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**Effect of Stroboscopic Vision Training on Dynamic Visual Acuity Scores:
Nike Vapor Strobe® Eyewear**

by

Joshua Holliday

A Plan B manuscript submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

In

HEALTH AND HUMAN MOVEMENT

Utah State University
Logan, UT

Abstract

The field of sports vision is continuing to grow, with athletes seeing the benefit of incorporating vision drills as part of their training regimen. Dynamic visual acuity (DVA) is a very important aspect of the visual system and is necessary for sport, providing the ability to track a moving object while our head is moving. A recently released product called the Nike Vapor Strobe® Eyewear introduces a stroboscopic effect to vision training. The effect of stroboscopic training on DVA is unexplored territory. **Purpose:** The main aims of this study were to test the immediate effect of stroboscopic training after one training session, after a two week training program, and two weeks post training. Additionally, we tested the effect of stroboscopic vision training on catching performance. **Methods:** Sixteen participants were divided evenly into two groups according to baseline DVA scores, recorded using the NeuroCom inVision system. Participants then completed 9 days of vision training with three DVA assessments: immediately after day one of ball training, the day after final ball training, and two weeks after the completion of ball training. **Results:** The experimental group had statistically significant improvement in test session two from test session one for left DVA, total vertical DVA, downward DVA, and upward DVA, with no change on test sessions three and four. The control group worsened in performance for total DVA, downward DVA, and upward DVA in test two, three, and four. Both groups had statistically significant improvement in ball catching performance. **Conclusion:** Stroboscopic training increased dynamic visual acuity (after one training session) and ball catching performance (over the course of the training) compared to training without a stroboscopic effect. The Nike Vapor Strobe eyewear is a practical tool for improving catching performance and dynamic visual acuity immediately following training.

Effect of Stroboscopic Vision Training on Dynamic Visual Acuity Scores: Nike Vapor Strobe® Eyewear

When it comes to sports training, great attention is focused toward training physical capabilities, in an attempt to get bigger, faster, and stronger. An area of training often overlooked is sports vision training. Sports vision training is a group of techniques directed to preserve and improve one's visual function with the goal of enhancing sports performance by improving visual ability, which is required for different sporting activities (Quevedo & Sole, 1995). Sports vision training involves the abilities of peripheral vision, visual concentration, hand-eye coordination, reaction time, and anticipation (Abernethy & Wood, 2001), among others. Visual ability is extremely important to the success of an athlete. Not only does vision steer and guide body movement (Balasaheb et al., 2008), but the link between the skill and visual capacity of an athlete influences his/her sport performance (Hitzeman & Beckerman, 1993).

Using baseball players, Clark et al. (2012) discovered that high-performance vision training can lead to an improvement in batting statistics. The participants trained three days a week for six weeks using a variety of vision devices, including strobe glasses, Dynavision (a eye-hand coordination device), a Tachistoscope (trains the brain to recognize images faster), and a rotary (vision pursuit device) (Clark et al.). Batting average increased from .251 to .285, indicating a positive relationship between vision training and batting statistics. In a review of literature, Stine et al. (1982) evaluated the research of vision and sports and explored the basis for training visual abilities to enhance sports performance. The literature revealed that vision performance may be trainable and transferable to athletic performance. Du Toit et al. (2011) studied whether sports vision exercises could improve visual abilities. Pretesting and post-

testing scores were obtained for visual acuity, eye dominance, focusing, tracking, vergence, sequencing, eye-hand coordination, visualization, and reflex. Vision exercises included throwing and catching, hitting a ball, and alphabet letter recognition. Du Toit et al. (2011) discovered that sports vision training practice (drills), when done correctly, leads to improvement in nearly all tested abilities (except focusing) and lead to an enhancement of motor and cognitive learning and performance. By using exercises that develop visual abilities and lead to an improvement in performance, consistency, accuracy, and stamina of the athlete's visual system, sports vision training is becoming a popular means of improving sports performance (Ludeke & Ferreira, 2003).

Visual characteristics such as reaction time, tracking, and hand-eye coordination are recognized as important components of sports vision, but equally important is the component of dynamic visual acuity. Dynamic visual acuity can be described as the ability of an individual to track a moving object, while his/her head is moving at the same time. More specifically, dynamic visual acuity is the ability of the visual system to resolve detail and to discriminate the fine parts of a moving object when there is relative movement between the object and the observer (Burg & Hulbert, 1961; Goebel et al., 2007; Hitzeman & Beckerman, 1993; Miller & Ludvigh, 1962). Dynamic visual acuity is a complex visual task that requires the observer to detect details of a moving object such as speed, color, texture, and direction (Hoffman, Rouse, & Ryan, 1981), and visually acquire it with eye movements, all in a relatively brief time period (Goodson, 1980).

In early research, dynamic visual acuity was measured by using a projector and slides and having subjects identify targets from the slides moving across a screen at different target

speeds. The participant's score (1-15) was the last correctly discriminated target orientation, preceding two consecutively missed targets. The Ortho-Rater scale was used to obtain a score (1-15) reflective of the maximal speed at which an object could move across a screen and still be perceived accurately by a subject (Burg & Hulbert, 1961; Miller & Ludvigh, 1962). A recent dynamic visual acuity assessment used projector slides with eye tracking to calculate how fast the eyes were moving while the target velocity changed on the screen. A visual target was projected on the screen through the slide projector, with the motion of the target being controlled by rotating a mirror that was located between the projector and the screen (Uchida et al., 2012). This measure of dynamic visual acuity tested both a free-eye-movement condition and a fixation condition. The free-eye-movement condition allowed the participant to make catch-up saccades, while the fixation condition did not (Uchida et al., 2012). Many recent studies have begun using a measure of dynamic visual acuity calculated by the NeuroCom InVision Dynamic Visual Acuity Test (Goebel et al., 2007; Schneiders et al., 2010; Yoo et al., 2009). This test uses a computer and a head sensor, and determines the velocity that the head is rotating, to allow a more controlled estimation of how well a person can recognize the orientation of an object on the computer screen (NeuroCom International, Inc.).

The NeuroCom dynamic visual acuity assessment aims at evaluating the efficiency of a person's vestibular ocular reflex (VOR), because the measures of VOR directly correlate with their measures of DVA (Neurocom International, Inc.). For an athlete to sufficiently track a moving object, the object of interest must remain centered on the fovea (a small retinal area with the greatest density of visual receptors; Neurocom International, Inc.). To achieve this visual tracking, the VOR stabilizes objects on the fovea by cancelling out head movements with

compensatory, reflexive eye movements (Neurocom International, Inc.). When the head moves, recognition of movement is provided by linear and angular acceleration receptors of the inner ear, which sends an electrical current along the vestibular nerve to the brainstem (Rutka, 2004). From the brainstem, the abducens cranial nerve is triggered to move the eyes in the appropriate direction (Rutka, 2004). In other words, the VOR keeps the eyes still in space by rotating the eyes in the opposite direction of the head (Neurocom International; Vilis, 2006), which maintains a stable retinal image during active head movement (Rutka, 2004). Dynamic visual acuity is one component of the vestibular ocular reflex that might improve as a result of increased demands and workloads, through visual exercises, placed on the visual and vestibular systems.

Dynamic visual acuity is an important visual skill in sports performance (Ludeke & Ferreira, 2003; Sanderson & Whiting, 1974) and good dynamic visual acuity is crucial in sports that involve a moving target, such as volleyball and basketball (Morris & Kreighbaum, 1977), baseball (Rouse et al., 1988), softball (Millsagle, 2000), and motocross (Schneiders et al., 2010). Dynamic visual acuity could also be important in hockey, lacrosse, and tennis, where athletes have to focus on quick moving objects, while their head is also moving. Dynamic visual acuity performance can be improved through practice (Miller & Ludvigh, 1962), and studies have shown an improvement in dynamic visual acuity associated with training of the visual system (Long & Rourke, 1989), as well as a significant correlation between dynamic visual acuity and catching capabilities, which directly relates to on-the-field performance (Sanderson and Whiting, 1974).

