The Effect of Training on Horizontal Saccades and Smooth Pursuit Eye Movements

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ABSTRACT

Previous studies have shown that eye movement function decreases with age, with pursuit showing more effect than saccades. The aim of this study was to assess whether these age-related changes were reversible with eye movement training.

This study with 28 young adults, 34 older adults and 36 control participants measured the effects of two weeks of training of both saccadic and pursuit eye movements. It was found that training resulted in a significant improvement in smooth pursuit function in both training groups, with the older group showing a greater improvement. No improvement occurred in saccadic function.

These results suggest that the age-related decline in eye movement function may be due to irreversible degenerative changes in the central nervous system. The differential improvement supports the hypothesis that in normal viewing the ocular motor system is maximally stimulated for saccades but not smooth pursuit movement. Eye movement training, by providing extra stimulation, resulted in improved smooth pursuit in both groups to the extent that the age-related decrease in function was reduced but still remained.

Keywords: Saccades, pursuit eye movements, aging, training.

INTRODUCTION

There have been several studies of the effects of training on eye movement responses. Some are in the context of improving function in the presence of ocular motor disorders, either to increase the rate of recovery of ocular motor problems after stroke, or to improve the general ocular functioning in children with cerebral palsy. Others are in the presence of normal ocular function.

One study attempting to demonstrate the effects of training on the recovery of ocular motor palsies reported that the recovery time was shortened, and that there was no transfer between pursuit and saccade training.[1] Abel et al[2] described one case study of a patient with a III nerve palsy where saccadic gain increased, though velocity did not, after occlusion of the good eye, with the changes being direction specific and reversible. Gur and Ron[3] stated that patients who had received training after brain injury showed a significant improvement in pursuit gain at a higher rate than untrained patients, but no details of statistical analysis were provided. These authors then hypothesised that similar results may be obtained in people with a 'small-range tracking capacity', moving from increasing the rate of recovery in those with brain injury to being able to increase the ability in those with a lower normal range of function without any pathological cause.

Duckman[4] described improvement after a visual training program in children with cerebral palsy. A study by Gauthier and Hofferer[5] also reported post-training improvement in pursuit in both children with cerebral palsy and children who were healthy, but those with cerebral palsy did not achieve the same level. There was no change in saccadic velocity, but an improvement in the slow latencies of the children with cerebral palsy, and a decrease in saccadic error for both groups. Another study trained saccadic function in a group of children with dyslexia, reporting that results were dependent on the condition trained with no transfer between tasks. However, the authors were unsure of any actual effect on reading skill as this was not assessed.[6]

Other studies have used visual training in an attempt to determine whether improvement in eye movement function would result in improved performance in other motor areas, in particular in sports achievement. McLeod and Hansen[7] reported improvement in static balance after visual skills training with a videotape program consisting of scanning and saccades. In contrast, Williams and Helfrich[8] suggested that eye movement training may improve eye movements, but that this will not consequently improve sporting performance. Shapiro and Raymond[9] aimed to determine whether specific ocular motor patterns could be trained and whether these influence skill acquisition, raising the concept of task specific strategies and whether training particular task components would have any effect on a complex perceptual motor skill. Other studies suggest that it may be the search strategies, rather than the eye movements themselves that are inefficient in less experienced sportspersons[10] or in the elderly.[11]

Another study tested the hypothesis that if visual training does improve performance, then pilots, because of their extensive visual training, would show improved eye movement performance.[12] As no significant differences in saccadic latency, duration or peak velocity were found, it was concluded that the oculomotor system is maximally stimulated and therefore performance is optimised naturally for all individuals. This result is supported by Hitzeman and Beckeman[13] in a review of the literature on sports vision, who concluded that most researchers suggest that elite athletes have visual skills that are superior to those of non-athletes, but that these were specific to the sport being investigated with little evidence to support the hypothesis that visual training will improve the visual skills.

