Archives of Rehabilitation Research and Clinical Translation (2021) 3, 100126

ACRM
AMERICAN CONGRESS OF REHABILITATION MEDICINE

Archives of Rehabilitation Research and Clinical Translation

Archives of Rehabilitation Research and Clinical Translation 2021;3: 1–8

Available online at www.sciencedirect.com

Original Research

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

Nicholas P. Murray, PhD [a], Melissa Hunfalvay, PhD [b], Claire-Marie Roberts, MS [c], Ankur Tyagi, MS [b], Jason Whittaker, DC [d], Cedrick Noel, DC [e]

[a] *Department of Kinesiology, East Carolina University, Greenville, North Carolina*
[b] *RightEye LLC, Bethesda, Maryland*
[c] *Department of Psychology, University of the West of England, Bristol, United Kingdom*
[d] *Neurdsolutions, LLC, Winnipeg, Manitoba, Canada*
[e] *Neurdsolutions, LLC, Roswell, Georgia*

KEYWORDS
Eye movement recording;
Neurological function;
Ocular behavior;
Rehabilitation;
Saccades

Abstract *Objectives:* To determine if participants with saccadic dysfunction improved after participating in a standardized oculomotor training program. A secondary objective was to accurately quantify change in saccades after training using eye tracking technology. A third objective was to examine patients' neurobehavioral symptoms before and after oculomotor training using the Neurobehavioral Symptom Inventory (NSI).
Design: A prospective study involving treatment and control group pre-post intervention design.
Setting: Data were collected in eye clinics with a standardized eye tracking equipment setup.
Participants: Participants in the bottom 25th percentile for saccadic eye movements (N=92; intervention=46, control=46) who were currently asymptomatic of specific disorder.
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: The ratio of the peak saccadic velocity over its average velocity (the Q ratio), saccadic targeting, and NSI.
Results: Results revealed significant interactions between control and intervention groups (P=.013). The control group increased 7% from pre to post; however, the intervention group exhibited a 6% decreased from pre to post. Participants in the intervention group demonstrated a 25% improvement in targeting saccade accuracy (P=.021). Additionally, there was a significant reduction in all neurobehavioral factors on the NSI in the intervention group, specifically the affective and cognitive factors relating to poor saccades.

List of abbreviations: ANOVA, analysis of variance; CG, control group; IG, intervention group; mTBI, mild traumatic brain injury; NSI, Neurobehavioral Symptom Inventory.

Disclosures: Melissa Hunfalvay is Cofounder and Chief Science Officer of RightEye, a health technology company headquartered in Bethesda, Maryland. Nicholas P. Murray, Melissa Hunfalvay, Ankur Tyagi, and Cedrick Noel have received financial compensation from RightEye.

Cite this article as: Arch Rehabil Res Clin Transl. 2021;3:100126

https://doi.org/10.1016/j.arrct.2021.100126

Conclusions: For this population, oculomotor training (Q ratio and saccade accuracy) resulted improved saccadic metrics and a significant reduction in overall symptoms as shown on the NSI. Future participants reported improved symptoms pre- and postintervention. Further research is needed to understand saccadic performance and gaze stability during specific tasks (such as reading).

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.[1] One purpose of a saccade is to reposition the eye to bring objects of interest onto the fovea. The fovea is used to see images 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. It is estimated that humans make 100,000 saccades a day.[1]

Conversely, fixations are stopping points that occur after a saccade and hold the image stationary 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 2 stationary targets in a fixed period.[2] Such saccades are most commonly clinically tested by asking a patient to look alternately at 2 targets held apart horizontally and vertically.[1] Saccades have several characteristics that can be used to measure their effectiveness. Saccadic velocity is the speed at which the saccade moves. Normal peak velocity varies from 30-700 degrees per second.[1,3] 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, spinocerebellar ataxia type 2 can be associated with slow saccadic velocity.[1]

