# Oculomotor Training for Poor Pursuits Improves Functional Vision Scores and Neurobehavioral Symptoms

**Abstract**

Smooth pursuit eye movements (SPEM) are critical to humans' ability to see and interact with the world. However, limitations exist in the assessment of oculomotor training designed to improve SPEM. The purpose of this study was to determine if participants with pre-determined poor SPEM improved via a standardized oculomotor training program. A secondary objective was to accurately quantify change in SPEM using eye tracking. A third objective was to examine participants' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory (NSI). Participants were randomly assigned to the control or intervention group. The intervention group engaged in 10 minutes of oculomotor training daily for 5 days. Results revealed significant interactions between groups. SPEM metrics showed improved tracking abilities (on-target, predictive and latent) for the intervention group. The NSI showed significant reduction in all neurobehavioral factors and of a total summation of symptoms. Future research should consider examination of eye movement metrics for saccades and gaze stability using this oculomotor training program.

Keywords: *Functional vision, oculomotor training, smooth pursuit eye movements*

**Acronyms**

| | |
|---|---|
| CG | Control group |
| CRT | Choice reaction time |
| CSP | Circular smooth pursuit |
| DRT | Discriminate reaction time |
| FVEQ | Functional Vision EyeQ |
| HS | Horizontal saccades |
| HSP | Horizontal smooth pursuit |
| IG | Intervention group |
| NSI | Neurobehavioral Symptom Inventory |
| MST | Middle superior temporal |
| MT | Middle temporal |
| SPEM | Smooth pursuit eye movement |
| PSP | Progressive Supranuclear Palsy |
| VSP | Vertical smooth pursuit |

## Introduction

Smooth pursuit eye movements (SPEM) are critical to our ability to see, process and respond to our environment. The purpose of SPEM is to stabilize the image of a moving object on the fovea. The fovea is used to see the image in detail and with high acuity, therefore where objects are moving, such as watching a ball in flight or a car in motion, smooth pursuit eye movements are used to see the ball and car in detail and to judge the speed of such objects to account for follow-on motor responses. By trying to stabilize the target on the fovea, SPEM is continually translating signals and converting deviations from the ideal trajectory into compensatory eye movements (Thier & Llg, 2005). Hence, SPEM is deeply integrated in the eye-brain connection. Eye movements, such as SPEM, have brain-related anatomical circuits that make distinct contributions to the eye movement and ultimately to action. SPEM are mediated by a cerebro-ponto-cerebellar pathway (Thier & Llg, 2005). The cerebral cortex contains several frontal and parietooccipital areas that have distinct roles in generating SPEM. Visual area middle temporal (MT) is a visual motion processor that contributes to smooth pursuit by extracting retinal motion of the target. Lesions in this area have resulted in an inability to track targets within the confines of the motion scotoma (Dursteler & Wurtz, 1988). SPEM are also foreseen by the middle superior temporal (MST) area that represents an object in motion in world-centered coordinates (Llg, Schumann & Thier, 2004). A lesion in the MST causes and directional error; lowered speed toward the side of the lesion (Wong 2008).

The cerebellum uses at least two areas for processing signals relevant to smooth pursuit: the flocculus–paraflocculus complex; and the posterior vermis. Lesions in the cerebellum show mild deficits in horizontal and vertical pursuits in both directions and Vestibular Ocular Reflex (VOR) cancellation if the lesion is unilateral in the VPF. Bilateral lesions of the flocculus and

VPF result in severe deficit in horizontal and vertical pursuits in both directions and VOR cancellation. Lesions in the vermis region of the cerebellum result in ipsiversive horizontal smooth pursuits. Lesions in the fastigial nucleus result in deficits in the contraversive horizontal pursuit (Wong, 2008). Lesions starting from the medial vestibular nucleus also affect the VOR because the pursuit and the VOR share similar pathways from this point forward. Hence resulting symptoms tend to overlap.

When a person can effectively use their eyes to smooth pursuit then follow on, cognitive processes are enabled. For example, effective tracking of a car allows the person to determine speed, time-to-interception and ultimately decision making such as when to cross the road. Such activities facilitate the integration of head movements into smooth-pursuit behaviors and the coordination of perception and action (IIg, Schumann & Thier, 2004). As a person ages, smooth pursuit performance often declines. This decline is commonly tied to the cerebellar disease and drugs that effect the nervous system (Leigh & Zee, 2000).

