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

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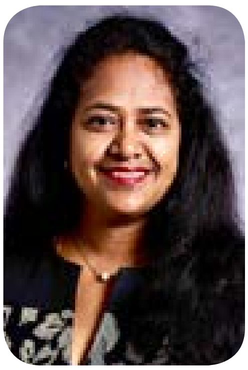

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ABSTRACT

Background: 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 whether participants with poor SPEM improved via a standardized oculomotor training program. The secondary objective was to quantify the change in SPEM accurately using eye tracking. The third objective was to examine participants' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory (NSI).

Methods: Four SPEM metrics, including Functional Vision EyeQ score, on target, latent and predictive pursuit percentages, and symptoms using NSI were assessed. Participants were randomly assigned either to the intervention (IG) or no intervention (NI) groups. The intervention group performed 10 minutes of oculomotor training daily for five days using the EyeQ Trainer, while the NI group did not receive any intervention. Each group comprised 46 participants, with mean ages of 35.43±22.9 and 41.59±22.3 years for the intervention and NI groups, respectively.

Results: There were significant interactions between groups (intervention and NI) and times (pre- and post-oculomotor training) for all four SPEM metrics and NSI symptoms ($p<0.05$). The SPEM metrics showed improved tracking abilities and a significant reduction in NSI symptoms in the intervention group compared to the NI group post training.

Conclusions: This study demonstrated that oculomotor training showed improved SPEM metrics and reduction in symptoms. Future research should consider the examination of eye movement metrics for saccades and gaze stability.

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

Introduction

Smooth pursuit eye movements (SPEM) are used to track and to stabilize the image of a moving object on the fovea. SPEM are also used to judge the speed of moving objects to account for follow-on motor responses. By trying to stabilize the target on the fovea, SPEM are continually translating signals and converting deviations from the ideal trajectory into compensatory eye movements.[1]

Eye movements such as SPEM have brain-related anatomical circuits that make distinct contributions to the eye movements and ultimately to action. SPEM are mediated by a cerebro-ponto-cerebellar pathway.[1] The cerebral cortex contains several frontal and parietooccipital areas that have distinct roles in generating SPEM. The middle temporal (MT) visual area 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.[2] SPEM are also foreseen by the middle superior temporal (MST) area that represents an object in motion in world-centered coordinates.[1,3]

A lesion in the MST causes directional error, with lowered speed toward the side of the lesion.[1]

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 ventral paraflocculus (VPF). Bilateral lesions of the flocculus and VPF result in severe deficits in horizontal and vertical pursuits in both directions, as well as 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 contraversive horizontal pursuit. Lesions starting from the medial vestibular nucleus also affect VOR because pursuit and VOR share similar pathways from this point forward. Hence, resulting symptoms tend to overlap.

When a person can effectively use their eyes for smooth pursuit, cognitive processes are enabled. For example, effective tracking of a car allows the person to determine its speed, to calculate the time to interception, and ultimately to decide about when to cross the road. Such activities facilitate the integration of head movements into smooth-pursuit behaviors and the coordination of perception and action.[1,3] As a person ages, smooth pursuit performance often declines. This decline is commonly tied to cerebellar disease and to drugs that affect the nervous system.[4]

Optimization and repair of smooth pursuits can be enhanced using oculomotor training.[5] Studies have shown significant improvement in eye movement functions following oculomotor training, even in adults with brain injury, demonstrating a preserved mechanism of neuroplasticity. Eye movement training has been used to improve skills in patients with clinical conditions who demonstrate poor performance, as well as in those who are trying to achieve elite performance in sports.[6,7] Oculomotor training, including pursuit training, has been shown to be successful in improving performance in patients with various clinical conditions, including gait functions;[8] macular degeneration;[9] progressive retinitis pigmentosa;[10] cognitive function, depression, and functional ability;[11] tunnel vision;[12] and progressive supranuclear palsy.[13] Additionally, training specific to pursuit eye movements has been successful in mitigating spatial neglect following a stroke.[14,15] Eye movement training has shown to improve performance in elite-level personnel as well. Zupan et al. used eye movement training to improve Air Force fighter pilots' reaction time, near-far focusing, and number of cycles of saccadic refixations in horizontal and vertical directions.[16]