In recognizing that dynamic visual acuity is an essential aspect of athletic performance, it is not surprising that the dynamic visual acuity of athletes has shown to be superior to that of non-athletes (Bouvier et al., 2011; Ishigaki & Miyao, 1993; Quevedo et al., 2011). Several studies have shown statistically significant differences in dynamic visual acuity between athletes and non-athletes in sports such as baseball (Rouse et al., 1988), tennis and badminton (Ishigaki & Miyao, 1993), softball (Millslagle, 2000), motor sports (Schneiders et al., 2010), and volleyball (Ishigaki, 2002). Furthermore, higher levels of dynamic visual acuity in athletes is attributed to an improved ability to track moving targets, rather than being better at perceiving moving objects in comparison to blurred images (Uchida et al., 2012). Because dynamic visual acuity is important for sport performance and can be improved by increasing the amount of stress placed on the visual system, through repetitive practice of visual exercises (Long & Rourke, 1989; Miller & Ludvig, 1962), it is necessary to determine the most effective way to train and improve an individual's dynamic visual acuity.

A recently released sports training tool, Nike Vapor Strobe® eyewear (see materials and methods), focuses on improving many visual characteristics such as concentration, reaction time, hand-eye coordination, depth perception, and visual endurance. The eyewear uses stroboscopic technology to interrupt vision while training. Instead of seeing a ball thrown the entire way, it is seen for segments, and the eyes and brain are forced to adjust to the limited frequency of information that the visual system has access to. The logic behind stroboscopic training is that the limited frequency of information that the visual system has access to will force individuals to reduce their reliance on visual feedback, causing them to react and make decisions more quickly (Appelbaum et al., 2011), therefore creating the opportunity to improve

the processing of visual information as well as to utilize other sensory information during sport performance.

By making better use of the limited visual information available in training, athletes should see improvements in multiple aspects of their sports vision capabilities. Previous research has indicated that stroboscopic training leads to improvement in the transfer of learned skills (Appelbaum et al., 2011; Reichow et al., 2010; Shroeder et al., 2011), information encoding in short-term memory (Appelbaum et al., 2012), anticipatory timing (Smith & Mitroff, 2012), and ice skills in hockey players (Mitroff et al., unpublished manuscript). The minimal research conducted using the Nike Vapor Strobe® eyewear supports the claims that the glasses provide an improvement in a variety of visual abilities (Nike Sparq Sensory Training, 2012). However, there is no literature regarding the effect of Nike Vapor Strobe® eyewear on dynamic visual acuity. Because of the importance of dynamic visual acuity to sport performance, it would be useful to know if training with the Nike Vapor Strobe® eyewear could increase dynamic visual acuity.

Dynamic visual acuity is necessary for an athlete to recognize and track a moving object, while his/her head is moving. Depending on the sport or activity, this object may not be constantly seen in the field of vision, and the athlete may have to locate the object while only limited visual information is available. An example would be a football receiver turning his head at the last second and having to find the ball before catching it, or a hockey goalie having to locate a puck moving behind several players or after a deflection. A similar scenario is presented with the strobe glasses. The Nike Vapor Strobe® eyewear are an ideal training tool for improving dynamic visual acuity, precisely because they progressively limit the duration of

information an athlete has to work with. Less visual information about the path of an object (e.g., ball, puck) should force an athlete to pick up on cues related to the future location of the unseen object and potentially react more quickly to the limited visual information that is available. It is also reasonable to infer that stroboscopic training will increase dynamic visual acuity because stroboscopic training decreases the reliance on visual feedback and increases the reliance on other predictive and reactive mechanisms important for dynamic visual acuity.

The purpose of the present research was to 1) Assess the effect of stroboscopic training, with the Nike Vapor Strobe® eyewear, on dynamic visual acuity scores after a two week training program. Vision training should lead to an increase in dynamic visual acuity scores whether training with stroboscopic glasses or not (Ludvigh & Miller, 1962; Long & Rourke, 1989), therefore, both the experimental group and the control group should expect an increase from baseline scores. Whether the experimental group improved significantly more than the control group, from baseline assessments to post-training, was important. It was hypothesized that stroboscopic vision training would have more of an effect on dynamic visual acuity scores compared to normal vision training because stroboscopic vision training puts restrictions and increased demands on the visual system, forcing it to work efficiently, as well as increases the reliance on other predictive and reactive mechanisms.

Aside from the primary goal of wanting to know the effect of stroboscopic training on dynamic visual acuity after a 2 week training program, there is also interest in 2) The immediate effects of stroboscopic training on dynamic visual acuity after one training session, as well as 3) How long the effects of dynamic visual acuity training last post training. These questions are important for a few reasons. If a statistically significant effect on dynamic visual acuity after one

session was evident, these glasses could prove to be a practical option for use during game day preparations, where an athlete wants to be at an optimal performance level. Effectiveness two weeks post training is useful for knowing if an athlete needs to train year round with the eyewear, or if they can train for two weeks, and have the effects last for an extended duration of time. Lastly, 4) It is important to see how training with the Nike Strobe eyewear improved ball catching performance over two weeks of ball training drills.

Methods

Participants

Sixteen NCAA Division I Football athletes from the Utah State University Football team participated as unpaid volunteers. Participants were recruited from a pool of randomly selected football players, using the current football roster (Spring 2013). Half of the participants were placed in the experimental group and the other half in the control group, based upon baseline DVA scores, to ensure there were no differences between groups. The participants had an age range of 19-25 years with the experimental group having a mean of 21.75 years, and a standard deviation of 1.98, and the control group a mean of 21 years, and a standard deviation of 2.36. Participants had an experience range of 4-16 years with the experimental group having a mean of 11.88 years, and a standard deviation of 2.36, and the control group a mean of 11.1 years and a standard deviation of 3.72. Six participants had corrected vision and ten did not. All 16 participants were right handed, and the group consisted of 2 quarterbacks, 3 wide-receivers, 2 offensive-linemen, 1 tight-end, 1 running-back, 3 line-backers, 3 defensive-backs, and 1 kicker. Participants were advised not to participate if

they had a history of seizures, migraines, or a sensitivity to light. Additionally, participants were also advised not to participate if they had a history of concussion in the previous three months or any other injury preventing them from running, catching, or moving quickly. No participants were omitted from this study because of these restrictions. Participants were allowed to participate if they had corrected vision, but were instructed to wear their contacts for every session. There was 100% compliance with the participants in this study. No participants missed a ball training session or DVA test. There were no statistically significant differences in any dependant variables when comparing the experimental and control groups at baseline (test 1) with a two-tailed independent t-test. Static, $t(14) = .59, p = .56$, perception time test, $t(14) = .89, p = .39$, horizontal DVA, $t(14) = .55, p = .59$, left DVA, $t(14) = 1.1, p = .56$, right DVA, $t(14) = -.30, p = .77$, vertical DVA, $t(14) = 1.2, p = .24$, downward DVA, $t(14) = 1.1, p = .31$, and upward DVA, $t(14) = 1.2, p = .25$.

Study Design

Participants completed a 2 week (10 day) study that lasted approximately 30 minutes each day, and included a 2 week posttest. Each participant completed both NeuroCom inVision dynamic visual acuity assessments and visual-motor training. There were four NeuroCom inVision dynamic visual acuity assessments and eight visual motor training sessions. The NeuroCom inVision assessments were administered prior to training, immediately after the first training session, the day after the final training session, and two weeks post training.

NeuroCom inVision Test

The NeuroCom inVision dynamic visual acuity protocol is “an impairment-level test that quantifies the combined influences of the underlying visual and VOR system pathologies on an athlete’s ability to perceive objects accurately while actively moving the head” (NeuroCom International, Inc.). The test measured the participant’s ability to recognize the orientation of a briefly presented optotype (the letter “E”) on a screen while the head was either still or moving, and gave a comprehensive report on three variables: static visual acuity, minimum perception time, and visual acuity difference (NeuroCom International, Inc.).

