



VISION TRAINING AND REACTION TRAINING FOR IMPROVING PERFORMANCE AND REDUCING INJURY RISK IN ATHLETES

Joseph F. Clark PhD¹, Bret E. Betz MD^{2,3}, Leila T.G. Borders MD^{2,4}, Aaron Kuehn-Himmler MS⁵,

Kimberly A. Hasselfeld MS² Jon G. Divine MD²

¹Department of Neurology and Rehabilitation Medicine; College of Medicine, University of Cincinnati, Cincinnati, Ohio, USA.

²Division of Sports Medicine, Department of Orthopaedic Surgery; College of Medicine, University of Cincinnati, Cincinnati, Ohio, USA.

³Department of Emergency Medicine; College of Medicine, University of Cincinnati, Cincinnati, Ohio, USA.

⁴Department of Internal Medicine; College of Medicine, University of Cincinnati, Cincinnati, Ohio, USA.

⁵Nova Care Rehabilitation Cincinnati, Ohio, USA.

Corresponding Author: clarkjf@gmail.com

Submitted: October 28, 2019. Accepted: December, 2020. Published: May 19, 2020.

ABSTRACT

Visual processing, visual fields, and visual reaction times are essential to the performance of numerous sports and play a role in athletic injuries. Vision training, a process using visual exercises as part of a structured sports conditioning program, can be used to both enhance sports performance and prevent injury by improving neurovisual processing.

In this review, evidence and methods concerning vision training programs are presented with the results suggesting performance enhancement and/or injury prevention, primarily concussion. Multiple studies are reviewed and utilized as examples that vision training programs designed to improve athletic performance or prevent injury are effective.

We conclude from the collected evidence and theoretical considerations that vision training for numerous sports can be implemented with goals to improve performance and/or decrease injuries, specifically concussion.

Key Points

(1) In this opinion paper, we believe that vision training improves neurovisual processing. The vision training improves certain brain functions. (2) That vision training programs as part of athlete conditioning can improve athletic performance. Eye-hand coordination, reaction times and peripheral awareness improve on the field of play. This benefit can be sport specific with some sports benefiting more than others. (3) There is emerging evidence that concussion rates can be decreased following pre-season vision training programs. The cause and effect need to be better established and future research should address this opinion.

Approximately 80 percent of the sensory input to the brain comes from the visual system and systems to process visual information. Multiple pathways in the central nervous system process visual inputs to determine where and what the eyes see, allowing the brain to analyze the location and movement of visual objects in space.¹ This visual-spatial analysis of the brain is a critical component of numerous sports and athletic skills. Conditioning and training for most sports focus on known methods for improving players' skills. According to the principle of specificity, a general principle of athletic training, the "training program must *stress* the physiological systems that are critical for optimal performance in a given sport to achieve specific training adaptations and goals."² Based on this principle, it would seem to that to optimize a player's skill, the visual-spatial analysis system—that is the eye-brain axis—should be an emphasis of conditioning and training. This is especially relevant in sports involving multiple players and a dynamic range of visual activity. The assumption being that the training is transferable to the sport's activities.

There is an emerging discipline of vision training for performance enhancement in sports—the theory being that if an athlete can see and process visual information better then their performance will improve as well.^{3,4} This discipline is gaining traction with some professional sports teams as well as college teams using vision training methods with their athletes.⁵⁻⁷ There are of course exceptions in that the visual abilities of a traditional wrestler may not be as critical as a football quarterback. The wrestler can do a lot of his/her sport by "feel" whereas the quarterback must be aware of and track up to 21 people on a football field.

In the process of using vision training to improve performance, it has been found that vision training may impact injury prevention.⁸ For coaches and athletes, preventing injuries that threaten a player's career of long-term health is paramount. Particularly with a growing body of research focusing on the neurologic sequelae of sport-related concussion, a growing emphasis is being placed on the prevention of traumatic brain injury from sport. The theory that vision training could help prevent injury, especially head trauma, is actively being elucidated in the literature. We believe that the brain training conditions the brain and helps

prevent the concussions by being more field aware and helps recovery by having experience in brain training for rehab post-concussion.