The current state of eye movement interventions has been created using clinically relevant principles of neuroscience, neurology, motor learning, and rehabilitation.[6,7] However, limitations exist in the use of eye movement outcome measures due to the complexity of objectively measuring eye movements and the interpretation of results from such interventions.[17] Therefore, the purpose of this study was to determine whether participants with pre-determined poor pursuits improved via a standardized, commercially available oculomotor training program. A secondary objective was to quantify the change in SPEM accurately using eye tracking. A third objective was to examine participants' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory (NSI).[18]

Methods

Participants

Participants were recruited through RightEye clinical providers. This includes certified optometrists, chiropractors, and functional neurologists in the U.S. who had access to the RightEye system. These participants underwent a routine eye examination with a certified optometrist prior to engaging in the study. Testers had completed and passed the RightEye training sessions. The nature of the study was explained to the participants, and they were provided with a written informed consent to participate, which was approved by the University. 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, the RightEye clinical providers administered the oculomotor testing and training for the participants. Participants were asked to complete a pre-screening test. Following pre-screening, participants completed the NSI questionnaire and then took the Functional Vision EyeQ (FVEQ) series of tests. Once testing was complete, they were randomly assigned either to the intervention group (IG) or to the no-intervention (NI) group. They were instructed not to engage in any training or intervention. If they were assigned to the IG, they would receive an email allowing them to sign up. The EyeQ Trainer exercises were automated within the software program. Testers were blinded to which group participants were assigned; that is, they were unaware of which participants were in the IG versus NI.

The IG trained using the RightEye "EyeQ Trainer" exercises and no other interventions. The NI did not do either the RightEye "EyeQ Trainer" exercises or any other intervention. After training was complete, the participants returned for a post-test FVEQ and completed the NSI and debriefing of the study.

Ninety-two individuals participated in the study. The IG included 46 participants who completed the EyeQ Trainer exercises and no other oculomotor training. The NI group included 46 healthy participants who were not engaged in any oculomotor training. Participants were between the ages of 12 and 68 years (M = 41.59, SD = 22.29) in the NI group. Participants in the IG were between the ages of 12 and 58 (M = 35.43, SD = 22.9). There were 13 males (28%) and 33 females (72%) in the IG. In the NI group, there were 24 males (52%) and 22 females (48%). The sample size was calculated using JMP (SAS) with an alpha of 0.05, beta at 0.80, and an effect size of 0.6347 as determined from a previous study.[5,19]

Inclusion/Exclusion Criteria

Participants were pre-selected via the clinical provider database from the RightEye system if they met the following criteria: (1) they had pursuit eye movements that were in the bottom 25th percentile compared to age-matched controls and (2) if it had been less than 30 days since their last visual assessment. The criteria for abnormal pursuit eye movement was set at the bottom 25th percentile of the comparative analysis of the pursuit data from age-matched normative data.[20] The providers were contacted to refer the eligible participants for the study. Those participants who were referred by non-eyecare professionals underwent full eye examinations by certified optometrists. Participants were excluded from the study if they reported past head injury, any neurological conditions, mood disorders, depression, post-trauma stress disorder (PTSD), or static best-corrected visual acuity worse than 20/400. Participants with glasses were tested with their habitual correction. If they were given new glasses, adequate refractive adaptation time was given before testing. Ocular health was determined by certified optometrists as part of an annual examination. Participants were also excluded if they were unable to pass a 9-point calibration sequence for the eye tracker.

Apparatus

Testing

Eye movement tests were presented using the RightEye 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 an adjustable chair. They sat in front of a desk in a quiet, private room. Participants' heads were unconstrained. The accuracy of the Tobii eye tracker was 0.4^0 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 (FVEQ), for both study groups.[5] These tasks included three smooth pursuit tests, two saccade tests, one fixation test, and two reaction time oculomotor outcome measures, all of which have high validity and reliability indices (Cronbach's alpha > 0.8).[5,19]

The FVEQ score is determined from a total of 54 metrics from the tasks, which include a non-linear combination of saccades, pursuits, fixation, and reaction time. These 54 metrics were derived from a logistic regression model, with each weighted differently based on the contribution of each variable to the variance.[20] Weights range from 0.1 to 13% across metrics. The higher the FVEQ score, the better the performance. Those participants with FVEQ scores less than the 25th percentile were included in the study. The participants were screened using the RightEye, and if they earned a FVEQ score on the RightEye that met the criteria, they were considered eligible for the study.