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.[1] The cerebral cortex directs control of the saccades via direct projection to the burst neuron circuits in the brainstem. Damage to the cerebral cortex through, for example, mild traumatic brain injury (mTBI)[2] results in abnormal self-paced (volitional) saccades. Furthermore, the dorsolateral prefrontal cortex is also considered to be involved in the control of self-paced saccades.[4] The cerebellum is important in maintaining saccadic accuracy for adaptation. Damage in the cerebellum causes saccades to overshoot or undershoot the target. Such inaccuracy or dysmetria of saccades can be seen clinically via cerebellar lesions usually causing hypermetria.[1] Typical symptoms of lesions in the cerebellum and frontal lobe include fatigue, a slowness to react, slower information processing, impaired executive function, multitasking issues, lack of mental clarity, brain "fog," and emotional lability. Typical risks include reading difficulties, being slower to complete tasks (eg, student may need extra time for examinations), being quicker to anger, and being more impulsive.

These lesions are often caused by mTBI, strokes, migraines, or other central nervous system-related disorders and will affect vestibular, somatic, cognitive, and affective systems. Several inventories are available to determine symptom severity; however, the Neurobehavioral Symptom Inventory (NSI),[5] although originally intended to measure mTBI, has been used to measure a variety of other medical conditions that share common level of symptomology such as depression, posttraumatic stress disorder, anxiety,[6,7] and non−traumatic brain injury neurologic damage.[8] Further presence of these symptoms results in eye movement dysfunction, which can increase symptom severity[9] as indicated by the NSI. Eye movement measurement is a reliable indicator of vestibular, cognitive, and affective dysfunction and disease state. For example, Hunfalvay et al[10] compared visual smooth pursuit eye tracking metrics to differentiate healthy participants without traumatic brain injury in varying degree of mTBI (eg, mild, moderate, severe). Further, Whitney and Sparto[11] demonstrated eye misalignment may affect recovery from mTBI and that there is a need to optimize saccadic control through oculomotor training to enhance recovery.

Eye movement training is based on neuroplasticity, which is the foundation of rehabilitation. Eye movement training has been used to improve those with clinical conditions who display poor oculomotor performance as well as those trying to achieve elite performance in sports.[12-14] Various types of oculomotor training has been shown to be successful in improving symptoms of various clinical conditions including gait functions[15]; cognitive function, depression, and functional ability poststroke[16]; progressive supranuclear palsy[17]; and patients with progressive retinitis pigmentosa.[18] Training specific to saccadic eye movements has also been successful improving reading tasks.[4] Additionally, eye movement training has been shown to improve elite level motor performance. For example, Zupan, et al[13] used eye movement training to improve Air Force fighter pilots' 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.

Despite the extant research pointing to the encouraging results from eye movement interventions and training, limitations exist in the sensitivity and specificity of the eye movement outcome measures. 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.[5]

Methods

Participants

A total of 92 participants (aged 16-62y; mean, 40±19y) were randomly assigned to the intervention group (IG) or control group (CG). The IG included 46 participants (20 male [44%] and 26 female [56%]) who completed the EyeQ Trainer exercises only (see below). The CG included 46 participants (24 male [52%] and 22 female [48%]) who did no oculomotor training whatsoever (fig 1) and were blind to the treatment group by completing a separate informed consent. The CG was informed of the full nature of study at its conclusion. The participants were currently asymptomatic for concussion and other neurologic disorders. To establish demographic clusters, a sample size of 92 participants was determined using JMP Sample Size and Power Platform.[a] To arrive at this sample size, α was set at 0.05, β was set at 0.8, and effect size was determined from previous work (0.6347; Murray et al[19]).

Apparatus

Stimuli were presented via the RightEye tests on a Tobii I15 vision 15" monitor[a] fitted with a Tobii 90 Hz remote eye tracker[b] and a Logitech (model Y-R0017) wireless keyboard and mouse.[c] The participants were seated in a stationary (nonwheeled) chair that could not be adjusted in height. They sat in front of a desk in a quiet, private room. Participants' heads were unconstrained, and the desk and screen height were adjusted to maximize accuracy of the eye tracker. 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

Pretests and posttests were conducted using the same set of oculomotor tasks, collectively called Functional Vision EyeQ. These tasks included 3 smooth pursuit tests, 2 saccade tests, 1 fixation test, and 2 reaction time tests. These eye tests, including Functional Vision EyeQ score, have high validity and reliability (Cronbach α>0.8).[20]

The Functional Vision EyeQ model 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%-13% across metrics.

