Inquiro, the UAB undergraduate science research journal

Volume 2013 | Number 7 Article 25

2013

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research paper

The effect of speed of processing training on microsaccade amplitude

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Abstract

Older adults experience cognitive deficits that lead to an increase in driving errors and result in a loss of mobility. Some of these cognitive deficits can be measured by the Useful Field of View (UFOV) test, and performance on the UFOV can be improved by Speed of Processing (SOP) training. Both involve simultaneous attention to a central and a peripheral stimulus. To date, the mechanisms behind Speed of Processing training remain unknown. We hypothesized that one mechanism underlying SOP training is a change in distribution of eye movements at different amplitudes. Microsaccades are small-amplitude eye movements made when fixating on a stimulus. They are thought to counteract the visual fading that occurs when static stimuli are presented. Due to retinal anatomy, larger microsaccadic eye movements are needed to move a peripheral stimulus between receptive fields and counteract visual fading. Alternatively, larger microsaccades may decrease performance due to neural suppression. Because larger microsaccades could aid or hinder peripheral vision, we examine the distribution of microsaccades during stimulus presentation. Our results indicate that there is no statistically significant change in microsaccade amplitude during a UFOV-like task before versus after training. Speed of Processing training does not result in changes in microsaccade amplitude in our limited size study, suggesting that the mechanism underlying SOP training is unlikely to rely on microsaccades.

Keywords: *microsaccade, peripheral, Speed of Processing, training, Useful Field of View*

Introduction

On average, 15 older adults are killed and 500 are injured in car accidents in the US every day.[1] One contributing factor leading to these accidents is a set of cognitive deficits that lead to an increase in driving errors[2] and declines in performance on other tests of everyday activities.[3] These cognitive declines result in a loss of mobility for the older adults,[4] which can increase their number of depressive symptoms.[5] Performance on these everyday activities is predicted by the Useful Field of View (UFOV) test, and deficits in everyday activities can be reduced by Speed of Processing (SOP) training.[6] Speed of Processing training improves participants' performance on tasks involving peripheral vision. The training involves presentation of increasingly complex central and peripheral stimuli for continually reduced durations of time. Although SOP training has been shown to increase the processing speed of older adults, the mechanisms behind this training are still unknown. Understanding the mechanism of training is a first step toward developing optimized training paradigms. We hypothesized that microsaccades may be a link between SOP training and the observed benefits.

Microsaccades are small, high-velocity eye movements produced 1-2 times per second during fixation. They are the most important of the eye movements responsible for restoring visibility to fading targets during fixation.[7] Fading prevention may result from moving the target to a different receptive field and will also be observed in peripheral vision. Moving a stimulus from one receptive field to another requires larger microsaccadic eye movements in the visual periphery[8] and is associated with better performance on some visual tasks.[7,9] Changes in oculomotor activity are associated with a participant's task set; in other words, participants change their patterns of eye movements depending on the task they perform.[10] Microsaccades represent an easily modified eye movement that has the potential to strongly influence behavior. Microsaccade production is involuntary,[11] and so modifications of microsaccades may be one mechanism through which behaviors may be altered. We hypothesize that training in a task involving peripheral stimuli may increase the proportion of large microsaccades.

Alternatively, SOP training could result in a decrease in the number of larger saccadic eye movements, which have been shown to suppress neural activity.[12-13] Microsaccades are small eye movements which make smaller changes to visual perception, and as such, their effect on visual perception is more controversial. However, a recent study has shown that microsaccades suppress neural activity during stimulus presentation in primates.[14] We also hypothesize that SOP training will reduce the number of larger microsaccades to prevent suppression of neural activity and aid perception of the stimulus. Only larger microsaccades would be suppressed, as they have the most impact on peripheral stimuli.

The purpose of this experiment was to determine whether Speed of Processing training affects the magnitude and/or distribution of microsaccades. Larger microsaccades would

aid performance in peripheral vision due to visual fading or detract from performance due to neural suppression while the stimulus is present. Because microsaccades can also be affected by the anticipation of the stimulus, we focus on a particular time frame around the stimulus that includes 450 ms before and after the stimulus is presented. We define this time frame as *peristimulus*. It was determined that the training had no measureable significant effect on the distribution or amplitude of microsaccades.

Methods

Participants

Twenty-one volunteers ranging from 65 to 90 years old—with normal or correctable-to-normal vision and without dementia, a history of stroke, neurological problems, cataract surgery, or claustrophobia—were recruited for the study and compensated for their participation. The participants were a subset of a parent study and were required to attain a score of 65% on a task similar to the UFOV (Figure 1) performed in an fMRI scanner. Additionally, participants were not considered if they had steel implants or a pacemaker or if their weight and girth exceeded 300 pounds and 60 inches, respectively.