Only a few studies have trained eye movements in normal subjects and studied the effects. Whittaker and Eaholtz[14] demonstrated post-pursuit eye movements in two subjects, who were trained to continue pursuit movements for more than one cycle after the target had disappeared. Fischer and Ramsperger,[15] in training saccades, concluded that practice can change the preparation time of saccades, maybe by learning to disengage attention from the fixation target. Elmurr and colleagues reported reduced saccadic reaction times in elite athletes[16] and in a further study reported a significant training effect in non-athletes after a five-week training program, with the greatest effect occurring in the first two weeks.[17] Other studies have also reported that eye movement training is specific and non-transferable in saccades[18] and pursuits.[19]

In this context it is important to consider the effects of repeated testing on these functions. Two studies reported no change in saccadic variables after repeat testing.[20, 21] In contrast, Schalen[22] found a significant difference in maximum velocity smooth pursuit gain and the amplitude of smooth pursuit.

In summary, some studies on the effect of eye movement training are in the context of improving function in the presence of an ocular motor disorder, either aimed at improving the rate of recovery of systems known to usually improve spontaneously: or at improving function in chronic conditions.[1-6] Other studies trained ocular motor function in the presence of normal eye movements, usually in an attempt to gain superior function. In one study, there was an improvement in parameters that were decreased, but no change in those functions approaching full adult function.[5] It appears that any improvement is training specific, with no transfer between ocular functions.[1, 6, 15, 18, 19] This raises the question that training in the presence of normal function may have a 'ceiling effect' where the performance is increased only to the level of optimal normal function, possibly reflecting an increase in awareness rather than an actual change in neurological processes. This level needs to be established prior to evaluating the effects of eye exercise programs on patients with eye movement disorders.

It is well accepted that there are changes in eye movement function with aging and it appears that the decrease in function may be related to increased target amplitude in saccades and increased target velocity in smooth pursuit movements.[20, 23-26] Therefore aging changes may only become apparent in the stressed situation, when the task requires optimal neurological functioning, but tasks within the range performed in normal daily viewing may show no decrement.[27] This study of the effect of training aimed to establish whether any change in the responses could be gained by eye movement practice in both a young and an older adult group. The saccadic amplitude and smooth pursuit velocity chosen for training were values greater than those performed in everyday viewing in order to ensure that the training performed was beyond the range of normal eye movement functioning. The aim was to demonstrate whether there is a 'ceiling effect' on performance, whether the eye movement changes associated with aging are reversible and whether there was a differential training effect for age.

METHOD

Participants

From an initial group of 181 participants in a study of the effects of aging,[27] a number were recruited to participate in this second study. There were three groups, two were assigned to practise eye movement exercises and another acted as a control group. One group of 28 participants (7 males and 21 females, 17 to 31 years, mean age 19.2, SD 3.12) was from the young adult group, another 34 participants (9 males and 25 females, 60 to 78 years, mean age 68.1, SD 4.17) were from the older adult group. There were 36 participants in a control group, selected from across the full age range (15 males and 21 females, 26 to 77 years, mean age 47.2, SD 14.39). Selection of those requested to participate in the training and control groups was by systematic sampling prior to the measurements of their initial ocular motor function.

The study was approved by the Faculty Human Ethics Committee, La Trobe University.

Instrumentation

Eye movements, saccades and smooth pursuit, were recorded using the Ober2 infrared reflection binocular measurement system, as reported in the previous study.[27]

Procedure

After gaining informed consent, the initial eye movement recording was completed. Measurements were made of saccadic latency, duration, mean and standard deviation of amplitude, and peak velocity of 10, 20 and 30 degree saccades: pursuit gain, pursuit time (percentage of recorded cycle that was defined as smooth pursuit), frequency and amplitude of catch-up saccades of 6.5, 12.0, 19.4, 25.9 and 38.6 degrees/second pursuit targets.

After completing the recording, the eye movement exercises were demonstrated to each of the participants recruited into the training groups. After this training session they were each given an exercise card, an exercise recording sheet and a return appointment. The exercise card was designed to practise saccades of 30 degrees amplitude and pursuit movements of 30 degrees/second velocity.

