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Vision Training Methods for Sports Concussion Mitigation and Management

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Abstract:	There is emerging evidence supporting the use vision training, including the Dynavision D2 (a light board training tool and FDA cleared medical device), as a concussion baseline and neuro-diagnostic tool and potentially as a supportive component to concussion prevention strategies. This paper is focused on providing detailed methods for select vision training tools and reporting normative data for comparison when vision training is a part of a sports management program. The overall program includes standard vision training methods including tachistoscope, Brock's string, and strobe glasses, as well as specialized light board training algorithms. Stereopsis is measured as a means to monitor vision training affects. In addition, quantitative results for vision training methods as well as baseline and post-

	testing A* and Reaction Test measures with progressive scores are reported. Collegiate athletes consistently improve after six weeks of training in their stereopsis, *A and Reaction Test scores. When vision training is initiated as a team wide exercise, the incidence of concussion decreases in players who participate in training compared to players who do not receive the vision training. Vision training produces functional and performance changes that, when monitored, can be used to assess the success of the vision training and can be initiated as part of a sports medical intervention for concussion prevention.
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Vision Training Methods for Sports Concussion Mitigation and Management

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SHORT ABSTRACT:
This paper describes a protocol to conduct, quantitatively monitor, and assess the success of vision training initiated as part of a sports medical management program including intervention for concussion prevention and performance enhancement.

LONG ABSTRACT:
There is emerging evidence supporting the use vision training, including light board training tools, as a concussion baseline and neuro-diagnostic tool and potentially as a supportive component to concussion prevention strategies. This paper is focused on providing detailed methods for select vision training tools and reporting normative data for comparison when vision training is a part of a sports management program. The overall program includes standard vision training methods including tachistoscope, Brock's string, and strobe glasses, as well as specialized light board training algorithms. Stereopsis is measured as a means to monitor vision training affects. In addition, quantitative results for vision training methods as well as baseline and post-testing *A and Reaction Test measures with progressive scores are reported. Collegiate athletes consistently improve after six weeks of training in their stereopsis, *A and Reaction Test scores.. When vision training is initiated as a team wide exercise, the incidence of concussion decreases in players who participate in training compared to players who do not receive the vision training. Vision training produces functional and performance changes that, when monitored, can be used to assess the success of the vision training and can be initiated as part of a sports medical intervention for concussion prevention.

INTRODUCTION:
Vision training, including the use of light board vision systems, has gained popularity as a means to improve sports performance[1,2]. Light board systems are often used for rehabilitation following brain injury[2,3] and for sports performance enhancement as part of a vision training regimen[1,4,5]. Vision training has also been used as a means of injury prevention[6].

The University of Cincinnati (UC) Division of Sports Medicine has used a light board vision tool for concussion management, diagnosis, return to play decision making, injury prevention and rehabilitation of athletes and performance enhancement[3,5,7]. Each athlete has baseline measurements collected at the beginning of the season and these values are used as a part of the concussion management program and specifically for an athlete's post-concussion evaluation and treatment. One of the strengths of the tool is the objective data collected: number of hits per unit time, location within the visual field of each hit, average reaction time per hit, multi-tasking drills and temporal output for observing progress.

The UC sports medicine team has used the *A and Reaction Test as part of concussion baseline assessments. Three additional, purpose built, programs are also used for concussion diagnosis. These are called Concussion 1, Concussion 2 and Concussion 3. The 3 concussion tests do not need to be included among the preseason baseline tests, because their differing levels of complexity allow each test result to serve as a reference for the others in the set.

When the programs are complemented with additional vision training methods the athlete gets a thorough training and the clinician obtains a wealth of baseline data in the event of a concussion. Several additional vision training methods complete the comprehensive program: Brock's string, EYEPORT training, accommodative flippers, tachistoscope, pinhole glasses or strobe glasses with pitch and catch, saccadic eye movement training, and near far training. This paper presents vision training methods with and without a light board system, normative data for baseline results for Division 1 college football players, and expectations and protocols concerning the use of the vision training protocol as part of a concussion management program.

PROTOCOL:

The protocol described below has components of a vision training program that is a part of the baseline testing performed on all UC athletes. Some of the components have been studied in research trials and in these instances the protocols were approved by the UC Institutional Review Board and the subjects signed informed consent statements.

1. Light Board Vision Training (takes about 8 minutes to complete this training)

1.1. *A Program[8-11]

1.1.1. Direct the subject to stand about 12 inches away from the light board and have the subject try to reach the lights in the outer ring. Move the subject closer or farther away if needed in order to reach all of the lights. Additionally, move the light board up and down using a power switch on the side so the subject is at eye-level with the center display board.

1.1.2. Have the subject stand in a ready position to be able to hit the lights. Have the subjects hold their hands up to their chest level to position the hands in the center of the rings.

1.1.3. Instruct the subject to hit the lights using both hands as fast as possible and deactivate as many as possible in one minute. Each light will remain illuminated until hit.

Note: When a subject successfully hits a light there is a beep that they can hear in addition to the light turning off.

1.1.4. Have the clinician select the *A program and have the subject hit (deactivate) as many lights as possible in one minute. With experience a subject will become comfortable with the menu for the system and be able to start the *A without assistance from the clinician, if desired.

1.1.5. Record the number of hits per minute for each session to track progress along with the average reaction time in seconds for the hits during the one minute test.

1.2. Reaction Test Program[11]

Note: The Reaction Test Program consists of six different tests, three for the right hand and three for the left hand.

1.2.1. Instruct the subject to select the Reaction Test and hit start. The lights for Test 1R (right hand) will light sequentially three times to show the subject which lights they will be hitting. Once the lights are done flashing in sequence, there will be a light to the right that will be lit for the first test. The five horizontal lights to the left of the center ring are utilized for Test 1R and the five to the right of the center are utilized for Test 1L.

1.2.2. Instruct the subject to hold down the lit light to the right (with right hand) and stand in front of and in the middle of the row of lights that lit up during the demonstration. Have the subject hold the left hand behind his/her back.

1.2.3. Have the subject scan the five horizontal lights that light up during the demonstration sequence. One of the five lights will come on randomly within five seconds. The distance between each light in the horizontal row is 14 inches. Have the subject move the right hand from the initial light to the reaction light as quickly as possible and deactivate it. (Figures 1A-C)

1.2.4. Once the subject completes a pre-determined number of hits, typically 5 times, instruct him/her to press the GREEN light at the bottom of the inner ring of lights. This will show the subject which lights for the next test will be involved. When ready, the subject holds down the lit light on the left, holds the right hand behind the back, and follows the above procedures. Point out to the subject to disregard the bottom green light during these tests as it is used to change from one test to another but is not one of the lights to be hit.

Note: Tests 1R and 1L involve a linear random target switch. Tests 2R and 2L are again random, unknown targets, which will appear along an arc in one of eight different planes. It is the middle ring of lights that is used for Test 2R and 2L. Tests 3R and 3L are a simple one light choice using the lights to the right and left of the t-scope.

1.2.5. Record the average reaction time for each Test plus an overall Reaction Time.

1.3. Concussion 1-3 Programs (novel programs developed by author JFC).

Note: The three programs are designed to be performed in sequence. The learning effect is seen in normal individuals. However, in concussion patients the learning effect is not seen and is considered as diagnostic for concussion. These programs are used for testing, not training. For the concussion testing The Dynavision A* and Dynavision Reaction Test can be used for baseline assessments. The three concussion tests are also used for concussion assessment but are generally not done by subjects in advance. The three concussion tests are designed to be multi-tasking and executive function tests that the subjects have not seen before[7].

1.3.1. Conduct the concussion 1 program, a one minute test that uses only the middle three concentric rings. The test is similar to the *A test, except the subject has single digit numbers (random numbers 1 through 9) flashing on the programmable screen for one second at eight second intervals. Ask the subject to read the numbers flashed on the screen out loud to the tester while still hitting the buttons that are lighting. The resultant score is the number of hits per minute and a report of missed numbers (if any).

1.3.2. Conduct the concussion 2 program, which is similar to Concussion 1 in that single digit numbers flash on screen. Instruct the subjects to call out the first number while still hitting buttons, remember it, and then when the second number flashes, add the first and second numbers together and call out the sum of the numbers. The subject continues to hit buttons while calling and adding numbers in pairs.

1.3.3. Conduct the concussion 3 program, which is similar to Concussion 2 with one additional task; 20% of the buttons are green. The subject is instructed to hit buttons and add numbers in pairs similar to the instructions in 1.3.2. In addition to those tasks, instruct the subject to hit the green buttons and also call out green. Therefore, there are two speaking tasks, calling green while calling and adding numbers in pairs. This is all done while hitting the both colors of buttons.

2. Brock's String[6,10,12]

2.1. Hold one end of the Brock string on the tip of the subject's nose while the other end is tied to a fixed point. The fixed point can be horizontal, elevated or declined with respect to the height of the nose point. Neutral is straight ahead (horizontal). The up or down angle should not be more than 45° in either direction. Typically the elevation is progressed from 10° to 25° to 45° over a time frame where the tasks are challenging but still comfortable. With some people who have prominent noses or eye brows there may be anatomic limitations that need to be observed.

2.2. Space the five colored beads on a length of string at least 12 inches apart starting about 10 inches from the nose. Instruct the subject to alternate fixation and focus from one bead to the next while noting the visual input of each eye and sensation of convergence (formation of an image at a single point). A measurement is not recorded as this is used as an exercise instead of a test.

2.2.1. Vary the spacing according to subject's needs. Needs may be based on sport or task. For example combat sports such as boxing may need more beads less than 3 feet away. Whereas field sports such as football and soccer might need beads around 10 feet. (Figures 2A-C)

2.3. Alternatively, use a task where the string is six feet and tied off at one end. Many people have a reach from their nose to the tip of their fingers of 4 feet. The farthest bead is placed at the extreme reach of the index finger. The subject touches the bead with his index finger and returns it to the side of the leg, alternating the right and left hands.

2.4. Alternatively, use a wand with tape the color of the ball on the Brock string. Space the tape three inches apart. When performing the exercise, instruct the subject to match the color of the tape on the wand to the color of the ball, calling out each color as he matches ball to tape.

3. EYEPORT Training[13]

3.1. For training 1, place alternating red and blue linear lights in the horizontal position and instruct the subject to sit 24 to 30 inches from the system. Have the subject hit the enter button to hear ten beeps and then follow the lights with his/her eyes. When the exercise is over the subject will hear a beep and should then close his/her eyes and rest until the next exercise.

3.2. For training 2, place the linear lights in the vertical position and repeat steps for Exercise 1.

3.3. For training 3, rotate the linear lights to the left from the vertical position and repeat steps for Exercise 1. Rotation is done in stages through 360 degrees. Common stages are 20 degrees at a time providing it is comfortable for the subject.

3.4. For training 4, rotate the linear lights to the right from the vertical position and repeat steps for Exercise 1.

3.5. For training 5, reposition the linear lights so the system touches the end of the subject's nose. Instruct the subject to follow the lights from near to far and far to near.

Note: Instruct the subjected to rest after each exercise before going to the next one. A measurement is not recorded as this is used as an exercise instead of a test.

4. Accommodative Flippers

4.1. Allow the subject to wear his/her habitual prescriptions. Perform all training binocularly.

The power of the flipper lenses used is varied to optimize the training effect. The two powers used should be challenging but not onerous to focus on an object as the flippers are alternated.

4.2. Instruct the subject to hold a 10 x 10 saccades chart at 14 inches from the spectacle plane.

4.3. Instruct the subject to read from left to right while moving the flippers up and down repeatedly. The flippers are moved only after the subject can focus on and read the saccade card.

4.4. Test for one minute or until the 100th character is reached.

4.5. Count and record the number of characters read in the one minute.

5. Tachistoscope

Note: This training uses a PowerPoint presentation designed by author J Clark.

5.1. Have the subject watch the timed presentation and make note of one or two specific bits of information based on questions posed after the flash. Typically several subjects can work on the projected tachistoscope training simultaneously.

5.2. As the flashed pictures have numbers and or letters randomly distributed throughout the pictures, have the subject note the numbers/letters. Also, ask additional questions such as player numbers from the photos, teams being played, etc.

5.3. Make the tachistoscope training progressively more complicated, by making the flash time shorter and/or the information to be obtained more complicated. (Figures 3A and B). The percentage of questions answered correctly can be recorded.

6. Pinhole Glasses or Strobe Glasses with Pitch and Catch

6.1. Give groups of subjects, typically two to six subjects, with 1 or 2 balls, pinhole glasses (Figure 4A) or strobe glasses (Figure 4B) and advise to throw the ball(s) around for approximately 2 - 5 minutes per session. (Figures 4C and 4D) Two to three sessions per week can be performed.

6.2. If strobe glasses and pinhole glasses are available, have subjects rotate strobes and pinhole glasses every minute or two. Strobe glass flash speeds start at the faster speeds and are slowed to make the tasks more challenging. Current strobe glasses have 8 speeds so typical starting speeds are 1 or 2, and are slowed to speeds 4 to 6.

6.3. Progress through the pitch and catch tasks throughout the sessions by varying the speed of the flash with the strobes or narrowing the visual field of the pinhole glasses.

6.4. Also, make the pitch and catch routines more complicated by having subjects turn away from their partner and having to turn and catch. A measurement is not recorded as this is used as an exercise instead of a test.