Specifically, we examined the Self-Paced Saccade test within the Functional Vision EyeQ model (for more details see Hunfalvay et al[9]). In the Horizontal Saccade test, participants were asked to look at a countdown of 3, 2, 1 in the center of the screen before moving their eyes back and forth between 2 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. From this, we examined the outcome

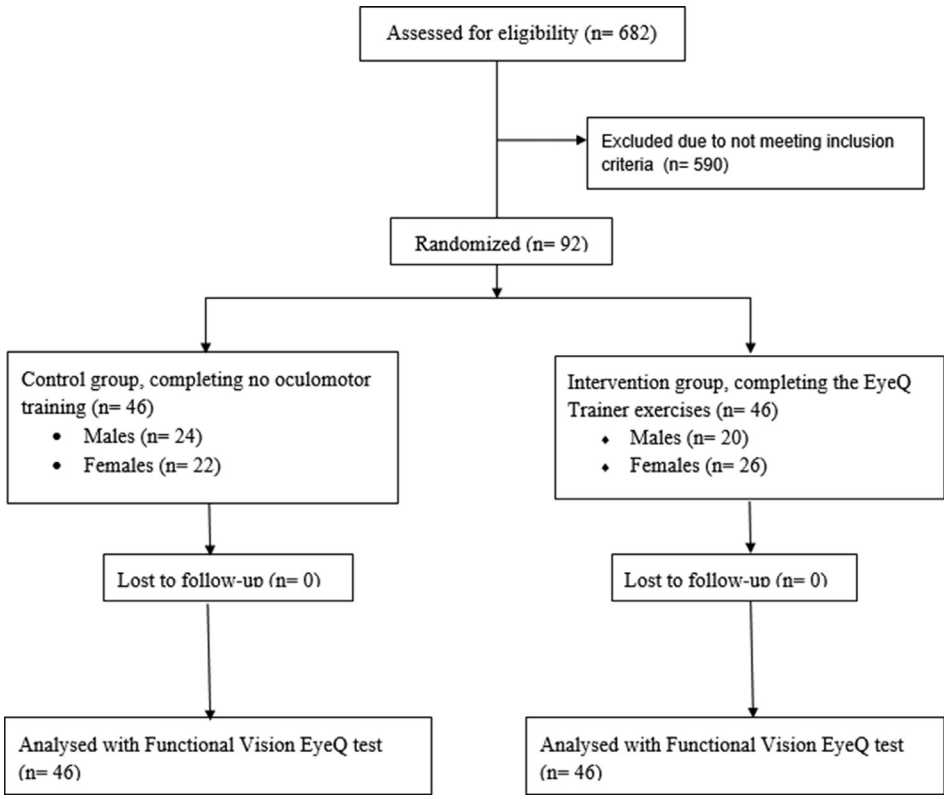

Fig 1 Consolidated Standards of Reporting Trials diagram. Diagram outlines the number of potential participants and path of participants into 2 groups without dropout.

variables of Q ratio and saccade targeting. The Vertical Saccade test is conducted similarly except for the direction of the eye movements. 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. A lower number is a closer distance and is therefore a better score.