Eyetracking session

A UFOV-like task containing four stages similar to those of the UFOV (a central stimulus, a central and peripheral stimulus, a central and peripheral stimulus with triangle distractors, and a central and peripheral stimulus with car-like distractors; Figure 1) was created with Psychtoolbox.[15-17] The participants were seated, and their heads were stabilized with a chinrest approximately 93 cm from the monitor. The Eyelink 1000 eye tracker was calibrated, and the participants performed the 4 stages of the UFOV-like task.[18] Prior to the stimulus, a fixation cross was presented at the center of the screen. The stimulus in each trial was presented for 450 ms, and all task levels contained a central stimulus to ensure continued fixation in the center of the screen. After the stimulus presentation, white noise was presented for 500 ms. Then, the participants were presented with two options as to which central stimulus was presented and, when applicable, an additional question with eight options referring to where the peripheral stimulus was located. The participants responded using a mouse, which has been shown to be a reliable method.[19] Participants were instructed to remain focused on the center of the screen. The participants performed 25 trials at each task level, forming a block. The entire test consisted of 20 blocks, 5 at each task level, and the eye-tracker was recalibrated after each block. An identical test was given as a pre-test before and a post-test after each type of training. No participants made saccades greater than 2.5 degrees, and the peripheral stimulus had an eccentricity of approximately 6 degrees, so the participants performed as instructed.

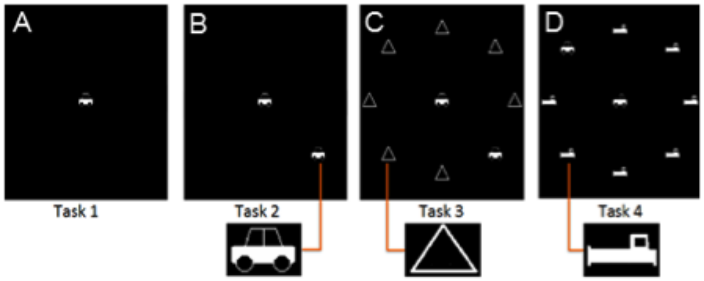

Figure 1. Eyetracking task. The Useful Field of View-like task consists of 4 task levels. (A) Task 1 presents a central stimulus as car or truck for fixation. (B) Task 2 includes a car (6° eccentricity) peripheral stimulus in one of eight spots near the edge of the screen. Task 3 and 4 are identical to task 2 aside from additional (C) triangle distractors in task 2 and (D) car-like distractors in task 4. Participants respond by clicking on a picture of the central stimulus and a box representing the location of the peripheral stimulus.

Training Overview

All participants underwent a screening session and a baseline behavioral session to acquire behavioral measures. Vision, mental status, UFOV performance, and performance on a UFOV-like task were assessed at the screening session. Participants were classified based on their performance on the first three subtests of the UFOV as either low-risk (with a score of 1 to 2) or high-risk (with a score of 3 or higher), as defined based on previous data.[20-21] The baseline behavioral session assessed the participants' performance on a range of neuropsychological tasks. After the baseline behavioral session, the participants underwent a pre-training eyetracking session. Participants were randomized to one of three training groups: a Speed of Processing training group (n=7), a social contact control group (n=6), or a no-contact control group (n=8). Both high-risk and low-risk participants were assigned to each group, and each trained for approximately 5 weeks. Following training, participants returned for a post-training behavioral session and a post-training eyetracking session.

Speed of Processing training involved five two-hour sessions. The training was customized for the participants based on their performance. Participants completed tasks that tested their ability to utilize processing speed, divided attention, and selective attention. The training was designed to improve the amount of visual information that an individual could process over brief periods of time. The specific protocol has been described in detail previously.[6,22]

Participants in the social contact control group attended five two-hour sessions over approximately five weeks during which they performed cognitively stimulating activities, e.g. crossword puzzles and brain teasers.

Measurement of Microsaccades

Raw gaze position data from the eye tracker output were

analyzed using MATLAB analyses described previously[23] to determine microsaccade amplitude and velocity during the 450 ms when the stimuli were displayed (post-stimulus) and 450 ms prior to stimulus presentation (pre-stimulus). Only trials from tasks 2 – 4 were analyzed because task 1 did not involve a peripheral stimulus and should not affect microsaccade amplitude. The distribution of microsaccades was normalized by the number of trials each participant performed. Paired t-tests were used to detect differences in the distribution with $\alpha = 0.05$. The microsaccade distributions of pre- and post-tests of each training group as well as the microsaccade distribution of pre-tests for high-risk and low-risk individuals were compared.