7. Saccadic Eye Movement Training[6,10,14]

7.1. Position the subject eight feet away from the saccadic eye charts and centered between two saccadic charts, which are positioned about five feet from the center line. Prior to beginning the exercise, ensure that the subject has full range of eye motion in order to see all letters on the saccadic chart. Adjust the distance from the charts accordingly to gain full vision of the chart.

Note: It is important to change distances to add a dynamic component to the accommodative systems and therefore subjects are asked to stand 8 feet away as opposed to the 12 feet used for light board training. There are vision training programs out there that use only a computer and computer screen and do not exercise the accommodative systems. So vary the lengths at which the tasks are performed. Each saccadic chart is constructed on an 8.5 x 11 inch sheet of paper. Each chart has 10 letters in a 36 point font per vertical line with 10 vertical lines on the chart (Figure 5).

7.2. Instruct the subject to read the charts for one minute each while keeping his/her head still and only moving his/her eyes. Ask the subject to read the first letter on the first line on the first chart and then alternate to the second chart to read the first letter of the first line. This completes one cycle.

7.3. Instruct the subject to read the second letter of the left chart followed by the second letter of the right chart. This completes another cycle. Alternate between charts and letters progressing across the line horizontally. As the subjects complete the first line on both charts, instruct them to move to the next line, etc., for one minute. Record the number of cycles completed in the one minute.

7.4. Place the charts at eye level and distance them six feet apart. A progression of this training exercise includes using unstable surfaces and varying placement of the charts to enhance eye speed and visual focus.

8. Near Far Training[6,10,14].

8.1. Utilize two charts for this exercise - a large chart and a smaller one. Use the saccadic eye chart for the large chart. Construct the small chart on a 3.5 x 2.5 inch sheet of paper where there are 10 letters in a 12 point font per vertical line with 10 vertical lines on the chart.

8.2. Fix the far chart at eye level with the subject positioned 10 feet from the chart. Have the subject hold the near chart with one hand approximately 4 – 6 inches from the nose. This allows the subject to see over the near chart to see the far chart (Figure 6A).

8.3. Instruct the subject to keep his head still and only move the eyes. Ask the subject to read the first letter on the first line of the far chart and then alternate to the near chart to read the first letter of the first line. This completes one cycle (Figures 6B and 6C).

8.4. Have the subject scan the eyes to read the second letter of the far chart followed by the second letter of the near chart. This completed another cycle.

8.5. Instruct the subject to alternate between charts and letters progressing across lines horizontally. As the first line on both charts is completed, have the subject move to the next line until the time expires for the one minute session. Record the number of cycles completed in the one minute.

8.6. Instruct the subject to be sure that both eyes come into focus on the near target as well as the far target when alternating from chart to chart.

9. Stereopsis

9.1. Place polarizing glasses on the subject and ask if “the Stereo Fly’s wings appear to be standing up at them and in three dimensions?”

9.2. Instruct subjects to observe the Stereo Fly at a distance of 14 inches from their nose. If the response is positive, instruct subjects to “reach out and point with a pen to the Stereo Fly’s right wing tip and to hold that position” (Figure 7A).

9.3. Record the distance between the photo and the center of the pinch with a millimeter ruler (Figure 7B).

Note: The higher the number, in mm, is indicative of better stereopsis when measured on the Stereo Fly[15] Based on our experience we have found that 85 mm appears to be the upper limit of the distance from the photo to the center of the pinch[3].

REPRESENTATIVE RESULTS:

Baseball, football and volunteer subjects have participated in the vision training program. All subjects have been college age men or women, between the ages of 18 and 26-years-old.

Football

The average *A score for 101 UC Football players the first time they performed it was 74.2 ± 10.3 hits per minute (hpm) and the average Reaction Test time for their first time performing it was 0.34 ± 0.03 seconds (n=79, note not all 105 players had a chance to complete the Reaction Test).

Sixty-three players were exposed to multiple years of light board training. The players participated in training pre-season and weekly during the season for maintenance. The first *A run on for these players was 70.25 ± 9.61 hpm and significantly improved with training to 89.9 ± 10.5 hpm (P≤0.01). Reaction Test results were 0.354 ± 0.034 seconds (s) and improved to 0.315 ± 0.031 s after training; P ≤ 0.001. The average number of repetitions of the *A program per athlete among the entire group was 7.31 ± 9.12.

Table 1 consists of data for 63 UC Football players who had trained on the light board for over a minimum of three years. The table shows the average times it took for the players to hit the individual rings. The outer rings took longer times to hit as opposed to the rings in the center of the board, which is the center of the visual field.

Peripheral vision reaction time ratio can be calculated to determine a subject's speed of reaction to what they see in their peripheral vision. The data collected during the *A session is used to calculate the average reaction timein the outer two rings of the vision board compared to the inner three rings. Each subject's peripheral vision reaction time ratio from one training session to another is calculated as the ratio of the mean reaction times for the outer two rings divided by the mean of the reaction times for the inner two rings and provides a data point in addition to the average reaction time. A higher ratio means it takes longer to see and hit the buttons in the periphery compared to the center of the visual field.

Table 2 shows the average time it takes for 10 players to hit the different rings when they start the vision training pre-season[7]. Data reported for each subsequent year reported is for the players who completed the vision training program each year. At the beginning of the season the team's intake values are repeated and tend to come to similar values for the first 3 years. After 4 years of vision training the sustained benefits of the training appears.

Table 3 consists of the first time on the system *A scores and Reaction Test scores broken down into groups based on years of play, positions, skilled or unskilled positions, or history of concussion[16].

Volunteers

Table 4 summarizes the data collected from 20 non-football volunteers completing the three purpose built concussion programs (Concussion 1-3). These results of 10 men and 10 women volunteers represent normative data values for these more complex test programs. This reveals that with increased multi-tasking of the concussion tests there is no significant decrement in performance between Concussion 1 to Concussion 3. The slight increase in performance from

Concussion 1 to 3 is also not significant, but could be an indication of a training effect.

Baseball

From the preseason (January) 2011 through to the end of the season (May) 2013 all hitters on the UC Division 1 Baseball Team underwent regular vision training. Out of season training was 20 minutes twice a week and in season was 20 minutes once per week. Traditional stereopsis (Stereo Fly) was performed and recorded. Players consistently presented with stereopsis ranging from 22 to 25 mm at the beginning of training. As a team they went back to this level consistently between seasons. Training increases this stereopsis effect. The 45 to 50 mm levels were consistently reached by the players during the season, data is in press.

Table 5 summarizes the average and standard deviation for the stereopsis measurements in mm for the UC Baseball Team as measured through the three years of vision training[5].

Table 1. Average length of time for hits per ring for the *A test for 63 UC Football players.

Table 2. Average length of time (in seconds) for hits per ring for the *A test per season of play (n=10 each year).

Table 3. Best *A and best Reaction Test times sorted by years of play, position, skilled or unskilled position and history of concussion.

Table 4. *A results for 20 volunteers who completed the three purpose built programs: Concussion 1, Concussion 2, and Concussion 3.

Table 5. Stereopsis measured for UC Baseball players through the three years of vision training. Statistical significance is reported as $P<0.05$.

Figures 1. Subject demonstrating placement in front of the system and ready for the start of a program. A: In front of the system. B: Placement of hand to start the first test. C: Hand sweeps left to the light that is lit.

Figures 2. Subject demonstrating Brock's string method. A: Focus on distant bead. B: Focus on closest bead. C: View from subject's perspective.

Figures 3. Tachistoscope - photos from UC football games where subject is asked to re-call the numbers in the box plus elements of the photo like player number.

Figures 4. A: pinhole glasses. B: strobe glasses. Subject catching ball with strobe (C) or pinholes (D) glasses on.

Figure 5. Saccade chart.

Figures 6. Placement of charts for near far training (A). Subject demonstrating this method (B and C).

Figures 7. A: subject pinching wing of Stereo Fly. B: calipers used to determine the distance.

DISCUSSION:

Vision training, when initiated as a team wide exercise, decreases the incidence of concussions in those players when compared to players who do not receive the vision training[7]. Vision training produces functional and performance changes that can be quantitatively monitored to assess the success of the training and can be initiated as part of a sports medical intervention for concussion prevention. Functional changes are something changes in the measurement, for example faster reaction times documented during vision training. The goal is to have a change in performance, such as an improved performance change when a snap off the ball is improved.

Details of vision training program methods and representative data are provided to be used as a frame of reference for clinicians who choose to use components of the training methods in their concussion management programs. These data references can also be used when monitoring a subject during recovery from an injury using one of the light board programs.

Components of the vision training program include the following. ***A Program** used traditional eye-hand reaction training to challenge an individual's eye hand coordination in multiple visual fields. **Reaction Test Program** assesses and trains visual and motor reaction times for the left and right hands. **Concussion Programs** used as a means to assess and monitor subjects who have had a concussion. **Brock's String** used to develop skills of convergence, ocular motor performance as well as to minimize suppression. It also helps fixation skills under binocular conditions. **Eye Exercises** designed to improve visual performance by training the speed, accuracy, and efficiency of the eyes. **Accommodative Flippers** used to enhance the reflex action of the eye to make the accommodative muscles move faster and with precision. **Tachistoscope** used to increase recognition speed, to show something too fast to be consciously recognized, or to test which elements of an image are salient. **Pinhole Glasses or Strobe Glasses with Pitch and Catch** used improve vision processing and focus. **Saccadic Eye Movement Training** used to develop the fast movement of the eyes. **Near Far Training** used to focus the eyes near and far. **Stereopsis** designed to evaluate both gross stereopsis and fine depth perception. Subjects can do all the types of training. Note that the concussion programs are not training. They are for testing purposes only.

Athletes consistently improve after vision training in their *A, Reaction Test and stereopsis scores. In addition, improvement in concussion assessment tasks are seen, which are increasingly more complicated by design.

It is critical steps that the subjects have pre-season and in season training to see maintained benefits. Twice a week, 20 minutes at a time for six weeks, has been found to benefit the athletes as does six times per week for 2.5 weeks in the pre-season. Then in season once per week can be performed as a maintenance program. The training also needs to be sport and or position specific when practicable, for example, trainings that include speed and strength of eye hand coordination for linemen on a football team versus trainings that include speed and precision for a wide receiver. Linemen have the task to quickly control the other linemen's arms which requires great strength and quick hands. This can be trained on the Dynavision with resistance bands on a person's wrists. Receivers need good eye-hand coordination with very good precision to be able to catch the balls under very dynamic circumstances such as while running down the field.

The training methods were adopted and pooled from existing methods and demonstrated to be effective in two different college sports[3,5,7,17]. Previous studies were anecdotal and not scientific whereas the methods described in this paper have been validated[3,5,7]. Therefore, these methods help the sports medical professional by demonstrating what to do and how to do the vision training to maximize their success in player performance and safety.

Injury prevention from improved functional peripheral vision could result from the athlete's improved recognition of what is occurring in their peripheral vision and a quicker response time without removing primary vision from the initial target[1,2,9]. For example, in the case of a wide receiver in football who has his central visual field on the football in the air, but has an oncoming defender approaching in his peripheral vision, that player may be able to make the catch while preparing to avoid or protect himself from the oncoming defender with a faster reaction time. Coaches often preach using peripheral vision during competition, but in the case of the light board system and the ratio of outer to inner rings training is quantitatively measuring the fidelity of peripheral vision. Peripheral vision's ability to discern colors and movement is a component of fidelity of peripheral vision. For the athlete doing vision training the ability to recognize an adversary versus the same team in the peripheral vision better would be considered an improvement in the fidelity of peripheral vision.

In Table 1, the outer rings take longer times to hit as opposed to the rings in the center of the board, which is the center of the visual field. One explanation may be that the increased distance to travel to reach the outer rings explains the delayed reaction time. While that may be somewhat true, if the distances required to reach the buttons as a cause of the time it takes were examined, ring three would be expected to have the fastest times as this is approximately shoulder width (21.5 inch diameter) where subjects tend to have their hands in a neutral position. Hands hitting ring three, therefore, would have the shortest distance to travel. What are seen in Table 1, however, are progressively longer times taken to hit the buttons based on distances from the central visual field. We take this to be support that the eye hand reaction times are faster in the central visual fields and slower in the peripheral visual fields.

Interpretation of the Concussion Tasks

Concussion 1 is a dual task or multi-tasking test. It requires the subject to perform a continuous visual-motor task (hit buttons) while also processing intermittent visual-speech information (calling numbers that appear on the screen). In this age group and based on our experience, a normal test should be 70 hits for the score for the first run on the Dynavision. This is based on our empirical experience of hundreds of college level athletes. Concussion 2 is a dual task utilizing executive function. It requires memory and the use of that memory to add numbers. Athletes should be able to do this task with little to no diminution in the mechanical performance of hitting buttons. With normal healthy athletes, this test should be 70 hits or above, with no substantial pauses and no more than one missed number or addition errors. Concussion 3 is a multi-tasking, memory and frontal lobe / differentiation task. The cognitive demand for this task requires many areas of the brain to work together with minimal decrement in the primary motor task. Subjects should call "green" only when or shortly after a green light occurs. The task also requires the subject to decide what to call, as well as to remember numbers when an interrupted speaking task occurs.