Two targets, **R** and **L**, were printed on a manila card, with a length of string attached as a distance marker. The participants were to be seated in a comfortable position with the card in front of them. They were instructed to practise saccades, looking alternately from the target **L** to the target **R** at the rate of one target per second for 20 movements (10 cycles) without any head movement. This was followed by a set of pursuit movements, practised by holding a pen in one hand against the exercise sheet and moving it smoothly from left to right and return at the rate of one movement per second, following the pen with the eyes as closely as possible for 20 movements (10 cycles). These two exercises took a total of 40 seconds of practice, followed by a 20 second period of rest. This set was repeated twice more, involving a total of 3 minutes. This training session was repeated 3 times daily for 2 weeks, allowing for the maximal training effect as proposed by McHugh and Bahill[19] in the time period suggested by Fischer and Ramsperger.[15] The time of each session was noted on the recording sheet.

On retesting approximately two weeks later, the completed exercise schedules were returned and they were asked to demonstrate the exercises as they had been practising them. The eye movement recordings were then repeated. Those who were assigned to the control group received no further instructions and were given an appointment to return for a repeat test in two weeks time.

Analysis

As the aim of this study was to investigate whether there was a different training response between the three groups, the saccade and smooth pursuit dependent variables were converted to change scores to allow a two-way ANOVA. The measurement of the first test was subtracted from that of the second test to obtain the change score.

In the study of saccadic function the two independent variables being investigated were group (three levels, young training, older training and control) and target amplitude (three levels of target amplitude, 10, 20 and 30 degrees). In the study of pursuit function the two independent variables being investigated were group (three levels, young training, older training and control) and target velocity (five levels of target velocity, 6.5, 13.0, 19.4, 25.9 and 38.6 degrees/second). For the analysis of saccades each of the dependent variable change scores was analysed using a two-way Group by Target Amplitude ANOVA and for smooth pursuit each of the dependent variables was analysed using a two-way Group by Target Velocity ANOVA. Rejection of statistical null hypotheses was set at £ 0.05.

The criteria was set as previously that only data from participants where there were at least six acceptable recordings within each set of ten samples was analysed.[27] For saccadic function the final number of participants from which the data for all variables was analysed was 18 in the young training group, 31 in the older training group and 31 in the control group. For smooth pursuit function this was from 27, 21 and 27 participants respectively.

RESULTS

The time between the first and the second test ranged from 13 to 26 days with a mean time of 14.4 (SD 2.33) days in the young group, 12 to 28 days with a mean time of 14.9 (SD 2.82) days in the older group and 12 to 35 days with a mean time of 16.8 (SD 4.8) days in the control group. The number of eye movement exercise sessions in each of the training groups were as follows; between 24 and 40 with a mean of 34.5 (SD 4.90) in the young group and between 31 and 48 with a mean of 39.3 (SD 3.87) in the older group.

Saccades

Latency

It can be seen in Figure 1, the latency scores pre- and post-training, that the mean latency was different for each of the groups at all target amplitudes, confirming the aging effect of saccadic latency reported previously,27 with the older group having the longest latency. Analysis of the change scores found no training effects for saccadic latency [F (2, 77) = 0.03, p = 0.9689], with no significant difference in the change in mean latency between the three groups. There was no consistent target amplitude effect on the change scores [F (2, 154) = 1.03, p = 0.3588]. Though the three groups each showed different directions of latency changes, there were no significant interaction effects [F (4,154) = 2.34, p = 0.0573].

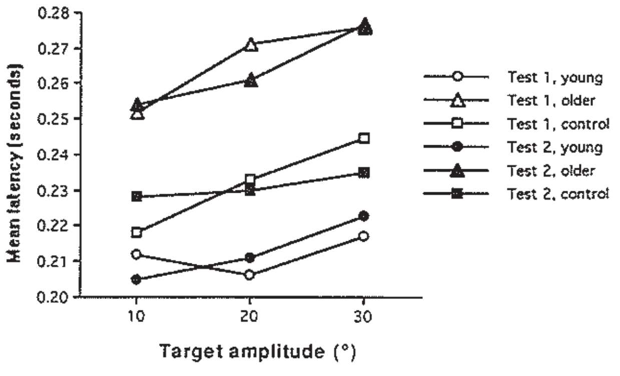

Figure 1 Mean latency scores on Test 1 and Test 2 for the three groups at each target amplitude