During the testing period, the participant was seated 10 feet away from a computer monitor and sequences of the optotype “E” were briefly presented in one of four possible random orientations (up, down, left, or right). When the patient correctly identified the orientation of the optotype, the test progressed and repeated until the orientation was no longer able to be determined. The patient’s visual acuity was determined via a validated statistical search algorithm. The units of measure for static and dynamic visual acuity were LogMAR (see explanation below) (NeuroCom International, Inc). For static visual acuity, minimum perception time, and horizontal and vertical dynamic visual acuity movements, a total of 3 rounds were completed, always in the same order. For horizontal and vertical dynamic visual acuity tests, all subjects performed practice trials until they were familiar with the test protocol before the data was officially collected. It was expected that experience with the NeuroCom inVision testing would affect both the experimental and control groups similarly. This dynamic visual acuity assessment test has been used in recent research and is considered a valid measure for quantifying dynamic visual acuity (Goebel et al., 2007; Schneiders et al., 2010; Yoo et al., 2009).

LogMAR. LogMAR is a measurement of visual acuity, which uses a finer grading scale and allows for greater accuracy and improved test/retest reliability. It is the recommended

Table 1

LogMAR

| <u>Snellen</u> | <u>LogMAR</u> |
|----------------|---------------|
| 20/40 | 0.3 |
| 20/32 | 0.2 |
| 20/25 | 0.1 |
| 20/20 | 0.0 |
| 20/16 | -0.1 |
| 20/12.5 | -0.2 |
| 20/10 | -0.3 |

Snellen – LogMAR Relationship

instrument of choice for measuring visual acuity, especially in the research setting. LogMAR scores are based on an equation within the computer that uses the smallest optotype that can be correctly identified 3/5 times. The visual acuity results reported from LogMAR charts correspond with the visual acuity results reported from Snellen charts (Table 1).

(Neurocom International, Inc.)

Static Visual Acuity Test. The first step was to determine the participant’s static visual acuity (SVA). The static visual acuity is the ability to perceive the correct orientation of the optotype while keeping the head still. With the head stationary, the participant correctly identified the orientation of the given optotype. The size of the optotype is reduced and the process repeated until the orientation of the optotype can no longer be reliably determined. The SVA value is the smallest optotype that can be accurately identified (NeuroCom International, Inc.). The participant identified the orientation of the optotype starting at 0.0 logMAR. Each optotype appeared for one second and the participant had to determine its orientation (e.g. left, right, up, down) (Goebel et al., 2007). The experimenter recorded the participant’s responses using the arrow keys on the keyboard or hand held clicker. Each

optotype size was presented a maximum of 5 times. If the participant responded incorrectly to 3/5 of the presentations, the optotype increased in size until the participant could correctly identify 3/5 presentations. Three out of five correct responses triggered a one level decrease in optotype size until the optotype was too small for identification (Goebel et al., 2007).

Perception Time Test. The second step was to determine the participant's minimum perception time using the perception time test (PTT). The minimum perception time measures the time taken to perceive the correct orientation of the optotype (NeuroCom International, Inc.). The participant identified the orientation of the optotype as the presentation time and optotype size was reduced, and the process was repeated until the orientation of the optotype could no longer be accurately identified (NeuroCom International, Inc.). The minimum perception time was used in determining the length of exposure of the optotype during the dynamic visual acuity testing.

Dynamic Visual Acuity. The third step was to determine the participant's dynamic visual acuity. The best dependent variable representation of dynamic visual acuity is the visual acuity difference report. The visual acuity difference is the difference between static and dynamic visual acuity for each head movement axis, is reported as a ratio based on the size of the optotype on the screen, and the distance the screen is away from the eye, and is automatically calculated by the computer (NeuroCom International, Inc.). To determine the participant's dynamic visual acuity, the participant wore a sensor on their head that continuously measured the position and velocity of head movements, allowing presentation of the optotype while the head was moving in a specific direction at or above the minimum velocity. To prevent prediction, presentations of optotypes for one direction (e.g. right) were

different than the presentations during another direction (e.g. left) (NeuroCom International, Inc.). The duration of the optotype presentation was set so that the participant had sufficient time to perceive the optotype during head movement but not enough time to initiate a catch-up saccade, thus focusing solely on dynamic visual acuity created by the vestibular ocular reflex (NeuroCom International, Inc.). The minimum display time interval was set at 45 milliseconds or the participant's minimum perception time, with the maximum set to the participant's minimum perception time plus 45 milliseconds (NeuroCom International, Inc.). As with the static visual acuity test, there were 5 optotype presentations at each acuity level. The response was recorded as an error if the incorrect orientation was reported. If the participant responded incorrectly to 3/5 presentations, the optotype size would increase by one level. If the subject correctly responded to 3/5 presentations, the optotype decreased by one level. This process was repeated until 3 consecutive errors were made for each direction of head movement (Goebel et al., 2007).

There were two head movements that were measured in this study, horizontal and vertical head movement. For horizontal head movement, the participant moved his/her head left and right at a target velocity fixed between 85-120 degrees per second. If the participant failed to maintain head movement at the target velocity for at least 40 ms or moved slower than 80 degrees per second, the test would be interrupted with feedback about how to move correctly (NeuroCom International, Inc.). If head movement was faster than 120 degrees, the bar turned from green to red and the tester instructed the participant to slow down their head movement (NeuroCom International, Inc.). For the vertical movement, the participant moved his/her head up and down at a target velocity fixed between 60-100 degrees per second. If the

participant moved his/her head too fast or too slow the same interruptions would occur.

Judgments of the optotype direction during these head resulted in 6 dependent variables – Left DVA, Right DVA, Horizontal DVA, Down DVA, Up DVA, and Vertical DVA.

Vision Training

The visual motor training was administered on eight different days over a two week time period. Participants were placed into experimental and control groups based on initial dynamic visual acuity test scores. This ensured that there was an equal baseline dynamic visual acuity mean between the control and experimental groups, creating an equal opportunity for an increase in dynamic visual acuity. During training, the experimental group wore the Nike Vapor Strobe® eyewear, while the control group wore eyewear that had no stroboscopic effect.

Nike Vapor Strobe® Glasses

The Nike Vapor Strobe® eyewear uses battery-powered liquid crystal filtered lenses that alternate between transparent and opaque states and provide varying lengths of occlusion that are under the control of the participant. The transparent state consists of complete visibility while the opaque state consists of a medium grey that is difficult to see through. The strobe effect is defined by opaque states that can be changed through eight different durations, ranging from 25-900ms of visual occlusion, while the transparent state is fixed at a constant 100 ms (Appelbaum et al., 2011); (See Table 2). This means that the amount of time the participant can see through the glasses never changes, but instead, the duration of time the glasses are opaque changes depending on the difficulty level. The shorter the opaque state, the greater the total opportunity to see a moving object.

Table 2. Nike Vapor Strobe Effect

| Level | Time Transparent | Time Occluded |
|-------|------------------|---------------|
| One | 100ms | 25ms |
| Two | 100ms | 43ms |
| Three | 100ms | 67ms |
| Four | 100ms | 100ms |
| Five | 100ms | 150ms |
| Six | 100ms | 233ms |
| Seven | 100ms | 400ms |
| Eight | 100ms | 900ms |

Stroboscopic Training Regimens

The training procedure was designed to have the participants perform ball catching tasks, that were intended to engage the visual-motor system and stimulate dynamic visual acuity. All testing used standard tennis ball and was conducted in a controlled indoor environment. Experimental and control participants trained separately to prevent awareness of experimental condition assignments. All participants participated in the same drills for the same amount of time. Each ball training session was approximately twenty-five minutes long. Prior to training, the experimental group was instructed on how to properly operate the eyewear as well as the criteria for increasing the strobe level (5 consecutive catches). The training regimen was two weeks long, with 5 days each week. Day one consisted of baseline NeuroCom inVision testing, day two was ball training followed by a NeuroCom retest, days 3-9 were only ball training days, and day ten was final NeuroCom testing. Two weeks after final testing, participant's visual acuity was tested again with the NeuroCom .