Optimization and repair of smooth pursuits 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 performance, as well as to those trying to achieve elite performance in sport. Oculomotor training, including pursuit training, has been shown to be successful in improving various clinical conditions including gait functions (Kwon-Young Kang, & Kyung-Hoon Yu, 2016); macular degeneration (Janssen & Verghese, 2016); progressive retinitis pigmentosa (Yoshida et al., 2014); cognitive function, depression and functional ability (Eksteen & Wyk, 2015), mitigation of tunnel vision (Ivanov, Mackeben, Vollmer, Martus, Nguyen & Trauzettel-Klosinski, 2016) and Progressive Supranuclear Palsy (PSP; Zampieri & Di Fabio, 2009).

Additionally, training specific to pursuit eye movements has been successful in mitigating spatial neglect following a stroke (Hill, Coats, Halstead, & Burke, 2015; Kerkhoff, Bucher, & Brasse, 2014). Eye movement training has shown to improve performance in elite level personnel as well. Zupan, Arata, Wile and Parker (2006) used eye movement training to improve Airforce fighter pilot's reaction time, near-far focusing and number 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 was to determine if participants with pre-determined poor pursuits improved via a standardized oculomotor training program. A secondary objective was to accurately quantify change in SPEM using eye tracking. A third objective was to examine a participants' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory (NSI; Cicerone, 1995).

## Methodology

### Participants

A total of 92 participants were considered for inclusion in this study. The Intervention Group (IG) included 46 participants who completed the "EyeQ Trainer" exercises and no other oculomotor training. The Control Group (CG) included 46 participants who no engaged in no oculomotor training at all. Participants were between the ages of 12-68 years ($M$ = 41, $SD$ = 22). Participants in the IG were between the ages of 12-58 ($M$ = 35, $SD$ = 23). There were 13 males (28%) and 33 females (72%) in the IG. In the CG there were 24 males (52%) and 22 females (48%). Participants were recruited through RightEye clinical providers.

### Apparatus

Testing and training interventions were carried out on the same apparatus. Stimuli were presented using 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. A 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): 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 of the screen as quickly and accurately as possible. The targets were 10 cm apart and 1 cm in diameter. The tests

were taken with a black background with white dots and lasted 10 seconds. The protocol for the Vertical Saccade (VS) test was the same as that for the HS test. However, the VS test was in a vertical plane.

*Fixation Test:* In the Fixation Test (FS), participants were asked to look at three different optotypes for seven seconds each with a three second break between. Optotype 1 was a cross the size of one-degree of visual angle. Optotype 2 was a circular dot, of one-degree in size. Optotype 3 was 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). 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, Up-gaze Central No-No, Down Right-Diagonal Saccades followed by Upward Pursuit, and Down Left-Diagonal Saccades followed by Upward Pursuit. For Down-gaze Central No-No, 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 were required to repeat the process, each time the target

jumped. For Up-gaze Central No-No, 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 were asked to repeat the process, each time the target jumped.

**Procedure**

Participants were pre-selected via the clinical provider database if they met the following criteria: (1) they had pursuit eye movements that were in the bottom 25$^{th}$ percentile compared to age-matched controls and (2) if they had less than 30 days since their last visual assessment.

****Table 1 about here****

The nature of the study was explained to the participants, and they were provided with a written University approved 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 test. 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. The IG did 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: "Functional Vision EyeQ" Score (#), latent, predictive and on-target smooth pursuit percentages between the two Groups (Control and Intervention) and over Time (Pre and Post Assessments). The NSI 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; Dretsch, et al., 2016). 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

*Functional Vision EyeQ Score*

The ANOVA results for the "Functional Vision EyeQ" Score (Figure 1) demonstrated a non-significant main effect for Group (Intervention, Control) ($p$ = .344); however there was a significant main effect for Time (Pre, Post), $F(1, 90) = 4.00$, $p = .048$, $\eta^2_g = .01$ and more importantly a significant interaction (Group x Time), $F(1, 90) = 4.65$, $p = .034$, $\eta^2_g = .01$. Simple effects revealed a slight decrease in the "Functional Vision EyeQ" Score for control from pre (53.15) to post (52.87); however, the intervention group's score increased from pre (53.20) to post (60.80) (See Table 2).

