Oculomotor Training for Poor Saccades Improves Functional Vision Scores and Neurobehavioral Symptoms

Melissa Hunfalvay, RightEye LLC, 7979 Old Georgetown Rd, Suite 801, Bethesda, MD 20814, U.S.A. (301) 979 7970 melissa@righteye.com

Nicholas P. Murray, Professor, East Carolina University, Department of Kinesiology, Minges Coliseum166, Greensville, NC 27858, U.S.A. (252) 737 2977 murrayni@ecu.edu

Ankur Tyagi, RightEye LLC, 7979 Old Georgetown Rd, Suite 801, Bethesda, MD 20814, U.S.A. (301) 979 7970 ankur@righteye.com

Jason Whittaker, DC, DACNB, FABCDD, 38 Proulx Place, Winnipeg, MB R3X 0C5, CANADA. (204) 230 5743; drjasonwhittaker@gmail.com

Cedric Noel, DC, DACNB, FABCDD, 45 W Crossville Rd, Suite 503, Roswell, GA 30075. drnoeldc@gmail.com

*Claire-Marie Roberts, Senior Research Fellow, University of the West of England, Bristol, Coldharbour Lane, Bristol, BS16 1QY, UK claire-marie.roberts@uwe.ac.uk

*Please direct all correspondence to Dr. Claire-Marie Roberts

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

Oculomotor Training for Poor Saccades Improves Functional Vision Scores and Neurobehavioral Symptoms

Abstract

Objectives: To determine if participants with pre-determined poor saccades improved after participating in a standardized oculomotor training program. A secondary objective is to accurately quantify change in saccades after training using eye tracking. A third objective is to examine patients' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory[1].

Design: The present study was experimental in nature and utilized a between- and within-subjects design.

Setting: Data were collected in eye clinics with a standardized eye tracking equipment set up.

Participants: Patients in the bottom 25th percentile for saccadic eye movements (*n*=92; intervention = 46, control = 46).

Interventions: Participants were randomly assigned to the control or intervention group. The intervention group engaged in 10 minutes of oculomotor training daily for 5 days.

Main Outcome Measures: Q-ratio, saccadic targeting, NSI.

Results: Results revealed significant interactions between control and intervention groups. Saccade metrics showed improved targeting accuracy for the intervention group. The NSI showed significant reduction in all neurobehavioral factors, specifically Affective and Cognitive factors relating to poor saccades were significantly improved after training.

Conclusion: Future research should consider examination of eye movement metrics for saccades and gaze stability while in a specific task such as reading.

Keywords: *Functional vision, oculomotor training, saccades*

Abbreviations*:*

ADL activities of daily living

CRT choice reaction time

CSP circular smooth pursuit

DLPFC dorsolateral prefrontal cortex

DRT discriminate reaction time

FEF frontal eye field

FT fixation test

FVEQ functional vision EyeQ score

HS horizontal saccades

HSP horizontal smooth pursuit

NSI Neurobehavioral Symptom Inventory

PSP Progressive Supranuclear Palsy

VS vertical saccades

VSP vertical smooth pursuit

Introduction

Saccadic eye movements play a critically important role enabling humans to navigate our environment. They are fast, conjugate eye movements that move both eyes quickly, in the same direction [2]. One purpose of a saccade is to reposition the eye to bring objects of interest onto the fovea. The fovea is used to see the image in detail and with high acuity. Another purpose of saccadic eye movements is to allow us to quickly view our environment ultimately enabling us to respond with appropriate motor behaviors. Saccades can be made toward visual-, auditory-, tactile- or memory-related targets. They are the fastest type of eye movement and are among the fastest movements of the human body. They need to be fast because during the movement visual blurriness and blindness occurs. Therefore, fast movement is required in order to minimize the "blindness" time and to quickly attain the target of interest. It is estimated that humans make 100,000 saccades a day [2].

Conversely, fixations are stopping points that occur after a saccade and hold the image stationary in order to see in detail. Together, saccades and fixations are eye movements that enable humans to navigate an environmental scene. Self-paced, intrinsically driven saccades are those where the saccade is voluntary and made between two stationary targets in a fixed period [3]. Such saccades are most commonly clinically tested by asking a patient to look alternately at two targets held apart horizontally and vertically [2]. Saccades have several characteristics that can be used to measure their effectiveness. Saccadic velocity is the speed at which the saccade moves. In normal subjects, peak velocity varies from 30 to 700 degrees per second [2]. The larger the saccade the higher the peak velocity. The ratio of peak velocity to average velocity during the saccadic interval can be used to determine whether a person's saccade is abnormally fast or slow. For instance, slow saccades may indicate spinocerebellar ataxia type 2 [2].