The aforementioned training regimen was established based on literature regarding both sports vision and stroboscopic training (Appelbaum et al., 2011; Du Toit et al., 2010; Reichow et al., 2010). All participants started each drill with the glasses set at “Level 1”. Training difficulty (strobe level) progressively increased after 5 consecutive catches at each strobe level. The difficulty continued to increase until the time limit of four minutes was reached for each drill. The highest level reached with each drill, as well as the percentage of catches for that drill, was recorded to evaluate improvement. Training consisted of four different drills, four minutes each, that all participants performed. Ball tosses were randomly prescribed using a random number generator from Microsoft Excel and a 3x3 grid on the wall behind the participant. One ball was thrown every six seconds for a total of approximately 40 throws per drill (Appelbaum et al., 2011; Nike Sparq Sensory Training, 2012; Strobe Training, 2012).

From the ball training, two dependent variables were recorded – average catch percentage and average strobe level reached. To obtain the average catch percentage, the average percentage of catches from each of the four drills were averaged together to yield a total catch percentage for that session. To evaluate improvement from beginning to end, only the catch percentage from session one and session nine were analyzed. For the experimental group, all catches were completed while wearing the strobe eyewear, and for the control group, all catches were completed while wearing eyewear with no strobe effect.

To obtain the average strobe level reached, the highest strobe levels for each of the four drills were averaged together to yield the average strobe level for each session. An increase in strobe level was defined as five consecutive catches. All participants started at level one with

the maximum level being level eight. For the experimental group, five consecutive catches signified an increase in strobe level on the glasses which resulted in an increase in difficulty. For the control group, there was no increase in difficulty, but five consecutive catches were still recorded as an increase in strobe level for comparison purposes.

Ball Catch Drill. For the ball catch drill, the experimenter and participant stood 20 ft apart, throwing the tennis ball back and forth between the participant and the researcher, with varied location, speed, and trajectory.

Wall Ball Drill. The participant faced the wall while standing approximately 12 ft away. The researcher threw the ball over the participant off of the wall, and the participant exploded forward to attempt to catch the ball.

Head Turn and Catch Drill. With the participant and researcher standing 30 ft apart, and the participant faced away from the researcher, the participant turned his/her head over his right shoulder looking toward the researcher. The researcher threw the ball, and the participant turned his head to the left, found the ball and caught it, while still facing away from the researcher. The participant rotated the starting position back and forth, looking over the right shoulder to the left.

Turn and Catch Drill. The participant and researcher stood 30 ft apart, with the participant facing away from researcher. The researcher threw the ball, yelling “ball” when released. The participant turned around and had to locate the ball during its flight path, and catch it.

Statistical Analysis

Six dependent variables were assessed in a 2 group (control vs. experimental) by 3 test (difference from baseline for day 2, 3, and 4) repeated measures ANOVA, using the difference between baseline (pre-training), and three post training assessments. Dependent variables were the visual acuity difference from zero for both horizontal and vertical movement, consisting of horizontal left, horizontal right, total horizontal, vertical down, vertical up, and total vertical for both control and experimental groups. These variables will be analyzed with Microsoft Excel, IBM SPSS software, and SASS software using a 2 group (control vs. experimental) by 3 testing session repeated measures analysis of variance. Confidence intervals were used to determine if dependent variables were statistically significant from zero, indicating a change from baseline.

For ball training, 2 dependent variables were assessed using paired t-test comparison. Mean and standard deviation were calculated for average catch percentage and average strobe level reached.

Additionally, independent t-tests were run to compare similarity of baseline scores for both the control and experimental groups. The alpha level was set at $p < .05$ to determine statistical significance.

Results

Table 3. DVA Difference From Test 1 for Experimental and Control Groups

| | <u>Experimental</u> (n = 8) | | | | <u>Control</u> (n = 8) | | | | |
|------------|--------------------------------|------------------------|------------------------|------------------------|---------------------------|------------------------|------------------------|------------------------|--------------------|
| | <u>Test 1</u> DVA | <u>Test 2</u> Diff. | <u>Test 3</u> Diff. | <u>Test 4</u> Diff. | <u>Test 1</u> DVA | <u>Test 2</u> Diff. | <u>Test 3</u> Diff. | <u>Test 4</u> Diff. | |
| Static | -0.26 | .01 | -.001 | .02 | Static | -0.28 | -.01 | -.01 | -.01 |
| PTT | 24.2 | 3.8 | 4.6 | -3.3 | PTT | 20.8 | .43 | .84 | .01 |
| Left | 0.13 | -.05* ¹ | -.02 | -.05* | Left | 0.10 | -.01 ¹ | -.04* | -.02 |
| Right | 0.10 | .002 | +.005 | -.024 | Right | 0.11 | -.01 | -.03 | -.002 |
| Horizontal | 0.12 | -.026* | -.01 | -.04* | Horizontal | 0.10 | -.01 | -.03* | -.02 |
| Down | 0.10 | -.02 ² | -.03 ³ | -.03 ⁴ | Down | 0.07 | +.03* ² | +.03* ³ | +.03* ⁴ |
| Up | 0.10 | -.04* ⁵ | +.02 | -.02 | Up | 0.07 | +.04* ⁵ | +.02 | +.01 |
| Vertical | 0.10 | -.05* ⁶ | -.03 | -.03 ⁷ | Vertical | 0.07 | +.01* ⁶ | -.0001 | -.003 ⁷ |

Note. All results reported as LogMAR

* Denotes statistically significant difference from 0;

Same numbers represent statistically significant differences between the experimental and control group for that condition.

Static Visual Acuity and Perception Time Test

There were no statistically significant differences between the experimental and control groups for static visual acuity or the perception time test, DVA, $F(1, 15) = 2.66, p = .13$, $\eta_p^2 = .043$, DVA, $F(1, 15) = .04, p = .85$ (see Table 3). There were likewise no statistically significant differences observed between the groups and the testing days for static visual acuity or the perception time test, $F(2, 28) = .056, p = .58$, $F(2, 28) = .88, p = .43$. The effect size of the group difference indicates a large effect and suggests that even with adding more subjects there would not likely be a statistically significant difference between groups.

Total Horizontal DVA

For total horizontal DVA there were no statistically significant differences between the experimental and control groups, $F(1, 15) = .07, p = .80, \eta_p^2 = .23$, nor was there any statistically significant difference observed between the groups and the testing days, $F(2, 28) = 2.74, p = .08$. The effect size of the group difference indicates a large effect and suggests that even with adding more subjects there would not likely be a statistically significant difference.

Left DVA

There was no overall statistically significant difference between the experimental and control groups, $F(1, 15) = .31, p = .59, \eta_p^2 = .02$ (see Figure 1). However there was a statistically significant day by group interaction, $F(2, 28) = 3.42, p = .05, \eta_p^2 = .196$, and a statistically significant difference between groups for test session 2, $F(1, 28) = 6.24, p = .02, \eta_p^2 = .182$. The experimental group score for left DVA, (.05) significantly improved in test session 2 over test session 1, as supported by a value statistically significant from zero, 95% CI [-.080, -.025]. The effect size of the group difference indicates a less than medium effect and suggests that adding more subjects creates the opportunity for seeing a statistically significant difference.