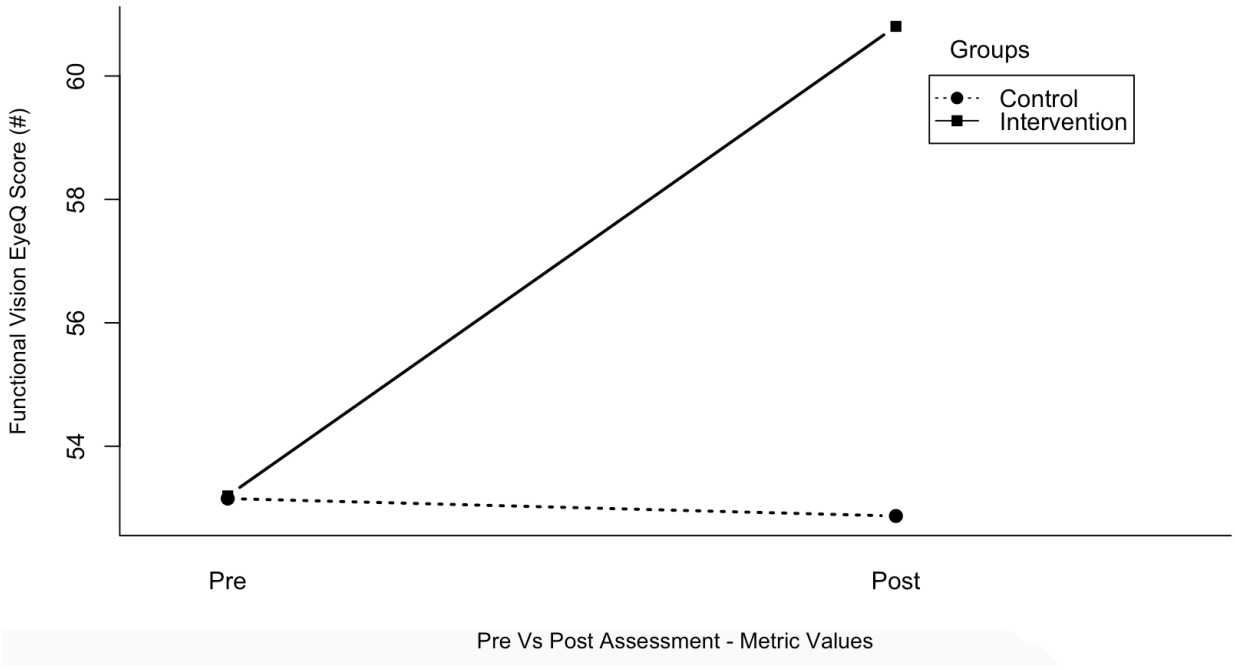


**Figure 1:** Pre and Post Assessment Functional Vision EyeQ Scores for Control and Intervention groups.

****Table 2 about here****

*On-Target Smooth Pursuit (%)*

On-Target Smooth Pursuit (Figure 2) demonstrated a non-significant main effect for Group (Intervention, Control) ($p$ = .776) and non-significant main effect for Time (Pre, Post), ($p$ = 0.253); however there was a significant interaction (Group x Time), $F(1, 90) = 4.29$, $p = .041$, $\eta^2_g$ = .01. Simple effects revealed a decrease in On-Target Smooth Pursuit for control from pre (63.89) to post (59.12); however, the intervention group's metric value increased from pre (59.81) to post (61.17).