The accuracy of a saccade is an additional metric that can determine saccadic normality. Overshooting (hypermetria) and undershooting targets (hypometria) in small amounts (less than 10% of the amplitude of the saccade) is normal. However, saccadic accuracy declines with age, fatigue, inattention and injury to the cerebellum [4]. Lesions to the cerebellum usually cause hypermetric saccades [2]. This may be explained by the deep integration of saccades in the eye-brain connection. Eye movements, such as saccades, have brain-related anatomical circuits that make distinct contributions to the eye movement and ultimately to action. For instance, burst neuron circuits in the brainstem provide motor signals to the extraocular muscles for the generation of saccades.

Eye movements involve a component of cognitive processing and behavior. The process of deciding when and where to make the saccade occurs in the cerebral cortex. The cerebral cortex regulates saccade size and accuracy of the saccade[2]. The cerebral cortex directs control of the saccades via direct projection to the burst neuron circuits in the brainstem. Damage to the cerebral cortex results in abnormal self-paced (volitional) saccades. Furthermore, the dorsolateral prefrontal cortex (DLPFC) is also considered to be involved in the control of self-paced saccades [5].

The cerebellum is important in maintaining saccadic accuracy for adaptation. Damage in the cerebellum causes saccades to over or undershoot the target. Such inaccuracy or dysmetria of saccades can be seen clinically via cerebellar lesions usually causing hypermetria [2]. Typical symptoms of lesions in the cerebellum and frontal lobe include fatigue, a slowness to react, slower information processing, impaired executive function, multi-tasking issues, lack of mental clarity, brain “fog”, emotional lability. Typical risks include reading difficulties, slower to complete tasks (e.g., student may need extra time for exams), quicker to anger, more impulsive.

Optimization and repair of saccades can be enhanced using oculomotor training. Eye movement training is based on neuroplasticity, which is the foundation of the rehabilitation. Eye movement training has been used to improve those with clinical conditions who display poor oculomotor performance, as well as to those trying to achieve elite performance in sport. Oculomotor training has been shown to be successful in improving various clinical conditions including gait functions [6]; cognitive function, depression and functional ability post stroke [7], and Progressive Supranuclear Palsy (PSP) [8]. Training specific to saccadic eye movements has also been successful improving reading tasks [5,9]. Eye movement training has shown to improve elite level performers as well. Zupan, and colleagues (2006)[10] used eye movement training to improve Airforce fighter pilot's reaction time, near-far focusing and frequency of saccades. The current state of eye movement interventions has been created using clinically relevant principles of neuroscience, neurology, motor learning and rehabilitation. However, limitations exist in the sensitivity and specificity of the eye movement outcome measures from such interventions. Therefore, the purpose of this study is to determine if participants with predetermined poor saccadic performance would improve as a result of a standardized oculomotor training program. A secondary objective is to accurately quantify change in saccades using eye tracking. A third objective is to examine a patients' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory [1].

Methodology

Participants

The total number of participants considered for this study were 92 (between 16-62 years; *M* = 40, *SD* = 19). The intervention group (IG) included 46 participants (20 males (44%) and 26 females (56%)) who completed the EyeQ Trainer exercises only. The Control Group (CG) included

46 participants (24 males (52%) and 22 females (48%)) who did no oculomotor training whatsoever.

Apparatus

Testing and training interventions were done on the same apparatus. Stimuli were presented via the RightEye tests on a Tobii I15 vision 15” monitor fitted with a Tobii 90 Hz remote eye tracker and a Logitech (model Y-R0017) wireless keyboard and mouse. The participants were seated in a stationary (non-wheeled) chair that could not be adjusted in height. They sat in front of a desk in a quiet, private room. Participants’ heads were unconstrained. The accuracy of the Tobii eye tracker was 0.4◦ within the desired headbox of 32 cm × 21 cm at 56 cm from the screen. For standardization of testing, participants were asked to sit in front of the eye tracking system at an exact measured distance of 56 cm which is the ideal positioning within the headbox range of the eye tracker.