Results

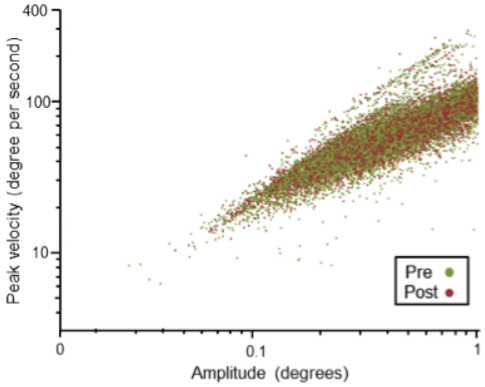

Figure 2. Main sequence plot. Comparing amplitude and velocity of eye movements demonstrates main sequence-specific to saccadic eye movements.

Microsaccades were defined based on raw eye position data captured by the eyetracker. Therefore, an analysis was performed to ensure that the eye movements extracted truly represented saccades or microsaccades. Previous literature has shown that the magnitude and peak velocity of microsaccades and saccades are logarithmically related according to a main sequence.[10] This relationship (which appears linear on a log-log plot) was observed in our data, confirming that the algorithm did reasonably well isolating microsaccades and saccades from our dataset (Figure 2). In order to determine whether the distribution of microsaccades changed following training, microsaccades were grouped into bins according to their amplitude. The number of microsaccades per trial, averaged across all participants, is displayed on the x-axis of Figure 3. Error bars displayed on the graph show within-participant standard errors of the mean,[24-25] which are appropriate for assessing differences between pre- and post-tests. For each bin for each group, t-tests were performed. This version of testing may result in false positives because multiple significance tests are being performed on the same dataset. The method is unlikely to result in false negatives; that is, the test is relatively unlikely to miss an effect that is present in these data. Comparing pre- and post-tests for each training group showed only one difference that met a threshold of $p < 0.05$ (as discussed, a relatively weak statistical threshold). This difference occurs for microsaccades between the amplitudes of 0.75 and 0.85 in the post-stimulus time frame (Figure 3B), where, consistent with the suppression hypothesis, pre-training shows slightly more microsaccades per trial than post-training (denoted by * in Figure 3). However, the *p*-value at this point was 0.0498, and does not meet a significant threshold after correction for multiple comparisons. For this reason, our data fail to reject the null hypothesis that the distribution of microsaccade amplitude do not change after training. Our data also fail to reject the microsaccade suppression hypothesis, as fewer large microsaccades were observed after training. Additionally, our data reject the hypothesis that training increases the proportion of large microsaccades.

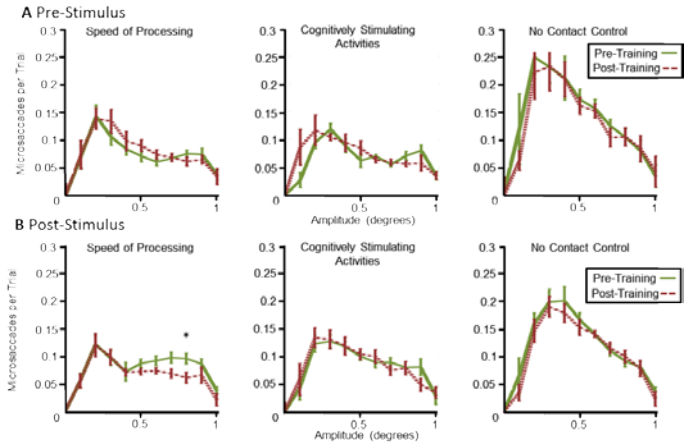

Figure 3. Comparison of training groups. Microsaccades were collected and sorted into bins for pre- and post-tests for each group. Error bars showing within-participant standard error of the mean are shown, and paired t-tests were used to analyze the distribution at each bin. (A) Pre-stimulus data show no significant difference between pre- and post-tests. (B) No significant difference in microsaccade amplitude was found except at 0.8 amplitude in the Speed of Processing group for post-stimulus data. This difference was only significant at $\alpha = 0.05$ prior to multiple comparisons correction, but it was consistent with the microsaccade suppression hypothesis.

To further detect any relationship between SOP and microsaccade amplitude, participants were separated into high-risk and low-risk groups based on their initial performance on the Useful Field of View test. Based on the visual fading hypothesis, we hypothesized that low-risk individuals would produce a greater number of microsaccades and larger microsaccades than the high-risk group because the high-risk group performed poorly. Based on the microsaccade suppression hypothesis, we expected low-risk individuals would produce a lesser number of microsaccades and larger microsaccades to reduce neural suppression and increase performance. The two groups displayed no statistically

significant difference for the post-stimulus timeframe, failing to disprove the null hypothesis (Figure 4B).

As described in the introduction, previous studies have shown that attention influences the rate of microsaccades.[8] In a further set of analyses, we addressed the question of whether training influences microsaccades during preparation for a visual stimulus. The same set of analyses were performed for data obtained in the 450-ms window prior to stimuli presentation (Figure 3A and Figure 4A). There were no significant changes in microsaccade amplitude distribution due to training and no significant differences in microsaccade amplitude between the high-risk and low-risk participants.