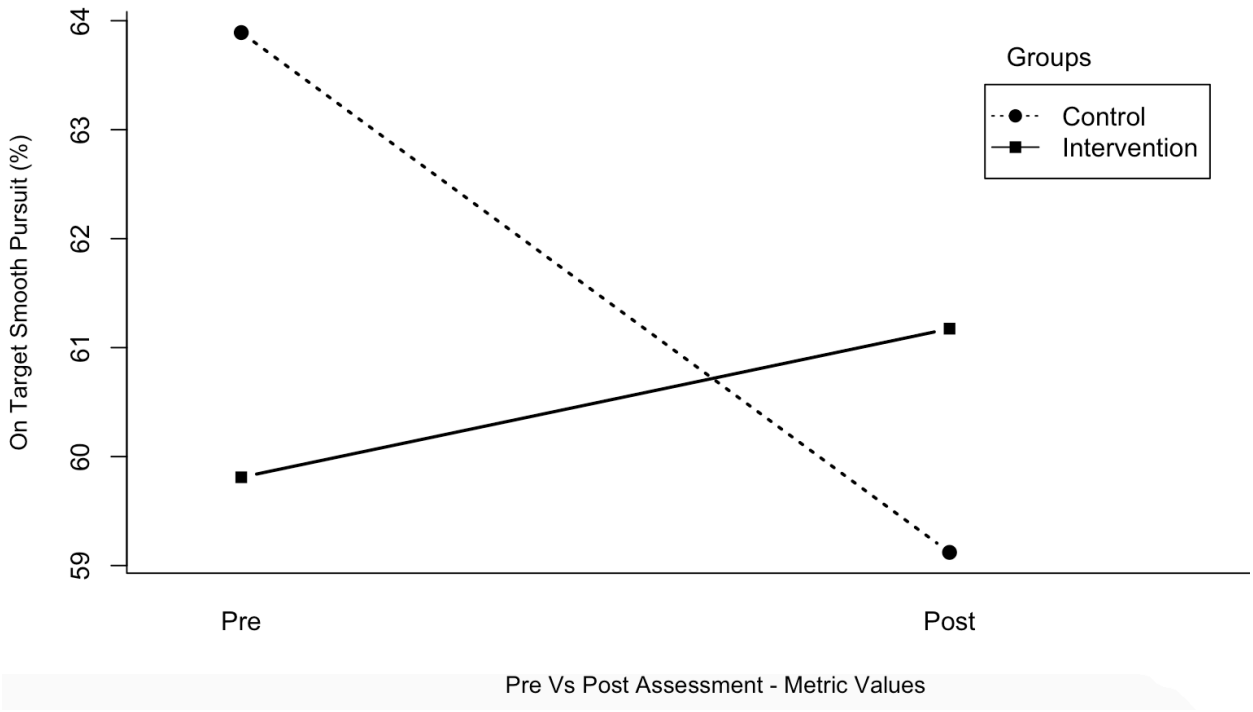


**Figure 2:** Pre and Post Assessment On-Target Smooth Pursuit (%) Scores for Control and Intervention groups.

*Latent Smooth Pursuit Metric*

Latent Smooth Pursuit (%, Figure 3) demonstrated a non-significant main effect for Group (Intervention, Control) ($p$ = .604) and non-significant main effect for Time (Pre, Post), ($p$ = .564); however there was a significant main effect for Interaction (Group x Time), $F(1, 26)$ = 4.87, $p$ = .036, $\eta^2_g$ = .05. Simple effects revealed an increase in the Latent Smooth Pursuit (%) for control from pre (28.25) to post (31.46); however, the intervention group's metric value decreased from pre (30.84) to post (25.32).