Oculomotor Testing Tasks. Pre and post-tests were conducted using the same set of oculomotor tasks, collectively called Functional Vision EyeQ. These tasks included three smooth pursuit tests, 2 saccade tests, one fixation test, two reaction time tests.

Pursuit Tests: Three types of pursuit tests were run: 1) Circular Smooth Pursuit (CSP), Horizontal Smooth Pursuit (HSP) and Vertical Smooth Pursuit (VSP). Participants were asked to “follow the dot, on the screen, as accurately as possible with their eyes.” The dot was 0.2 degrees in diameter and moved at a speed of 25 degrees of visual angle per second. The tests were taken with a black background with white dot and lasted 20s. The diameter of movement of the CSP circle was 20 degrees.

Self-Paced Saccade Tests (for more details see Hunfalvay, Roberts, Murray, Tyagi, Kelly, & Bolte, 2019)[11]: In the Horizontal Saccade (HS) test, participants were asked to look at a countdown of three, two, one in the center of the screen before moving their eyes back and forth between two dots. Their goal was to 'target each dot' on the left and right/top and bottom of the screen as quickly and accurately as possible.

Fixation Test: In the Fixation Test (FT), participants are asked to look at three different optotypes for seven seconds each with a three second break between. Optotype 1 is a cross the size of one-degree of visual angle. Optotype 2 is a circular dot, of one-degree in size. Optotype 3 is a small four-point diamond, that is 3 cm in size on the edge. The tests were taken with a white background with black dots and lasted a total of 30-seconds, including the breaks.

Reaction Time Tests: Two reaction time tests were given; a Choice Reaction Time test (CRT) and Discriminate Reaction Time test (DRT; see Lange, Hunfalvay, Murray, Roberts, Bolte, 2018)[12]. In brief, the CRT test, the participant viewed three stimuli and was asked to provide one of three responses. In the DRT test, the participant viewed three stimuli and was required to respond to only one stimulus.

The Functional Vision EyeQ Score (FVEQ): includes a linear combination of saccade, pursuit, fixation and reaction time oculomotor variables. A total of 58 metrics make up the model. Weights range from 0.1 to 13% across metrics.

Oculomotor Training Tasks. Training exercises took 5 minutes and were conducted twice a day, once in the morning and once in the evening, for a total of five days. The training exercises assigned took participants through a series of exercises including: Down-gaze Central No-No where participants are asked to tilt their head to the top line and then back to center, when they see the target presented on screen. They had to repeat the process, each time the target jumps. The Up-gaze Central No-No where participants are asked to move their head one time to the bottom line and then back to the center, when they see the target presented on screen. They had to repeat the process, each time the target jumps. Plus, Down Right-Diagonal Saccades followed by Upward Pursuit, and Down Left-Diagonal Saccades followed by Upward Pursuit.

Procedure

Participants were pre-selected via a patient database if they met the following criteria: 1) they had saccadic eye movements that were in the bottom 25th percentile compared to age-matched controls and 2) they had less than 30 days since their assessment.

Table 1

Summary of time interval between pre and post assessments, for Intervention vs Control Group.

Variable	Control	Intervention
	Mean ± SD	Mean ± SD
Days difference between Pre- and Post-Assessment	18 ± 8	16 ± 8

SD = Standard Deviation

The nature of the study was explained to the participants, and all participants were provided a informed consent to participate. The study was conducted in accordance with the tenets of the Declaration of Helsinki. The study protocols were approved by the Institutional Review Board of East Carolina University. Following informed consent, participants were asked to complete a pre-screening.

Participants were excluded from the study if they reported past head injury, any neurological condition, or static visual acuity of greater than 20/400. Participants were also excluded if they were unable to pass a 9-point calibration sequence. Following pre-screening, participants completed the Neurobehavioral Symptom Inventory (NSI) and then took the Functional Vision EyeQ series of tests. Once testing was complete, they were randomly assigned to the oculomotor training (IG) or to the CG. Participants were randomly assigned to the groups. The IG completed the RightEye EyeQ Trainer exercises and no other interventions. The CG did not do the RightEye EyeQ Trainer exercises nor any other intervention. After training was complete the participant returned for a post-test Functional Vision EyeQ and completed the NSI and debriefing of the study.