Neurobehavioral Symptom Inventory

The Neurobehavioral Symptom Inventory (NSI)[5] is primarily used as a measure for mTBI; however, several of the core symptoms are nonspecific to mTBI. Currently, the NSI clinical use represents the quantification of perceived symptom severity and is a 22-item self-report questionnaire designed to assess vestibular, somatic, cognitive, and affective symptom severity on Likert scale (ranging from 0: none to 4: very severe). In addition, we added a 23rd question to have the participants rate their overall symptoms on the same scale. The NSI has also shown high reliability (Cronbach α>0.8) and has been shown elsewhere to be a valid measure with high internal consistency.[19]

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 5 days, which represent a similar number of training sessions as previous work.[13] 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 jumped. The Up-gaze Central No-No where participants are asked to move their head 1 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 jumped. Plus, they completed Down Right-Diagonal Saccades followed by Upward Pursuit as well as Down Left-Diagonal Saccades followed by Upward Pursuit. The IG group trained on 5 days after pretest, and after the completion of the training participants were given the posttest as soon as possible. There was some variability in when the posttest was administered because of scheduling within the clinic (table 1). The training was done through a cloud-based program in which the training group logged on and completed the training protocol once a day for 5 consecutive days. If they did not complete the training they would have been excluded from the study. No participant missed a training day, so no participant was excluded from the study for this reason.

Table 1 Summary of time interval between pre- and postassessments for intervention vs control group

Variables	Control Mean ± SD	Intervention Mean ± SD
Days difference between pre- and postassessment	18±8	16±8

The CG group was given the pretest, and they returned 6 days later for the posttest.

Procedure

Participants who were asymptomatic for a specific disorder were selected via a patient database of a clinical practice if they met the following criteria: (1) their saccadic eye movements (Q ratio and saccadic targeting) were in the bottom 25th percentile compared with age-matched controls and (2) they had <30 days since their assessment. All assessments were done using the same RightEye system, and all research personnel are fully trained in the use of this system.

The nature of the study was explained to the participants, and all participants were provided an 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. After informed consent, participants were asked to complete a prescreening.

Participants were excluded from the study if they reported past head injury, any neurologic condition, or static visual acuity that was worse than 20/400 (worse than 20/400 is considered profound visual impairment[21]). Participants were required to pass a 9-point calibration sequence by fixating on 9 dots that appear 1 at a time. Participants are required to hold their fixation long enough to be calibrated by system. The system ensures their fixation and the dot are the same. If they do not hold their fixation long enough to calibrate then the participant would fail the calibration and be removed from the study. After prescreening, participants completed the NSI and then took the Functional Vision EyeQ Self-Paced Saccade test. Once testing was complete, they were randomly assigned to the oculomotor training group (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 posttest Functional Vision EyeQ and completed the NSI and debriefing of the study.

Data analysis

We used separate 2×2 (group×time) repeated-measures analyses of variance (ANOVAs) to determine differences in RightEye Test Metrics: Q ratio and Saccadic Targeting Accuracy between the 2 groups (control and intervention) and over time (pre- and postassessments). No adjustments for multiple testing were applied given interest in individual preplanned hypotheses.[22,23] Effect sizes are reported with Cohen's *d* (small=0.2; medium=0.5; large=0.8) for main effects and with ω^2 (small=.01; medium=0.06; large=0.14) for significant interactions.

The NSI was similarly analyzed (2×2 [group×time] ANOVA) using the dependent variables of overall symptoms (Q23), which asked participants to "rate your overall symptoms." Total Score and the 4-factor scoring approach (vestibular, somatosensory, cognitive, 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 interactions. All analyses were completed with SPSS Statistics software package.[d] Also, when necessary, violations of the sphericity assumption were corrected using Greenhouse-Geisser adjustments of the degrees of freedom.

Results

Q ratio

All assumptions were met before conducting parametric testing. The Q ratio metric demonstrated a nonsignificant main effect for group (intervention, control) (P=.160) and nonsignificant main effect for time (pre, post), (P=.958); however, there was a significant interaction (group×time), $F_{1,90}$=6.38, P=.013, ω^2=0.06. Simple effects (P<.05) revealed an increase in Q ratio for control from pre (mean, 2.48±0.49) to post (mean, 2.64±0.64), with a significant decrease for the IG from pre (mean, 2.51±0.53) to post (mean, 2.36±0.30) (fig 2).