For SPEM, the three types of pursuit tests that were run include a Circular Smooth Pursuit (CSP), a Horizontal Smooth Pursuit (HSP), and a Vertical Smooth Pursuit (VSP). In the CSP test, the stimulus moves in a circle with a radius of 10 degrees. For HSP, the stimulus moves horizontally across the screen, moving from center to far right, then to far left, and then back to the center. For VSP, the target moves in the vertical direction in a similar fashion. Participants were asked to "follow the dot on the screen as accurately as possible with your eyes." The dot was 0.2 degrees in diameter and moved at a speed of 25 degrees of visual angle per second.[21] The white test stimuli were presented on a black background, and the stimulus duration was 20 seconds.

The SPEM outcome measures (FVEQ score and latent, predictive, and on-target smooth pursuits for CSP) were obtained from the eye tracker. The latent smooth pursuit refers to the user's eyes within a velocity range of the target and positioned behind the stimulus between 2 and 5 cm. The on-target smooth pursuits refer to the user's eyes within a velocity range of the target, positioned on the stimulus within 2 cm. The predictive smooth pursuit refers to the user's eyes within a velocity range of the target and positioned ahead or in front of the stimuli between 2 and 5 cm and reported as a percentage. These three oculomotor parameters for CSP were reported as percentages and sum up to 100%. The higher the percentages, the better the performance.[20]

The Neurobehavioral Symptom Inventory (NSI) is primarily used as a measure of symptom severity in mild TBI. It is a 22-item self-report questionnaire designed to assess vestibular, somatic, cognitive, and affective symptom severity using a Likert scale (ranging from 0: none to 4: very severe).[22] The total score ranges from 0 to 88. In addition, a 23rd question was added to the NSI questionnaire to rate participants' overall symptoms on the same scale. NSI is a valid and reliable tool to assess the severity of symptoms with a high reliability score of > 0.8.[23]

Training

Training tasks were conducted on a 10.2-inch Apple iPad. Participants were instructed to sit at 45 cm from the device. The device was positioned at a 45-degree angle for ease of viewing.

Oculomotor Training using RightEye EyeQ trainer: Oculomotor training exercises were done for 5 minutes and were conducted twice per day for each individual participant, once in the morning and once in the evening, for five consecutive days, giving a total training period of 50 minutes. The training protocol 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 were asked to look down at a fixed target at the bottom center of the screen. While keeping the eyes focused, they were asked to move the head slowly to the right, to the left, and then return to center (see video of Down-gaze Central No-No saccades here, https://vimeo.com/righteyellc/review/283538105/baca97a69b.). For Up-gaze Central No-No, participants were asked to look up at a fixed target at the top center of the screen (https://vimeo.com/righteyellc/review/283537934/f38fae91ea). While keeping the eyes focused, they were asked to move the head slowly to the right, to the left, and then return to center.

For Down Right and Down Left-Diagonal Saccades followed by Upward Pursuit, participants were asked to follow the moving target with their eyes, keeping the head still. The target moved from the center of the screen to the bottom right and bottom left, respectively, in multiple small saccades, followed by straight up along the vertical margin of the screen to the center right and center left of the screen, respectively, in a pursuit motion (see video here, https://vimeo.com/righteyellc/review/283538056/76142bbdd9).

All participants completed the same set of training exercises for five consecutive days and were reevaluated within 7 days post-training. After each intervention training session, the RightEye system records the login information of participants and whether all of the training exercises were performed. It then provides the gaze information into a calendar. The system also prompts a checkbox for participants to confirm that the training exercises were completed after each session.

Data Analysis

A two-way repeated measures ANOVA was performed for comparing the groups (IG vs. NI) and time (pre- vs. post-training) on all four CSP metrics and the NSI score. A pairwise comparison was performed using simple effects post-hoc test. All analyses were completed using SPSS Statistics software. Also, when necessary, violations of the sphericity assumption were corrected using Greenhouse-Geisser adjustments of the degrees of freedom. Statistically significant difference was considered to be p values less than 0.05.