Data Analysis

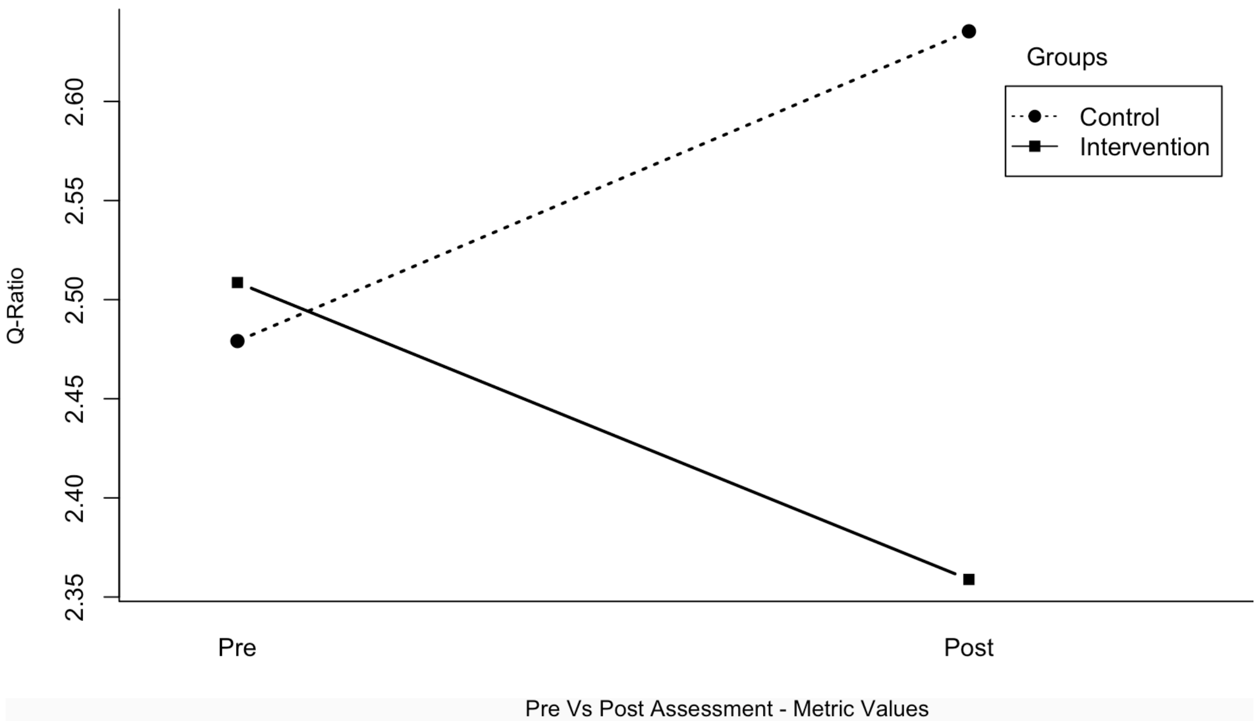
Separate 2 (Group) x 2 (Time) repeated measures ANOVAs were used to determine differences in RightEye Test Metrics: Q-Ratio and Targeting Accuracy between the two Groups (Control and Intervention) and over Time (Pre and Post Assessments). The Q-Ratio is defined as the ratio of the peak velocity to average velocity in the saccadic interval. Velocity is measured in degrees per second. A lower number is a better score. Targeting accuracy refers to the distance the eye is from the target, measured in millimeters (mm). A lower number is a closer distance and is therefore a better score.

The NSI was similarly analyzed (2 (Group x 2 (Time) ANOVA) using the dependent variables of Q23, which asked participants to "rate your overall symptoms." Total Score and the 4-Factor scoring approach (Vestibular, Somatosensory, Cognitive, and Affective)[13]. The 4-Factors included vestibular (n = 3), somatosensory (n = 7), cognitive (n = 4) and affective (n = 6). As well as a summated total score of 22 factors. We used simple effects post hoc test for significant main effects and interactions.