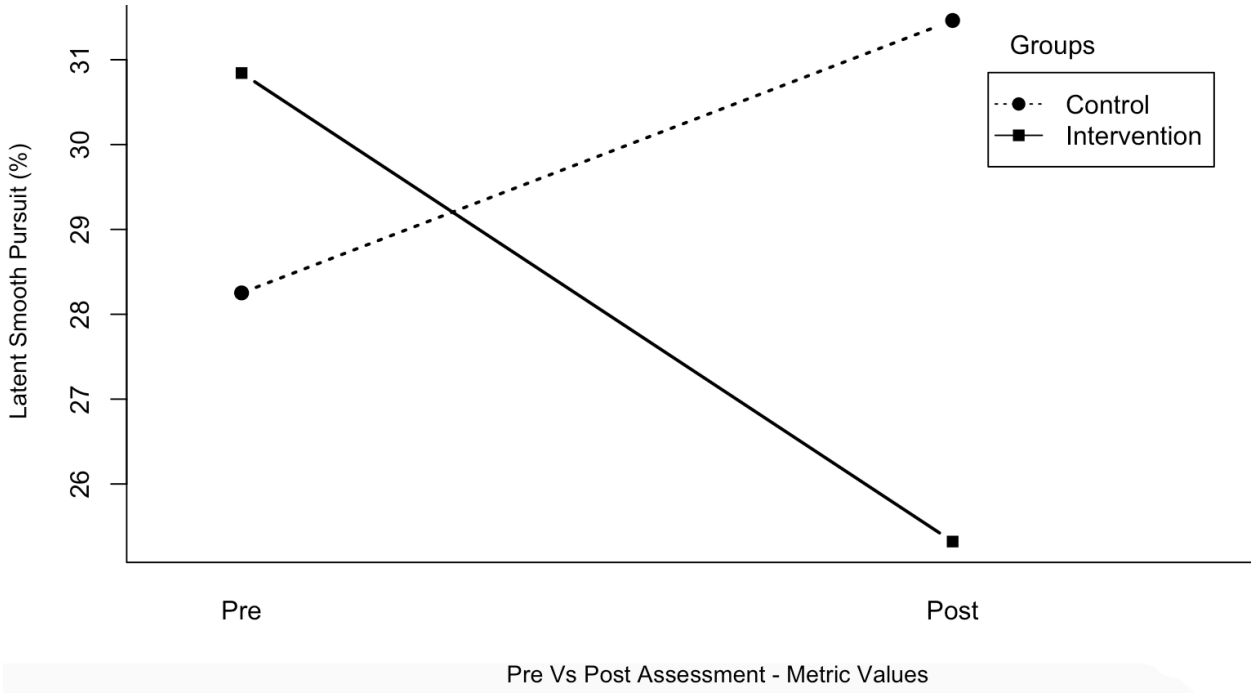


**Figure 3:** Pre and Post Assessment Latent Smooth Pursuit (%) Scores for Control and Intervention groups.

*Predictive Smooth Pursuit (%)*

Predictive Smooth Pursuit (Figure 4) demonstrated a non-significant main effect for Group (Intervention, Control) (p = .865); however there was a significant main effect for Time (Pre, Post), $F(1, 94) = 5.65$, $p = .019$, $\eta^2_g = .01$ and a significant interaction (Group x Time), $F(1, 94) = 7.30$, $p = .008$, $\eta^2_g = .02$. Simple effects revealed an increase in the Predictive Smooth Pursuit for control from pre (8.65) to post (8.87); however, the intervention group's metric value reduced from pre (10.29) to post (6.80) (See Table 2).