There are several studies using vision training programs and methods to improve athletic performance as well as injury prevention. The studies reviewed involve various sports, including baseball, football, softball, soccer, basketball, and table tennis, and various proficiency levels of athletes, from high school to elite professionals. While the studies often focus on performance enhancement or injury prevention, this opinion paper presents both to link the two and as similar vision training methods seem to improve both endpoints based on the studies reviewed. By implementing vision training as part of athletic conditioning, performance enhancement and injury prevention can be improved together, thus giving it value for the entire sports team—athlete, coaches, medical staff, and parents.

METHODS OFTEN USED FOR VISION TRAINING

Vision training incorporates the concept of "lighting up" complex pathways of cortical function. The goal is to train or "*stress*" those pathways. Visuomotor skills require the processing of sensory information and coordination between the occipital lobe and motor cortex. Goodale and Milner introduced an influential model of visual processing in 1992, which incorporated two distinct anatomic visual processing pathways in the primary visual cortex. They postulated a dorsal and ventral stream—the "what" and "how" pathways, respectively. The dorsal stream involves "conscious perception" or the "what" component which includes characterization of objects with long term, action planning of remembered information; while the ventral system controls real-time guidance, immediate action, and reaction to visual input or the "how" pathway. It has also been postulated that the ventral system is critical in "object vision" while the dorsal system is crucial in "spatial vision."^{9,10} For a football quarterback tracking 21 objects on the field of play requires the integration of both systems. The independence of these pathways has been debated since the concept was introduced, with newer theories suggesting a more dynamic interplay that guides perception and action.¹¹

These pathways and coordination with the motor cortex are critical for optimal athletic performance. While immediate reaction to visual sensory information plays an important part in athletic competition, the conscious perception of recognized patterns of visual information is also important.

Several vision training methods have been used both for performance enhancement and injury prevention. The following is not comprehensive but is designed to give a short overview of some of the methods used in studies referenced here.

Dynavision D2 light board (Dynavision International LLC., West Chester, Ohio): This is an FDA-cleared device used to train reaction time and implement executive processing. In this exercise, the athlete stands in front of the Dynavision board and uses peripheral and central vision to press flashing lights as they appear. They also simultaneously complete executive and verbal tasks, such as calling out or adding numbers, word-finding, or memory tests.

Tachistoscope: This is a device used to train the brain to recognize images faster and improve conscious perception. Sports-related images are flashed on a screen for 0.3 seconds with numbers. The athlete must call out the numbers. As the training progresses, the amount of numbers increases with varying backgrounds to work on contrast sensitivity and executive processing. The athletes are then required to recall the numbers and describe the images associated. When an alphanumeric and image description is the output task it is thought that the athlete is training left and right brain executive functions to improve speed and ability to process said visual information.

Strobe glasses: These stroboscopic glasses are designed to improve visual processing, specifically coordination between the occipital and motor cortex. They have an LED lens that flashes on and off with a prescribed duty cycle, blocking visual input during catching drills. For example, a ball is thrown to the glasses-wearer and the image of the ball coming towards the wearer appears and disappears rapidly. The lenses speed of flash is highest in the initial training stages, allowing more visual input. The rapidity with which they flash slows as the athlete adapts, forcing the athlete to rely on less visual input to process spatial information of an object in flight. People with a seizure

disorder or seizure susceptibility should consult their physician before using strobe glasses.

Saccadic eye charts or Hart charts: This equipment consists of two charts of rows of letters, one small and one large. These can be used in varying ways to improve accommodation, eye movements (saccades), and visual attention. For example in one method, the participants stand approximately ten feet away from the larger chart and hold the smaller chart in hand. The participant then alternates reading a line from the distance chart and near chart. Overtraining, the distances of these charts are altered. This activity trains eye discipline in that the eyes need to use muscle memory to go between two sites. The task also trains the athlete to scan the field faster and more effectively. The complexity can be progressed as subjects train to include pattern recognition, word-finding, etc.¹²

Brock string: Different colored beads (red, green, and yellow, etc.) are placed on along a string. One end of the strings is attached to a fixed object (i.e., a wall) and the participant holds the other end up to his/her nose. The participant focuses on one bead, he/she should see two strings coming in and out of the bead forming an x — physiologic diplopia. This tests suppression (one eye not being used) and convergence (both eyes focusing on the same object). By moving the beads or focusing on the beads, in turn, suppression and convergence can be improved. Accommodation is also trained with this task. The ability to change focus (focal length) is important in several sports and the brock string can aid in such training. As this drill tends to be a convergence type of drill with the medial recti muscles doing much of the work it is often contraindicated for people with esophoria.