Results

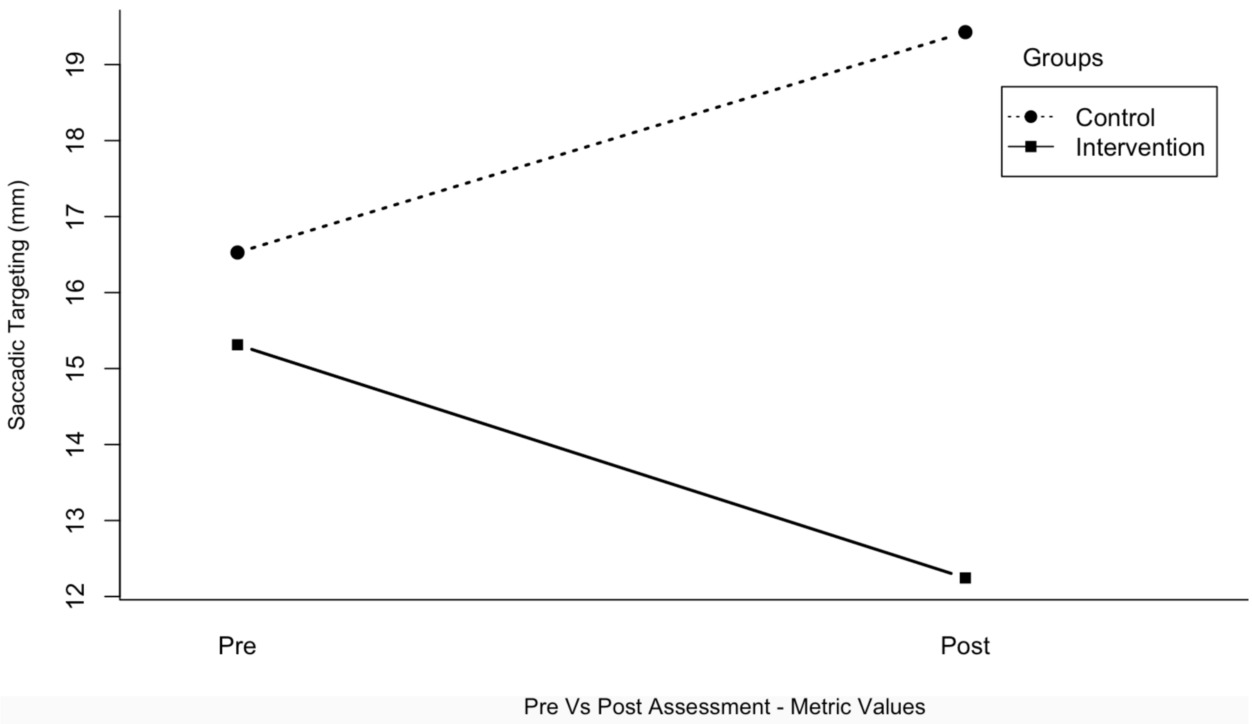
Q-Ratio

Q-Ratio metric demonstrated a non-significant main effect for Group (Intervention, Control) (p = .160) and non-significant main effect for Time (Pre, Post), (p = 0.958); however there was a significant interaction (Group x Time), $F(1, 90) = 6.38$, $p = .013$, $\eta^2_g = .02$. Simple effects revealed an increase in Q-Ratio for control from pre (2.48) to post (2.64); however, the intervention group's metric value decreased from pre (2.51) to post (2.36).



Saccadic Targeting (mm)

The ANOVA results for Saccadic Targeting demonstrated a non-significant main effect for Group (Intervention, Control) (p = .114) and non-significant main effect for Time (Pre, Post), (p = .947); however there was a significant main effect for Interaction (Group x Time), $F(1, 26) = 5.49$, $p = .021$, $\eta^2_g = .01$. Simple effects revealed an increase in the Saccadic Targeting metrics for control from pre (16.53) to post (19.43); however, the intervention group's metric value decreased from pre (15.31) to post (12.24).



Neurobehavioral Symptom Inventory (NSI)