Comparing the scores from Concussion 1, Concussion 2 and Concussion 3 tests, there was a small and non-significant improvement in scores as the multi-tasking is increased. This is likely a practice effect. The Concussion 1 to 3 programs are progressively more complex, but normal healthy individuals are shown here to improve their motor performance while performing more complex tasks; although not significantly. When a suspected concussion patient has a substantial fall in performance an impairment in complex brain multitasking may be indicated.[10,18] Based on these data, a range of 10% for scores in the three Concussion programs be considered normal for an individual. Similarly if a subject has had a baseline test based on recent papers[11,13,19,20], the scores are repeatable, thus a greater than 10% decrement should be considered indicative of an abnormal test. Individual practitioners need to use their clinical judgment when making a diagnosis[21].

When the *A and Reaction Tests along with all three concussion tasks are completed, the subject has numerous cognitive systems assessed: motor, vision, left right symmetry, memory, executive function, multi-tasking, and consistency through the five tasks. It takes approximately eight minutes to complete all five tests. Careful observation of the suspected concussion patient can provide additional information concerning the performance of the subject[22]. For example; systematic errors when missing buttons can be observed in some subjects post-concussion suggesting a visual field deficit or peripheralization. Peripheralization is generally used by neurologic and related health care workers to describe the general phenomenon where a patient uses one side more than the other. It includes hemiparesis, neglect and conversion disorders. The sum of these observations can be used by the diagnosing clinician to make an assessment of the subjects' cognitive status.

Interpretation of Stereopsis Measurements

To perceive the distance of an object, or its depth of field, the brain uses the eyes' vergence angles and size information to determine distances. The brain uses the eyes' angles for convergence to estimate distance. This information, for a baseball player, is important for determining speed and trajectory of a ball; whether a pitch, throw or hit. The Stereo Fly tends to assess the depth perception skill of the vergence. Vision training improves this depth perception measure and by extension may help a subject improve their ability to assess the characteristics of a ball in flight. Baseball players use and need depth perception at distance (fielders etc.) as well as up close (hitters and infielders) to maintain field awareness and optimal performance. Improved depth perception for a batter might mean being less likely to be fooled by a change-up pitch[23-25].

If it is assumed that the vision training has a causal effect concerning the stereopsis changes observed, it begs the question why might this occur. It is possible that the vision training, which includes ocular motor and neuro visual conditioning, leads to an improvement in the coarse and fine motor control of the extra ocular and intra ocular muscles of the eyes. This likely includes an improvement in proprioception. The eyes are able to more precisely "focus" on a point, remain there with good "eye discipline" and give the brain better information concerning vergence. Hence the brain improves its depth perception. To an extent in the players this may help increase awareness of where that point is in physical space. It is highly likely that the Stereo Fly results were improved because the ability to detect the angles for the triangulation was better. This could occur with an improved proprioception of the extraocular muscles and/or improved precision as to the position of the eyes. The timing of the improvements is consistent with a muscle training effect. As mentioned in the results, the players consistently come into the season with stereopsis 23.7 mm and six weeks of training increases this stereopsis to and improve to 36.9 mm. The players return from the off season, and after not doing vision training for six plus months with stereopsis numbers similar to their baselines. This suggests that there is a detraining affect in the absence of vision training.

Neurovisual processing coupled with the ocular motor proprioception is believed to improve stereo depth perception, which is the ability to use the convergence angles to perceive depth [8,26]. This improvement is lost during the off season, which is consistent with a detraining effect. At this time we cannot determine if extended continuous vision training over years would provide better benefits as we see detraining when vision training is discontinued post season. Either way, the vision training has apparent positive benefits. Continued or regular vision training can regain and/or maintain these improvements.

Troubleshooting. Vision and/or eye exercises can often cause eye fatigue or headache. This is likely related to a type of delayed onset muscle soreness and should be considered as normal, but resolved before a season starts. It is also an important reason why training must start pre-season and be in a maintenance phase in season. Decreasing or changing the training sessions can lessen the eye fatigue should this occur. If headache or discomfort persists an eye care and or healthcare professional should be consulted.

Limitations. The limitations of the study are that it takes time to do the training and the training should begin pre-season. When practicable it is best to have baseline data on subjects, but with large teams that is often difficult. Some tasks do have drawbacks with pre-existing ocular motor problems. For example double vision due to "cross eyed" adduction can be exacerbated with Brock's string. Therefore good eye health and tolerance ranges should be verified by a trained optometrist or ophthalmologist before starting a vision training regimen.

The current report provides a unique perspective on the improved depth perception of high caliber athletes following vision training. A previous paper indicated improved performance with vision training[3], and the current results reinforce vision training for performance enhancement. The emerging data also indicates that depth perception and vision training can continue to improve concerning performance enhancement as well as injury prevention[7].

As we have seen improvements in reaction times and improvements in peripheral vision we ascribe these in part to improvements in brain processing. We believe that improved visual acuity cannot account for such changes as the brain processing is needed to have eye hand coordination speed changes. Regarding the peripheral visual fields the retina's cones and rods may be functioning but the brain is not processing those signals to the fullest degree. The vision training that results in improved peripheral vision is most likely to occur along with constitutive brain processing changes. Future research to assess the brain's changes with vision training are needed to better address this.

Future work to better optimize the methods used to improve certain tasks as well as what metrics to use when monitoring the success of the vision training methods is warranted.

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The authors have nothing to disclose.

The Dynavision D2 may be a tool that clinical practitioners can use to provide added information concerning neurologic health of the athlete with a concussion[10,22,23,27]. The device does not make the diagnosis but assists the clinician in making a clinical decision by providing objective measures of the performance parameters for that patient or athlete.

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Figure 1C

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Figure 2A

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Figure 3A
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Figure 3B
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Figure 4A
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Figure 4B

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Figure 4C

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Figure 4D

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Figure 5

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I	O	Q	P	M	C	Z	E	B	L
Y	W	T	S	A	H	F	3	R	V
B	4	K	J	D	W	T	N	C	4
5	U	Q	L	R	M	W	P	K	Y
V	Q	2	I	K	I	G	2	D	B
O	P	A	T	X	M	6	E	X	1
U	C	G	M	W	P	O	X	Z	Q
8	B	K	D	B	7	1	9	X	F
F	A	Q	Z	D	N	C	O	E	P
U	V	C	2	H	G	J	H	L	U

Figure 6A
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Figure 6B
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Figure 6C
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Figure 7A

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Table 1
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Variable	Ring 1 Mean ± SD	Ring 2 Mean ± SD
Average length of time to hit (seconds)	0.52 ± 0.08	0.57 ± 0.11
Diameter of rings (inches)	8.125	17.25

Ring 3 Mean ± SD	Ring 4 Mean ± SD	Ring 5 Mean ± SD
0.62 ± 0.08	0.71 ± 0.09	0.81 ± 0.10
21.25	34.75	43.5

Table 2
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Pre Season	**Ring 1** **Mean ± SD**	**Ring 2** **Mean ± SD**	**Ring 3** **Mean ± SD**
2010	0.56 ± 0.08	0.56 ± 0.06	0.69 ± 0.11
2011	0.62 ± 0.21	0.64 ± 0.19	0.72 ± 0.20
2012	0.55 ± 0.12	0.56 ± 0.12	0.64 ± 0.15
2013	0.52 ± 0.08	0.53 v 0.09	0.57 ± 0.07

Ring 4 Mean ± SD	Ring 5 Mean ± SD	Functional Peripheral Vision Ratio
0.77 ± 0.12	0.98 ± 0.18	1.52
0.85 ± 0.26	1.02 ± 0.25	1.48
0.77 ± 0.20	0.91 ± 0.33	1.51
0.67 ± 0.10	0.80 ± 0.19	1.4

Table 3
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	Results Based on Years of Play	
	Played college football > 2 years at time of testing	Played college football < 2 years at time of testing
A* (hits per minute)	97.3 ± 12.18 (n=29)	92.0 ± 10.07 (n=68)
Reaction Test (sec)	0.33 ± 0.031 (n=29)	0.34 ± 0.038 (n=65)
	Results for Offensive versus Defensive Players	
	Defensive Player	Offensive Player
A* (hits per minute)	94.5 ± 13.28 (n=42)	93.4 ± 8.97 (n=55)
Reaction Test (sec)	0.33 ± 0.033 (n=42)	0.34 ± 0.038 (n=52)
	Results Based on Skilled versus Non-skilled Positions	
	Skilled Position	Non-skilled Position
A* (hits per minute)	93.8 ± 8.51 (n=45)	93.6 ± 12.75 (n=52)
Reaction Test (sec)	0.33 ± 0.040 (n=44)	0.34 ± 0.035 (n=50)
	Results Based on History versus No History of Concussion	
	History of Concussion	No History of Concussion
A* (hits per minute)	96.3 ± 12.34 (n=28)	92.1 ± 9.19 (n=69)
Reaction Test (sec)	0.33 ± 0.034 (n=27)	0.33 ± 0.036 (n=67)

P value
<u><</u>0.05
0.26

P value
0.31
<u><</u>0.05

P value
0.45
0.41

P value
<u><</u>0.05
0.39

Table 4
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	Number of Hits per Minute Mean ± SD
Concussion 1 Program	88.4 ± 12.0
Concussion 2 Program	88.3 ± 11.6
Concussion 3 Program	90.4 ± 10.3

Table 5

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Season	**Pre-Season**	**Start of Season**
2010		
Average (mm)	22.7	36.5
SD (mm)	10.6	15.7
t-Test	$\leq$0.0001	
2012		
Average (mm)	23.6	36.7
SD (mm)	12.8	12.9
t-Test	$\leq$0.01	
2013		
Average (mm)	24.7	44.2
SD (mm)	12.9	8.6
t-Test	$\leq$0.01	

Excel Spreadsheet- Table of Materials/Equipment

Click here to download Excel Spreadsheet- Table of Materials/Equipment: Materials used in methods 1.19.2015.xls

Name of Material/ Equipment	Company	Catalog Number
Dynavision D2	Dynavision International	
EYEPORT Vision Training System	Exercise Your Eyes, Dove Canyon, CA	
accommodative flippers	Various manufacturers	
pinhole glasses	Various manufacturers	
strobe glasses - Nike Sparq	Nike	

Comments/Description

http://dynavisioninternational.com/shop.html

http://www.promolife.com/cart/eyeport-vision-training-system

http://www.amconlabs.com/product.asp?pid=4511&categoryname=&prodCatFrom=206

http://www.amazon.com/SaveGoodBuy-Exercise-Eyesight-Improving-Glasses/dp/B0090BXVVK/ref=sr_1_1?ie=UTF8&qid=1409165383&sr=8-1&keyword

http://palmensports.com/order-the-nike-sparq-vapor-strobes-eyewear/

s=pinholes+glasses

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Manuscript JoVE52648R2 "Vision Training Methods for Sports Concussion Mitigation and Management"

Editorial comments:

Changes to be made by the Author(s):

1. Please use the attached document for all manuscript revisions.
Used the document that was attached.

2. What quantitative measurement is recorded from step 2.2?
A measurement is not recorded as this is used as an exercise instead of a test. Clarification has been added to the text.

3. Are there any measurements taken for sections 3-9?
Yes – where measurements can be recorded has been noted. When tasks are for exercise and training only is also noted.

4. References are missing some DOIs
DOIs when available have been added.

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Reviewers' comments:

Editor's Note: Please note that the reviewers raised some significant concerns regarding your method and your manuscript. Please thoroughly address each concern by revising the manuscript or addressing the comment in your rebuttal letter.

Reviewer #1:
Manuscript Summary:
Sentence structure makes many concepts very difficult to comprehend; many confusing phrases presented in sequence, which makes transition between ideas somewhat convoluted. I suggest converting complex sentences into multiple simpler successive sentences, each of which should contain a single main point that is more readily understood by the reader. Specific recommendations for content revisions and queries about unclear text are presented below.

Major Concerns:
Line number(s):
123-124: The phrase "as they are their own controls" makes more sense as follows: "The 3 concussion tests do not need to be included among the preseason baseline tests, because their

differing levels of complexity allow each test result to serve as a reference for the others in the set."

The recommended sentence above has been inserted into the manuscript.

149: The word "alternatively" implies that the preceding instructional content could be disregarded. Vertical adjustment of the light board is not an "alternative" consideration to subject positioning; it is an "additional" consideration.

"Alternatively" has been replaced with "Additionally"

155-156: The reader may not know that each target button will remain illuminated until hit.

The following sentence has been added to 1.1.3: "Each light will remain illuminated until hit."

161-162: Is the program typically selected by the "subject" or the "clinician" who is administering the test?

Sentence has been revised to read as "The clinician will select the *A program and the subject will hit (deactivate) as many lights as possible in one minute." An additional sentence has been added, "With experience a subject will become comfortable with the menu for the system and be able to start the *A without assistance from the clinician, if desired."

In addition section 1.1.5. has been modified to read, "Record the number of hits per minute for each session to track progress along with the average reaction time in seconds for the hits during the one minute test." This should clarify what is recorded for the reader.

167-169: The references to "Reaction Test" imply that there is only one test. The content of this section discusses 6 different tests. How many lights sequentially illuminate, and which ones are they?

Section 1.2.1 has been modified to read, "The Reaction Test Program consists of six different tests, three for the right hand and three for the left hand. Instruct the subject to select the Reaction Test and hit start. The lights for Test 1R (right hand) will light sequentially three times to show the subject which lights they will be hitting. Once the lights are done flashing in sequence, there will be a light to the right that will be lit for the first test. The five horizontal lights to the left of the center ring are utilized for Test 1R and the five to the right of the center are utilized for Test 1L.