These devices and techniques, along with others not described here,^{5,6} were combined in most studies into training and conditioning programs of various lengths and designs.

PERFORMANCE ENHANCEMENT AND VISION TRAINING

Visual performance has been anecdotally connected to sports performance since the early 1920s. In “Eye, Ear, Brain, and Muscle tests on Babe Ruth,” Fullerton attributes a link between Ruth’s visual acuity and reaction to his athletic prominence.^{13,14} However,

the exact role of vision and vision training on athletic performance continues to be debated.¹⁵⁻¹⁷

Sports vision refers to the dynamic visual functioning including depth perception, peripheral vision, dynamic visual acuity, and visuomotor skills. It also incorporates complex cognitive processing functions as well. Studies have shown that dynamic visual acuity is superior in skilled athletes in various sports, including softball, volleyball, basketball, and tennis.¹⁸⁻²¹ Goa et al. found increased visuomotor skills, convergence, accommodative facility, and dynamic acuity in athletes when compared to non-athletes with the largest differentiation in “critical visuomotor skills” which included manual interception, visually guided locomotion, and depth judgement.²² When evaluating the mean visual reaction time of professional baseball players, Classe et al, found a statistically significant association between visual reaction time and batting skill as represented by batting average. Visual reaction time had no association between pitching or fielding skills in these players.²³ Similarly, a study of Division I collegiate hockey players found that using a Nike SPARQ sensory training station to measure reaction time, visual memory, and visual discrimination could successfully predict a higher proportion of goals scored.²⁴

At the same time, many studies have shown that visual performance itself can be trained and improved with practice. A small study with collegiate athletes showed that with training sessions, simple eye-hand reaction time could be reduced, as well as binocular vision training for spatial orientation.^{25,26} Studies of the University of Cincinnati baseball team’s vision training program found that vision training produced not only demonstrable improvements in stereopsis but also improvements in eye-hand coordination and tracking that lead to better batting averages.^{5,6} These studies were done from 2010 to 2013 and demonstrated improved depth perception using stereopsis measurements before and after participation in fall and pre-season training periods. Similarly, the team’s batting average increasing from 0.251 to 0.285 from the 2010 to 2011 seasons. The University of Cincinnati baseball team changed coaches after 3 years of vision training and discontinued the vision training under the direction of the new coach. The year vision

training was discontinued the batting average of the team fell by 25 points (unpublished observations of Clark et al.). Similarly, in a study by Mazyn et al, stereovision was evaluated as it related to a catching skill. Poor catchers, who scored less than 50 percent on a standardized catching activity were evaluated for performance in stereovision and divided into groups with normal or abnormal stereopsis. All individuals participated in an intensive training program practicing ball catching. Results showed that individuals with abnormal stereopsis did not significantly improve their catching rate after training, while individuals with normal stereopsis improved significantly from 18% to 59% catch rate.²⁷ These results indicate that although stereopsis and perhaps other visual performances can be learned, the heterogeneity of baseline characteristics may influence the ability of learning.

Abernathy and Wood have published multiple studies debating the efficacy of visual training programs.^{28,29} In one study, groups were randomized to with vision training (experimental) or without vision training (control). They found that both control and experimental groups had improved visual performance characteristics in static visual acuity, accommodation, choice reaction time, static visual field sensitivity and peripheral response time. Similarly, motor and sport-specific tasks were tested with significant improvements in both groups without respect to visual training, indicating that the test results could be the result of test familiarity.^{28,29}