Results

An independent samples t-test of groups was conducted to determine whether there were demographic group differences. The IG and NI groups did not differ by age (p=0.075; IG age=35.43, SD=22.9; NI age=41.59, SD=22.29).[1,3] In addition, using a chi-square analysis, gender was not significantly different between the IG (13 males/33 females) and NI groups (24 males/22 females), X^2 (1, N = 92) = 2.831; 0.092. Those participants who had glasses wore their

Table 1. Mean (SD) of FVEQ and Key Measures for CSP for Each Group (IG/NI) and by Time (Pre-/Post-training)

	Intervention		No Intervention	
	Pre	Post	Pre	Post
FVEQ Score	53.20 (20.11)	60.80 (18.74)*	53.15 (20.40)	52.87 (23.17)*
On-Target Smooth Pursuit (%)	59.81 (20.13)	61.17 (19.65)*	63.89 (15.48)	59.12 (18.24)*
Latent Smooth Pursuit (%)	30.84 (13.99)	25.32 (13.14)*	28.25 (10.10)	31.46 (10.84)*
Predictive Smooth Pursuit(%)	10.29 (5.62)	6.80 (5.57)*	8.65 (4.58)	8.87 (6.19)*

SD- Standard deviation, FVEQ- Functional Vision EyeQ, CSP- Circular smooth pursuits, *significant at 0.05 probability level

habitual correction for pre- and post-tests. Thirty-one participants had progressive addition lenses, while 61 participants did not use any refractive correction. Table 1 presents the results for FVEQ, On-Target Smooth Pursuit, Latent Smooth Pursuit, and Predictive Smooth Pursuit. Tables 2 and 3 represent the NSI symptoms for the IG and NI group for pre- and post-intervention.

Functional Vision EyeQ Score (FVEQ)

The ANOVA results for the FVEQ score (Figure 1 and Table 1) demonstrated no significant main effect for Group (p=0.344); however, there was a significant main effect for Time ($F(1, 90) = 4.00$, p=0.048, $\eta^2g=0.01$) and a significant interaction effect between Group and Time ($F(1, 90) = 4.65$, p=0.034, $\eta^2g=0.01$). A post-hoc analysis using simple effects model revealed a slight decrease in the FVEQ score from pre (53.15) to post (52.87, $p<0.05$) for the NI group; however, the IG's score increased by a significantly greater amount from pre to post (Pre FVEQ score = 53.20, post FVEQ score = 60.80, $p<0.05$). This increase in FVEQ score in the IG supports the efficacy of oculomotor training in improving eye movement parameters.

On-Target Smooth Pursuit (%)

On-Target Smooth Pursuit (Figure 2) demonstrated neither a significant main effect for Group (p=0.776) nor a significant main effect for Time (Pre, Post), (p=0.253); however, there was a significant interaction between Group and Time ($F(1, 90) = 4.29$, p=0.041, $\eta^2g=0.01$). The significant interaction effect between Group and Time indicates that there was a significant change in the % of On-Target Smooth Pursuits between the study groups (IG and NI) and Time (pre- and post-training). Simple effects revealed a significant decrease in the On-Target Smooth Pursuit score for the NI group from pre (63.89) to post (59.12, $p<0.05$); however, the IG group showed an increased mean score for On-Target Smooth Pursuit from pre- to post-training (Pre: 59.81; Post: 61.17%, $p<0.05$).

Latent Smooth Pursuit (%)

Latent Smooth Pursuit demonstrated neither a significant main effect for Group (p=0.604) nor a significant main effect for Time (Pre, Post), (p=0.564) (Figure 3); however, there was a significant