187-189: Does the "linear random target switch" involve a horizontal row of lights? How many? What distance from one end to the other? Which of the concentric rings corresponds to the "unknown targets, which will appear along an arc" for Tests 3 and 4?

Section 1.2.3. has been modified to clarify that for Tests 1R and 1L there are five horizontal lights used for the test. The first two sentences now read, "1.2.3. Have the subject scan the five horizontal lights that light up during the demonstration sequence. One of the five lights will come on randomly within five seconds. The distance between each light in the horizontal row is 14 inches."

At the end of Section 1.2.4. the following clarifying sentence has been added, "Point out to the subject to disregard the bottom green light during these tests as it is used to change from one test to another but is not one of the lights to be hit."
The Note has been expanded and clarified to read, "Note: Tests 1R and 1L involve a linear random target switch. Tests 2R and 2L are again random, unknown targets, which will appear along an arc in one of eight different planes. It is the middle ring of lights that is used for Test 2R and 2L. Tests 3R and 3L are a simple one light choice using the lights to the right and left of the t-scope."

187-189: Apparently, Tests 1-2, 3-4, and 5-6 represent 2-trial sets of 3 different tests. Is this correct? If so, designation of the tests by numbers 1-6 is confusing.
Have modified to designate them as 1R (for right hand), 1L (for left hand), 2R, 2L, 3R, 3L.

218: How much might the fixed point be "elevated or declined" in relation to the tip of the nose?
The following explanation has been added, "Neutral is straight ahead (horizontal). The up or down angle should not be more than 45° in either direction. Typically the elevation is progressed from 10° to 25° to 45° over a time frame where the tasks are challenging but still comfortable. With some people who have prominent noses or eye brows there may be anatomic limitations that need to be observed."

223: I suggest inclusion of a definition of convergence: "i.e., formation of an image at a single point"
This definition has been added to Section 2.2.

241: Specify "EyePort Vision Training System" with company name, city, and state. Although a web link was provided, an illustration of the system is needed for the reader to understand the content of the "Eye Exercises" section.
Have added "Exercise Your Eyes, Dove Canyon, CA".
We can include a video or we are okay with this one being referenced - https://www.youtube.com/watch?v=JPN6xTeT9G8

248: Rotate the linear lights to the left - how far?

Have added "Rotation is done in stages through 360 degrees. Common stages are 20 degrees at a time providing it is comfortable for the subject."

259: An illustration of "Accommodative Flippers" is needed.
We can add a short video of this method if desired, or reference the following:
https://www.youtube.com/watch?v=1htUxVcuZwA, but it is not a great video.

273: I assume that "Tachistoscope" refers to the Dynavision D2 T-scope. If so, this should be specified.
This a PowerPoint presentation designed by author J Clark. This has been added to 5.1.

289: Are any "pinhole glasses or strobe glasses" acceptable, or do they need to meet

specifications? I suggest inclusion of recommended manufacturer/distributor company names and model numbers.
For pinhole glasses any are acceptable. For strobe we use the Nike Sparq and this has been added.

315: The phrase "the horizontal and vertical charts" implies that there are 2 different charts that are positioned perpendicular to one another. Do you mean "rows and columns" of a single chart? This is very confusing. An illustration is needed to understand the meaning of the terms for chart orientation and spacing of the charts.
We have modified this section to clarify.

357-358: Are any "polarizing glasses" adequate? What is the source of the "Stereo Fly" image? Has the procedure been validated? If so, cite a reference.
This Stereo Fly test only works with the use of the stereo glasses that come with the kit. http://precision-vision.com/products/stereo-vision-tests/stereo-fly-test.html#.VL2JDUfF-Sp. Somers and Hamilton reference has been added.

393-396: The phrase in line 394 "compared to the inner three rings" is contradicted by the phrase in line 396 "divided by the mean of the reaction times for the inner two rings."
These are actually two distinct data points. Have tried to clarify this by modifying it to read as, "The data collected during the *A session is used to calculate the average reaction time in the outer two rings of the vision board compared to the inner three rings. Each subject's peripheral vision reaction time ratio from one training session to another is calculated as the ratio of the mean reaction times for the outer two rings divided by the mean of the reaction times for the inner two rings and provides a data point in addition to the average reaction time."

473: What is the difference between "functional" and "performance" changes?
The following has been added, "Functional changes are something changes in the measurement, for example faster reaction times documented during vision training. The goal is to have a change in performance, such as an improved performance change when a snap off the ball is improved."

505-507: What is "strength of eye-hand coordination for linemen"? How is it quantified? How is "precision for a wide receiver" different?
The following has been added, "Linemen have the task to quickly control the other linemen's arms which requires great strength and quick hands. This can be trained on the Dynavision with resistance bands on a person's wrists. Receivers need good eye-hand coordination with very good precision to be able to catch the balls under very dynamic circumstances such as while running down the field."

515: Is there some difference between "functional peripheral vision" and generic peripheral vision?
Functional peripheral vision is defined as the peripheral vision reaction time ratio

534: What exactly is "fidelity" of peripheral vision?

The following has been added, "Peripheral vision's ability to discern colors and movement is a component of fidelity of peripheral vision. For the athlete doing vision training the ability to recognize an adversary versus the same team in the peripheral vision better would be considered an improvement in the fidelity of peripheral vison."

543: Because better reaction time is represented by a smaller value, and vice-versa, the phrase "slower times taken to hit the buttons" can be confusing. I suggest replacing the term "slower" with "longer" to emphasize that more time elapses.
We have changed "slower" to "longer".

550: What is the basis for designation of "70 hits" as normal?
We have revised and added to now read, "In this age group and based on our experience, a normal test should be 70 hits for the score for the first run on the Dynavision. This is based on our empirical experience of hundreds of college level athletes."

551: Table 2 does not present any information that is relevant to the content of the section of the text.
We have deleted Table 2.

584-585: Why is the term "vergence angles" presented in parentheses? The brain uses the eye's what? Whatever this is supposed to be, shouldn't the plural possessive eyes' be used to describe the process?
Has been revised – "To perceive the distance of an object, or its depth of field, the brain uses the eyes' vergence angles and size information to determine distances. The brain uses the eyes' angles for convergence to estimate distance."

596-597: How are "control" and "fidelity" of muscles different?
These were explained in the sentences before their use.

605: What is the muscle training effect "coupled" with?
The word "coupled" has been deleted.

612: Is "stereo depth perception" the same thing as "stereopsis"? If so, why use a different term?
They are not the same. The sentence has been revised to read "Neurovisual processing coupled with the ocular motor proprioception is believed to improve stereo depth perception, which is the ability to use the convergence angles to perceive depth [8,28]."

613-615: This is an example of convoluted sentence structure that makes its mean very hard to readily comprehend.
Sentence has been revised.

Minor Concerns:
N/A

Reviewer #2:

Overall, you have obviously put a lot of time and effort into this paper. It will make a wonderful video that others will be able to duplicate. The really good things include many points in the discussion section. The concept of monitoring a subject during the recovery process from an injury, the fact that there are improvements in concussion assessment tasks, the results description of Table 2 and the summary of improved functional vision possibly resulting from the improved recognition followed by a wonderful football example. Great troubleshooting paragraph toward the end. And page 14, line 577 "takes approximately eight minutes to complete all five tests." is great, but hidden, buried in your text. That should be prominently positioned.

My major five concerns are:
1) The concept of injury prevention. By enhancing peripheral awareness through conscious activities, you can eventually have subconscious awareness of surroundings improve and can lessen the amount of injuries, but in any sport, there are always going to be injuries that can not be prevented. In football, hits from behind, in tennis, a misstep, etc. I have a large problem with the wording of "injury prevention" that is used throughout the paper.
We have chosen to use injury prevention because we have a paper in press with that result in football. Briefly concussion in football decreased 80% consistently for 5 consistent years with the University of Cincinnati football team. That paper is now referenced in the paper when "injury prevention" is mentioned.

2) Weak references. Many are reused, others are not peer reviewed, one is a news reporter, and your key reference, the one that "proves" your point is In-Press and not accessible. **The pdf of the paper is attached with publication scheduled for March in Optometry and Visual Performance.**
The retrospective study that is cited says that there was a very small sample size with subjective reporting of concussions after vision training had begun. You mention reference 28 a couple of times in the disclosure and the paper on page 14, but my list only goes up to 26.
References have been corrected.

Where is the reference that says that enhancement on a sterofly test of a non-moving target at nearpoint with a seated patient will 100% transfer to enhancement of depth perception of moving targets at a distance with a moving person? **This paper is the companion paper in Optometry and Visual Performance due out in March. A pre-print of this paper is attached.**

3) Lack of brain processing being included -- the whole article hinged on "neuro-visual processing" yet the brain wasn't mentioned -- just the eyes and eye muscles. Peripheral signals from the retina link with head position centers in the brain as well as spatial coordinate systems, etc.
The following paragraph is added to address.
As we have seen improvements in reaction times and improvements in peripheral vision we ascribe these in part to improvements in brain processing. We believe that improved visual acuity cannot account for such changes as the brain processing is needed to have eye hand coordination speed changes. Regarding the peripheral visual fields the retina's cones and rods may be functioning but the brain is not processing those signals to the fullest degree. The vision training that results in improved peripheral vision is most likely to occur along with constitutive brain processing changes. Future research to assess the brain's changes

with vision training are needed to better address this.

4) Missing alternatives to avoid the loss of abilities. In other words, the paper implies that the peripheral awareness skills were lost if not maintained during downtime. (page 14, line 609) This would be the equivalent of an orthodontist using braces for a year, then removing them without a retainer. The purpose of a retainer is to get the brain to change its habit. Then, it can be removed. There is no discussion of how the brain's (the neuro-visual processing that IS mentioned) shifting of habits (from old to newly acquired) could be achieved. Perhaps a retainer pair of glasses could be worn to continually stimulate the peripheral eyesight? And, although the mention of having a thorough evaluation to check for eye health problems such as double vision or a crossed eye is mentioned, it might be interesting to see if a group of people who received eyeglasses to balance peripheral and central eyesight would either learn the skills more quickly or maintain the skills longer.
With all due respect to the referee, the vision training is not the same as glasses. So there is no technology or data to suggest that glasses would help maintain the training. Also, the orthodontist analogy is not an appropriate analogy here. A better analogy would be weight lifting. A football player and high caliber athlete who has worked out with weight lifting to improve strength WILL get weaker if they stop weight conditioning. The vision training has benefits when the subject is training and that conditioning is lost when training stops.

5) Statistical comparisons not seemingly equal. For instance, you mention that the player who have had vision training average 1.4 concussions per 100 player seasons as compared to players who did not receive the vision training which is 9.2 concussions per 100 game exposures; P <0.001). Game exposure is different from player seasons. Then you show that the amount of concussions was done as a retroactive study with no control group where the number was subjectively recalled after the fact.
It is common to report numbers as per season or per player exposure. This is explained in the attached reprint.

Minor concerns include:
1) The wording chosen.
For instance,
a) in the list of activities, among the specific list of "tachistoscope, accommodative flippers, saccadic eye movement testing, etc." is simply "eye exercises". Aren't they ALL eye exercises?
We were using the phrase "eye exercises" to describe EYEPORT training but since it is confusing we have changed it to EYEPORT training in the manuscript.

b) On page 7, line 267, the word "once" is ambiguous. It is intended to mean "after", but it reads, "the flippers are moved only once" implying only one time. Then it goes on to say read for a minute or until 100 characters are reached. Do the flippers continue to move? It is meant to say that the flippers actually flip back and forth (or up and down) continually while the person's focusing readjusts, but that is not how a layperson would read it.
Section 4.3 has been changed to read – "Instruct the subject to read from left to right while moving the flippers up and down repeatedly. The flippers are moved only after the subject can focus on and read the saccade card."

c) On page 12, line 489 what is "reflex action" of the eye? Pupils? vestibulo-ocular reflex? Optokinetic reflex? Menance reflex? Perhaps it should read focusing action of the eye. But accommodation only occurs after central attention and interest is placed on a target. So, there is a bit of brain function involved also.
The reflex action is accommodation. Yes, there is brain function on the processing. But the task was to make the accommodative muscles move faster and with precision. Sentence has been modified.

d) page 13, line 570 states "recent papers" yet the two references refer to papers from 20 years ago. Not recent.
Have added number citations for newer references.

e) on page 14, line 580, I don't know what peripheralization is. The term is typically used to classify spinal signal pathways.
The following has been added, "Peripheralization is generally used by neurologic and related health care workers to describe the general phenomenon where a patient uses one side more than the other. It includes hemiparesis, neglect and conversion disorders."

f) page 14, line 597, the word fidelity is an odd choice for an eye muscle.
Has been changed.

g) page 15, line 628, diplopia might not be known by the reader.
This has been changed to "double vision"

h) on the next line, 629, eye health might be better written as eye health and tolerance ranges, or something like that, because you are discussing exacerbation of symptoms, which is functional not exactly health related.
This change has been made.

i) page 12, line 491. Perhaps the word memorable might be better as "salient".
This change has been made.