Duration

It was previously reported that there was a small but significant increase in duration with age.[27] Figure 2 presents the mean saccadic duration of each group pre- and post-training. Analysis of the change scores found no overall training effect [F (2,77) = 1.83, p = 0.1673], nor any consistent target amplitude effect [F (2, 154) = 2.83, p = 0.0622]. However, a significant interaction effect was found in the mean duration change scores [F (4,154) = 3.16, p = 0.0157]. The older training group remained essentially stable from the first to the second test at all target amplitudes, with mean duration of 64 and 87 milliseconds (msecs) for 20 and 30 degree saccades respectively, changing by only 0.13 and 0.32 msecs. However, both the young training group and the control group showed an increase in duration in the order of 2 to 4 milliseconds for 20 and 30 degree saccades.

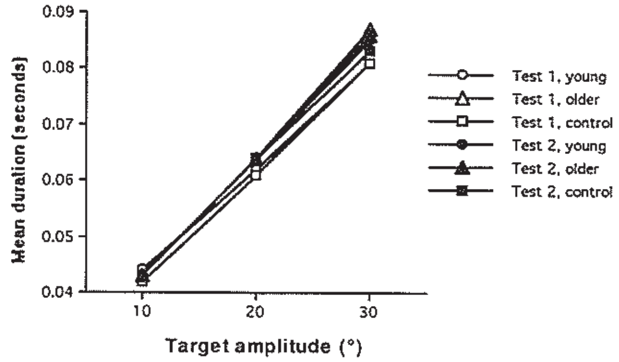

Figure 2 Mean duration scores on Test 1 and Test 2 for the three groups at each target amplitude

Amplitude

Figures 3 and 4 present the mean and the standard deviation of saccadic amplitude pre- and post-training respectively. The decrease in saccadic accuracy with age is seen in Figure 4, as individual variance increases with age, as previously reported.[2]7 There were no significant differences in the mean saccadic amplitude change scores [F (2, 77) = 0.25, p = 0.7761] or in the individual standard deviation change scores [F (2, 77) = 0.49, p = 0.6171] between the three groups, indicating no training effects for mean saccadic amplitude or saccadic accuracy as measured by individual variance. A significant target amplitude effect was found [F (2, 154) = 5.76, p = 0.0039], but as saccadic amplitude was the measured variable, the difference between the two test results was expected to be larger as amplitude increased and was therefore of no interest. Though the three groups demonstrated some differences in saccadic amplitude change at different target amplitudes, there were no interaction effects for either mean saccadic amplitude [F (4, 154) = 1.15, p = 0.3353] or standard deviation of saccadic amplitude [F (4,154) = 0.19, p = 0.9438] further confirming the lack of training effect on saccadic accuracy.

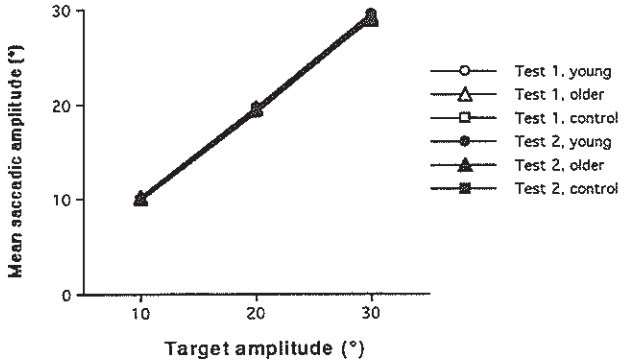

Figure 3 Mean saccadic amplitude scores on Test 1 and Test 2 for the three groups at each target amplitude