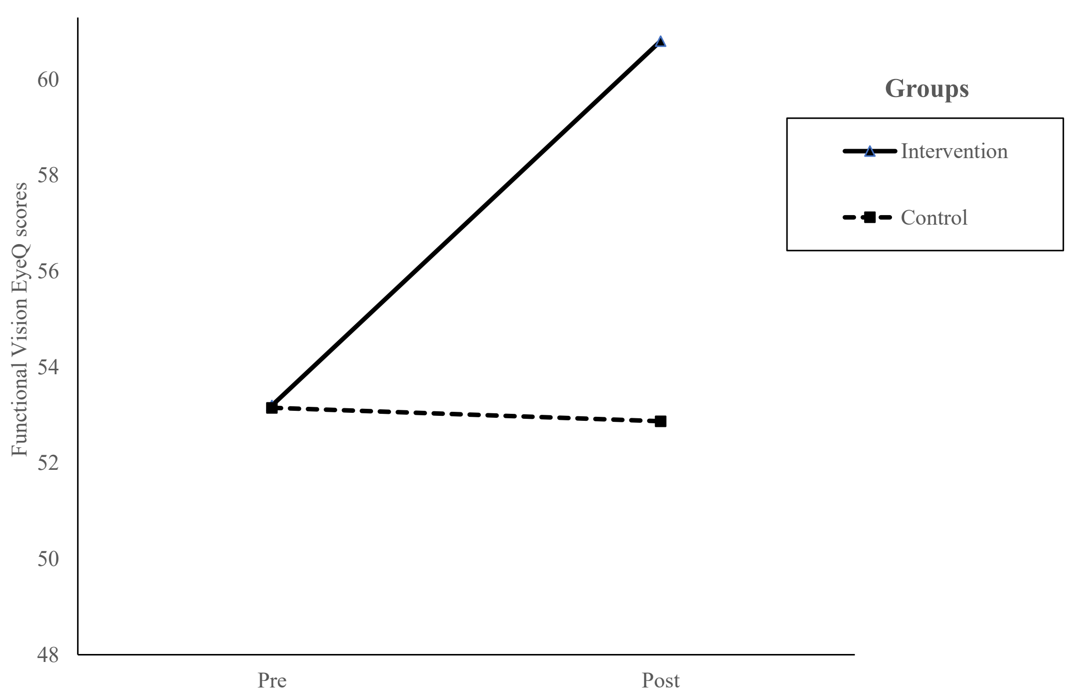

Figure 1. *Pre- and post-assessment Functional Vision EyeQ scores for control and intervention groups*