2) The descriptions of the activities.
a)Lack of figures for the eye exercises testing and accommodative flippers.
We did not include figures to keep within the requested length of the paper. We can add some if desired.
b) The ambiguity of the various testing. Should it be seated, standing, standing with feet apart (wide or narrow stance), standing on an uneven surface? As part of the concussion protocol that was created to assess mental functions, was physical stress, such as an uneven surface, such as a balance board to stand on, while touching the lighted board, a possibility? There are balance boards with sensors that can objectively track center of gravity. After concussions, often people experience visual midline shifts. A balance board could assess this objectively -- currently your paper wrote that observers could see differences in head movement. It would be nice to measure shifts in center of gravity, thus posture and head position.

We believe that the ambiguity will be diminished with the addition of the demonstration videos.

c) Clarification on page 13, paragraph beginning with line 536. I was confused regarding the exact task and that it says, and why/how it could conclude with "this is further support..."
Sentence has been deleted.

3) Discussion additions
On page 10 line 407, why is it taking 4 years for the sustained benefits to appear?
In an abundance of caution we wanted to be sure the results were maintained. They were and are in press with preprints supplied.

Why on page 10, line 428, does it say "data not shown"?
We have corrected to "in press".

On page 12, line 511, it says this paper's methods were validated. Put in by who at that point, even though it is redundant
Have added the references.

I don't mean to be picky, but this topic is so controversial, you have to have all your ducks lined up to face the barrage of criticism from adversarial communities who will view this.

Reviewer #3:
Manuscript Summary:
The current paper presented the detailed information of conducting vision training on university athletes to improve their eye-hand coordination, reaction time and stereopsis. The detailed information is valuable for sports medicine clinic as well as for civilians who would like to improve their visual functions. But the paper needs to make some changes for better understanding.

Major Concerns:
1) The authors specified three types of vision training: light board, three concussion programs, and vision therapy. The three types training were applied on three different groups according to the description in the paper. But the instruction was read as all subjects did whole three types of training.
Subjects can do all the types of training. The concussion programs are not training. They are testing. This has been noted in the paper.

2) Were those vision therapy tasks also used as comparison before and after concussion?
The following has been added to the paper along with reference to the Clark 2015 paper in press. "For the concussion testing The Dynavision A* and Dynavision Reaction Test can be used for baseline assessments. The three concussion tests are also used for concussion assessment but are generally not done by subjects in advance. The three concussion tests are designed to be multi tasking and executive function tests that the subjects have not seen before."

3) In 1.1 *A protocol, did the subject do touching by both hands or just one hand? Roughly how large the visual field would be covered in this task?
1.1.3. has been modified to reflect "using both hands".

4) In 1.3 Concussion 1-3 programs, did the subject run the three programs in a random sequence? If it was always starting from the easiest one, no wonder there was a learning effect.
The following has been added to 1.3, "The three programs are designed to be performed in sequence. The learning effect is seen in normal individuals. However, in concussion patients the learning effect is not seen and is considered as diagnostic for concussion."

5) In line 227, should "beet" be "bead"?
Correction has been made.

6) In line 229, how can the subject touch a bead 6 feet away with the index finger?
The string is 6 feet and tied off at one end. Many people have a reach from their nose to the tip of their fingers of 4 feet. The farthest bead is placed at the extreme reach of the index finger. Section 2.3 has been modified to read, "Alternatively, use a task where the string is six feet and tied off at one end. Many people have a reach from their nose to the tip of their fingers of 4 feet. The farthest bead is placed at the extreme reach of the index finger. The subject touches the bead with his index finger and returns it to the side of the leg, alternating the right and left hands."

7) In Accommodative flippers, what's the power of lens used for flipper?
Details have been added – "The power of the flipper lenses used is varied to optimize the training effect. The two powers used should be challenging but not onerous to focus on an object as the flippers are alternated."

8) What's the flashing frequency of the Strobe glasses?
This has been explained in 6.2.

9) In Saccadic eye movement training protocol, why did the subject stand 8 feet from the target but not 12 feet used in the light board protocol?
We have added the following note in case the reader wonders about this. "Note: We believe it is important to change distances to add a dynamic component to the accommodative systems and therefore subjects are asked to stand 8 feet away as opposed to the 12 feet used for light board training. There are vision training programs out there that use only a computer and computer screen and do not exercise the accommodative systems. So we vary the lengths at which the tasks are performed."

10) In stereopsis protocol, what's the upper limit of the distance from the photo to the center of the pinch? In how many arc min?
We have personal experience of 85 mm. We reference Somers and Hamilton as well as Clark et al., concerning this method. We have added the following sentence plus the Somers and Hamilton reference, "Based on our experience we have found that 85 mm appears to be the upper limit of the distance from the photo to the center of the pinch."

11) In the results presented, were those football players participating a maintenance practice of light board practice during the season? Or just at the beginning of each season?
The following sentence has been added to clarify – "The players participated in training pre-season and weekly during the season for maintenance."

12) In table 4, the authors should consider an interaction effect of position, training times of *A and the history of concussion, since there is a significant effect of training times and history of concussion. Only report the comparison of positions would overlook the effect from training times and concussion.
In the future we can examine this. The current paper is on the methods. Other work will examine the mechanisms.

13) Why the concussed subjects had better results than non-concussed subjects??
We do not think it has clinical significance at this time.

14) I suggested the authors separate the subjects had the history of concussion from the analysis and only use those non-concussion for baseline comparison.
We would like to include the concussion data.

15) Although the authors listed many vision therapy protocols, only the results from stereopsis were reported. It would be better if the authors can report the results in the future
Results are in press and copies of these papers have been included in this revision submission.

16) The statistical analysis looks not appropriate in the paper. The authors should use mixed linear model or repeated ANOVA if the same subjects participated in the study. A simple t test is not suitable for repeated measurement.
The results have come from our peer reviewed papers that have been published or are in press and the statistics selected have been accepted.

Minor Concerns:
1) Are "A*" and "*A" the same in the paper?
It should be "*A" and we have corrected the places where it was wrong.

2) In line 98, it sounds like the football players did the three concussion assessment tests. But the results are not reported in the paper. Are they the same as non-player controls?
This sentence has been removed.

Rebuttal Comments
Click here to download Rebuttal Comments: Baseball stereopsisVersionInPress 2015.pdf

Possible Stereopsis Enhancement in Collegiate Baseball Players with Vision Training

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Key Words: Stereopsis, Depth Perception, Vision Training, Baseball

Running title: Stereopsis and vision training

Abstract.

Introduction. Vision training is rapidly becoming a component of sports enhancement but quantifiable and validated improvement in visual performance has not been clearly demonstrated in high caliber and / or collegiate athletes. We have performed vision training for the last three seasons on the University of Cincinnati Baseball team's hitters. The goal for the work was for performance enhancement and for monitoring purposes, we measured stereopsis pre and post vision training.

Methods. From the preseason (January) 2011 through to the end of the season (May) 2013 all hitters in the University of Cincinnati baseball team underwent regular vision training. Out of season training was 20 minutes twice a week and in season was 20 minutes once per week. Traditional stereopsis (stereo fly) was performed and recorded. Vision training typically consisted of: Dynavision light board, Brock string, Strobe Glasses, Eyeport, saccades and near far.

The players consistently come into the season with stereopsis 23.7 +1.0 mm and six weeks of training increases this stereopsis to and improve to 36.9 + 0.49 mm (P<0.0001).

Discussion. There was a consistent and significant improvement in stereopsis measured by stereo fly with the baseball team after 6 weeks of vision training. Equally the stereopsis returned to baseline out of season. Temporal benefits seemed to continue post 6 weeks of vision training. We conclude that in a population of healthy and high caliber athletes that stereopsis can improve with training and suffer from detraining effects as well. We suggest that vision training for sports that require good stereo acuity be considered.

Introduction

Baseball is a vision intensive sport with batting being one of the most visually demanding activities [1, 2] . The ball can depart the pitchers hand at greater than 90 miles per hour leaving only about 0.4s seconds, or so, before it crosses the plate [3-9]. That means the batter needs to see the ball, recognize, process and decide on the swing in a fraction of a second. The mechanics of the swing takes up much of that 0.2s seconds, which means less than 0.2 seconds is needed for the visual and cognitive systems to provide information for making a swing decision [5].

An important component of the assessment of the pitch is speed, which is in part determined by using the depth perception to determine how fast the ball is coming at the batter [10]. The change in distance divided by unit time determines speed [11]. The brain does this calculation subconsciously. We felt that improving visual skills, including depth perception, may be way to improve batting [12]. We previously published results on how vision training improved performance [5] and in the current paper we investigated whether vision training had demonstrable changes in a visual parameter such as depth perception [13]. Depth Perception can be defined as the visual ability to perceive the world in three dimensions and the distance of an object. Depth Perception arises from a variety of depth cues. These are both Monocular and Binocular. Binocular cues include stereopsis, the others are convergence and shadow stereopsis. This is information derived from the different projection of objects onto each retina to judge depth. Using two images of the same scene obtained from lightly different angles, makes it possible to triangulate the distance to an object with a high degree of accuracy. This will be true whether at 16 inches or 60 feet. The premise is that vision training will improve stereopsis and that depth perception improvement will be quantifiable using the stereo-fly. We report on significant improvements in depth perception with vision training and a detraining effect out of season.

Methods

Human Subjects. The vision training was performed as part of the pre-season and regular season practices. All batters were included in the training, which was twice a week pre-season for six weeks and once or twice a week during the season as the schedule allowed. Baseline stereopsis was obtained at pre-season, beginning of the season, end of season. The testing and training was a team wide (hitter wide) activity. The activity has been reviewed by the University of Cincinnati Institutional Review Board and is compliant with all human subjects rules. A total of 16 players were examined and reported here.

Participants: At the beginning of the vision training session, sixteen members of the University of Cincinnati Intercollegiate Baseball Team participated in this study. The 16 participants were between the age of 18 – 22. They were all hitters and field position players as per the mandate from the coach.

All participants were refracted prior to the start of the fall baseball season to ensure the participants had appropriate acuity and binocular vision. Each player was refracted at 20 feet which is a standard testing measure for binocular vision and they were measured at 60 feet.

Baseline stereopsis measurements were obtained in August prior to the beginning the fall baseball season and the beginning of the fall vision training session. The second measurement was taken in January at the beginning of pre-season baseball conditioning and training and prior to start of the pre-season vision training session. The third measurement was taken in February at the end of the baseball pre-season conditioning and training sessions and the beginning of the intercollegiate baseball season and the end of the pre-season vision training session.

Each player was tested for stereopsis using the Stereo Fly Test [Stereo Optical Company, Inc Chicago, Il]. The Stereo Fly was fixed on the wall with each player positioned sitting on a stool 16 inches from the Stereo Fly and at eye level of the Stereo

Fly. During each testing session each player was given a practice session where they got comfortable with the test. The second attempt was measured and reported.

During each vision training session all exercises/skills were conducted in a circuit training method with two repetitions of each exercise/skill at one minute each repetition of each exercise/skill. A 30 second rest was given in between each exercise/skill. Basic visual skill development was initiated during the first 3 weeks of the fall and pre-season training sessions. The purpose was to re-develop oculomotor strength and convergence and divergence movement of the eyes. The remaining weeks of the training sessions escalated in additional cognitive function and visual training skill as it relates to baseball skill.

The Vision Training Program Design, Tools and Equipment

Three vision training sessions were conduct in which all sixteen participants were involved in the training sessions. The sixteen participants were divided into 4 groups of 4 with all groups receiving the same training on the same days. The first session was during fall baseball (5 weeks) with two 25 minute training sessions per week per group. The second training session consisted of the pre-season (7 weeks) with two 25 minute training sessions per week per group. The third training session was conducted during the competitive baseball season (12 weeks) averaging one 25 minute training session per week per group. The vision training sessions were designed and implemented using the following equipment: Eyeport Vision Training System, Brock String, Rotation Trainer, Saccadic Eye Charts, Near/Far Saccadic Eye Charts, Accommodative Flippers, and Nike Strobe Glasses.

Brock String.

The Brock string used consisted of a white string 12 feet in length with 5 small wooden beads of different colors [5, 9, 14]. It is used to develop skills of convergence as well as to disrupt suppression of one of the eyes. It is a valuable procedure for developing accurate fixation skills under binocular conditions.

During the training session the one end of the Brock string is held on the tip of the nose while the other end is tied to a fixed point. The five colored beads are spaced on a length of string at least 12 inch long. The patient is instructed to alternate fixation and focus from one bead to the next while noting the visual input of each eye and sensation of convergence. The patient can use variable techniques to make easier or more difficult by bringing the beads closer\further to the nose.

A the beginning of the second half of (4-7 week) A variation of this exercise was placing the fixed end of the string to the floor or to the ceiling while the patient was standing. Also, the string was shortened to six feet with the player touching the bead with his index finger and return to the side of the leg. They alternated using the right hand and left hand.   A wand with tape the color of the ball on the Brock string was also used. The tape was spaced 3 inches apart. When implementing the exercise, the player would have to match the color of the tape on the wand to the color of the ball calling out each color as he matched ball to tape. The athlete would progress from the nearest ball to the furthest ball on the string and repeat [15].

Eyeport

Eyeport Vision Training System: The Eyeport Vision Training System (Exercise Your Eyes, Dove Canyon, CA) is designed to improve visual performance by training the speed, accuracy, and efficiency of the eyes [16]. This electronic device uses alternating red and blue lights. Since viewing red and blue light creates opposing effects in the eyes, alternately looking at these colors creates a rocking action that stimulates and relaxes the eye's aiming and focusing mechanisms. The Eyeport has 10 different speed settings and changeable speed options. The Eyeport was placed in two different positions during each training session; vertical, horizontal, and diagonal eye movement. A progression of low speed to high was utilized in the program. The player was progressed in speed on an individual basis throughout the training session [5]. Each player performed two repetitions of this device at each session.