Saccadic targeting (mm)

The ANOVA results for saccadic targeting demonstrated a nonsignificant main effect for group (intervention, control) (P=.114) and nonsignificant main effect for time (pre, post) (P=.947); however, there was a significant interaction (group×time), $F_{1,90}$=5.49, P=.021, ω^2=.04. Simple effects (P<.05) revealed an increase in the saccadic targeting metrics for control from pre (mean, 16.53±11.10) to post (mean, 19.43±23.79), whereas the IG significantly decreased from pre (mean, 15.31±8.21) to post (mean, 12.24±5.48) (fig 3).

Neurobehavioral Symptom Inventory

For the NSI, the findings were similar across all the total score and the 4-factor scoring approach (tables 2 and 3). Specifically, the total score analysis indicated a main effect for time (P<.001) and for group, (P<.001), but more interesting was a significant interaction of time×group, $F_{1,94}$=702.60, P<.001, ω^2=0.879. Similarly, the vestibular

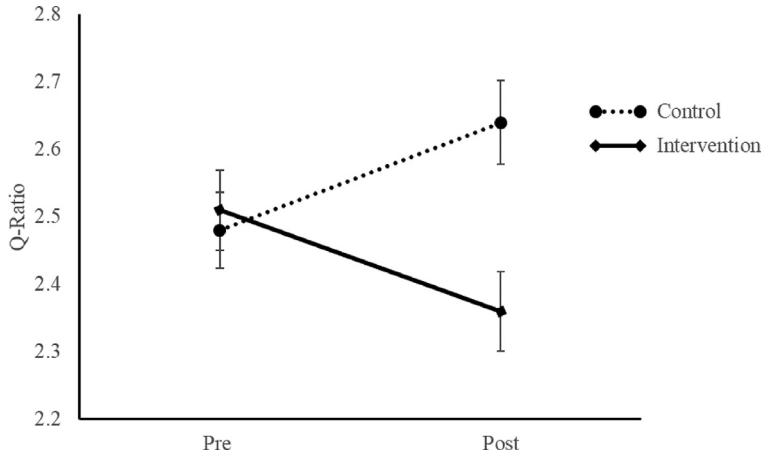

Fig 2 Mean (SE) Q ratio values by group pre/postintervention.

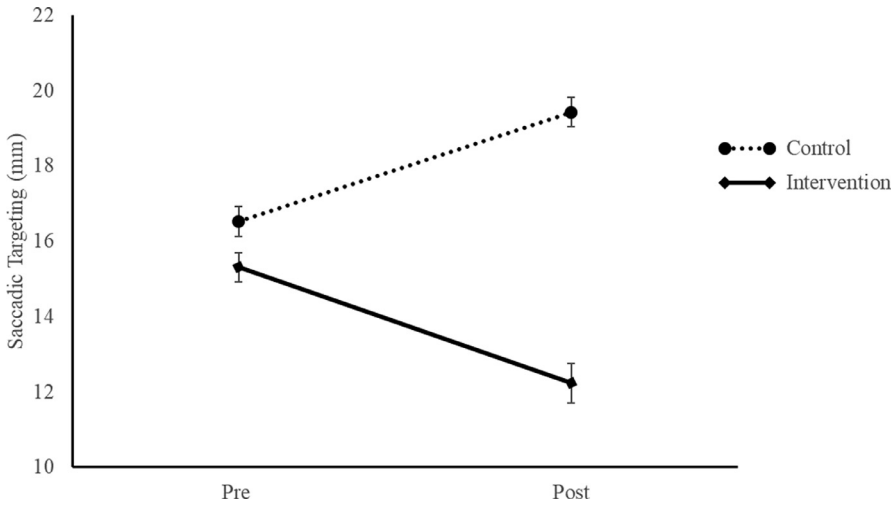

Fig 3 Mean (SE) values for saccadic targeting by group pre/postintervention.

