

TRAUMATIC BRAIN INJURY IN SPORT

Although this topic is beyond the scope of this article, SVT procedures also have been used to evaluate and rehabilitate sports-related concussions. There is ample evidence that, in addition to reduced visual processing speeds [54], concussions lead to binocular vision deficits, oculomotor dysfunctions, and visual field deficits [55]. Therefore, vision therapy and, by extension, SVT approaches that addresses the component skill deficits, may provide important therapeutic benefits as part of a comprehensive multidisciplinary approach to manage concussions. Studies have demonstrated that vision therapy can improve outcomes in postconcussion vision disorders [46,56].

SUMMARY

This article has highlighted the many options available to help athletes see their sport better. An approach to consider for each athlete is shown in Fig. 3. The first step is a thorough evaluation of visual performance abilities with consideration of the visual demands of the sport. The vision examination should carefully measure refractive error to determine if refractive compensation, or a change in refractive prescription, is merited. If the athlete would benefit from refractive compensation, care should be taken to determine the best option for delivering that prescription. In most cases, CLs provide the best optical solution for use during sport, although consideration of sports protective eyewear and laser refractive surgery may also be warranted. The environmental factors encountered during the sport should guide a discussion of filter options, with an emphasis on tints that enhance the important visual information for sport performance while minimizing glare disability. With recent advances in the understanding of the role of nutrients in visual and cognitive performance, it may

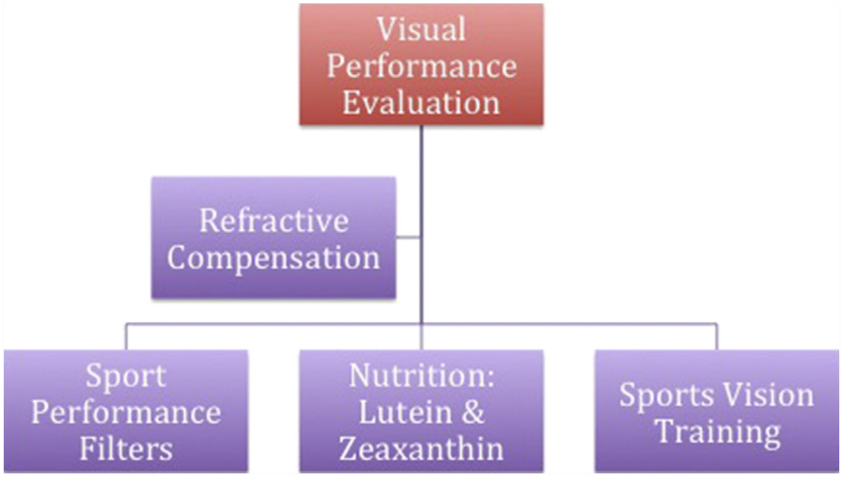

Fig. 3. Proposed steps and options for optimizing visual performance in athletes.

be beneficial to also discuss dietary and supplementation options with the athlete. Finally, SVT approaches provide another opportunity for the athlete to enhance vision and visual performance factors that are important for their sport. Consideration should be given to the enhancement of component visual skill training, as well as naturalistic training options.

In most sports, vision is a critical element for successful performance. Optimal vision is important for the athlete so that visual performance is not responsible for limitations in sports success. Optimization of visual performance is predicated on a reliable and ecologically valid evaluation that guides the recommendations of refractive compensation, filter choice, nutritional supplementation, and SVT. There is ample evidence that these approaches can provide the athlete with optimal vision for the demands of their sport.

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