Rotary

The rotation trainer (Bernell Corporation of Mishawaka, IN) is a piece of equipment to test and enhance eye/hand coordination, perceptual and space awareness, dynamic visual acuity and dynamic fusional training. This piece of equipment includes 20-1/2" diameter plastic disc with a two colored geometric design with drilled holes and an attachment hub and heavy-duty base. It is powered by an electronic control unit with reversible and variable speeds (5-32 RPM). Letters of the alphabet and numbers 1-10 that were constructed of plastic 1x1 inch squares were placed randomly on the plastic disc with velcro. Each player was positioned 8 feet from the disk. The player held a laser light at the tip of their nose and had to identify the letters of the alphabet in order with the light as well as verbally identify the letter. The progression started at 5 RPM and improved up to 24 RPM as they achieved 50 percent of identifying the letters in the alphabet. Each training session alternated the disc in moving clockwise or counterclockwise.

Accommodative Flippers.

Accommodative Flippers were used to enhance the reflex action of the eye. The accommodation reflex is a reflex action of the eye, in response to focusing on a near object, then looking at distant object (and vice versa), comprising coordinated changes in vergence, lens shape and pupil size (accommodation). Utilizing +/- flippers gives the effect of stretching the muscles of accommodation and convergence, much the same as we do before physical exercise. This stretching can help reduce/prevent increases in myopia as well as prolonging presbyopia. The accommodative flippers were used in the preseason training session in 50% of the weekly training sessions. The flippers were implemented in the progression of starting with the .50 and progressing to 3.00 based upon individual ability.

Strobe Glasses

The Nike SPARQ Vapor Strobe are glasses in which liquid-crystal lenses flash between transparent and opaque at a rate set by the user. The purpose of these glasses assists in Visual alignment to have both eyes work together to focus on one object; Hand/eye coordination to assist with reaction time; Visual memory to assist your eyes and brain communicate more efficiently. The Nike SPARQ Vapor Strobe Goggles work by slowing down movement with a constant flicker in the lens. This effect helps to improve coordination and the ability to process visual information and the timing of movements.

Strobe glasses were used to train two different skills appropriate for this population. The occlusion of vision acts as an interruption of visual information and is somewhat analogous to a base-runner running in front of the subjects' visual field. With practice the athletes learn to focus on the task at hand are may be less likely to be distracted. Also, the relatively rapid interruption of visual input is thought to train the visual systems to take in and process more information when available. So it is thought vision processing improves with strobe glasses training.

Dynavision

The Dynavision is a eye-hand coordination device that tests and improves visual motor skills [9, 17]. We typically perform two one minute sessions on the athletes. The reason for doing multiple sessions is to demonstrate consistency and improvement with the tests. The staged and progressive nature of the tests also helps keep the athletes engaged.

The off the shelf, *A training session is an established Dynavision protocol [5, 17]. It uses traditional eye-hand reaction training to assess visual fields and improve reaction times. This training drill takes one minute. The result is a number of hits in one minute as well as the average reaction time for each hit. Targeted programs were written to improve the perception of the strike zone, and eye hand performance and precision.

Saccades

Saccadic Eye Movement Training: A saccadic eye chart is used to develop the fast movement of the eyes [5, 7, 14]. This saccadic eye exercise emulates a quick simultaneous movement of both eyes in the same direction. This exercise serves as a mechanism for scanning, fixation, and rapid eye movement.

Each player was positioned 8 feet away from the saccadic eye chart and centered between two saccadic charts, which were positioned about five feet from the center line. Prior to beginning the exercise each player had to have full range of the eye motion in order to see all letters on the saccadic chart. The distance from the charts was adjusted accordingly to gain full vision of the chart. Each saccadic chart is constructed on an 81/2 x 11 inch sheet of paper. Each chart has 10 letters with a 36 point font per vertical line with 10 vertical lines on the chart.

This exercise was performed reading the horizontal and vertical charts for one minute each. The player kept their head still with only moving their eyes. The player was asked to read the first letter on the first line on the first chart and then alternated to the second chart to read the first letter of the first line. This completed one cycle. The athlete then would scan the eyes to read the second letter of the left chart followed by the second letter of the right chart. This completed another cycle. The player would alternate between charts and letters progressing across the line horizontally. As they completed the first line on both charts, they moved to the next line etc for one minute.

The horizontal charts were placed at eye level and the vertical charts were distanced 6 feet apart. A progression of this exercises included using unstable surfaces and varying placement of the charts to enhance eye speed and visual focus.

Near Far Training

Near/Far Eye Movements: Near/far eye movements change focus quickly and accurately from a near point to a far point [5, 7, 14]. The two charts utilized for this exercise are a large chart and a smaller chart. The saccadic eye chart was used for the large chart and the small chart was constructed on a 3 1/2 x 2 1/2 inch sheet of paper. Each small chart has 10 letters with a 12 point font per vertical line with 10 vertical lines on the chart.

The far chart was fixed at eye level with the player positioned 10 feet from the chart. The player held the near chart with one hand approximately 4 – 6 inches from the nose. This allowed the player to see over the near chart to see the far chart. The player was instructed to keep their head still with only moving their eyes. The player was asked to read the first letter on the first line of the far chart and then alternate to the near chart to read the first letter of the first line. This completed one cycle. The athlete then would scan the eyes to read the second letter of the far chart followed by the second letter of the near chart. This completed another cycle. The player would alternate between charts and letters progressing across the line horizontally. As they completed the first line on both charts, they moved to the next line until the time expired for the one minute session. The player was instructed to be sure that both eyes came into focus on the near target as well as the far target when they were alternating from chart to chart.

Stereopsis Measurement

In this observational study the dependent variable whose changes we measured based on the vision training is stereopsis Vision training, above, is the independent variable. We measured depth perception with the stereo fly at intervals before, during and after training. Measurement of Stereopsis was accomplished with the Stereo Fly (Stereo Optical Company, Inc. Chicago, IL). This Stereo Fly test is designed for the evaluation of both gross stereopsis and fine depth perception. The Stereo Fly test is used as a standard in stereo testing. The test only works with the use of the stereo glasses.

Polarizing glasses were placed on the subject and asked if "the fly's wings appeared to be standing up at them and in three dimensions?" Subjects were instructed to observe the Fly at a distance of 14 inches from their nose. If the response was positive, they were instructed to "reach out and pinch the fly's right wing tip with their thumb and forefinger and to hold that position." The distance between the photo and the center of the pinch was recorded with a millimeter ruler. The higher the number, in mm is indicative of better stereopsis when measured on the Stereo Fly. Randot testing measures increasingly smaller increments of stereopsis. So there is a change in stereo fly results in mm. This method is considered to be accurate within + 1-2 mm (personal communication James Ellis).

The Vision Training Procedure.

Three distinct training sessions were conduct during the calendar year. The first session was the fall season (5 weeks) with two 25 minute training sessions per week. The second training session consisted of the pre-season (7 weeks) with two 25 minute training sessions per week. The third training session was conducted during the competitive season (12 weeks) averaging one 25 minute training session per week. During each session all vision training skills were conducted in a circuit training with two repetitions at one minute each repetition.

Basic visual skill development was initiated during the first 3 weeks of the fall and pre season training sessions. The purpose was to develop oculomotor strength and convergence and divergence movement of the eyes. The remaining weeks of the training sessions escalated in additional cognitive function and visual training skill as it relates to baseball skill.

The stereopsis testing was completed five times during the three baseball training sessions. This included the pre and post fall baseball season (5 weeks), preseason and post preseason (seven weeks), and at the completion of the competitive season (12 weeks).

During each vision training session an average of 5 vision exercises were performed. All exercises were conducted in a circuit training method with two repetitions of each exercise at one minute each repetition. A 30 second rest was given in between each vision exercise. Basic visual skill development was initiated during the first 3 weeks of the fall and pre-season training sessions. The purpose was to re-develop oculomotor strength and convergence and divergence movement of the eyes. The remaining weeks of the training sessions escalated in additional cognitive functional and visual training skill as it relates to baseball. The competitive season training sessions were designed to maintain the oculomotor control that was developed during the preseason session.

During the first three weeks of the fall and preseason training sessions the exercises performed were the horizontal/vertical saccadic eye chart, near/far saccadic eye chart, brock string, eyeport, and the rotary trainer. The exercises were performed at an introductory level on a stable surface. A variation of unstable surfaces such as a dyna disc and half foam roll were added to escalate the difficulty in performing the respective exercise.

During the remaining weeks of the fall and preseason training sessions the exercises were progressed to increase variation and difficulty. This included a progression to unstable surfaces in performing the exercises as well as adding accommodative flippers and Nike Strobe glasses. Nike Strobe glasses were utilized with vision exercises and functional hand eye coordination with a ball and bat.

Statistics.

Paired, two tailed, student T-Test was used go compare the changes in stereopsis for the players. Statistical significance is $P<0.05$.

Results.

Table 1 summarizes the average and standard deviation (SD) for the stereopsis measurements in mm for the University of Cincinnati baseball team as measured through the three years of vision training. Statistical significance is reported as P<0.05.

Table 1 Stereopsis Measurements of University of Cincinnati Baseball Players

2010	Pre-Season	Start of Season
Average	22.7	36.5
SD	10.6	15.7
T-Test	0.00004	
2012		
Average	23.6	36.7
SD	12.8	12.9
t-Test	0.01	
2013		
Average	24.7	44.2
SD	12.9	8.6
t-Test	0.01	

The players consistently present with stereopsis ranging from 22 to 25 mm at the beginning of training. As a team they go back to this level consistently between seasons. Training increases this stereopsis effect. We consistently reached the 45 to 50 mm levels with the players during the season, data not shown.

Discussion

Depth Perception. Depth Perception in humans is achieved in two main ways. **1.** By assessing the size of an object and estimating its distance based on the size observed. This is how the military trains snipers to estimate distances; based on how big a person was in their sights. It takes training and practice and can be done consciously or subconsciously. Baseball players, especially fielders, will need this skill to estimate where a fly ball will land after the hit. This is done by estimating the change in distance with time and trajectory of the ball [18]. With experience and practice high caliber players can better estimate where a ball will land shortly after being hit. **2.** Depth perception can also be done by a form of triangulation where the vergence of the eyes produces an angle that converges on the target. So if the eyes are looking parallel, there is no vergence and the triangulation estimate is infinity. But as the eyes start to "cross" the angle of the crossing indicates distance. The distance between the eyes forms the base of the triangle, for the triangulation calculation, and the angle of the eyes to vergence gives the brain information concerning distance. Along with the triangulation there is some assistance in depth perception with focus. But this is lost when distances are greater than the hyperfocal length. The focusing method requires eye muscle tone so for this paper it is considered a subcomponent of triangulation. Distance is therefore determined by individuals with a cognitive component concerning size estimations and motor component concerning the eyes' vergence. Together these provide the individual with depth information and speed of the ball is inferred by the change in depth and change in time.

Larsen reported improved depth perception using fusing training in combination with a form of cover test training [13]. This report had a small sample size and the details concerning duration of training, frequency, and intensity of the training was not clear. Notwithstanding, the inference from this work and others [9, 19] strongly supports the concept for improving depth perception. However this is a novel systematic study of a group of high caliber athletes showing consistent and reproducible improvement in stereopsis.

To perceive the distance of an object, or its depth of field, the brain uses the eye's (vergence angles) and size information to determine distances. This information, for a baseball player, is important for determining speed and trajectory of a ball; weather a pitch, throw or hit. The stereo fly tends to assess the depth perception skill of the vergence. Vision training improved this depth perception measure and by extension may help a player improve their ability to assess the characteristics of the ball in flight. Baseball players use and need depth perception at distance (fielders etc) as well as up close (hitters and infielders) to maintain field awareness and optimal performance. Improved depth perception for a batter might mean being less likely to be fooled by a change up pitch [20, 21, 22].

<u>Training</u>. If we assume that the vision training has a causal effect concerning the stereopsis changes observed it begs the question why might this occur. We believe that the vision training, which included ocular motor and neuro visual conditioning led to an improvement in the control and fidelity of the extra ocular and intra ocular muscles of the eyes. This likely included an improvement in proprioception. The eyes were able to more precisely "focus" on a point, remain there and give the brain better information concerning vergence. Hence the brain improves its depth perception. To an extent in the players this may help increase awareness of where that point is in physical space. It is highly likely that the stereo fly results were improved because the ability to detect the angles for the triangulation were better. This could occur with an improved proprioception of the extraocular muscles and / or improved precision as to the position of the eyes. The timing of the improvements are consistent with a muscle training effect coupled. As mentioned in the results, the players consistently come into the season with stereopsis 23.7 +1.0 mm and six weeks of training increases this stereopsis to and improve to 36.9 + 0.49 mm ($P<0.0001$). The players return from the off season, and after not doing vision training for 6 plus months with stereopsis numbers similar to their baselines. This suggests that there is a detraining affect in the absence of vision training.