However, despite debate and some negative studies, many studies have found the positive effects of visual training. McLeod tested nine female Canadian University soccer players by placing them in a vision training program to test its ability to improve sport-specific motor function. After a four-week vision training program, visually trained athletes had better performance in eye-hand coordination, balance, and a sport-specific dribble test when compared to controls.³⁰ Hopwood et al found that the addition of visual perception training led to increased testing scores in fielding success in skilled cricketers when compared to players who received only on-field training (increase 21.7% in experimental vs. 16.2% in controls).¹¹ Similarly, in a study by Clark et al, collegiate baseball players at a Division I university were placed into a six-week

visual training program before the 2011 season. The training program included thrice-weekly sessions including training with eye-hand coordination (Dynavision D2 device), convergence, rotary device, strobe glasses, saccades, and near-far training. Training then occurred twice weekly during the season. Batting statistics were then compared between the 2010 team and other Big East Conference competition in 2011. The baseball team improved their batting average from 0.251 to 0.285 after vision training, a rise of 0.034 points, while the rest of the Big East batting average fell 0.034, a statistically significant improvement in the experimental group.⁵

Vision Training an Injury Prevention

Vision training is an easily implementable adjunct to traditional pre-season conditioning and training that should be considered for injury prevention. Several studies have shown that poorer neurocognitive function, including visual attention, results in a higher risk of musculoskeletal injury.^{31,32} Recently, more studies have been undertaken to elucidate whether structured vision training can improve performance and reduce the risk of injury.

Further research is needed to establish a relationship between vision training and injury prevention in baseball. However, if vision training produced improvements in ball tracking as suggested by the

studies performed by Clark et al with Univ. of Cincinnati baseball players, it could be postulated that injury prevention from being struck by the ball is also improved. While concussions only represent a small proportion of injuries in baseball, there is a significant risk of concussion via being hit by a pitch.³³⁻³⁵

Another study looked at increased concussion rates in high school girls' soccer versus boy's soccer and postulated that this could be due to lack of eye discipline, i.e. having closed eyes when heading the ball and therefore not being able to detect and avoid injury. By reviewing 100 images of females and an equal number of male soccer players heading the ball, it was shown that the females had their eyes closed 90 percent of the time, while the male players had their eyes closed in 79% of the images. Figure 1 supports this concept concerning closed eyes during headers in college soccer players. This suggested a potential causal relationship between having closed eyes during play and concussion incidence. The study further postulated that eye closing during header plays is likely secondary to the startle reflex that could be suppressed with training and coaching, thus providing another potential means of injury prevention.³⁶

A primary area of continued interest in sports-related injury and concussion is in football players, the sport which has the highest rates of concussion.³³⁻³⁵

FIG. 1 University of Cincinnati Women's Soccer player observed to be heading the ball with eyes closed. Keeping eyes open with neurovisual training including improved eye discipline may improve performance as well as prevent injuries associated with heading the ball.



J Sports Perf Vis Vol 1(1):e8-e16; May 19, 2020.

This article is distributed under the terms of the Creative Commons Attribution-Non Commercial 4.0 International License. ©Clark et al.

A study done of data obtained from four seasons of play by the University of Cincinnati football team showed that vision training was undertaken as part of the preseason and in-season conditioning program resulted in a statistically significant reduction in concussion rates when compared to seasons where vision training was not implemented.³⁷ The training methods used were similar to those used in previous studies with the baseball team, mentioned above, including the Dynavision light board, Brock string, and strobe glasses. During the study time (2006-2013), the concussion incidence went from an average of 8.75 diagnosed concussions per season to 1.5 per season after vision training. During this time of the study, there was a rise in concussion rate among men's collegiate football was noted, further implying a potential causal relationship between vision training and injury reduction.³⁸

There is also some limited research into vision and retinal assessment and monitoring of concussion and subsequent brain damage. One small study showed that central and peripheral vision reaction times are prolonged in patients with visual dysfunction after a concussion.³⁹ The study used a Dynavision light board to test central vision reaction time and peripheral vision reaction time in a patient with diagnosed concussions with post-concussion visual symptoms. Prolonged reaction times were found in the concussed patients as compared to a matched non-concussed control group. This study postulated that measuring these times could be utilized as a means of diagnosis of concussion and assessing return to play by looking at changes over time in the reaction times.³⁹ Another study found that there are statistically significant sustained chronic retinal nerve fiber layer thickness changes in athletes who reported sustaining a previous concussion when compared to athletes without a history of concussion. This was found by measuring the retinal nerve fiber layer via optical coherence tomography.⁴⁰ This measurement is particularly significant in that an increase in thickness of 3 nanometers was found in previously concussed athletes compared to never-concussed athletes; however, these previously concussed athletes did not perform more poorly on balance assessments using a Bosu ball and the Dynavision light board than those athletes who had

never had a concussion previously.⁴¹ Assessment of this could be used to risk-stratify athletes at risk for structural brain injury who are no longer showing any symptoms or evidence on the injury on exams. Further research is needed to evaluate these measurements, as well as to elucidate if vision dysfunction related to prior concussion increases the risk of subsequent concussion.

