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Vision Training Methods for Sports Concussion Mitigation and Management

Joseph F. Clark,[1] Angelo Colosimo,[2] James K. Ellis,[3] Robert Mangine,[3] Benjamin Bixenmann,[4] Kimberly Hasselfeld,[2] Patricia Graman,[5] Hagar Elgendy,[2] Gregory Myer,[6] and Jon Divine[2]

[1]Neurology and Rehabilitative Medicine, University of Cincinnati
[2]Division of Sports Medicine, Department of Orthopaedic Surgery, University of Cincinnati
[3]Department of Athletics, University of Cincinnati
[4]Department of Neurosurgery, University of Cincinnati
[5]College of Education, Criminal Justice, and Human Services, University of Cincinnati
[6]Division of Sports Medicine, Cincinnati Children's Hospital Medical Center
Correspondence to: Kimberly Hasselfeld at hasselky@ucmail.uc.edu

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.

Keywords: Behavior, Issue 99, Vision training, peripheral vision, functional peripheral vision, concussion, concussion management, diagnosis, rehabilitation, eyes, sight, seeing, sight

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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

It takes about 8 min to complete this training.

1. *A Program[8-11]
    1. Direct the subject to stand about 18 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 screen in the board. Have the subject stand in a ready position to be able to hit the lights. Have the subject hold his/her hands up to chest level to position the hands in the center of the rings.
    2. 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.
    3. 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.
    4. 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.
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. 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. Four horizontal lights to the left of the center ring are utilized for Test 1R and the four to the right of the center are utilized for Test 1L.
    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.
    3. Have the subject scan the four horizontal lights that light up during the demonstration sequence. One of the four 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 (**Figure 1A-C**).
    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.
    5. Record the average reaction time for each Test plus an overall Reaction Time.
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. 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).
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.
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]

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. Initially the string is held in the horizontal position and then 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. 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.
    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 (**Figure 2A-C**).
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.
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]

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.
2. For training 2, place the linear lights in the vertical position and repeat steps for Exercise 1.
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°. Common stages are 20 degrees at a time providing it is comfortable for the subject.
4. For training 4, rotate the linear lights to the right from the vertical position and repeat steps for Exercise 1.
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 subject 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

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.
2. Instruct the subject to hold a 10 x 10 saccades chart at 14 inches from the spectacle plane.
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. Test for one minute or until the 100th character is reached.
5. Count and record the number of characters read in the one minute or note the time it takes to read 100.

5. Tachistoscope

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

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

6. Pinhole Glasses or Strobe Glasses with Pitch and Catch

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 min per session. (**Figure 4C** and **4D**) Two to three sessions per week can be performed.
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.

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.
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]

1. Position the subject eight feet away from the saccadic eye charts and centered between two saccadic charts, which are positioned about eight 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 18 inches 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**).
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.
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.
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]

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.
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**).
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 (**Figure 6B** and **6C**).
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.
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.
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

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?”
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**).
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 min (hpm) and the average Reaction Test time for their first time performing it was 0.34 ± 0.03 sec (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 ($p \leq 0.01$). Reaction Test results were 0.354 ± 0.034 sec and improved to 0.315 ± 0.031 sec after training; $p \leq 0.001$. 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 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. 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 appear.

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 min twice a week and in season was 20 min 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 are 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].

Variable	Ring 1	Ring 2	Ring 3	Ring 4	Ring 5
Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	
Average length of time to hit (seconds)	0.52 ± 0.08	0.57 ± 0.11	0.62 ± 0.08	0.71 ± 0.09	0.81 ± 0.10
Diameter of rings (inches)	8.125	17.25	21.25	34.75	43.5

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

Pre Season	Ring 1	Ring 2	Ring 3	Ring 4	Ring 5	Functional Peripheral Vision Ratio
Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**		
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	1.4

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

Results Based on Years of Play			
	Played college football > 2 years at time of testing	**Played college football < 2 years at time of testing**	**P value**
A* (hits per minute)	97.3 ± 12.18	92.0 ± 10.07	≤0.05
(n=29)	(n=68)		
Reaction Test (sec)	0.33 ± 0.031	0.34 ± 0.038	0.26
(n=29)	(n=65)		
Results for Offensive versus Defensive Players			
	Defensive Player	**Offensive Player**	**P value**
A* (hits per minute)	94.5 ± 13.28	93.4 ± 8.97	0.31
(n=42)	(n=55)		
Reaction Test (sec)	0.33 ± 0.033	0.34 ± 0.038	≤0.05
(n=42)	(n=52)		
Results Based on Skilled versus Non-skilled Positions			
	Skilled Position	**Non-skilled Position**	**P value**
A* (hits per minute)	93.8 ± 8.51	93.6 ± 12.75	0.45
(n=45)	(n=52)		
Reaction Test (sec)	0.33 ± 0.040	0.34 ± 0.035	0.41
(n=44)	(n=50)		
Results Based on History versus No History of Concussion			
	History of Concussion	**No History of Concussion**	**P value**
A* (hits per minute)	96.3 ± 12.34	92.1 ± 9.19	NS
(n=28)	(n=69)		
Reaction Test (sec)	0.33 ± 0.034	0.33 ± 0.036	0.39
(n=27)	(n=67)		