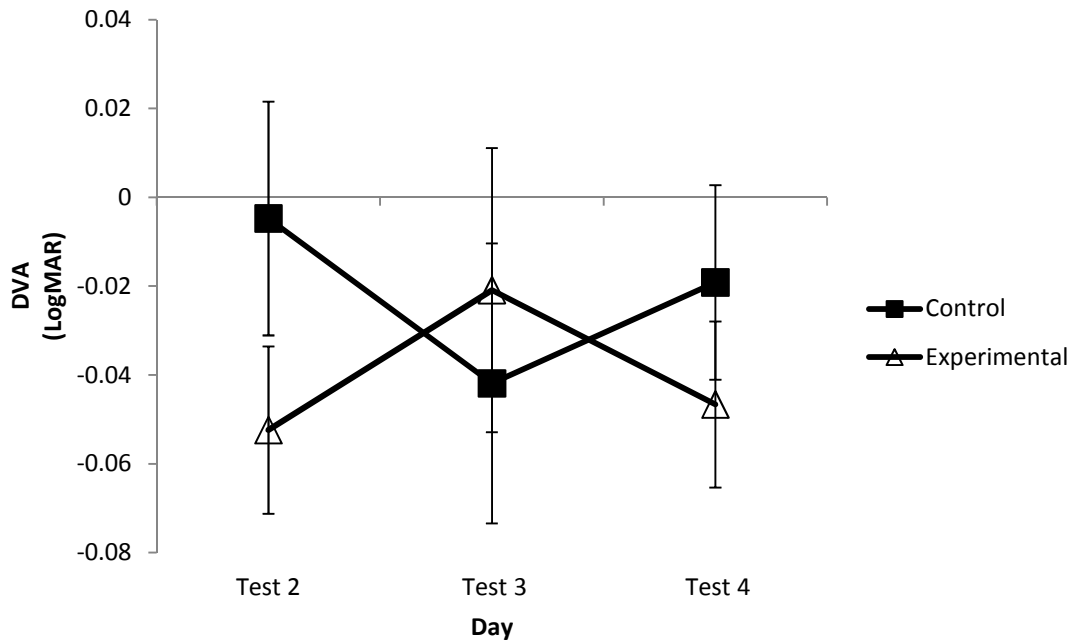


Figure 1. Left DVA for test session 2, 3, and 4, comparing Control and Experimental groups. Error bars represent standard errors.

Right DVA

For right DVA there were no statistically significant differences between the experimental and control groups, $F(1, 15) = .06, p = .81, \eta_p^2 = .049$, nor were there any statistically significant difference observed between the groups and the testing days, $F(2, 28) = 1.34, p = .28$. The effect size of the group difference indicates a less than medium effect and suggests that adding more subjects creates the opportunity for a change in level of difference.

Total Vertical DVA

There was a statistically significant difference between groups for total vertical DVA, $F(1, 15) = 9.22, p = .01, \eta_p^2 = .394$ (See Figure 2), as well as a statistically significant difference between groups for session 2, $F(1, 28) = 11.59, p = .002, \eta_p^2 = .293$, and session 4,

$F(1, 28) = 7.40, p = .01, \eta_p^2 = .209$. The experimental group total vertical DVA (-.03) significantly improved in test session 2 over test session 1, 95% CI [-.054, -.001], and the control group total vertical DVA (.04) significantly worsened in test session 2 over test session 1, 95% CI [.008, .061]. Although there was a statistically significant difference between groups for total vertical DVA in test session 4, the contrasts did not support a statistically significant difference from zero for either the control or the experimental group.

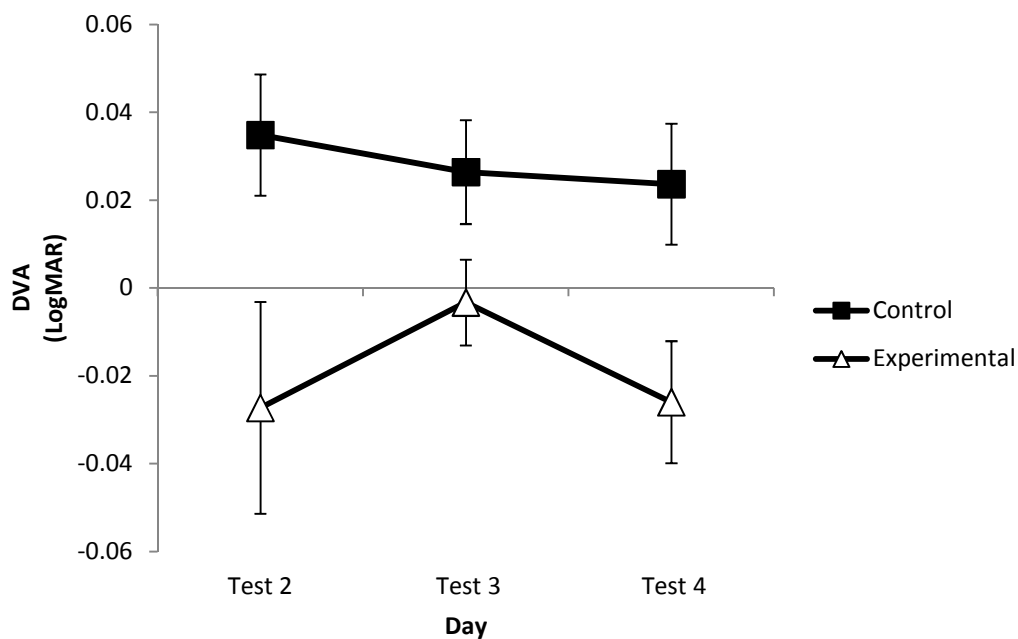


Figure 2. Vertical DVA for test session 2, 3, and 4, comparing Control and Experimental groups. Error bars represent standard errors.

Downward DVA

There was a statistically significant overall difference between groups for downward DVA, $F(1, 15) = 5.28, p = .04, \eta_p^2 = .274$ (See Figure 3), as well as between groups within test sessions 2, 3, and 4, $F(1, 28) = 6.49, p = .02, \eta_p^2 = .204$, $F(1, 28) = 7.35, p = .01, \eta_p^2 = .208$, and $F(1, 28) = 6.09, p = .02, \eta_p^2 = .179$. The experimental group experienced statistically significant

improvement in downward DVA (-.02), as supported by an average value statistically significant from zero, 95% CI [-.037, -.003]. In comparison, the control group experienced a statistically significant decrease in scores for downward DVA (.03) for all three days, 95% CI [.015, .048], indicating a worse performance than in the baseline test.

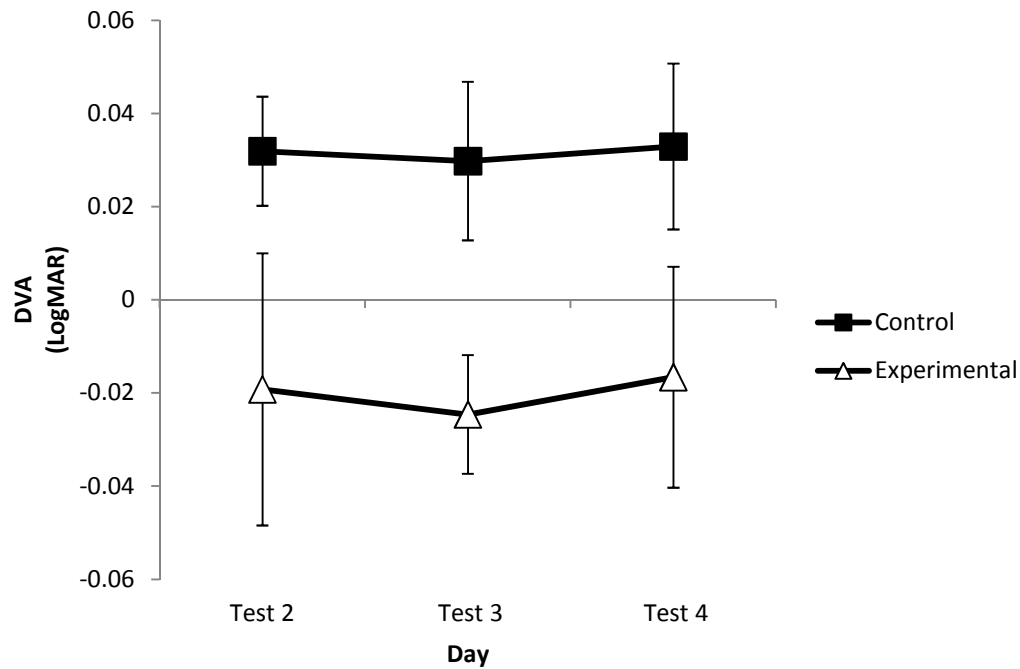


Figure 3. Downward DVA for test session 2, 3, and 4, comparing Control and Experimental groups. Error bars represent standard errors.