The studies of vision training and its relationship to injury prevention are not without flaws. The studies reported here had small sample sizes, and the studies in the University of Cincinnati baseball and football teams did not include control groups. Also, players did not uniformly participate in vision training during their seasons of play due to various factors. Further prospective controlled studies are needed to validate these findings and further elucidate causal relationships between vision training and injury prevention. Concerning our athletes, we have performed a risk assessment concerning concussion risk at the University of Cincinnati. We have found that the average intercollegiate athlete in the University of Cincinnati has a 1% per year risk of suffering from a concussion (unpublished data of Clark, et al). The national average for concussion (traumatic brain injury risk) is 1.1% per year (www.cdc.gov and the census bureau). Our goal has been and continues to be to mitigate injury risk for our athletes via our neuro visual training program. Having the risk of a traumatic brain injury for our athletes essentially be the same as the risk for the general population in the USA seems to be a step towards achieving that goal.

DISCUSSION AND CONCLUSION

In this opinion paper, we have presented a summary of the current literature concerning vision training in sports performance and concussion. The implication being that appropriate sports vision training can improve performance for athletes in several sports. Also, the vision training that engages neuro visual pathways and neuro visual conditioning may decrease injuries such as concussions.

Vision training programs have shown both promising and equivocal results as it relates to sports performance.^{5,42,43} Clarity in choosing sports, athletes and matching vision training methods is needed in the

area of what types of vision training programs work best. Some studies show good results from pre-season training followed by maintenance of skills during the season, but these are limited studies and further studies are required.^{5,12} Heterogeneity in results can be assumed due to the varying structure of vision training programs across studies as well as varying degrees of pre-existing proficiency in neuro visual abilities.⁴² Methods of enhanced peripheral vision and reaction with the Dynavasion D2, incorporating executive functioning tasks with tachistoscope, and using strobe glasses to improve spatial processing all focus on training visual and executive functions at the same time. These training methods focus on the improvement in the processing of visual information and its translation in cognitive and motor function. Vision is an important sensory pathway with significance in ball sports, but the interaction of reaction, visual processing, and interpretation are also at play. Athletic performance and safety rely on spatial processing and immediate reaction to visual input as well as conscious decision making. Sensory input begins in the visual axis with information received via the retina and optic nerve and is processed in the visual pathways in the occipital lobe. The coordination between the visual axis and higher cortical processing and action then becomes the essence of visual training.

There is promise in the utility of vision training increasing performance and safety in the athletic arena, although more studies with improved controls and randomized controlled trials are needed. It can be assumed that training of peripheral vision, faster reaction times, and improved conscious processing of visual information will lead to enhanced performance and higher levels of safety, but the extrapolation of this into field results is yet to be determined. Concerning reduction to practice of vision training athletes, the concept of melding the performance enhancement with the injury prevention has promised with dealing with athletes, coaches, medical staff and administration. Athletes and coaches are encouraged to participate when motivated by performance enhancement. Administration and medical personnel can be engaged by the prospect of mitigating risks such as on-field injuries. Thus, we firmly believe that vision training

for the competitive athlete has a dual-threat of benefit that can be adopted by all concerned.

In conclusion, based on the research put forth thus far, there may be a benefit of incorporating vision training into athletic conditioning and training as a means of performance enhancement and injury prevention. While no studies demonstrated harm to the athlete as a result of vision training, initiation of a sports vision training program or neurovisual training should be performed in consultation with a trained eye care professional.

DISCLOSURE

The authors have no financial interests in the publication of this paper and the data herein.