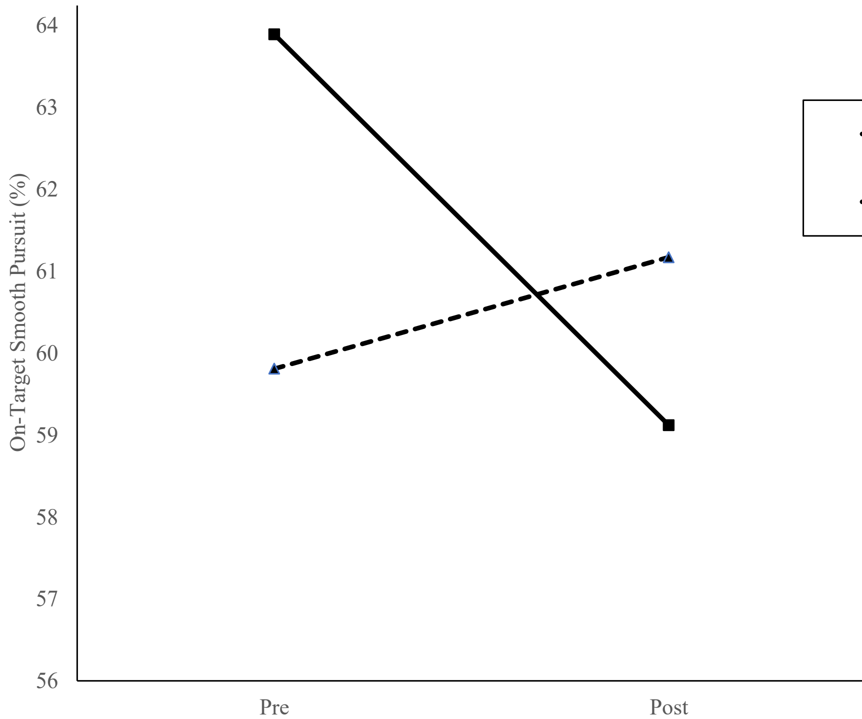

***Figure 2.** Pre- and post-assessment On-Target Smooth Pursuit (%) scores for control and intervention groups*

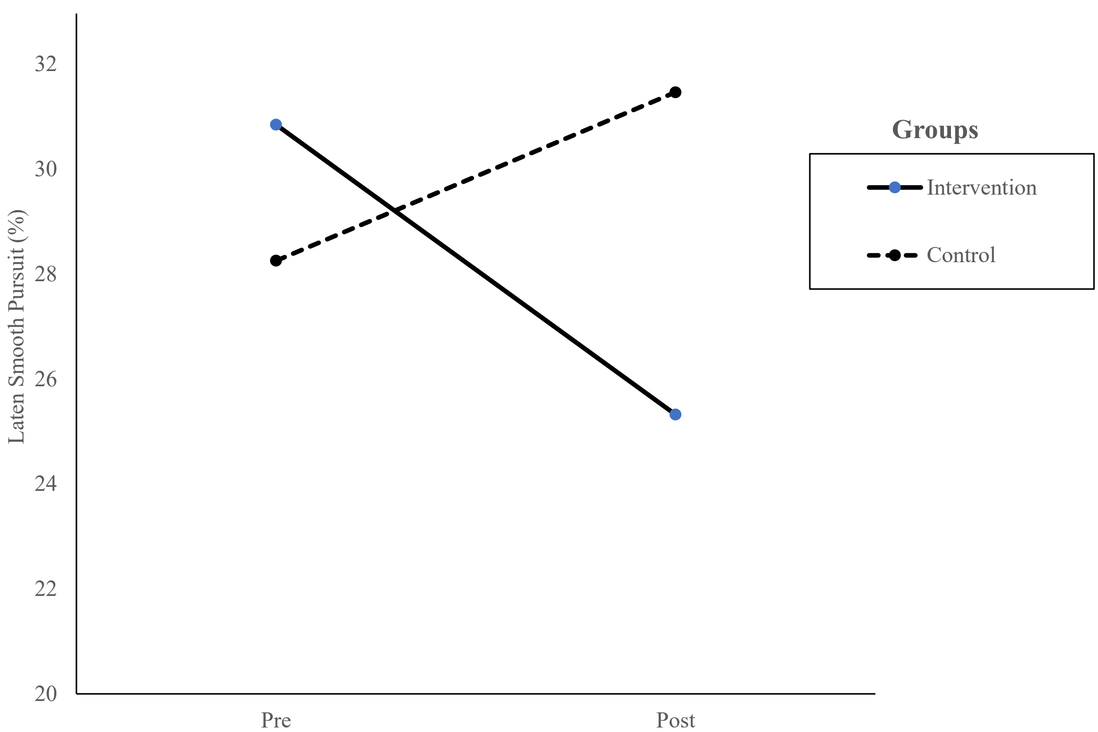

***Figure 3.** Pre- and post-assessment Latent Smooth Pursuit (%) scores for control and intervention groups*

interaction effect between Group and Time ($F(1, 26) = 4.87$, $p=0.036$, $\eta^2 g=0.05$). Simple effects revealed an increase in the mean Latent Smooth Pursuit (%) score for the NI group from pre (28.25) to post (31.46, $p<0.05$); however, the IG's mean metric value decreased significantly from pre (30.84) to post (25.32), ($p<0.05$).

Predictive Smooth Pursuit (%)

Predictive Smooth Pursuit (Figure 4) demonstrated no significant main effect for Group ($p=0.865$); however, there was a significant main effect for Time ($F(1, 94)=5.65$, $p=0.019$, $\eta^2 g=0.01$) and a significant interaction effect between Group and Time ($F(1, 94) =7.30$, $p=0.008$, $\eta^2 g=0.02$). Simple effects revealed an increase in the mean predictive smooth pursuit score for the NI from pre (8.65) to post (8.87, $p<0.05$);