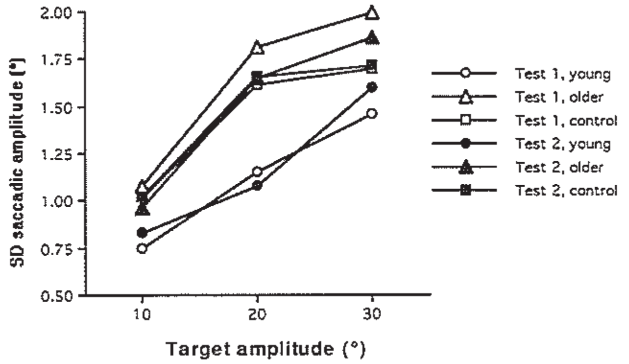

Figure 4 Mean standard deviation of saccadic amplitude scores on Test 1 and Test 2 for the three groups at each target amplitude

Peak velocity

It can be seen in Figure 5, the peak velocity scores pre- and post-training, that there was a decrease in mean peak velocity from the first to the second test for both the young and the control groups, particularly for 20 and 30 degree saccades, but very little change in peak velocity for the older subjects. Analysis of the change scores found a significant training effect for mean peak velocity [F (2, 77) = 3.49, p = 0.0356]. The mean peak velocity change scores for both the young and the control groups increased with increasing target amplitude, but this was not found to be a significant target amplitude effect [F (2, 154 = 2.20, p = 0.1141]. There was no significant interaction effect [F (4, 154) = 0.84, p = 0.5009]. The mean peak velocity decreased post-training for the young group, from 554 to 528 degrees/second for 20 degree saccades and from 747 to 678 degrees/second for 30 degree saccades; in the control group the values decreased from 536 to 505 and from 686 to 645 in 20 and 30 degree saccades respectively. Whereas the older group increased from 490 to 513 degrees/second in 20 degree saccades and remained stable at 638 for 30 degree saccades.

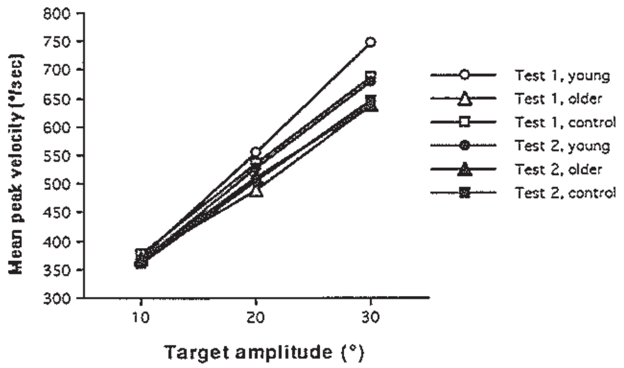

Figure 5 Mean peak velocity scores on Test 1 and Test 2 for the three groups at each target amplitude

Smooth pursuit

Pursuit gain

It can be seen in Figure 6 that the gain values were less in the older group than the young group as reported in the previous study.27 Regardless of the initial level of pursuit gain, a significant training effect was demonstrated by an increased mean pursuit gain post-training at all target velocities for both the young and the older training groups, and a decreased mean gain for the control group [F (2, 72) = 6.24, p = 0.0032]. The gain increase was larger in the older than the young training group at all but the two slowest velocities. The greatest difference in pursuit gain increase was seen at 19.4 degrees/second target velocity, with the young group increasing from 0.86 to 0.88 and the older group from 0.71 to 0.79. At 25.9 degrees/second velocity the young group increased from 0.80 to 0.82 and the older group from 0.61 to 0.66, and at 38.6 degrees/second the young group increased pursuit gain by 0.036 while the older group increased by 0.074. Pursuit gain decreased minimally at all target velocities in the control group, with the amount varying from 0.001 to 0.048 at different velocities. There were no significant target velocity [F (4, 288) = 0.56, p = 0.6886] or interaction [F (8, 288) = 1.66, p = 0.107] effects for pursuit gain change scores