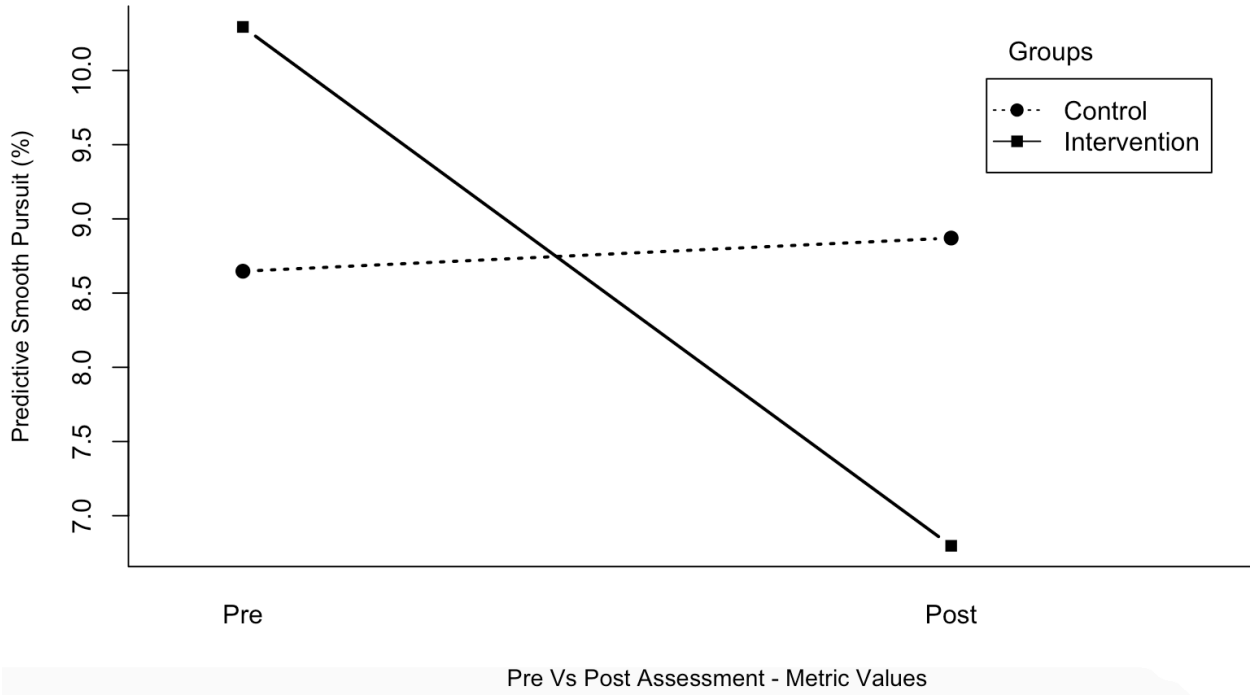


**Figure 4:** Pre and Post Assessment Predictive Smooth Pursuit (%) Scores for Control and Intervention groups.

*Neurobehavioral Symptom Inventory (NSI)*

For the NSI, the findings were similar across all the total score and the 4-factor scoring approach (See Table 3 and 4). Specifically, the total score analysis indicated a main effect for Time, $F(1, 94) = 1595.28$, $p < .001$, $\eta_p^2 = .944$, for Group, $F(1, 94) = 17.22$, $p < .001$, $\eta_p^2 = .943$, but more interesting was a significant effect for the interaction of Time x Group, $F(1, 94) = 2433.82$, $p < .001$, $\eta_p^2 = .963$. Similarly, the Vestibular [$F(1, 94) = 221.96$, $p < .001$, $\eta_p^2 = .702$; $F(1,94) = 351.632$, $p < .001$, $\eta_p^2 = .789$], Somatosensory [$F(1,94) = 898.44$, $p < .001$, $\eta_p^2 = .905$; $F(1,94) = 1208.77$, $p < .001$, $\eta_p^2 = .230$], Cognitive [$F(1,94) = 127.89$, $p < .001$, $\eta_p^2 = .576$; $(1,94) = 106.318$, $p < .001$, $\eta_p^2 = .149$], and Affective factors [$F(1,94) = 103.83$, $p < .001$, $\eta_p^2 = .525$; $F(1,94) = 137.49$, $p < .001$, $\eta_p^2 = .682$] demonstrated significant main effect for Time and Group Comparisons, respectively. In addition, there was a significant interaction of Time x Group for all factors: Vestibular ($p < .001$, $\eta_p^2 = .789$), Somatosensory ($p < .001$, $\eta_p^2 = .912$), Cognitive test

253 ($p< .001$, $\eta_p^2 = .730$); Affective ($p< .001$, $\eta_p^2 = .682$). Lastly, results for overall symptom change
254 (Q23), before and after analysis showed a main effect for Time, $F(1,94) = 52.39$, $p< .001$, $\eta_p^2 =$
255 .650 and for Group, $F(1,94) = 20.68$, $p< .001$, $\eta_p^2 = .548$; however, more importantly a
256 significant Time x Group interaction, $F(1,94) = 34.27$, $p< .001$, $\eta_p^2 = .548$ analysis.

257 **Table 3:** NSI itemized scores for each Group (Intervention/Control) and by Time (Pre/Post)

| | Intervention | | Control | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| Dizzy | 2.78 (0.89) | 1.60 (0.68) | 2.56 (1.013) | 2.56 (1.19) |
| Balance | 2.36 (1.21) | 0.71 (0.77) | 2.76 (0.74) | 3.16 (0.76) |
| Poor Coordination | 3.17 (0.60) | 0.76 (0.67) | 2.2 (0.75) | 2.4 (0.80) |
| Headaches | 3.36 (0.57) | 1.00 (0.63) | 1.4 (1.21) | 1.58 (1.48) |
| Nausea | 2.63 (0.60) | 1.36 (0.48) | 1.6 (1.37) | 1.6 (1.37) |
| Vision Problems | 3.39 (0.49) | 1.04 (0.59) | 2.42 (1.23) | 2.24 (0.79) |
| Sensitivity to light | 2.08 (0.91) | 3.5 (0.50) | 1.4 (1.37) | 1.2 (1.17) |
| Hearing Difficulties | 1.71 (0.58) | 1.06 (0.85) | 0.64 (0.82) | 0.84 (1.18) |
| Sensitivity to Noise | 1.84 (0.69) | 1.19 (0.54) | 0.8 (0.75) | 0.8 (0.80) |
| Numbness | 1.89 (0.60) | 1.19 (0.61) | 0.62 (0.53) | 0.62 (0.53) |
| Change in taste or smell | 1.76 (0.87) | 1.28 (0.75) | 0.62 (0.53) | 0.62 (0.53) |
| Loss of Appetite | 2.36 (0.48) | 1.23 (0.67) | 0.64 (0.52) | 0.84 (0.76) |
| Poor Concentration | 2.26 (0.90) | 0.63 (0.48) | 1.6 (0.49) | 1.8 (0.40) |
| Forgetfulness | 2.19 (1.02) | 2 (0.89) | 1.4 (0.49) | 1.4 (0.49) |
| Difficulty Making Decisions | 2.56 (0.62) | 1.80 (0.65) | 1.42 (0.83) | 1.42 (0.83) |
| Slowed Thinking | 2.30 (0.66) | 1.47 (0.98) | 1.42 (0.53) | 1.8 (0.75) |