Table 2 NSI itemized mean ± SD scores and ES; Cohen *d* for each group (intervention/control) and by time (pre/post)

Variables	Intervention			Control		
	Pre	Post	ES	Pre	Post	ES
Dizzy	2.69±0.91	1.60±0.49	1.491	2.50±0.99	2.44±1.12	0.057
Balance	2.45±1.02	0.69±0.62	2.085	2.74±0.75	3.08±0.75	0.453
Poor coordination	2.63±1.04	0.93±0.85	1.79	2.24±0.82	2.40±0.83	0.194
Headaches	2.89±0.97	1.28±0.77	1.838	1.44±1.21	1.62±1.48	0.133
Nausea	2.80±0.74	1.71±0.45	1.78	1.56±1.37	1.56±1.37	0
Vision problems	2.69±0.62	1.28±0.77	2.017	2.34±1.22	2.14±0.85	0.19
Sensitivity to light	3.32±0.70	2.17±0.85	1.477	1.30±1.26	1.48±1.40	0.135
Hearing difficulties	2.56±0.74	1.04±0.78	1.999	0.72±0.90	0.90±1.19	0.171
Sensitivity to noise	2.67±0.79	1.00±0.51	2.512	0.82±0.77	0.82±0.74	0
Numbness	2.56±0.91	1.06±0.67	1.877	0.64±0.52	0.62±0.53	0.038
Change in taste or smell	2.19±1.14	1.41±0.88	0.766	0.68±0.62	0.70±0.64	0.032
Loss of appetite	2.84±0.63	1.45±0.88	1.816	0.64±0.56	0.82±0.77	0.267
Poor concentration	2.39±0.88	1.00±0.51	1.933	1.52±0.50	1.72±0.45	0.42
Forgetfulness	2.71±1.00	2.19±0.74	0.591	1.36±0.48	1.40±0.49	0.082
Making decisions	2.91±0.86	1.91±0.69	1.28	1.36±0.82	1.40±0.83	0.048
Slowed thinking	2.91±0.86	2.17±0.67	0.96	1.38±0.49	1.80±0.72	0.682
Fatigue	2.84±0.81	1.73±0.87	1.321	1.80±0.78	1.84±0.76	0.052
Difficulty falling asleep	2.65±0.87	1.97±0.97	0.738	2.72±0.96	2.72±0.96	0
Feeling anxious	2.71±0.86	1.97±0.53	1.036	1.08±0.27	1.26±0.44	0.493
Feeling depressed	2.23±1.25	1.45±0.72	0.765	0.82±0.74	0.82±0.43	0
Irritability	2.30±0.89	1.23±0.48	1.496	1.02±0.14	1.42±0.53	1.032
Poor frustration	2.36±1.40	1.30±1.15	0.827	1.22±0.99	1.40±0.83	0.197

Abbreviation: ES, effect size.

($P<.001$), somatosensory ($P<.001$), cognitive ($P<.001$), and affective factors ($P<.001$) demonstrated significant main effect for time and group, respectively. In addition, there was a significant interaction of time×group for all factors: vestibular ($P<.001$), somatosensory ($P<.001$), cognitive ($P<.001$), and affective ($P<.001$). Lastly, results for overall symptom change (Q23) before and after analysis showed a main effect for time *(*$P<.001$) and for group ($P<.001$); however, more importantly it showed a significant time×group interaction ($F_{1,94}=159.62$, $P<.001$, $\omega^2=0.622$).

Discussion

The primary purpose of this study was to determine if a series of oculomotor exercises improved participants' saccadic performance. Results revealed significant improvement of Q ratio and targeting of saccades after 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. The saccade metrics, total NSI score, and "Overall Symptoms" question, 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" effect on 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 used 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. The IG results showed a reduction in distance from the target from pre- to posttraining for the IG with a corresponding increase in saccadic targeting for the CG, without any intervention. Curiously, the CG showed increases in poor saccadic targeting behavior by almost 3 mm. The accuracy of a saccade is an additional metric that can determine saccadic normality. Overshooting (hypermetria) and undershooting targets (hypometria) in small amounts (<10% of the amplitude of the saccade) is normal. However, saccadic accuracy declines with age, fatigue, inattention, and injury to the cerebellum.[21,24] Lesions to the cerebellum usually cause hypermetric saccades.[1] This may be explained by the deep integration of saccades in the eye-brain connection. Eye movements, such as saccades, have brain-related anatomic circuits that make distinct contributions to the eye movement and ultimately to action.[9] For instance, burst neuron circuits in the brain stem provide motor signals to the extraocular muscles for the generation of saccades. Results showed a reduction in Q ratio from pre- to posttraining in the IG. As such, the CG, without any intervention, showed increases in Q ratio of 0.17. It is unclear in this study why the CG increased and if a person who has poor saccadic targeting will continue to