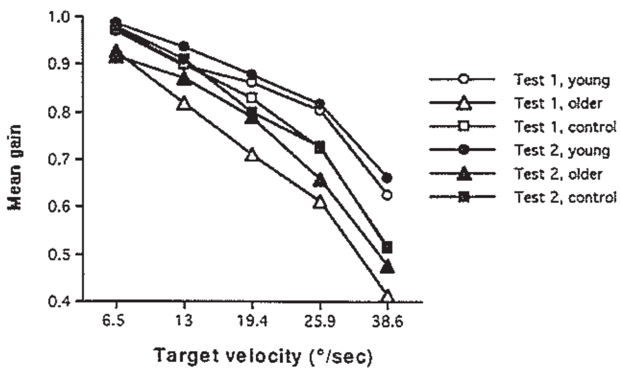

Figure 6 Mean gain scores on Test 1 and Test 2 for the three groups at each target velocity

Pursuit time

Similar to the findings of pursuit gain, an aging effect can be seen for mean pursuit time, with the young group demonstrating a higher percentage of time than the control and the older groups, as previously reported.[27] It can be seen in Figure 7 that mean pursuit time was increased post-training in both the older and the young group with the control group changing only minimally, demonstrating a significant training effect [F (2,72) = 10.99, p = 0.0001]. For both training groups the pursuit time change scores showed a greater increase post-training as the target velocity increased, with a significant target velocity effect [F (4, 288) = 12.20, p = 0.0001]. The older group improved more than the young group, but the control group varied from a minimal increase to decrease as target velocity changed, demonstrating a significant interaction effect [F (8, 288) = 4.36, p = 0.0001]. For example the mean percentage increased from 95.9% to 96.6% in the younger group and from 93.2% to 95.2% in the older group at the target velocity of 19.4 degrees/second, and from 85.6% to 87.5% in the younger group and from 80.8% to 84.9% in the older group at 38.6 degrees/second.

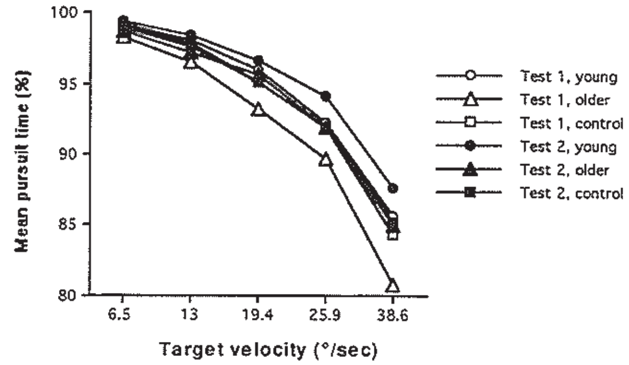

Figure 7 Mean pursuit time scores on Test 1 and Test 2 for the three groups at each target velocity

Saccadic frequency

Concurrently with the increase in pursuit gain, a significant training effect was demonstrated as a decrease in the frequency of catch-up saccades post-training during pursuit movements at all target velocities [F (2, 72) = 3.63, p = 0.0315] as demonstrated in Figure 8, the saccadic frequency scores pre- and post-training. The older group demonstrated a greater improvement than the young group. The high saccadic frequency found in the older adult group pre-training, particularly at the slow target velocity of 6.5 degrees/second, was reduced, which may reflect a decrease in distractibility. There was a small decrease in the saccadic frequency recorded at the second test by the control group at the two slowest target velocities, but at all other velocities the frequency was minimally increased. As previously reported, there was a difference in saccadic frequency between the young and older groups at all velocities, though minimal at the fastest target velocity of 38.6 degrees/second.[27] There were no significant target velocity [F (4, 288) = 2.11, p = 0.0799] or interaction [F (8, 288) = 0.73, p = 0.663] effects.