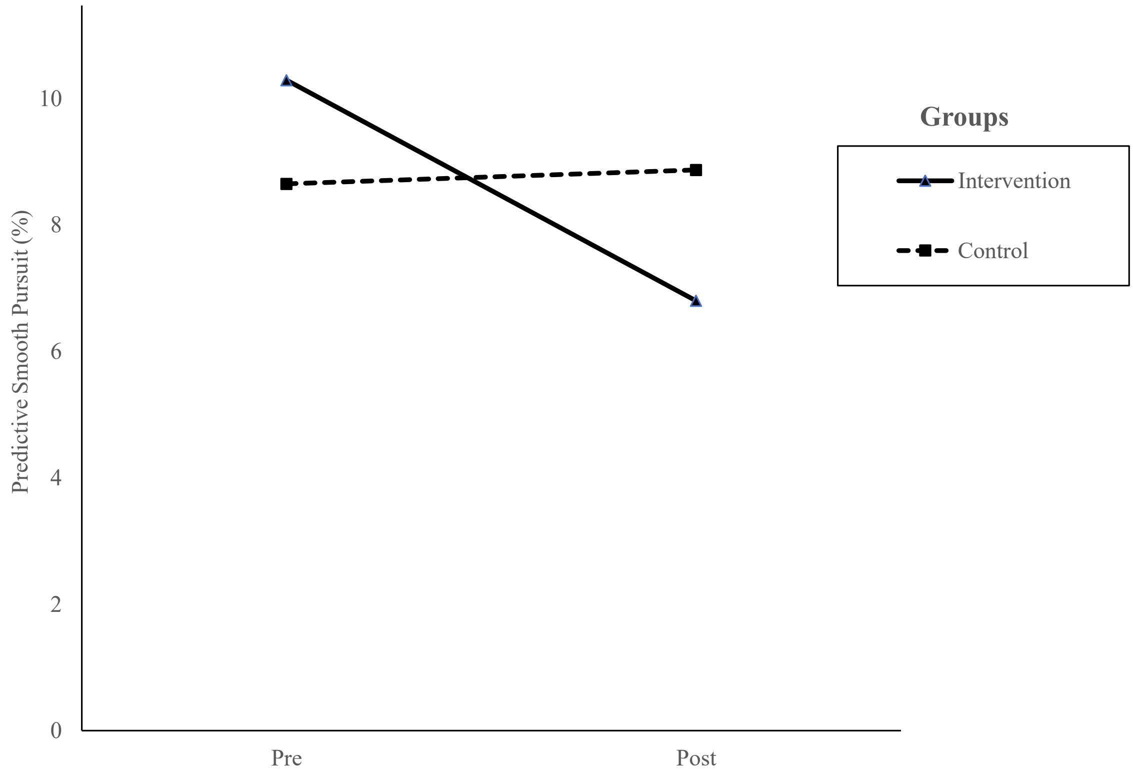

***Figure 4.** Pre- and post-assessment Predictive Smooth Pursuit (%) scores for control and intervention groups*

however, for the IG, mean value decreased from pre- (10.29) to post-training (6.80, ($p<0.05$)).

Neurobehavioral Symptom Inventory (NSI)

Tables 2 and 3 show the NSI scores for the IG and NI groups for pre- and post-training. For the NSI, the results were similar for both the total score and the four-factor scoring approaches. Specifically, the total score analysis indicated a main effect for Time ($F(1, 94)=1595.28$, $p<0.001$, ηp2=0.944) and Group ($F(1, 94)=17.22$, $p<0.001$, $\eta p^2=0.943$), but more interesting was the significant interaction between Time and Group, ($F(1, 94)=2433.82$, $p<0.001$, $\eta p^2=0.963$). Similarly, the vestibular [$F(1, 94)=221.96$, $p<0.001$, $\eta p^2=0.702$; $F(1,94)=351.632$, $p<0.001$, $\eta p^2=0.789$], somatosensory [$F(1,94)=898.44$, $p<0.001$, $\eta p^2=0.905$; $F(1,94)=1208.77$, $p<0.001$, $\eta p^2=0.230$], cognitive [$F(1,94)=127.89$, $p<0.001$, $\eta p^2=0.576$; $F(1,94)=106.318$, $p<0.001$, $\eta p^2=0.149$], and affective factors [$F(1,94)=103.83$, $p<0.001$, $\eta p^2=0.525$; $F(1,94)=137.49$, $p<0.001$, $\eta p^2=0.682$] demonstrated significant main effects for Time and Group comparisons, respectively. In addition, there was a significant interaction between Group and Time for all factors: vestibular ($p<0.001$, $\eta p^2=0.789$), somatosensory ($p<0.001$, $\eta p^2=0.912$), cognitive test ($p<0.001$, $\eta p^2=0.730$); and affective ($p<0.001$, $\eta p^2=0.682$). Lastly, results for overall symptom change (Q23) before and after training showed a significant main effect for both Time ($F(1,94)=52.39$, $p<0.001$, $\eta p^2=0.650$) and Group ($F(1,94)=20.68$, $p<0.001$, $\eta p^2=0.548$), and a significant Time and Group interaction effect ($F(1,94)=34.27$, $p<0.001$, $\eta p^2=0.548$). There was a significant difference between the overall NSI scores for pre- and post-training for IG but not for NI groups (IG: Pre=53.23, Post=28.71, $p<0.001$; NI group: Pre=31.88, Post=34.46).

Discussion

The primary purpose of this study was to determine whether a series of oculomotor exercises improved the pursuit metrics of participants who had poor SPEM. The results revealed that the FVEQ score significantly improved post-training in participants in the IG. In addition, the significant reduction in NSI symptoms reveals that the improvement of ocular motility metrics achieved with the eye tracking exercises relieved subjective symptoms along with objective SPEM metrics.