Table 3 NSI Overall Symptoms (Q23), total, and 4-factor mean ± SD scores for each group (intervention/control) and by time (pre/post)

Variables	Intervention			Control		
	Pre	Post	ES	Pre	Post	ES
Overall symptoms	2.56±0.65	0.45±0.50	3.639	2.34±0.74	2.30±0.76	0.053
Total score	58.41±12.48	32.65±6.89	2.555	31.90±12.12	34.36±11.47	0.208
Vestibular	7.78±2.52	3.23±1.40	2.232	7.48±2.34	7.92±2.37	0.187
Somatosensory	19.15±3.74	9.93±3.02	2.712	8.78±6.46	8.94±6.23	0.025
Cognitive	10.93±3.02	7.28±1.80	1.468	5.62±2.01	6.32±1.84	0.363
Affective	15.13±4.82	9.69±2.87	1.371	8.66±2.27	9.46±2.37	0.345

Abbreviation: ES, effect size.

decline in saccadic velocities without oculomotor training. Oculomotor training did move 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 NSI.[5] In addition to the total NSI score and "Overall Symptoms" question, 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.[21] Therefore, lesions in brain areas associated with these eye movements will result is neurobehavioral symptoms for factor 1: Vestibular. Although such eye movement metrics are not measured in this study, future research should look to specifically examine eye movement metrics related to 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, and 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 decisions, and slowed thinking. The affective factor consisted of questions relating to fatigue, difficulty falling asleep, feeling anxious, feeling depressed, irritability, and 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, multitasking issues, lack of mental clarity, brain "fog," and emotional lability. Typical risks include reading difficulties, being slower to complete tasks (eg, student may need extra time for examinations), being quicker to anger, and begin more impulsive.[1,21] 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, because the neurologic 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 effect training has on this task. The groups demonstrated differences at baseline on some measures, which is potentially a limitation. However, generally the interaction effect for the NSI and eye variables indicated differences in the degree of change comparing pre and postassessment for control and IGs. The CG performance worsened on the eye variables with little change on the NSI variables. For the eye data, the CG had considerably more variation at the postdata time point, which partially explains their unexpected increase in saccadic targeting even though they received no treatment. The IG data were homogeneous, indicating improvement in saccadic performance because of intervention. In addition, we did not adjust *P* values, which could be viewed as a limitation because this study was exploratory, involving post hoc testing of planned comparisons and we reported exact *P* value for each individual test. Lastly, the control and treatment group assignments were randomized before informed consent so there would be no contamination of the CG (ie, the CG was blind to treatment). This approach can potentially affect random assignment to groups if a participant refuses to consent or if there is dropout after consent. For the current study, neither of these cases occurred.

Future research might consider use of a standardized functional reading test, such as the Pepper Visual Skills for Reading Test[25] assessment, to detect benefits of the eye movement training protocol. Further, it is not clear why the CG was worse on their second test. Future work should examine the outcome of oculomotor training postintervention across time (eg, 3mo, 6mo, etc), and it will be important to examine if persons continue to decline when they have poor saccadic targeting and engage in no oculomotor training.

Conclusions

In conclusion, this study examined the pre- and postscore 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.

Suppliers

a JMP Sample Size and Power Platform; SAS Analytics Software & Solutions.
b I15 vision 15" monitor; Tobii Dynavox.
c 90 Hz remote eye tracker; Tobii Dynavox.
d Y-R0017 wireless keyboard and mouse; Logitech.
e SPSS Statistics; IBM.