REFERENCES

1. Blumenfeld H. Neuroanatomy Through Clinical Cases. Sinauer Associates, Inc.; Second edition (May 1, 2011). ISBN-13: 978-0878936137.
2. Kenney W, Wilmore J, Costill D. Physiology of Sport and Exercise. 6th ed. Human Kinetics; 2015. ISBN-13: 978-1450477673.
3. Ishigaki H and Miyao M. Differences in dynamic visual acuity between athletes and nonathletes. *Percept Mot Skills* 1993 Dec;77(3 Pt 1):835–9.
4. Kauffman DC, Clark JF, Smith JC. The influence of sport goggles on visual target detection in female intercollegiate athletes. *J Sports Sci* 2015;33(11):1117–23. doi: 10.1080/02640414.2014.987156. Epub 2014 Dec 24. PubMed PMID: 25537065.
5. Clark JF, Ellis JK, Bench J, Houry J, Graman P. High performance vision training improves batting statistics for University of Cincinnati baseball players. *PLoS ONE* 2012;7(1):e29109.
6. Clark JF, Graman P, Ellis JK. Depth perception improvement in collegiate baseball players with vision training. *Optom Vis Perf* 2015;3(2):106–15.
7. Mangine R, Clark J, Hasselfeld K. Vision training: preventing injury, enhancing athletic performance. *Training and Conditioning* May 18, 2016.
8. Wilkerson GB, Simpson KA, Clark RA. Assessment and training of visuomotor reaction time for football injury prevention. *J Sport Rehabil* 2017 Jan;26(1):26–34. doi: 10.1123/jsr.2015-0068. Epub 2016 Aug 24.
9. Goodale MA, Milner AD. Separate visual pathways for perception and action. *Trend Neurosci* 1992;15(1):20e25.

10. Medendorp WP, de Brouwer AJ, Smeets JB. Dynamic representations of visual space for perception and action. *Cortex* 2016 Nov 30. pii: S0010-9452(16)30338-0. doi: 10.1016/j.cortex.2016.11.013. [Epub ahead of print]
11. Hopwood MJ, Mann DL, Farrow D, Nielsen T. Does visual-perceptual training augment the fielding performance of skilled cricketers. *International J Sport Sci Coach* 2011;6(4):523–36.
12. Clark JF, Colosimo A, Ellis JK, et al. Vision training methods for sports concussion mitigation and management. *J Vis Exp* 2015 May 5;(99). doi: 10.3791/52648. PMID: 25992878.
13. Fullerton C. Eye, Ear, brain and muscle tests on Babe Ruth. *Western Opt World* 1925;13(4):160–1.
14. Hitzeman SA, Beckerman SA. What the literature says about sports vision. *Optom Clin* 1993;3(1):145–69.
15. Stine CD, Arterburn MR, Stern NS Vision and sports: a review of the literature. Stine CD, *J Am Optom Assoc* 1982;53(8):627–33.
16. Stein RM, Squires G, Pashby T, Easterbrook M. Can vision training improve athletic performance? *Can J Ophthalmol* 1989;24(6):295.
17. Paterno JV. Importance of vision in college athletics. *J Am Optom Assoc* 1980 Jul;51(7):654.
18. Millslagle DG. Dynamic visual acuity and coincidence anticipation timing by experienced and inexperienced women players of fast pitch softball. *Percept Mot Skills* 2000 Apr;90(2):498–504.
19. Beals RP, Mayyasi AM, Templeton AE, Johnston WL. The relationship between basketball shooting performance and certain visual attributes. *Am J Optom Arch Am Acad Optom* 1971;48(7):585–90.
20. Sanderson FH, Whiting HT. Dynamic visual acuity: a possible factor in catching performance. *J Mot Behav* 1978;10(1):7–14.
21. Morris GS, Kreighbaum E. Dynamic visual acuity of varsity women volleyball and basketball players. *Res Q* 1977;48(2):480–3.
22. Gao Y, Chen L, Yang SN, et al. Contributions of visuo-oculomotor abilities to interceptive skills in sports. *Optom Vis Sci* 2015;92(6):679–89.
23. Classé JG, Semes LP, Daum KM, et al. Association between visual reaction time and batting, fielding, and earned run averages among players of the Southern Baseball League. *J Am Optom Assoc* 1997;68(1):43–9.
24. Poltavski D, Biberdorf D. The role of visual perception measures used in sports vision programmes in predicting actual game performance in Division I collegiate hockey players. *J Sports Sci* 2015;33(6):597–608. doi: 10.1080/02640414.2014.951952.
25. Ciuffreda KJ. Simple eye-hand reaction time in the retinal periphery can be reduced with training. *Eye Contact Lens* 2011;37(3):145–6.
26. Zwierko T, Puchalska-Niedbał L, Krzepota J, et al. The effects of sports vision training on binocular vision function in female university athletes. *J Hum Kinet* 2015;49:287–9.
27. Mazyn LI, Lenoir M, Montagne G, et al. Stereo vision enhances the learning of a catching skill. *Exp Brain Res* 2007;179(4):723–6.
28. Wood J, Abernathy B. An assessment of the efficacy of sports vision training programs. *Optom Vis Sci* 1997 Aug;74(8):646–59.
29. Abernathy B, Wood JM. Do generalized visual training programmes for sport really work? An experimental investigation. *J Sports Sci* 2001 Mar;19(3):203–22.
30. McLeod B. Effects of eyerobics visual skills training on selected performance measures of female varsity soccer players. *Percept Mot Skills* 1991;72:863–66.
31. Wilkerson GB. Neurocognitive reaction time predicts lower extremity sprains and strains. *Int J Athlet Ther Train* 2012;17:4–9.
32. Herman D, Zaremski J, Vincent H, Vincent K. Effect of neurocognition and concussion on musculoskeletal injury risk. *Curr Sports Med Rep* 2015;14(3):194–99.
33. Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. *Am J Sports Med* 2012;40(4):747–55.
34. Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. *Clin Sports Med* 2011 Jan;30(1):1–17, vii. doi: 10.1016/j.csm.2010.08.006. Review.
35. Gessel L, Fields S, Collins C, Dick R, Comstock RD. Concussions among United States high school and collegiate athletes. *Journal of Athletic Training* 2007;42(4):495–503.
36. Clark JF, Elgendy-Peerman HT, Divine JG, Mangine RE, Hasselfeld KA, Houry JC, Colosimo AJ. Lack of eye discipline during headers in high school girl's soccer: possible mechanism for increased concussion rates. *Medical Hypotheses* 2017;100:10–14.
37. Clark JF, Graman PM, Ellis JK, et al. An exploratory study of the potential effects of vision training