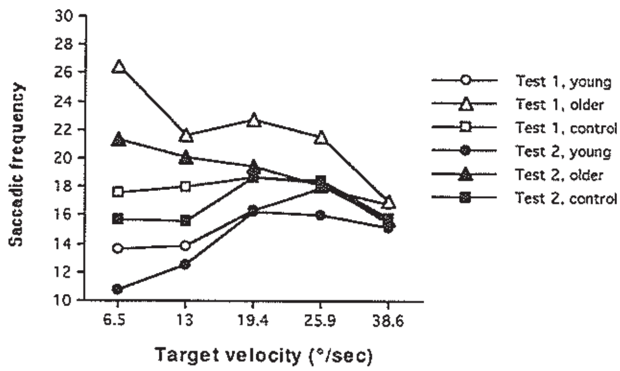

Figure 8 Mean saccadic frequency scores on Test 1 and Test 2 for the three groups at each target velocity

Saccadic amplitude

A significant training effect was demonstrated at all target velocities with a decrease in the mean saccadic amplitude of catch-up saccades, slightly greater in the older than the young training group, with no real change in the control group [F (2, 72) = 3.24, p = 0.045] as can be seen in Figure 9. The significant increase in saccadic amplitude change scores with target velocity is due to the effect of the increasing size of catch-up saccades as target velocity increased [F (4, 288) = 4.31, p = 0.0021]. As previously reported, the older training group demonstrated significantly larger catch-up saccades than the young group.[27] There was no significant interaction effect [F (8, 288) = 1.66, p = 0.107].

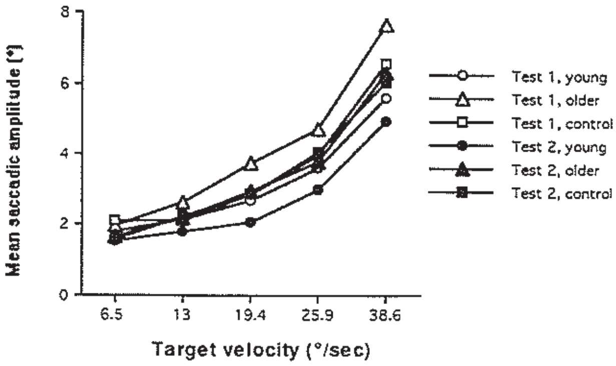

Figure 9 Mean saccadic amplitude scores on Test 1 and Test 2 for the three groups at each target velocity

DISCUSSION

The results of this present study have found some interesting effects on saccadic function after eye movement training. There were no differences between the three groups in the change scores of saccadic latency and accuracy post-training. In contrast, saccadic duration increased and peak velocity decreased in both the young group after training and the control group on the second test, whereas in the older group after training both of these variables remained essentially stable.

Previous studies have reported minimal training effects on saccades in the presence of normal ocular motor function. The finding of no change in peak saccadic velocity after eye movement training, as demonstrated by the older training group, agrees with that of other studies.[5,12] One study with only three subjects reported a decrease in peak velocity similar to the young and control groups over two test sessions.[28] Two studies reported no significant differences on test-retest of peak saccadic velocity,[20, 21] a finding not supported by the present study. Gauthier and Hofferer5 reported an increase in saccadic accuracy in a group of normal children.

In comparison, training effects have been demonstrated in both children with ocular motor disorders due to chronic neurological conditions and in adults with acute neurological conditions with an expectation of recovery. Two studies reported post-training improvement in saccadic function in children with cerebral palsy.[4,5] One reported increased latency and accuracy, but no change in peak velocity,[5] the other graded improvement on observation only, so no detail was available.[4] In adults with ocular motor palsy, improvements in saccadic gain have been reported post-training,[1,2] but with no change in peak velocity.[2]

The present study has shown training effects on all variables of smooth pursuit function, demonstrated by increased mean pursuit gain and increased percentage of pursuit time, with decreased saccadic frequency and amplitude. The older group improved by a greater amount than the young group, with the control group showing a minimal decrease in function for most of the measured variables.