Upward DVA

The experimental group had statistically significant lower upward DVA scores than the control group, $F(1, 15) = 4.76, p = .05, \eta_p^2 = .254$ (See Figure 4). Contrasts between groups within each day revealed a statistically significant difference between groups for test 2, $F(1, 28) = 10.49, p = .003, \eta_p^2 = .275$. The experimental group scores for upward DVA (-.04) significantly improved in test session 2 over test session 1, 95% CI [-.068, -.003], while the control group score for up DVA (.04) significantly declined, 95% CI [.005, .071].

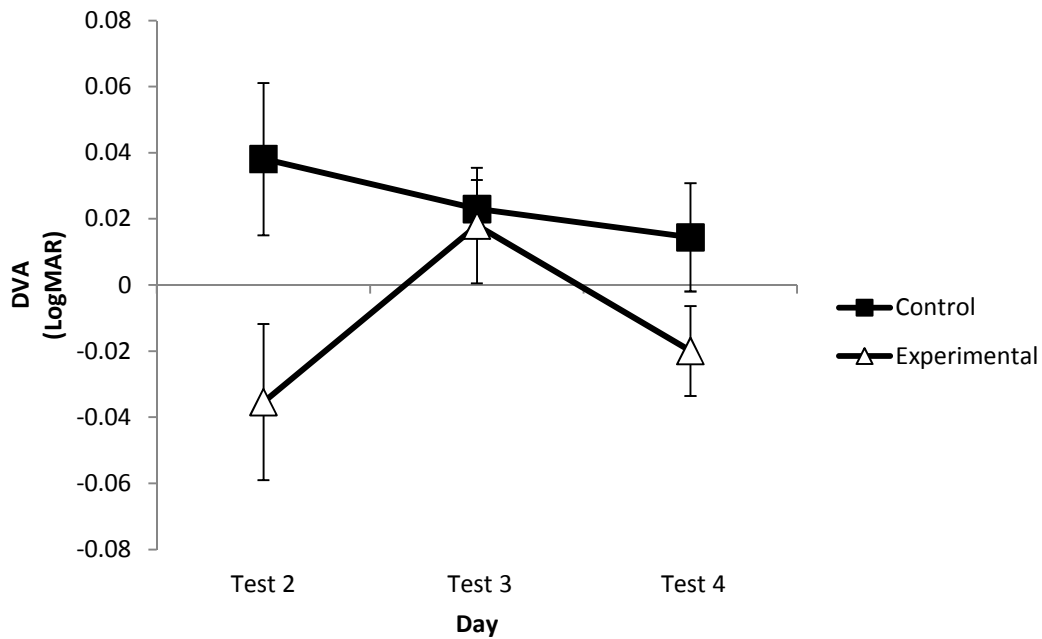


Figure 4. Upward DVA for test session 2, 3, and 4, comparing Control and Experimental groups. Error bars represent standard errors.

Ball Training

A paired-samples t-test was conducted to compare average catch percentage in session 1 and session 8 for both the experimental and control groups (See Figure 5). For the experimental group there was a statistically significant difference in the scores from session 1 ($M = .84$, $SD = .08$) and session 8 ($M = .93$, $SD = .03$) for average catch percentage, $t(7) = -5.45$, $p = .001$. For the control group there was also a statistically significant difference in the scores from session 1 ($M = .96$, $SD = .04$) and session 8 ($M = .98$, $SD = .02$) for average catch percentage, $t(7) = -3.27$, $p = .01$.

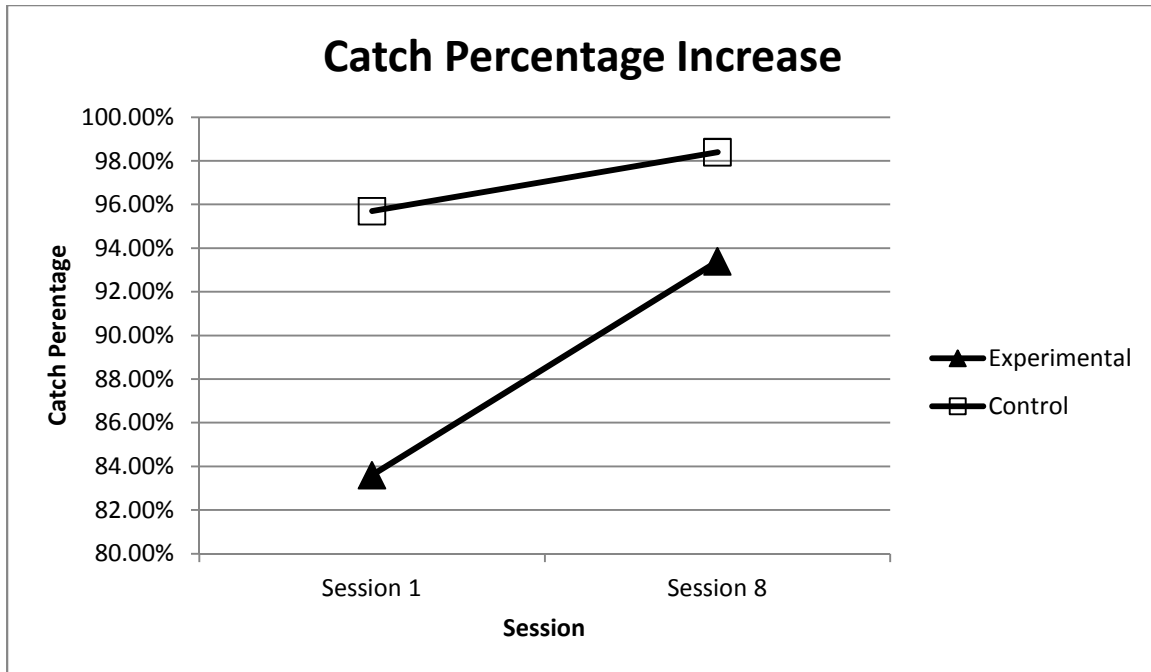


Figure 5. Catch percentage increase for ball session 1 and 8, comparing Control and Experimental groups.

In addition, a paired-samples t-test was conducted to compare average level reached (5 consecutive catches) in session 1 and session 8 for both the experimental and control groups (See Figure 6). For the experimental group there was a statistically significant difference in the scores from session 1 ($M = 5.6$, $SD = .96$) and session 8 ($M = 7.7$, $SD = .50$) for average level reached, $t(7) = -6.8$, $p = .000$. For the control group there was a statistically significant difference in the scores from session 1 ($M = 7.4$, $SD = .64$) and session 8 ($M = 7.8$, $SD = .30$) for average level reached, $t(7) = -2.97$, $p = .021$.