We kept to a minimum the number of times that the subjects did the stereo fly to prevent the athletes from subjectively improving their performance. The time between stereo fly tests was typically six weeks. It is felt that the pre-season values and the consistent return to similar pre-season values enforces this goal. The reproducible improvement in depth perception with vision training is striking and we believe that the vision training has a causal effect on the stereo fly results. This is, somewhat, reinforced by the observed detraining in the off season with a return to a lower stereo fly results at the beginning of each season along with a relatively consistent improvement in depth perception. We believe that improved neurovisual processing coupled with the ocular motor proprioception leads to improved stereo depth perception [11, 23]. This improvement is lost during the off season, which is consistent with a detraining effect. At this time, however, we are unable to definitely say if the apparent detraining post season vision training is because of incomplete or plateau of the ocular performance or detraining. Either way, the vision training has apparent positive benefits. Continued or regular vision training can regain and/ or maintain these improvements.

We believe that this is a unique report on the improved depth perception of high caliber athletes following vision training. Our previous paper suggested improved performance with vision training [5], and the current results reinforce vision training for performance enhancement. We also believe that depth perception and vision training can continue to improve concerning performance enhancement as well as injury prevention. For example we did not address the “size recognition” component of depth perception. There are methods for training this and they may improve the ability to track and predict the trajectory of a fly ball. Nor did we address the possibility that the subjects were concentrating better from the training.

The weaknesses of a study like ours are that the players changed drastically over the 3 years of the study. Only 4 players were present throughout the 3 years. So all the data presented are a population of the team year by year. No individual or small group performance data are used in this study

In comparison to statistics from the 2011-2012 vision training sessions we determined the post vision training depth perception was reproducible in 2 consecutive years. The team's responses were reproducible in that the pre-season stereopsis was 22.7+10.6 vs 23.6+12.7 mm. After 6 weeks of vision training the stereopsis was 36.6+15.7 and 36.7+12.9 over two consecutive years.

The 66 foot distance we used is important to measure for the batters as this is the distance between home plate and the pitcher's mound. It is important for the hitter to spot the pitcher's finger position on the ball prior to its release [21,22,24]. Coaching strategy indicates for the batter to watch the ball from the bottom of the wind-up position of the pitcher during the throwing motion.

Limitations. We used stereopsis as an indicator of vision training progress. In this paper we have utilized standard stereopsis measure of stereo fly in a non-standard way to observe apparent stereopsis change caused by vision training. While the data clearly show significant changes in the "pinch height" on the stereo fly the method has not yet been directly correlated to the standard method for quantifying stereopsis. Future studies validating the "pinch height" to standard stereopsis methods are warranted. Notwithstanding the data demonstrate that this stereo fly method produces apparently quantifiable results that may be helpful for monitoring ando / or quantifying the effects of vision training. Also, it is not clear, based on our data, what the time course and time to peak is for stereopsis. Nor can we say how long the training lasts or the best dose (frequency and duration of sessions) is for the vision training. There does appear to be some detraining late in the season as the sessions become less frequent.

Further, such vision training methods may improve field and situational awareness, which we believe may prevent injuries. Therefore vision training may be an aid to injury prevention as well; but future studies are needed to investigate this thesis.

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An Exploratory Study of the Potential Effects of Vision Training on Concussion Incidence in Football

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ABSTRACT

Abstract

Background: Vision training has become a component of sports enhancement training, however quantifiable and validated improvement in visual performance has not been clearly demonstrated. In addition, there is literature related to the effects of vision training on sports performance and injury risk reduction. The purpose of the current investigation was to determine the effects of vision training on peripheral vision and concussion incidence.

Methods: Vision training was initiated among the University of Cincinnati football team at the beginning of the 2010 season and continued for four years (2010 to 2013). The sports vision enhancement was conducted during the two weeks of preseason camp. Typical vision training consisted of Dynavision D2 light board training, strobe glasses, and tracking drills. Strobe glasses and tracking drills were done with pairs of pitch and catch drills using footballs, and tennis balls with instructions to vary arc, speed and trajectory. For skilled players "high ball" drills were focused on, whereas for linemen, bounce passes and low pitch drills were focused on. Reaction time data was recorded for each athlete during every Dynavision D2 training session. We monitored the incidence of concussion during the four consecutive seasons of vision training to the previous four consecutive seasons and compared incidence of concussions; (2006 to 2009-referent seasons vs. 2010 to 2013 vision training seasons).

Results: During the 2006 - 2013 pre- and regular football seasons, there were 41 sustained concussion events reported. The overall concussion incidence rate for the entire cohort 5.1 cases per 100 player seasons. When the data were evaluated relative to vision trained versus referent untrained player seasons, a statistically significant lower rate of concussion was noted in players season in the vision training cohort (1.4 concussions per 100 exposures) compared to players who did not receive the vision training (9.2 concussions per 100 exposures; $P \leq 0.001$). The decrease in injury frequency in competitive seasons with vision training was also associated with a concomitant decrease in missed play time.

Discussion: The current data indicates an association of a decreased incidence of concussion among football players during the competitive seasons where vision training was performed as part of the preseason training. We suggest that better field awareness gained from vision training may assist in preparatory awareness to avoid concussion causing injuries. Future large scale clinical trials are warranted to confirm the effects noted in this preliminary report.

key words: athletic training, concussion, dynavision, football, injury, injury prevention, peripheral vision, vision, vision training

INTRODUCTION

Football is a complex skilled sport with the need to integrate sensory input to be successful, and our opinion is that vision plays a key component.[1] There are 22 players on the field of play, and players need to see, track, and identify multiple targets for successful performance, as well as avoid injuries. Success in football requires robust vision tracking, the substantial intake of visual information and analysis this information rapidly.[2-3] This requires processing of information in the central and peripheral visual fields. Since rule changes in the 1970's, the concept of see what you hit has reduced the risk of catastrophic injury, yet the number of concussions remains high[4].

In recent years the management of traumatic brain injury (TBI) in sports has come under scrutiny from academia and media both noting the short and long term outcomes associated with concussions. Athletic concussions have been in the forefront of the public's focus due to the high profile injuries, deaths, and lawsuits concerning long term consequences from concussion. [5-6] Recently the reported incidence rate for TBI, which includes concussions, went from 1.75 million annually to 3.6 million annually,[7] and likely reflects, in part, increased awareness by both the athletes and support personnel, as well as an increase in the reporting of TBI's. This apparent doubling of reported concussions is supported by recent media reports concerning the burden and seriousness of concussions in sports such as football with some teams reporting 20 concussions per year, up from 10 per year.[7]

Over the last 10 years, the volume of literature that defines or describes the process of injury, assessment processes, and rehab strategies has expanded. The primary emphasis has been on neuro-psychological tools, balance systems, postural position. Although multiple organizations associated with sports have published recommendations, a gold standard still does not exist in terms of post traumatic management, and pre-participation assessment.[1,8-9] In 2004 the National Athletic Trainers Association (NATA) published a position statement based on the available research and clinical practice trends at that time. The position statement included recommendations to its association membership for concussions, however research is evolving at a pace that often overshadows many recommendations. NATA outlines multiple sections in its 2004 position statement,[9] from defining, to pre-participation to evaluation, to assessment, to post concussion management and to return to play. The primary emphasis is on the management of post traumatic brain injury and recommended pre-participation assessment tools.

The National Collegiate Athletic Association (NCAA) guidelines also in 2013[10] focused on the assessment process and recommended that member institutions formulate a concussion management plan with recommendations for baseline testing, neuropsychological evaluation and a return to play pathway. Minimal to no information contained in either policy reflects vision assessment nor the role of vision in return to play. On an annual basis the NCAA publishes a guideline on sports related concussions, which the membership holds as the standard set by the organization.

Little to no emphasis is placed on prevention or training to reduce the risk of traumatic brain injury. Primary work occurs in the area of equipment alteration, by way of either adding a layer for load absorption or in the direction of monitoring impact size and location. However, efforts to use performance training as a tool to reduce injury risk, has received minimal attention in the literature. There remains the question, "Is there a viable option to provide the athlete the opportunity to train neuro-cognitive function to avoid and/or assist the brain in the recovery process?"

The prevention of TBI in football up to this point has received minimal attention, [11] and primary emphasis has been on rule changes and interpretation, equipment evolution, and base line neurological assessment testing. Studies designed to reduce the risk by way of performance training the athlete directly has received minimal attention. Since the equation for injury involves both intrinsic and extrinsic factors at some point intrinsic factors must be addressed. With that as a direction our group assessed available techniques and training modalities to address this issue.

Unfortunately, helmets and concussion mitigation strategies reported to date have been ineffective. [11] What is needed is a strategy that can decrease the risk of injury from collisions and concussive injuries that is easily adoptable by coaches and medical practitioners. The purpose of this study was to evaluate the potential for vision training to decrease the incidence of concussive injury in elite football players. We hypothesized that preseason vision training would significantly reduce both practice and competition concussion incidence in football.

Methods

Human Subjects

Vision training was incorporated into the preseason football camp training schedule of all University of Cincinnati football team members from the 2010 to the 2013 seasons. The testing and training was a team wide activity. No informed consents were signed as this was implemented as part of the standard evaluation for concussions and training was integrated into the performance enhancement segment of the athletes' program. The University of Cincinnati Institutional Review Board (IRB) reviewed the project and determined that it did not meet the criteria for research involving human subjects and therefore IRB oversight was not required.

Dynavision

The Dynavision is a device designed to evaluate and train eye-hand coordination to improve visual motor skills.[7-8] Training typically consists of two one-minute sessions with the athletes. The reason for doing multiple sessions is to demonstrate consistency and improvement with the tasks. The staged and progressive nature of the tasks also helps keep the athletes engaged.

The off-the-shelf, "*A training session" is an established Dynavision protocol.[12-15] "*A", is the program name that comes as part of the package for the Dynavision machine and is a one minute task of hitting lights on the board as quickly as possible. It uses traditional eye-hand reaction training to challenge an individual's eye hand coordination in multiple visual fields. This training drill takes one minute. The resultant output provides that athlete with feedback relative to the number of hits in one minute, as well as the average reaction time for each hit. Targeted programs were written to improve the perception of the regions of interest and eye hand performance and precision. For example, quarterbacks focused on their "blind side" while linemen focused on central visual fields.

The other off-the-shelf training program that is also completed on the Dynavision was the reaction test. The reaction test is a task where the subjects use one hand at a time to hold down one button and when a light lights up, hits that light. The subject is required to scan an area or region of interest in preparation for the light to be hit. When the light is lit, the computer records how long it takes for the subject to initiate a response to that light; moving their hand from the button they were holding. Then the subject hits the newly lit light and the task is completed. So, two tasks in one are performed; seeing the light and responding and hitting the light [15]. It assesses visual and motor reaction times for the left and right hands. The lights that could illuminate are arranged horizontally, vertically (with an arc), and a single light. The subjects are told to scan the area where the lights could illuminate and respond when lit. Alternately, the subjects are told to keep their eyes on one point and uses peripheral vision to see and respond to the lights. Thus the training enhances scanning practices and peripheral vision response times.

Peripheral vision reaction time ratio is a calculation to determine an athlete's speed of reaction to what they see in their peripheral vision. We used the data collected during the Dynavision program; "*A" session during the 2013 preseason football camp for each athlete and calculated the average reaction time for the buttons hit in the outer two rings of the vision board compared to the inner three rings. We compared every athlete's peripheral vision reaction time ratio from the first training session of football camp to their last training session of football camp. The ratio was calculated by taking the mean reaction times for the outer two rings divided by the mean of the reaction times for the inner two rings. A higher ratio means it takes longer to see and hit the buttons in the periphery compared to the center of the visual field.

Strobe Glasses

Strobe glasses (Nike SPARQ Vapor Strobe) are LED lenses that flash and block the light signal to the eyes. [14] They are set to flash more rapidly in the initial training stages and are gradually slowed up as the athlete gets adapted to the training. The slower the interval, the more difficult the task is because of the reduced visual input due to the LED's interruptions.

The Vision Training Procedure

Vision training was divided up by position with targeted drills for each position. This included Dynavision, Strobe Glasses, Pitch and Catch and Tachistoscope. Typically this training occurred during pre-season once-per-day during training camp. Vision training was considered part of conditioning and groups of players rotated through the vision training stations. We typically ran 3 main vision training stations during the football camp and subjects did the vision training daily as part of their pre-season conditioning (Figure 1).

Dynavision Methods.

During football camp, typically 2.5 weeks immediately prior to the start of camp, players had ~40 minutes of structured vision training per day 6 or 7 days per week. The vision training typically consisted of 20 minutes of Dynavision. The Dynavision training programs performed on the light board were purpose built programs that were structured to be appropriate to the players' position. For example receivers and defensive backs would do training requiring the subjects to see and hit lights over their head. Linemen would have specific tasks but with less reaching over their heads as their positions do not require many overhead actions like catching high balls.

All players were required to do dual task drills with their vision. This required tasks that had the subjects' call numbers, words or characters flashed on the Tachistoscope while hitting buttons. The instructions for these drills, were to use eye discipline and keep their eyes on the scope, while using peripheral vision to see the buttons and hit the buttons. This, we believe, helps train functional peripheral vision. Peripheral vision reaction training was also done on the Dynavision where subjects had to react to flashing lights in their peripheral visual fields while focusing on the Tachistoscope or another light.

Tachistoscope.