Previous studies which have trained pursuit function in the absence of any ocular motor disorder have reported improvements in adults[14-19] and children.[5] Larsby et al[24] described reduced pursuit gain in a group of young children, in comparison to the expected adult level, and suggested that inattention and lack of motivation may be the cause of this reduction. This may be confirmed by adult studies demonstrating improved pursuit with alerting to the task[29] or when a detailed target was used.[30]

As in saccadic function, smooth pursuit has been shown to improve in the presence of ocular motor disorders. Two studies reported improvement in pursuit function in children with cerebral palsy,[4,5] though it was noted that these children still did not improve to the level found in a healthy group.[5] Two studies reported increased pursuit gain and decreased recovery time in patients with pursuit disorders following neurological damage.[1,3]

Various studies have suggested that ocular motor training is specific to the task required, some in the context of elite athletes having superior visual skills, but only within the requirements of the particular task,[13] others questioning whether training a particular task component has any effect on the complex perceptual motor task,[8,9] others more specifically stating that learning is individual to each training task.[1,6,15,18,19] This would suggest that there is no transfer between functions served by separate neural pathways.

It has been suggested that the training improvements in the presence of ocular motor disorders may be due to changes in central nervous system programming and processing, rather than brainstem areas, as saccadic velocity remains unchanged.[2-5] In children with cerebral palsy it might be suggested that as well as having neurological pathology, they may not gain the usual level of maximal visual stimulation due to the constraints placed on them by their general motor disorder and so ocular motor training may in some way provide this. For those changes effected in children with no known neurological or ocular motor disorder it was apparent that they had not yet achieved full ocular motor function and that possibly training either provided increased stimulation to assist normal development or more likely raised the level of attention.

The decreased saccadic function associated with aging demonstrated by increased latency, increased duration and decreased accuracy, are all thought to be due to degeneration of central nervous system areas such as the cerebral cortex and cerebellum. It appears that these changes are not readily amenable to training in older adults in the way they may be in children, where the process may be to achieve optimal functioning of a not yet completely functioning system, whereas in older adults there are irreversible changes causing the decrement in function.

In the present study the decreased smooth pursuit function associated with aging was demonstrated by decreased pursuit gain and decreased pursuit time, compensated by increased saccadic frequency and amplitude. Each of these changes was improved by training, both by the young and the older adults, with a minimal decrease in function demonstrated by the control group. The older training group showed greater improvement in each of these functions than the young training group, but a 'ceiling effect' was evident in that even though the training effect was greater, the pursuit function of the older group was not improved to the level of the young adults.

The role of visual awareness must be considered in any study of eye movement function. Studies have shown improvement in eye movement performance in relation to attention.[7, 14, 19, 29, 30] The eye movement responses at the second testing in the control group showed a decrease in function in several of the variables of saccade and smooth pursuit function. The decreased function demonstrated by the control group may be considered to be related to reduced motivation or visual attention on repeated testing. It is interesting that this result of decreased function was also shown by the young training group for saccadic eye movements. This presents the contrast where the pursuit system improved post-training in the group of young adults, but the saccadic system showed a decrease in some variables of measurement.

The differential improvement between saccade and pursuit function may be due to the fact that smooth pursuit eye movements, where the head and body are stable and only eye movement occurs, are not practised in normal everyday viewing. This would link with the hypothesis suggested by Enderle12 that eye movement performance is optimised naturally for all people by practise in normal viewing conditions. So where saccades are maximally stimulated at all times in normal viewing conditions, pursuit training may have resulted in an improvement in function as a result of stimulation that was above the level of that provided during normal viewing. This would be supported by the improvement in pursuit function demonstrated by both training groups in the absence of an improvement in saccade function and in fact, in the presence of a decrease in saccadic function in the young group. Also the greater training effect shown by the older group may be interpreted as an age-related decline in function of an under-stimulated system which could be improved by stimulation, but that this occurs concurrently with an actual decrement of the central nervous system.

CONCLUSION

In the present study saccadic function showed no improvement post-training in either the young or the older adults, whereas smooth pursuit function demonstrated improvement in both groups. This finding suggests that the age-related decline in ocular motor function due to cerebral cortex and cerebellar degeneration, increased neural conduction time and extraocular muscle changes is not reversible by exercise, but that some improvement in pursuit movement can be gained by maximally stimulating the pursuit system and by increasing the subject's awareness of eye movement functioning. It is important to consider this finding of relative improvement in smooth pursuit function, as any measured improvement with eye movement training must be considered against this baseline level.

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