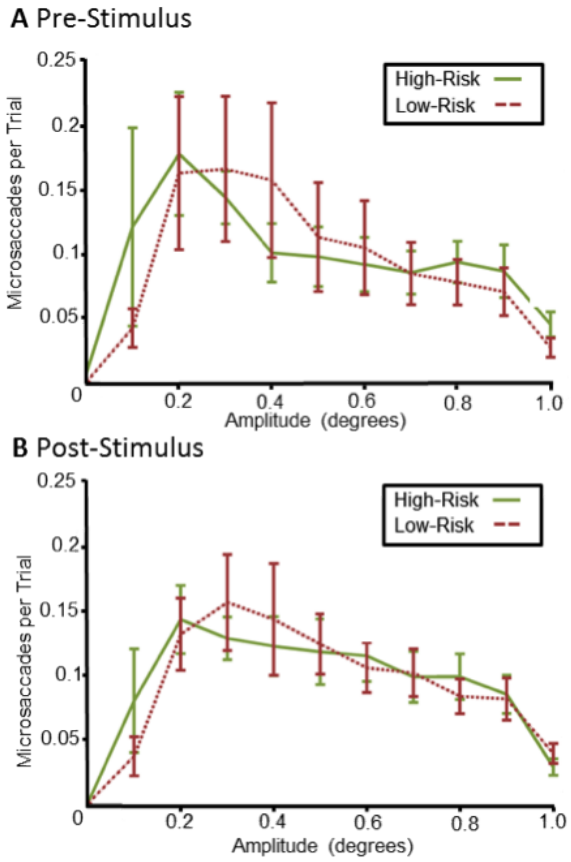

Figure 4. Microsaccades in high and low-risk groups. Participants were designated as high-risk or low-risk based on initial UFOV scores. Pre-test microsaccade distributions were compared for these groups, and no difference was observed in microsaccade distribution for both pre-stimulus data (A) and post-stimulus data (B). Error bars show standard error of the mean.

Discussion

We found that Speed of Processing training does not have a statistically significant effect on microsaccade magnitude as measured by distributions of amplitudes of microsaccades. The SOP training group was compared to a control group and a social contact group, both of which showed similar results. Prior to multiple comparisons correction, the only statistically significant difference observed was consistent with the microsaccade suppression hypothesis. However, our data fail to reject the null hypothesis that training does not influence microsaccade amplitude. Additionally, the same analysis was performed on data that included saccades over the one-degree-microsaccade cutoff point to avoid potential ceiling effects, and little difference was observed between pre- and post-tests.

One limitation of this study is that it was performed on a relatively small dataset (n = 7, n = 6, and n = 8 respectively) and thus has relatively weak statistical power. Additionally, receptive fields may be too small to affect the distribution of microsaccade amplitudes. It has been shown that the minimum angle of resolution for a six-degree peripheral stimulus is around 0.04 degrees.[26] This is significantly smaller than microsaccades measured using current techniques. Furthermore, the participants displayed a high percentage of correct responses on the UFOV-like task, which suggests that the task may have been too easy, reducing the effect of training. Finally, any effects found could be due to the speed of saccades rather than size, since they are tightly correlated.

Future research should target other possible mechanisms of Speed of Processing training. The time frame that the stimulus was presented (450 ms) may have been too short for visual fading to occur and the time interval may have been too long for saccadic neural suppression to impact perception. Microsaccade suppression may occur during stimulus presentation, but, due to the small sample size, may not be detectable. Additionally, the pre-stimulus time period did not show any statistically significant differences between pre- and post-test curves. This leads us to believe Speed of Processing training does not influence preparation for a stimulus through microsaccade amplitudes. Determining the mechanism behind Speed of Processing training is still important because if the mechanism can be discovered, we can develop more effective future therapies, potentially improving quality of life for many older adults.

Acknowledgements

We would like to acknowledge support from the Dana Foundation, UAB Center for Clinical And Translational Science UL1 TR000165, Vision Science Research Center P30 EY003039, Civitan International Research Center, McKnight Brain Research Foundation, UAB Edward R. Roybal Center for Research on Applied Gerontology, and the UAB Comprehensive Center for Healthy Aging.

The study was approved by the University of Alabama at Birmingham Internal Review Board. Written informed consent was obtained after a complete explanation of the study.

Author Contributions

Conceived and designed the experiments: WKB KMV LAR. Performed the experiments: SJL WGM CRD WKB. Analyzed the data: SJL WGM. Contributed reagents/materials/analysis tools: KMV LAR. Wrote the paper: SJL. Critical revision for important intellectual content: KMV LAR.

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