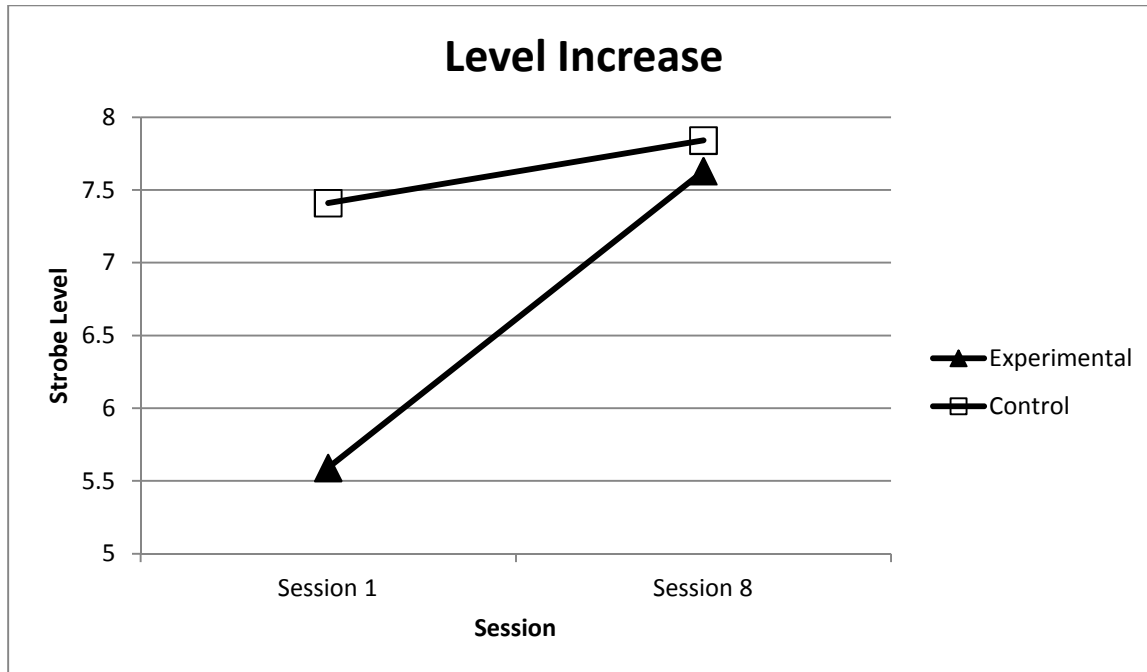


Figure 6. Level increase for ball session 1 and 8, comparing Control and Experimental groups.

An Independent-samples t-test was conducted to determine similarities between the experimental and control group for average catch percentage in session 1 and session 8. For session 1 there were statistically significant differences between the experimental group ($M = .84$, $SD = .08$) and control group ($M = .96$, $SD = .04$) for average catch percentage, $t(14) = -4.1$, $p = .001$. For session 8 there were statistically significant differences between the experimental group ($M = .93$, $SD = .03$) and control group ($M = .98$, $SD = .02$) for average catch percentage, $t(14) = -4.4$, $p = .001$.

An Independent-samples t-test was conducted to search for similarities between the experimental and control group for average level reached in session 1 and session 8. For session 1 there were statistically significant differences between the experimental group ($M = 5.6$, $SD = .96$) and control group ($M = 7.4$, $SD = .64$) for average level reached, $t(14) = -3.5$,

$p=.004$. For session 8 there were no statistically significant differences between the experimental group and control group for average strobe level reached.

Discussion

There were four main aims of this study. These aims were 1) to test the immediate effect of stroboscopic training after one training session, 2) to test the effect of a two week stroboscopic eyewear vision training program on dynamic visual acuity, 3) to test the lasting effect of the 2 week training period by examining DVA 2 weeks post training, and 4) to test the effect of stroboscopic vision training on catching performance. Currently, no previous study has examined the effect of stroboscopic vision training on DVA. The results gathered from this study are ground breaking, and provide insight to the field of vision, stroboscopic training, and DVA. Additionally, this study is the only one of its kind to evaluate DVA scores on a day of vision training, the day after vision training, and after an extended time period following training.

Immediately following one training session, the experimental group yielded a greater improvement in comparison to the control group. The experimental group significantly improved from test session 1 with total vertical DVA, and upward DVA, as well as improvement in left DVA in the horizontal movement. For horizontal movements, the control group had no statistically significant differences in test session 2 from session 1, but had a statistically significant decline from test session 1 for total vertical DVA, downward DVA, and upward DVA. These findings support our hypothesis that stroboscopic eyewear would have a greater immediate effect on dynamic visual acuity when compared to training without stroboscopic

eyewear. Our results support the literature that training leads to improved performance and DVA (Du Toit et al., 2011; Long & Rourke, 1989; Miller & Ludvig, 1962; Stine et al., 1982).

However, contrary to previous literature, there was no lasting influence of stroboscopic training on DVA, as seen in research provided by Long and Rourke (1989), and Miller and Ludvig (1962). With post training (test 3 & 4), no improvements were seen over baseline for any dependent variable. It has previously been discussed that according to literature, athletes have higher levels of DVA in comparison to non-athletes. Because this study was composed entirely of athletes, there may have been less room for improvement in DVA for the participants chosen as opposed to participants who may have been non-athletes (Bouvier et al., 2011; Ishigaki & Miyao, 1993; Quevedo et al., 2011).

Interestingly, the control group did exhibit a statistically significant decline in downward DVA for test session 3 and 4. Seeing that scores did not improve refutes the previous research indicating that DVA can be improved with vision training (Long & Rourke, 1989; Miller & Ludvig, 1962), but supports Abernethy and Wood (2001), who stated that vision training provided no benefit to performance. Why did the control group's vertical DVA scores get worse for test sessions 2, 3, and 4? With this study, the control group was still participating in the ball training drills, so there should have been at least slight improvement. The most likely reason for the decline with the control group is a lack of motivation. The control group may have heard from other participants about the Nike Vapor Strobe eyewear, and in knowing their eyewear had no special function, were less motivated to perform their best during the DVA testing. Further research is necessary to explore this postulation.

Also interesting is that no lasting effect of the stroboscopic training was seen. The most influential findings were that the greatest improvement was observed for test session 2 for those who participated in the strobe training, and that improvements were primarily with vertical movement DVA scores. Seeing a statistically significant improvement in the scores of the experimental group in test session 2 is important because they support the claim that the Nike Vapor Strobe eyewear are an effective training tool to improve dynamic visual acuity immediately following one 20 minute training session. The results suggest that the best use of these eyewear would thus be for a situation where an athlete uses the eyewear during ball catching drills prior to a competition, to obtain an immediate improvement in dynamic visual acuity that could benefit the player during his/her competition. The results from the experimental group in test session 2 support the literature from Miller and Ludvigh (1962), and Long and Rourke (1989), suggesting that DVA can be improved through repetitive practice using the visual system. How long this improvement in DVA lasts after the 20 minute training session has not been tested.

There are a few reasons the most statistically significant improvement in scores were observed in test session 2, and that the statistically significant scores were for vertical DVA. One reason is that the stroboscopic effect of the eyewear puts a stress on the visual and vestibular ocular reflex systems and forces the eyes to locate a ball during conditions of limited visual feedback. These difficult conditions cause a temporary improvement in the VOR, resulting in an increase in dynamic visual acuity immediately after training (Neurocom International, Inc.). Another reason for the increase in vertical DVA is that with every ball drill, vertical tracking was required, which in turn worked the vertical DVA more than the horizontal

DVA. This is explained in greater depth later in the discussion. This study is unlike earlier studies that used the NeuroCom system to measure DVA in that we chose to evaluate vertical DVA in addition to horizontal DVA. All previous studies (Goebel et al., 2007; Schneiders et al., 2010; Yoo et al., 2009) only evaluated horizontal DVA. Therefore, the improvement we see in vertical DVA may be normal with vision training, but just has not been recorded before in research.

It is important to mention that the study was designed so that test session 2 was the only test session completed immediately after a ball training session, as test session 3 was completed one day following the final ball training session. Seeing that improvement in dynamic visual acuity is statistically significant only after test session 2 supports the hypothesis that stroboscopic training has an immediate effect on dynamic visual acuity. Had DVA testing been completed immediately following the last ball training session, similar results to those in test session 2 may have been observed.

For ball catching performance measures, both the experimental and control groups improved in both average catch percentage and strobe level reached. This is important because it shows that whether training with or without strobe eyewear, ball catching performance improved. The improvement seen in catching performance and DVA is supported by other studies that have examined the benefits of strobe training on a number of different tasks. (Appelbaum et al., 2011; Appelbaum, 2012; Mitroff et al., unpublished; Smith & Mitroff, 2012). These findings also support previous literature that shows a high correlation between catching ability and DVA (Sanderson & Whiting, 1974). As previously stated, all ball catching scores for the experimental group were obtained while the group was wearing the stroboscopic

eyewear, while the scores for the control group were obtained while wearing eyewear with no stroboscopic effect. This was likely part of the reason that the control group had such high baseline catch percentage and strobe level, thus limiting the room for improvement.