- on concussion incidence in football. *Optom Vis Perf* 2015;3(2):116–25.
38. Zuckerman S, Kerr Z, Yengo-Kahn A, Wasserman E, Covassin T, Solomon G. Epidemiology of sports-related concussion in NCAA athletes from 2009-2010 to 2013-2014. *Am J Sports Med* 2016 Jan;44(1):NP5. doi: 10.1177/0363546515623241.
39. Clark JF, Ellis JK, Burns TM, Childress JM, Divine JG. Analysis of central and peripheral vision reaction times in patients with postconcussion visual dysfunction. *Clin J Sport Med* 2017 Sep;27(5):457–61.
40. Bixenmann B, Bigsby K, Hasselfeld KA, Khoury J, Mangine RE, Pyne-Geithman GJ, Clark JF. Retinal and balance changes based on concussion history: a study of division 1 football players. *Int J Phys Med Rehabil* 2014;2:5 <http://dx.doi.org/10.4172/2329-9096.1000234>.
41. Bigsby K, Mangine RE, Clark JF, et al. Effects of postural control manipulation on visuomotor training performance: comparative data in healthy athletes. *Int J Sports Phys Ther* 2014 Aug;9(4):436–46. PMID: 25133072.
42. Schmidt J, Guskiewicz K, Mihalik J, Blackburn JT, Siegmund G, Marshall S. Does visual performance influence head impact severity among high school football athletes? *Clin J Sport Med* 2015;25(6):494–501.
43. Clark JF, Mangine RE, Divine JG. In response: does visual performance influence head impact severity among high school football athletes? *Clin J Sport Med*: October 17, 2016 - Volume Publish Ahead of Print - Issue – ppg. doi: 10.1097/JSM.0000000000000335.