Typically several players could work on the projected Tachistoscope training simultaneously. Using football photos from the University of Cincinnati games a timed power point program was developed where flashed pictures (still photos) of the games were projected. The subjects were to watch the timed power point and make note of one or two specific bits of information based on questions posed after the flash. The flashed pictures had numbers and or letters randomly distributed throughout the pictures and the players had to note the numbers/letters. Also additional questions were asked of the players such as player numbers from the photos, teams being played etc. This Tachistoscope training was made progressively more complicated during the training camp by making the flash time shorter and the information to be obtained more complicated. Subjects were tasked to do the Tachistoscope training for ~7-10 minutes per session.

Pinhole glasses, strobe glasses and pitch and catch.

Groups of players, typically 2 to 6 players, were given balls, pinhole glasses and strobe glasses and advised to throw the ball(s) around. This was done for approximately 7-10 minutes per session. Subjects rotated strobes and pinhole glasses every minute or two. The pitch and catch tasks were progressed throughout camp by varying the speed of the flash with the strobes, narrowing the visual field of the pinhole glasses etc. Also pitch and catch routines were made progressively more complicated by having subjects turn away from their partner and having to turn and catch.

In Season Training – Maintenance Phase.

During football season a maintenance phase of vision training was initiated. This was exclusively using the Dynavision. Subjects could use the Dynavision at any time on their own, but there was also once weekly structured training typically 10 minutes at a time where subjects were run through a series of Dynavision routines that they had done at camp. No new routines were initiated during the season. In season training sessions were expanded and contracted based on practice and game schedules.

Definition of a Concussion

The concussion management team for the University of Cincinnati sports medicine division uses the American Association of Neurological Surgeons (AANS) definition of concussion at its core; A trauma induced alteration in brain function that is documentable. [16] The documentable component to the definition can come from a change in brain function from a baseline or an abnormal parameter in the absence of baseline.

For the University of Cincinnati the process for identifying a concussion starts on the field.

- A big hit of concern or athlete going down triggers an athletic trainer to assess the athlete.
- If the athlete has a suspected concussion the athletic trainer pulls the athlete from play for a further evaluation by other members of the concussion management team.
- Typical side line concussion assessment test (SCAT) II, SCAT III, and question and answer are performed.
- If the initial concussion suspicion is not founded the player may return to play.
- If the suspicion of concussion remains, the athlete is pulled from all play that day and referred to be evaluated by a physician or physician designate such as a sports neuro specialist.
- The final diagnosis of concussion is made by the team physician based in part on the report of the neuro specialist, the trainers and his/her observations.
- The treatment, rehab, and return to play pathway is initiated for the athlete.

For this study the past concussions were confirmed based upon retrospective review of injury logs generated by the athletic trainer, concussion management team member's report, and the team physician's final diagnosis based on the two reports and in combination with his/her assessment. Currently the diagnosis is unchanged, but the records were being kept as part of an IRB approved concussion protocol so a historical analysis was not needed as they were directly entered into the system.

Helmets

All team members for each season used the same helmet models from the same two manufactures (Ridell and Schutte). All helmets were properly fitted by individuals well-trained in proper helmet fitting and maintenance. Helmets were checked weekly for damage and repaired or replaced as needed. The ratio of helmet type on the team was recorded annually.

Athlete Season Exposures

The relative rates reflect the reported concussions from the beginning of the fall training season (usually August) through the end of the season, including bowl games (except for the 2013-2014 season which did not include the bowl).

Statistics

The initial statistical approach was to compare the pre vision training years' incidence rates to the post vision training years' rates using an unpaired Student's t-Test. The secondary approach for data analysis was an examination of rate of concussion for total player year exposure at the categorized grouping of vision training versus control year sample. Concussion rates were compared between vision training and referent untrained condition using a chi-square test with a Yates correction. Statistical significance was established a priori at $P \leq 0.05$.

RESULTS

Number of injuries

During the 2006 -2013 pre- and regular football seasons, there were 41 sustained concussion events reported. The concussion incidence rate for the entire cohort 5.1 cases per 100 player seasons. When the data were evaluated relative to vision trained versus referent untrained player seasons, a statistically significant lower rate of concussion was noted in players in the vision training cohort (1.4 concussions per 100 player seasons) compared to players who did not receive the vision training (9.2 concussions per 100 game exposures; $P < 0.001$).

The average number of diagnosed concussions per season for the four years prior to vision training was 8.75 ± 1.7. This compares to 1.5 ± 1.0 concussion per season over the four years after initiation of vision training ($P < 0.001$). The years of 2006 to 2009 and 2010 to 2013 each covered two different coaching staffs (Table 1).

Peripheral Vision

The average peripheral vision reaction time ratio calculated during the Dynavision *A training session from the first vision training session of football camp in 2013 was 1.50 ± 0.23. This improved to a ratio of 1.42 ± 0.15 following two weeks of vision training ($P < 0.01$; N=105). Recall that the ratio was calculated by taking the mean reaction times for the outer two rings divided by the mean of the reaction times for the inner two rings.

In Table 2 we see the reaction times taken to hit the Dynavision D2 buttons reported by year and broken down by ring to give a clearer indication of the functional peripheral vision changes seen. What we see is the year to year improvement for the intake of upperclassmen who have had vision training.

A comparison of pre and post training functional peripheral ratios was made to assess the impact of the training program using data from the 2013 camp. Preseason athletes had an average ratio of 1.50 ± 0.23. After vision training these athletes had a ratio of 1.42 ± 0.15 ($P \leq 0.01$).

DISCUSSION

The concept of vision training to improve the athlete's on field performance has evolved into a common practice for the University of Cincinnati sports teams. [14] Multiple authors have suggested that training the visual field may improve several elements of competition. [13-14, 17] There is a growing body of evidence that vision training may have an added benefit of injury prevention [18-19]. The objective of training would be to improve specific visual parameters allowing athletes in sports such as football and baseball may impart an improved ability to focus on the field of play and prepare for or avoid injuries, including mild traumatic brain injury.

In this paper we report that a comprehensive pre-season vision training program is associated with a reduction in concussion incidence in elite football players. It would be easy to criticize the association of vision training to a decrease in injury rate if this were a one-year study. But, this trend was seen over multiple years and coaching regimes (four different coaches). Further, it might be suggested that the decrease in reported injuries was not a causal relationship to vision training as vision training might have had no other demonstrable effects. However, we found that functional peripheral vision (defined by the peripheral vision reaction time ratio) was improved in the team following vision training (Table 2). The research team had previously used vision training methods to improve batting performance in baseball players, so there is familiarity with the initiation and implementation of vision training. [14] A main difference between the training regimen performed for baseball and football is that football was limited to the summer camp about 2.5 weeks whereas baseball was 6 weeks. Finally, the decrease in concussions was seen at a time when most other universities were reporting a rise in concussions.[7] Thus, we believe that there is a strong association between vision training and injury prevention.

The question remains as to how might vision training prevent injuries. We believe that the vision training we performed is broadening the athlete's field of awareness or functional peripheral vision. It may be that with training, the eyes and brain are able to use information obtained within the field of functional peripheral vision to react faster to their changing environment and avoid injury causing collisions. In a post hoc analysis we attempted to assess if the peripheral vision might have improved. To do this we analyzed the Dynavision ™ data from the University of Cincinnati Football team at the beginning and end of the 2013 camp. The improvement from 1.50 ± 0.23 before training to 1.42 ± 0.15 ($P \leq 0.01$) after vision training suggests that the ability of the athletes to see and respond to the lights in their peripheral vision improves with training, and by extension we posit that they may become better able to respond to situations and avoid injuries. It should be recalled that the higher ratio means it takes longer to see and hit the buttons in the periphery compared to the center of the visual field.

Rationale for Vision Training

The vision training was initiated in 2010 for baseline concussion testing and performance enhancement. Also, we published our results on the performance enhancement associated with vision training of baseball players where batting performance was enhanced. [14] For football, the Dynavision and strobe glasses were the main vision training methods used as this was being done as part of concussion management and position specific performance enhancement.

Empirical evidence indicates that the vision training, which included ocular motor and visual conditioning, led to an improvement in the control and fidelity of the extra ocular and intra ocular muscles of the eyes. [12-14, 17, 20-24] This likely included an improvement in muscle memory for the arms to hit the buttons effectively. The eyes were able to more precisely "focus" on a point, remain there and give the brain better information concerning information from peripheral visual fields. This to an extent, this may be what the athletes use during competition to increase awareness of where that point is in physical space. [14, 15, 24]

Limitations

A limitation of this study is that it is a retrospective analysis of reported concussions after the initiation of vision training. There was no control group. The vision training was performed during the summer camp on all players and continued to a limited extent during the football season; in compliance with contact hour rules. This restricted vision training to once a week to less than 15 minutes per session. The vision training was always directed by the same person for all four years and the focus on the vision training was for concussion management and presented to the students as performance enhancement. Thus, there was a dual purpose for the vision training. We estimate that the average player had 20 minutes of vision training on the Dynavision during camp, which is two weeks. This includes all players and all positions. Plus there was an additional 20 minutes doing other vision training related activities. This training duration is similar to what we reported for the University of Cincinnati baseball players of about twelve minutes of vision training per week. [14] While the results of this study provide important preliminary data on the potential benefits of vision training to reduce sport related concussion in football, the small sample size indicates that interpretation of these results should be taken with caution. Before applying these results to clinical applications, a prospective controlled study designed is needed to confirm the finding of the current study

CONCLUSION

Future prospective studies are needed to determine a causal relationship of vision training and injury prevention. Further, from this retrospective analysis, it is not clear what vision training method or methods are most beneficial to support concussion injury risk reduction. Future prospective randomized clinical trials are warranted to better assess the cause and effect of vision training and its potential to reduce concussion incidence in football players.

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Table 1 shows the results from the individual years.

Table 1	Number of Concussions	Number of Players	Coach that year
2006	9	103	M. Dantonio
2007	8	102	B. Kelly
2008	7	103	B. Kelly
2009	11	109	B. Kelly
2010*	1	113	B. Jones
2011	3	110	B. Jones
2012	1	109	B. Jones
2013	1	105	T. Tuberville

*Vision training was initiated Aug 1 2010.

Table 2 * Average Hit Time + SD Pre Season	Ring 1	Ring 2	Ring 3	Ring 4	Ring 5	Functional Peripheral Vision Ratio
2010	0.56 ± 0.08	0.56 ± 0.06	0.69 ± 0.11	0.77 ± 0.12	0.98 ± 0.18	1.52
2011	0.62 ± 0.21	0.64 ± 0.19	0.72 ± 0.20	0.85 ± 0.26	1.02 ± 0.25	1.48
2012	0.55 ± 0.12	0.56 ± 0.12	0.64 ± 0.15	0.77 ± 0.20	0.91 ± 0.33	1.51
2013	0.52 ± 0.08	0.53 v 0.09	0.57 ± 0.07	0.67 ± 0.10	0.80 ± 0.19	1.40
Diameter of Rings (inches)	8.125	17.25	21.25	34.75	43.5	

* time in seconds

Table 2 shows the average time it takes for subjects to hit the different rings when they start the vision training pre-season. The 2010 year was of subjects who had not had vision training. Each subsequent year reported is from subjects with vision training. At the beginning of the season the team's intake values are repeated and tend to come to similar values for the first 3 years. After 4 years of vision training the sustained benefits of the training appears.

Figure Legend

Figure 1.

In this Figure we see the scheme for vision training of University of Cincinnati football players' pre-season where there is very regular and intense training. During these two plus weeks the complexity and demands of the vision training are escalated as the training proceeds. During the season, no new drills are added and a maintenance phase is initiated where subjects perform exclusively the Dynavision once weekly in approximately ten minute sessions.

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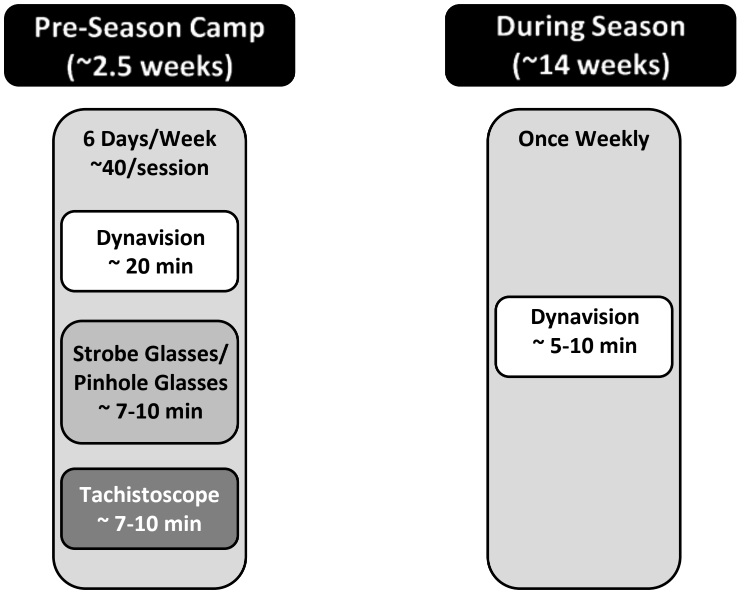
Figure 1



Pre-Season Camp
(~2.5 weeks)
6 Days/Week
~40/session
Dynavision
~ 20 min
Strobe Glasses/
Pinhole Glasses
~ 7-10 min
Tachistoscope
~ 7-10 min
During Season
(~14 weeks)
Once Weekly
Dynavision
~ 5-10 min