The FVEQ score includes three types of eye movements: SPEM, saccades, and fixations. Each measure is weighted in accordance with a linear combination of oculomotor variables.[20] A significant positive change in this score reveals an overall improvement in oculomotor behavior. The fact that there were no significant main effects for group or time for FVEQ score, on-target, latent, and predictive

Table 2. Mean (SD) NSI itemized scores for Group (IG/NI) and Time (Pre/Post training)

	Intervention		No Intervention	
	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)
Frustration	2.15 (1.11)	0.86 (0.80)	1.24 (1.02)	1.44 (0.83)

SD- Standard deviation, NSI- Neurobehavioral Symptom Inventory

Table 3. NSI Q23, Total, and 4-Factor Mean (SD) Scores for Each Group (IG/NI) and by Time (Pre-/Post-Training)

	Intervention		No Intervention	
	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)

SD- Standard deviation, NSI- Neurobehavioral Symptom Inventory *significant at 0.001 probability level

pursuits shows that there was no difference in the four SPEM metrics between the groups pre-training. However, the significant interaction effect consistently observed for all metrics clearly demonstrated that oculomotor training resulted in a significant impact on improving the tracking abilities in the IG.

The efficacy of oculomotor training is further supported by a significant reduction in overall symptoms, as shown on the NSI. The mean total score revealed statistically significant differences for main effects for group and time, and more importantly, for the interaction of group and time. The results indicate that participants who engaged in the eye movement training had an overall reduction in symptoms as assessed using the 4-factor analysis. Furthermore, when specifically asked to rate their overall symptoms pre- and post-training, the results were consistent with the NSI total score.

The FVEQ score, total NSI score, and overall symptoms question (Q23) for the IG collectively revealed a broad improvement not only in the oculomotor variables but also in self-reported symptoms. This link between signs and symptoms is critical to evaluate in intervention research. In other words, while clinicians value the quantitative improvements in oculomotor function, patients value the resulting reduction in the symptoms that were adversely impacting their activities of daily living.

A secondary objective of this study was to quantify change in SPEM accurately and specifically 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 group and time in all three SPEM metrics (on-target, latent, and predictive pursuit %). 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 NI group, without any intervention, showed an increase in poor SPEM behavior, which manifested as increased latent and predictive SPEM and decreased (4.77%) on-target SPEM. This finding was important in two respects. First, if no oculomotor training is undergone when a person has poor SPEM, they continue to decline. Second, if oculomotor training is provided, an improvement in SPEM behavior occurs.

The third objective of this study was to examine participants' neurobehavioral symptoms before and after oculomotor training using the NSI questionnaire.[23] The significant main effects for group and time and the interaction effect between group and time demonstrated that the oculomotor training using the EyeQ trainer was effective in alleviating neurobehavioral symptoms. In addition to the total NSI score and overall symptom question (Q23), the analysis revealed significant differences in all 4 factors. The first factor, classified as vestibular, consists 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.[4] Therefore, lesions in brain areas associated with these eye movements will result in neurobehavioral symptoms for factor 1. Vestibular symptoms are affected by poor pursuits if the brain lesion is at the level of the medial vestibular nucleus because vestibular and pursuit pathways are shared. The vestibulo-ocular reflex and gaze stability (fixations) also affect vestibular-related neurobehavioral symptoms. Therefore, future research should specifically examine eye movement metrics related to vestibular symptoms when engaged in this eye movement training protocol.

The second factor, classified as somatosensory, consists of questions relating to headaches, nausea, vision, sensitivity to light and noise, numbness, and changes in taste. Results for somatosensory factors were also highly significant. The third factor, classified as cognitive, consists of questions relating to poor concentration, forgetfulness, difficulty making a decision, and slowed thinking. Results obtained from the NSI revealed significant main effects and interactions for the cognitive factor. Hence, future research should 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.[25]

The fourth factor, classified as affective, consists of questions relating to fatigue, difficulty falling asleep, feeling anxious, feeling depressed, irritability, and frustration. Results obtained from the NSI revealed significant main effects and interactions for the affective factor. Emotional lability, including increased frustration, impulsiveness, and quickness to anger, have been linked to frontal lobe areas of the brain that are also associated with saccadic eye movements. Yoshida and colleagues observed that eye movement training that consisted of various eye movements (fixations, pursuits, and binocular training) showed remarkable improvement in other eye movements (e.g., saccades).[10] Hence, the neurological pathways for some eye movements overlap. The resulting neurobehavioral symptoms may also overlap, especially if a symptom is of a broad nature, such as a brain "fog."

In conclusion, this study examined the pre- and post-oculomotor training scores of subjects with poor SPEM in relation to an eye movement training protocol. Results showed significant improvements in SPEM in the IG group, as well as a decline in SPEM metrics in the NI group who did not engage in oculomotor training. Furthermore, the NSI confirmed that eye movement training significantly reduced neurobehavioral symptoms. Future research should examine other eye movements in relation to this study's oculomotor training regime.

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