For the NSI, the findings were similar across all the total score and the 4-factor scoring approach (See Table 2 and 3). Specifically, the Total Score analysis indicated a main effect for Time, $F(1, 94) = 478.97$, $p < .001$, $\eta_p^2 = .836$, for Group, $F(1, 94) = 32.17$, $p < .001$, $\eta_p^2 = .255$, but more interesting was a significant effect for the interaction of Time x Group, $F(1, 94) = 702.60$, $p < .001$, $\eta_p^2 = .882$. Similarly, the Vestibular [$F(1, 94) = 118.60$, $p < .001$, $\eta_p^2 = .558$; $F(1,94) = 28.309$, $p < .001$, $\eta_p^2 = .558$], Somatosenory [$F(1,94) = 569.26$, $p < .001$, $\eta_p^2 = .858$; $F(1,94) = 30.11$, $p < .001$, $\eta_p^2 = .243$], Cognitive [$F (1,94) = 75.21$, $p < .001$, $\eta_p^2 = .445$; $(1,94) = 55.86$, $p < .001$, $\eta_p^2 = .373$], and Affective factors [$(1,94) = 116.48$, $p < .001$, $\eta_p^2 = .553$; $F(1,94) = 29.05$, $p < .001$, $\eta_p^2 = .236$] demonstrated significant main effect for Time and Group, respectively. In addition, there was a significant interaction of Time x Group for all factors: Vestibular ($p<.001$, $\eta_p^2 = .650$), Somatosensory ($p <.001$, $\eta_p^2 =.867$), Cognitive test ($p < .001$, $\eta_p^2 = .635$); Affective ($p < .001$, $\eta_p^2 = .692$). Lastly, results for overall symptom change (Q23), before and after analysis showed a main effect for Time, $(1,94) = 172.21$, $p < .001$, $\eta_p^2 = .647$ and for Group, $(1,94) = 52.42$, $p < .001$, $\eta_p^2 = .358$; however, more importantly a significant Time x Group interaction, $F(1,94) = 159.62$, $p < .001$, $\eta_p^2 = .629$ analysis.

Table 2: NSI itemized scores for each Group (Intervention/Control) and by Time (Pre/Post)

	Intervention		Control	
	Pre	Post	Pre	Post
Dizzy	2.69 (0.91)	1.60(0.49)	2.50 (0.99)	2.44 (1.12)
Balance	2.45 (1.02)	0.69 (0.62)	2.74 (0.75)	3.08 (0.75)
Poor Coordination	2.63 (1.04)	0.93 (0.85)	2.24 (0.82)	2.40 (0.83)
Headaches	2.89 (0.97)	1.28 (0.77)	1.44(1.21)	1.62 (1.48)
Nausea	2.80 (0.74)	1.71 (0.45)	1.56 (1.37	1.56 (1.37)
Vision Problems	2.69 (0.62)	1.28 (0.77)	2.34 (1.22)	2.14 (0.85)
Sensitivity to light	3.32 (0.70)	2.17 (0.85)	1.30 (1.26)	1.48 (1.40)
Hearing Difficulties	2.56 (0.74)	1.04 (0.78)	0.72 (0.90)	0.90 (1.19)
Sensitivity to Noise	2.67 (0.79)	1.00 (0.51)	0.82 (0.77)	0.82 (0.74)
Numbness	2.56 (0.91)	1.06 (0.67)	0.64 (0.52)	0.62 (0.53)
Change in taste or smell	2.19 (1.14)	1.41 (0.88)	0.68 (0.62)	0.70 (0.64)
Loss of Appetite	2.84 (0.63)	1.45 (0.88)	0.64 (0.56)	0.82 (0.77)
Poor Concentration	2.39 (0.88)	1.00 (0.51)	1.52 (0.50)	1.72 (0.45)
Forgetfulness	2.71 (1.00)	2.19 (0.74)	1.36 (0.48)	1.40 (0.49)
Difficulty Making Decisions	2.91 (0.86)	1.91 (0.69)	1.36 (0.82)	1.40 (0.83)

Slowed Thinking	2.91 (0.86)	2.17 (0.67	1.38 (0.49)	1.80 (0.72)
Fatigue	2.84 (0.81)	1.73 (0.87)	1.80 (0.78)	1.84 (0.76)
Difficulty Falling Asleep	2.65 (0.87)	1.97 (0.97)	2.72 (0.96)	2.72 (0.96)
Feeling Anxious	2.71 (0.86)	1.97 (0.53)	1.08 (0.27)	1.26 (0.44)
Feeling Depressed	2.23 (1.25)	1.45 (0.72)	0.82 (0.74)	0.82 (0.43)
Irritability	2.30 (0.89)	1.23 (0.48)	1.02 (0.14)	01.42 (0.53)
Poor Frustration	2.36 (1.40)	1.30 (1.15)	1.22 (0.99)	1.40 (0.83)

Table 3: NSI Q23, Total, and 4-Factor Mean (SD) scores for each Group (Intervention/Control) and by Time (Pre/Post)