Open in a separate window

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

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

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

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

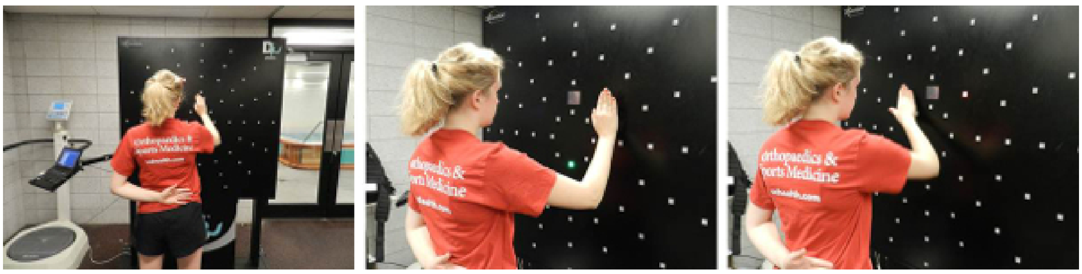

Figure 1: Subject demonstrating placement in front of the system and ready for the start of a program. (**A**) In front of the system. (**B**) Placement of hand to start the first test. (**C**) Hand sweeps left to the light that is lit.

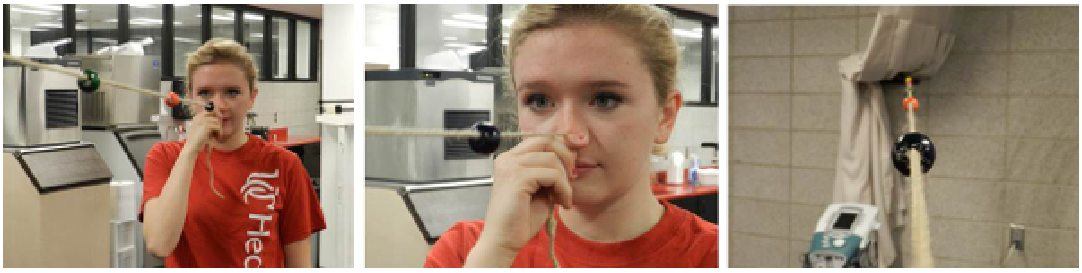

Figure 2: Subject demonstrating Brock's string method. (**A**) Focus on distant bead. (**B**) Focus on closest bead. (**C**) View from subject's perspective.

Figure 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.

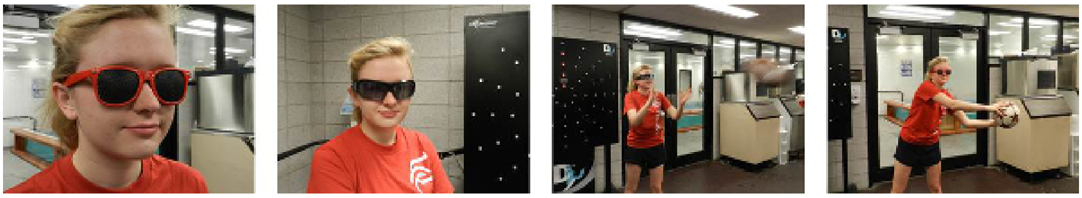

Figure 4: (**A**): pinhole glasses. (**B**) strobe glasses. Subject catching ball with strobe (**C**) or pinholes (**D**) glasses on.

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 5: Saccade chart.

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

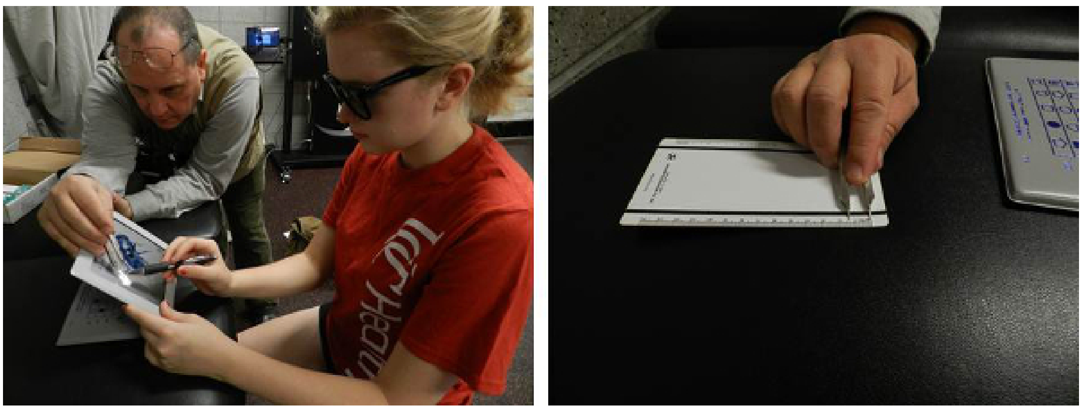

Figure 7: (**A**) subject pinching wing of Stereo Fly. (**B**) calipers used to determine the distance.

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 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 assessed and trained 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 that the subjects have pre-season and in season training to see maintained benefits. Twice a week, 20 min 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 can 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.

Disclosures

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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