| | | | | |
|---|---|---|---|---|
| Fatigue | 2.15 (0.63) | 1.58 (0.49) | 1.78 (.73) | 1.78 (.73) |
| Difficulty Falling Asleep | 2.84 (0.78) | 1.89 (1.10) | 2.76 (0.98) | 2.76 (0.98) |
| Feeling Anxious | 2.21 (0.69) | 1.65 (0.87) | 1.02 (0.14) | 1.22 (0.41) |
| Feeling Depressed | 2.10 (0.97) | 1.17 (0.73) | 0.78 (0.73) | 0.8 (0.40) |
| Irritability | 1.63 (1.040) | 1.06 (0.85) | 1 (0) | 1.38 (0.49) |
| Poor Frustration | 2.15 (1.11) | 0.86 (0.80) | 1.24 (1.02) | 1.44 (0.83) |

**Table 4:** 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 |
| Q23 Symptom | 2.60 (0.61) | 0.71 (0.80) | 2.42 (0.83) | 2.22 (0.78) |
| Total Score | 53.23 (5.27) | 28.71 (5.54) | 31.88 (12.10) | 34.46 (11.49) |
| Vestibular | 8.32 (1.31) | 3.08 (1.29) | 7.52 (2.39) | 8.12 (2.47) |
| Somatosensory | 18.39 (1.43) | 9.17 (1.88) | 8.66 (6.41) | 8.86 (6.18) |
| Cognitive | 9.32 (1.57) | 5.91 (1.91) | 5.84 (2.12) | 6.42 (1.90) |
| Affective | 13.10 (3.38) | 8.23 (2.56) | 8.58 (2.24) | 9.38 (2.33) |

## Discussion

The primary purpose of this study was to determine if a series of oculomotor exercises improved participants who had poor SPEM. Results revealed that the FVEQ score significantly improved. This score includes three types of eye movements – SPEM, saccades and fixations. Each is weighted in accordance to a linear combination of oculomotor variables. A significant

positive change in this score reveals an overall improvement in oculomotor behavior. Improvement in the FVEQ score is further supported by a significant reduction in overall symptoms as shown on the NSI. The total score revealed statistically significant differences for main effects (group, time) and more importantly for the interaction of group and time. 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 FVEQ score, 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 SPEMs using eye tracking. The eye tracking technology employed in this study allowed for specific location recording of SPEM in relation to the target. Results revealed a significant interaction between the groups in all three SPEM metrics (on-target, latent and predictive). Although no main effects were found for the IG all metrics were trending in the right direction. Results showed a reduction in latent and predictive SPEM and an increase in on-target SPEM. In contrast, the CG, without any intervention, showed increases in poor SPEM behavior. This was seen by increases in latent and predictive SPEM and decrease (4.77%) in on-target SPEM. This finding was important in two respects. First, if no oculomotor training is engaged in when a

person has poor SPEM they continue to decline. Second, if oculomotor training is engaged in this stops the decline and moves the SPEM behavior is a desirable, improved, direction.

A third objective of this study was to examine a participants' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory (NSI; Cicerone, 1995). 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. VOR, fixations and pursuits are all in the functional class of eye movements that stabilize gaze and keep images steady on the retina (Leigh & Zee, 2015). Therefore, lesions in brain areas associated with these eye movements will result is neurobehavioral symptoms for factor 1: Vestibular. Vestibular symptoms are affected by poor pursuits if there is a brain lesion is starting from the level of the medial vestibular nucleus because vestibular and pursuit pathways are shared from this point forward (Wong, 2008). VOR and gaze stability (fixations) also affect vestibular related neurobehavioral symptoms. Therefore, 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 factor classified as Cognitive consisted of questions relating to poor concentration, forgetfulness, difficulty making decision and slowed thinking. Results obtained from the NSI revealed significant main effects and interactions for the Cognitive factor. Hence, future research should look to examine metrics

related to saccades when engaged in this eye movement training protocol. Saccades are associated with a variety of Cognitive and Somatosensory neurobehavioral symptoms.