	Intervention		Control	
	Pre	Post	Pre	Post
Question 23	2.56 (0.65)	0.45 (0.50)	2.34 (0.74)	2.30 (0.76)
Total Score	58.41 (12.48)	32.65 (6.89)	31.90 (12.12)	34.36 (11.47)
Vestibular	7.78 (2.52)	3.23 (1.40)	7.48 (2.34)	7.92 (2.37)
Somatosensory	19.15 (3.74)	9.93 (3.02)	8.78 (6.46)	8.94 (6.23)
Cognitive	10.93 (3.02)	7.28 (1.80)	5.62 (2.01)	6.32 (1.84)
Affective	15.13 (4.82)	9.69 (2.87)	8.66 (2.27)	9.46 (2.37)

Discussion

The primary purpose of this study was to determine if a series of oculomotor exercises improved participants saccadic performance. Results revealed Q-ratio and targeting of saccades had significant group interactions post oculomotor training. Improvement in the saccade metrics is further supported by a significant reduction in overall symptoms as shown on the NSI. The results reveal that participants who engaged in the eye movement training had an overall reduction in symptoms using the 4-Factor analysis. Furthermore, when specifically asked to rate their overall symptoms pre- and post-, the results were consistent with the NSI total score. Adding further validation to the belief that participants "felt better" after engaging in oculomotor training. The saccade metrics, total NSI score and "Overall Symptoms" question (Q23), collectively reveal a broad improvement not only in the oculomotor variables, but also in self-reported symptoms. This is a critical link in intervention research. In other words, it is important to show oculomotor change, however, from a participants' perspective it is perhaps more important that the changes in oculomotor behavior have "real life" impact to their quality of life and activities of daily living.

A secondary objective of this study was to accurately and specifically quantify change in saccades using eye tracking. The eye tracking technology employed in this study allowed for specific location recording of saccades in relation to the target (Saccadic Targeting). Results revealed a significant interaction between the groups in saccadic targeting. Although no main effects were found for the IG all metrics were trending in the right direction. Results showed a reduction in distance from the target from pre to post-training for the IG. In contrast, the CG, without any intervention, showed increases in poor saccadic targeting behavior by almost 3 millimeters. This finding was important in two respects. First, if no oculomotor training is engaged in when a person has poor saccadic targeting they continue to decline. Second, if oculomotor training is engaged in this stops the decline and moves the saccade behavior is a desirable, improved, direction.

Q-Ratio, the peak velocity to average velocity, resulted in a significant interaction between the groups. Although no main effects were found for the IG all metrics were trending in the right direction. Results showed a reduction in Q-Ratio from pre to post-training in the IG. In contrast, the CG, without any intervention, showed increases in Q-Ratio 0.17. This finding was important in two respects. First, if no oculomotor training is engaged in when a person has poor saccadic targeting, they continue to decline in saccadic velocities. Second, if oculomotor training is engaged in this stops the decline and moves the saccade velocities in a desirable, improved, direction.

A third objective of this study was to examine a patients' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory[1]. In addition to the total NSI score and "Overall Symptoms" question (Q23), the analysis revealed significant differences in all 4-factors. The first factor, classified as Vestibular consisted of questions relating to dizziness, poor balance and coordination. Vestibulo-ocular reflex, fixations and pursuits are all in the functional class of eye movements that stabilize gaze and keep images steady on the retina[4]. Therefore, lesions in brain areas associated with these eye movements will result is neurobehavioral symptoms for factor 1: Vestibular. Although not such eye movement metrics are not measured in this study, future research should look to specifically examine eye movement metrics related vestibular symptoms when engaged in this eye movement training protocol.

The second factor, classified as Somatosensory consisted of questions relating to headaches, nausea, vision, sensitivity to light and noise, numbness, changes in taste. Results for Somatosensory factors were also highly significant. The third and fourth factors were classified as Cognitive and Affective respectively. The Cognitive factor consisted of questions relating to poor concentration, forgetfulness, difficulty making decision and slowed thinking. The affective factor consisted of questions relating to fatigue, difficulty falling asleep, feeling anxious, feeling depressed, irritability, poor frustration. Results obtained from the NSI revealed significant main effects and interactions for the Cognitive and Affective factors. Typical symptoms of poor saccades relate to cognitive affects such as fatigue, slowness to react, slower information processing, impaired executive function, multi-tasking issues, lack of mental clarity, brain "fog", emotional lability. Typical risks include reading difficulties, slower to complete tasks (e.g. student may need extra time for exams), quicker to anger, more impulsive [2,4]. Hence, results from the Cognitive factor of the NSI make sense when related to improvement in saccades.