Although stroboscopic training improved catching ability, the improvement may have been less had the experimental group done baseline testing without the stroboscopic eyewear prior to training, and then tested again without the eyewear post training. This would make the experimental group more comparable to the control group. The strobe level scores may be a bit skewed for the control group as well. The experimental group was aware that for every five consecutive catches, the strobe level (difficulty) was to increase by one level, starting at level one and maxing out at level eight. Therefore, the experimental group may have put forth more effort in an attempt to make more catches, especially when they knew they had caught three or four in a row. For the control group, a “strobe level” was considered to be five consecutive catches, replicating the experimental group’s ability to increase their strobe level after five consecutive catches. The control group had no means of increasing their difficulty and was not aware of the recording of five consecutive catches. Being unaware that their performance in consecutive catches was recorded, the control group could have been less motivated than the experimental group to make catches. It was also much easier to make 5 catches in a row without the strobe effect, thus the reason for the higher strobe level scores. Whether wearing the strobe glasses or glasses with no strobe, two weeks of ball training had a positive effect on catching performance, supporting the results from Stine et al. (1982) and Du Toit et al. (2011), that vision training leads to improved performance. Although there was

statistically significant improvement for both the experimental and control groups, improvements were greater for the group that trained with the strobe goggles.

The lack of change in total horizontal DVA and right DVA, and improvement in total vertical DVA, and upward DVA may be a result of our activities of daily living. Many things we do every day involve horizontal head movements and tracking of objects moving horizontally (e.g. driving a car, observing a crowd, crossing the street, etc.) but not many activities extensively involve vertical head motions or tracking of vertically moving objects. Therefore it may be more difficult to improve in areas where we already excel. Another contributing factor is that, although certain drills incorporated horizontal head movement, vertical tracking was required on every throw, which may have given participants more exposure to vertical movements and tracking during the ball training drills. Furthermore, the only horizontal movement that significantly improved in test session 2 was left DVA. This may be for similar reasons as the improvement seen with vertical movement, in that left DVA may not be as utilized in our activities of daily living, as well as all of the participants being right handed. For example, checking your mirrors while driving a car involves looking to the right to check your rearview mirror, writing or typing involves following the text from left to right, and playing sports can put you in positions that require more visual attention and favoring of your dominant hand or foot. These actions require a majority of the concentration of our vision to move from neutral to the right, which causes higher levels of right DVA, and leaves room for improvement for left DVA. Overall, both the experimental and control groups significantly improved after 2 weeks of ball training in both average catch percentage and strobe level reached, however, ball training with stroboscopic goggles significantly improved vertical DVA

movements immediately following a 20 minute ball training session, but not after 2 weeks of ball training, or two weeks post training. In comparison, ball training without stroboscopic goggles significantly worsened dynamic visual acuity immediately after a 20 minute ball training session, after 2 weeks of ball training, and 2 weeks post training. Other studies that showed improvement in DVA with vision training (Long & Rourke, 1989) did DVA testing on a separate day than vision training. Although seeing improvements in DVA, Long and Rourke mentioned that those participants who had the greatest improvement were the ones who initially had lower DVA scores. With the participants for the current study consisting only of athletes, our initial DVA scores were relatively high lessening the opportunity to see a statistically significant change.

Stroboscopic training can be beneficial for a variety of athletes, especially those in sports that rely heavily on vertical DVA. Athletes in baseball, football, volleyball, or any sport that emphasizes vertical tracking, who are looking for an improvement in their dynamic visual acuity, could benefit from the current vision training protocol. The design of this study could easily be adapted to meet the needs of athletes looking for sports specific drills, such as a football receiver wearing the glasses during football routes, or a hockey goalie wearing the glasses during shooting drills. By taking 20 minutes to do simple ball catching drills with stroboscopic eyewear, an athlete can experience immediate, short-term improvements in dynamic visual acuity. Based on these results, it is reasonable to imply that the Nike Vapor Strobe eyewear provide an immediate training benefit, and serve as a tool for any individual looking to get a performance edge by adding vision training to their pre-game regimen.

Limitations

Due to the lengthy nature of this study, there was a limit to the number of participants that were able to be tested during the testing window. Although sixteen participants may have been a smaller sample than desired, we still showed large effect sizes (Cohen, 1992) for all movements other than right and left DVA, suggesting that even with more subjects, we would not have reported different results. Another limitation was the single population focus. The target group of this study was collegiate football players only from Utah State University. By choosing this target group, results may be reflective of athletes in general, and represent a similar population of football athletes. The length of the study was also a drawback for recruiting participants. Being that each participant took an average of 12 hours of research time, and the target population consisted of collegiate football players, it can be hard for athletes to have enough time for school, practice, weights, and meetings, let alone being able to set aside 30 minutes every day for two weeks to participate in a vision study. Aside from the population and length of the study, another limitation was that throughout the course of training, the control group saw a decline in their vertical DVA scores in each dynamic visual acuity test when compared to baseline. An increase in scores (worse performance), makes it more difficult to interpret the results of the experimental group. With the ball training, the control group was unaware of the recording of 5 consecutive catches, resulting in less motivation and worse catching performance. It may have been more beneficial to have informed the control group of this recording. Also, the average catch percentage and strobe level reached for the experimental group was recorded when wearing the strobe eyewear, while the control group wore glasses with no effect. Recording pre and post training scores for

both groups under the same conditions would make the two groups more comparable. A final limitation was that the dynamic visual acuity testing protocol, using the NeuroCom inVision testing program, accounted only for dynamic visual acuity that was a direct result from the vestibular ocular reflex. This was achieved with head movement speeds set so the chance for predictive and catch-up saccades, also important for dynamic visual acuity, was eliminated. A dynamic visual acuity testing protocol that involved predictive and catch-up saccades (Uchida et al., 2012) may have yielded different results. Our results are limited to changes in dynamic visual acuity specifically related to the vestibular ocular reflex.

Future Work

Ideas for future work may include focusing only on the immediate effect of stroboscopic training. Since improvement was primarily seen in test session two, and minimal changes in session three and four, it could be beneficial to invest time researching more of the effects of immediate training. In exploring the immediate effect of stroboscopic training, one could experiment with changing the target population to include a variety of athletes, as well as possibly testing and comparing improvement in both athletes and non-athletes. This could yield interesting results seeing how different the dynamic visual acuity among athletes of different sports can differ and improve. In addition, completing further research to see how long the improvement in DVA lasts after completion of the 20 minute training session could be beneficial as well. Another possible idea would be to change the training duration. Instead of 20 minutes of ball training, it could be interesting to see the effect of longer or shorter training duration, as well as a change in ball catching drills. Different ball catching drills can involve different eye movements and tracking directions, which could affect dynamic visual acuity

differently. Another idea is to add a second control group who did absolutely no ball training. By having a third group, this would allow us to test the effect of ball training on improving or hindering the DVA scores, separate from the influence of the strobe goggles. Further testing to determine the reason for the decrease in vertical DVA scores for the control group is necessary as well.

Wrap-Up

The results of this study give supporting evidence to the claim that stroboscopic training with the Nike Vapor Strobe eyewear not only provides performance benefits, but improvements in dynamic visual acuity. Stroboscopic training led to an increase in dynamic visual acuity (after one training session) and ball catching performance (over the course of the training) compared to the group who trained without a stroboscopic effect. The impact of stroboscopic vision training on athletic performance is statistically significant and shows its necessity as a component of a pregame routine. The Nike Vapor Strobe eyewear are a practical tool for improving catching performance and dynamic visual acuity immediately following training and could be used by athletes looking to improve their immediate dynamic visual acuity.

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