The fourth factor classified as Affective 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 Affective factor. Emotional lability, including increased frustration, impulsiveness and a quickness to anger have been linked to frontal lobe areas of the brain that are also associated with saccadic eye movements. Yoshida and colleagues (2012) observed that eye movement training that consisted of various eye movements (e.g. fixations, pursuits and binocular training) showed remarkable decreases in other eye movements (e.g. saccades). Hence 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".

In conclusion, this study examined the pre and post score of SPEMs in relation to an eye movement training protocol. Results showed improvements in SPEMs 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. Future research should examine other eye movements in relation to this oculomotor training regime.

## References

Cicerone K D (1995). Neurobehavioral Symptom Inventory (NSI): *J Head Tr Rehabil*. 10(3), 1-17.

Colby CL, Duhamel JR, Goldberg ME (1993). Ventral intraparietal area of the macaque: anatomic location and visual response properties. *J Neurophysiol,* 69, 902-914.

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. *J Head Trauma Rehabil*, 31(1), 23–29.

Dursteler MR, Wurtz RH. (1988). Pursuit and optokinetic deficits following chemical lesions of cortical areas MT and MST. *J Neurophysiol,* 60, 940-965.

Eksteen CA, Van Wyk A. (2015). The effect of saccadic eye movement training integrated into task-specific activities on cognitive functions, depression and functional ability post-stroke. *Physiotherapy,* 101(1), e349.

Hill D, Coats RO, Halstead A, Burke MR. (2015). A systematic research review assessing the effectiveness of pursuit interventions in spatial neglect following stroke. *Transl Stroke Res,* 6, 410-420.

Hunfalvay M, Roberts C-M, Murray N, Tyagi A, Kelly H, Bolte T. (2019). Horizontal and vertical self-paced saccades as a diagnostic marker of traumatic brain injury. *Concussion* 4(1).

Ivanov IV, Mackeben M, Vollmer A, Martus P, Nguyen NX, Trauzettel-Klosinski S. (2016). Eye movement training and suggested gaze strategies in tunnel vision – A randomized and controlled pilot study. *PLoS ONE* 11(6) 14-18.

354 Janssen CP, Verghese P. (2016). Training eye movements for visual search in individuals with
355 macular degeneration. *J Vis*. 16(15):29.
356 Kang K-Y, Yu K-H. (2016). The effects of eye movement training on gait function in patients
357 with stroke. *J Phys Ther Sci* 10, 22-27.
358 Kerkhoff G, Bucher L, Brasse M, Leonhart E, Holzgraefe M, Volzke V, et al. (2014). Smooth
359 pursuit ‘‘bedside’’ training reduced disability and unawareness during the activities of
360 daily living in neglect: a randomized controlled trial. *Neurorehabil Neural Repair* 28,
361 554-563.
362 Lange B, Hunfalvay M, Murray N, Roberts C-M, Bolte T. (2018). Reliability of computerized
363 eye-tracking reaction time tests in non-athletes, athletes, and individuals with traumatic
364 brain injury. *Optometry & Visual Performance* 6(3): 165-180.
365 Leigh JR. Zee DS. (2015). *The Neurology of Eye Movements.* Oxford University Press. NY: New
366 York.
367 Llg UJ, Schumann S, Their P. (2004). Posterior parietal cortex neurons encode target motion in
368 world-centered coordinates. *Neuron,* 43:145-151.
369 Schlack, K.P., Hoffman, F., Bremmer, F. (2003). Selectivity of macaque ventral intraparietal
370 area (area VIP) for smooth pursuit eye movements. *J Physiol,*551:551-566.
371 Their P. Llg UJ. (2005). The neural basis of smooth-pursuit eye movements*. Curr Opin*
372 *Neurobio,* 15(6): 645-662.
373 Wong AMF. (2008). *Eye Movement Disorders.* Oxford University Press, New York NY. pp. 78.
374 Yoshida M, Origuchi M, Urayama S, et al. (2014). fMRI evidence of improved visual function in
375 patients with progressive retinitis pigmentosa by eye-movement training. *Neuroimage*
376 *Clin*. 5: 161–168.

377 Zampieri C. Di Fabio RP. (2009). Improvement of gaze control after balance and eye movement
378 training in patients with progressive supranuclear palsy: a quasi-randomized controlled
379 trial. *Arch Phys Med Rehabil* 90: 263-70.
380 Zupan MF, Arata AW, Wile A, Parker R. (2006). Visual adaptations to sports vision
381 enhancement training. *Occupational Therapy* 104: 43-48.