Study Limitations

The design of the present study did not include an eye-tracked reading test measuring saccades. Adding comprehension questions and content that is grade level appropriate would provide further insight into the Cognitive and Affective factors and thereby enhance the oculomotor training data. Additionally, as the neurological pathways for some eye movements overlap, the resulting neurobehavioral symptoms may also overlap, especially if that symptom is of a broad nature, such as a brain "fog". Hence, with a multimodal oculomotor training program for individuals with poor saccades should also consider changes in metrics to other eye movements such as fixations and pursuits. Fixations are important in reading and therefore would provide a more complete picture of possible impact training has on this task.

Conclusion

In conclusion, this study examined the pre and post score of saccades in relation to an eye movement training protocol. Results showed improvements in saccades as well as decline in the CG who did not engage in oculomotor training. Furthermore, the NSI confirmed that the eye movement training reduced neurobehavioral symptoms significantly, Specifically in Cognitive and Affective factors related to saccades. Future research should examine other eye movements in relation to this oculomotor training regime and a cross-functional task such as reading to determine changes in everyday activities.

References

1. Cicerone, KD. Neurobehavioral Symptom Inventory (NSI): J Head Tr Rehabil 1995;10(3):1-17.
2. Wong AMF. *Eye Movement Disorders.* Oxford University Press, New York NY. *2008:* pp. 78.
3. Taghdiri, F., Chung, J., Irwin, S., Multani, N., Tarazi, A et.al. (2018). Decreased number of self-paced saccades in post-concussion syndrome associated with higher symptom burden and reduced white matter integrity. Journal of Neurotrauma, 35(5):719-729. DOI: 10.1089/neu.2017.5274
4. Leigh JR. & Zee DS. *The Neurology of Eye Movements (2015)*, pp. 16.
5. Pierrot-Deseilligny, C., Milea, D., Müri, R.M., 2004. Eye movement control by the cerebral cortex. Current Opinion in Neurology 17, 17–25. http://dx.doi.org/10.1097/00019052-200402000-00005.
6. Kang K-Y & Yu K-H. "The effects of eye movement training on gait function in patients with stroke." *Journal of physical therapy science* (2016).
7. Eksteen, CA, Van Wyk, A. The effect of saccadic eye movement training integrated into task-specific activities on cognitive functions, depression and functional ability post-stroke. *Physiotherapy, 2015;* 101(1): e349. http://dx.doi.org/10.1016/j.physio.2015.03.558
8. Zampieri C, Di Fabio RP. Improvement of gaze control after balance and eye movement training in patients with progressive supranuclear palsy: a quasi-randomized controlled trial. *Arch Phys Med Rehabil 2009;* 90:263-70.6.

9. Yoshida M, Origuchi M, Urayama S, et al. fMRI evidence of improved visual function in patients with progressive retinitis pigmentosa by eye-movement training. *Neuroimage Clin*. 2014;5:161–168. Published 2014 Feb 26. doi:10.1016/j.nicl.2014.02.007

10. Zupan MF., Arata, A.W., Wile, A., Parker, R. (2006). Visual adaptations to sports vision enhancement training. *Occupational Therapy* p. 43-48.

11. Hunfalvay M. Roberts C-M. Murray N. Tyagi A. Kelly H. & Bolte T. Horizontal and vertical self-paced saccades as a diagnostic marker of traumatic brain injury. *Concussion 2019*; 4(1) https://doi.org/10.2217/cnc-2019-0001

12. Lange B. Hunfalvay M. Murray N. Roberts C-M. Bolte T. Reliability of computerized eye-tracking reaction time tests in non-athletes, athletes, and individuals with traumatic brain injury. *Optometry & Visual Performance 2018;* 6(3) pp. 165-180.

13. Dretsch, M., Bleiberg, J., Williams, K., Caban, J., Kelly, J., Grammer, G., & DeGraba, T. (2016). Three scoring approaches to the Neurobehavioral Symptom Inventory for measuring clinical change in service members receiving intensive treatment for combat-related mTBI. The Journal of Head Trauma Rehabilitation, 31(1), 23–29. https://doi.org/10.1097/HTR.0000000000000109