Corresponding author

Nicholas P. Murray, PhD, Department of Kinesiology, East Carolina University, Minges Coliseum 72, Greenville, NC 27858.
E-mail address: murrayni@ecu.edu.

References

1. Wong AMF. Eye movement disorders. New York: Oxford University Press; 2008. p. 78.
2. Taghdiri F, Chung J, Irwin S. Decreased number of self-paced saccades in post-concussion syndrome associated with higher symptom burden and reduced white matter integrity. J Neurotrauma 2018;35:719–29.
3. Krupenevich RL, Murray NP, Rider P, Domire Z, DeVita P. The relationships between muscle force steadiness and visual steadiness in young and old adults. Motor Control 2015;19:60–74.
4. Pierrot-Deseilligny C, Milea D, Müri RM. Eye movement control by the cerebral cortex. Curr Opin Neurol 2004;17:17–25.
5. Cicerone KD. Neurobehavioral Symptom Inventory (NSI). J Head Trauma Rehabil 1995;10:1–17.
6. Belanger HG, Kretzmer T, Vanderploeg RD, French LM. Symptom complaints following combat-related traumatic brain injury: relationship to traumatic brain injury severity and post-traumatic stress disorder. J Int Neuropsychol Soc 2010;16:194–9.
7. Donnell AJ, Kim MS, Silva MA, Vanderploeg RD. Incidence of post-concussion symptoms in psychiatric diagnostic groups, mild traumatic brain injury, and comorbid conditions. Clin Neuropsychol 2012;26:1092–101.
8. Meares S, Shores EA, Taylor AJ, et al. Mild traumatic brain injury does not predict acute post-concussion syndrome. J Neurol Neurosurg Psychiatry 2008;79:300–6.
9. Hunfalvay M, Roberts CM, 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:CNC60.
10. Hunfalvay M, Roberts CM, Murray N, et al. Vertical smooth pursuit as a diagnostic marker of traumatic brain injury. Concussion 2020;5:CNC69.
11. Whitney SL, Sparto PJ. Eye movements, dizziness, and mild traumatic brain injury (mTBI): a topical review of emerging evidence and screening measures. J Neurol Phys Ther 2019;43 (Suppl 2):S31–6.
12. Murray NP, Hunfalvay M. A comparison of visual search strategies of elite and non-elite tennis players through cluster analysis. J Sports Sci 2017;35:241–6.
13. Zupan MF, Arata AW, Wile A, Parker R. Visual adaptations to sports vision enhancement training. Occup Ther 2006: 43–8.
14. Kubitz K, Roberts CM, Hunfalvay M, Murray NP. A comparison of cardinal gaze speed between Major League Baseball players, amateur prospects, and nonathletes. J Sports Perform Vision 2020;2:17–28.
15. Kang KY, Yu KH. The effects of eye movement training on gait function in patients with stroke. J Phys Ther Sci 2016;28: 1816–8.
16. 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:e349.
17. 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.
18. 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; 5:161–8.
19. Dretsch M, Bleiberg J, Williams K, et al. 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 2016;31:23–9.
20. Murray N, Kubitz K, Roberts C, Hunfalvay M, Bolte T, Tyagi A. An examination of the oculomotor behavior metrics within a suite of digitized eye tracking tests. Vision Dev Rehabil 2019;5: 269–84.
21. Leigh JR, Zee DS. The neurology of eye movements. New York: Oxford University Press; 2015. p. 16.
22. Armstrong RA. When to use the Bonferroni correction. Ophthalmic Physiol Opt 2014;34:502–8.
23. Perneger TV. What's wrong with Bonferroni's adjustment. BMJ 1998;316:1236–8.
24. Dandona L, Dandona R. Revision of visual impairment definitions in the International Statistical Classification of Diseases. BMC Med 2006;4:7.
25. Stelmack J, Stelmack TR, Fraim M, Warrington J. Clinical use of the Pepper Visual Skills for Reading Test in low vision rehabilitation. Am J Optom Physiol Opt 1987;64:829–31.