The effect of aging on horizontal saccades and smooth pursuit eye movements

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ABSTRACT

A review of the literature indicated that the decrease in ocular motor function with aging may only become apparent as saccadic amplitude and pursuit velocity increase. Tasks within the normal range of movement may show no decrement.

This study with 181 adult participants, from 17 to 78 years of age, measured the effects of aging by testing saccades and smooth pursuit movements, both those that were within the normal range of function and those that were greater. It was found that certain aspects of both saccadic and smooth pursuit eye movement function significantly declined with age - saccadic latency, duration and accuracy; pursuit gain, pursuit trace time and both frequency and amplitude of catch-up saccades. However, smooth pursuit movement showed a more marked decline with aging than saccades.

These results suggest that the age-related decline in eye movement function is due to degenerative changes in the central nervous system and raise the question as to whether these changes affect visual tasks or everyday activities.

INTRODUCTION

Eye movement characteristics are used as part of the diagnosis for a wide variety of neurological conditions, as disorders of either the central or the peripheral nervous system can result in eye movement problems. For example, studies have shown that saccades or pursuits may be affected in adults who have suffered a stroke or neurological trauma[1-3] or in individuals with schizophrenia.[4,5] It is very important that the diagnosis of eye movement abnormality is assessed in the context of age-related normals in order to discriminate between changes occurring as a result of pathology and those related to the normal aging process. Several authors have stated the necessity to establish the normal range of responses from a large range of healthy subjects prior to the diagnosis of eye movement pathology[6-10] with Versino and colleagues[11] stating that aging is one of the most important physiological variables in human function.

Saccades are rapid, conjugate eye movements used to gain foveation and to change fixation from one object to another, they may be voluntary or involuntary. Neurological control is complex, with contribution from various areas, including the frontal eye fields, supplementary eye fields, occipital cortex, posterior parietal cortex, posterior eye fields, dorsolateral prefrontal cortex, thalamus, pulvinar, basal ganglia, superior colliculi and cerebellum. Input from these areas is projected to the paramedian pontine reticular formation (PPRF), the horizontal gaze centre, to produce a temporally coded innervational response from the spatially coded stimulus.[12]

Smooth pursuit movements are present in foveate animals and enable continuous clear vision of moving objects. The stimulus for pursuit is movement of the image on the retina and it is thought to be a negative visual feedback, closed-loop control system where retinal slip results in eye movement to stabilise the image on the fovea. Various cortical areas play a role in smooth pursuit control, with several stages of afferent and efferent processing including the primary visual cortex, middle temporal visual area, medial superior temporal visual area, posterior parietal cortex, frontal eye fields and supplementary eye fields. Neurons from these areas project to the cerebellum and dorsolateral pontine nuclei.[12] There is a final common pathway from the ocular motor nuclei to provide the co-ordinated conjugate eye movements required for all horizontal gaze.

Saccades may be described according to various characteristics which include saccadic latency, duration, amplitude and peak velocity. Saccadic latency is a reflection of the total time required for the afferent and efferent processes required to see the stimulus, to make the decision to perform a saccade, to break fixation and to program and execute the eye movement. Regular saccades are those with a latency in the order of 200 milliseconds.[12] The literature is inconsistent as to the effect of amplitude on saccadic latency. It has been reported that latency increases with amplitude,[12-14] though Versino and colleagues[11] found that latency was not dependent on amplitude. It has also been reported that latency varies with predictability of the target.[12,13,15,16] Peak velocity is related to amplitude in a quasi-linear manner up to amplitudes of 15 - 20 degrees, where it reaches a soft saturation limit and then does not increase as rapidly.[17] This non-linear relationship has been confirmed by various authors, [12,14,18-22] with many authors commenting on the considerable intra-subject variability of peak velocity.[14,21,23-27] Saccadic gain (saccade amplitude/target amplitude) is a measure of the initial accuracy of a saccade. The normal range of saccadic dysmetria is considered to be 10% undershoot.[12,14]

Smooth pursuit latency, the time delay between movement of the stimulus and the eye movement response, is reported to be in the order of 130 milliseconds,[12] with latency not dependent upon target velocity.[28] Smooth pursuit is measured by pursuit velocity, which may then be converted to pursuit gain as the ratio of eye velocity to target velocity. The level of smooth pursuit velocity that can be achieved is considered to reach a maximum in the order of 30 - 40 degrees/second,[12,28,29] with pursuit gain decreasing as the target velocity increases.[28-35] When gain falls below one, the smooth pursuit movement is compensated by saccadic corrections or 'catch-up' saccades, which combine with the pursuit movement to form the eye movement response. The frequency of these saccades increases with target velocity.[29] It is stated that pursuit of predictable targets is better than unpredictable targets.[12,28,32,36,37]

Senescence, the act of growing old or aging, is associated with a decline in various functions, therefore it would be expected that changes may be noted in eye movement function across the adult age range. These ocular motor system changes have been given different levels of importance by various authors. Those studies that assessed ocular motor function in the total context of overall neurological function, stated that the eye movement changes were not commonly believed to cause any substantial disability in the elderly, that they did not interfere with reading or any other functional tasks,[38,39] nor did they result in any symptoms or outward signs of ocular motor disease.[40] In contrast, Hutton and Morris[41] commented that slowness in initiating saccades, inappropriate scanning and abnormal smooth pursuit, compounded by age-related limitations in upgaze, visual fields and contrast sensitivity, may all provide a 'faulty visual framework on which perceptual abnormalities and impaired judgement are superimposed'.

The effect of aging on saccadic function has been studied by several authors. All researchers have found that saccadic latency increases with age.[7-11,14,15,23,42-46] However the effect of age on saccadic peak velocity and duration have remained inconsistent. Several studies report no significant difference in peak saccadic velocity with age.[6,11,25,42] Others reported a difference as the saccadic amplitude increased.[7,9,10,14,46] In contrast, one reported a significant decrease in peak saccadic velocity.[8] The reported effect of age on saccade duration is also inconsistent.[11,14,23] Some studies have reported a decrease in accuracy with age,[9,10] while others found no difference.[7,11,14,42,44]

The effect of aging on pursuit function has also been studied by various authors, again with some conflicting results. Pursuit latency was found to be significantly prolonged with age,[28,34] particularly with higher velocities.[32] However, a later study by Morrow and Sharpe[47] found no difference in latency between a young and an elderly group. There have been many studies of the effect of aging on pursuit gain. All but one of the studies have found pursuit gain to decrease significantly with age, though there are inconsistent results concerning the effect at different target velocities.[5,7,28,31,32,35,38,39,47-53] The frequency of catch-up or corrective saccades provides an indication of the compensatory mechanisms for reduced pursuit gain that occurs with increased velocity or with aging. Several studies found an increase in the frequency of saccades with aging.[5,7,32,51,52]

The specific effects of aging on eye movement function are still uncertain, though it appears that the decrement in eye movement function is related to increased target amplitude in saccades and increased target velocity in smooth pursuit. The differences in results and conclusions are most likely to be due to methodological differences between the research studies. The studies all use different techniques for target stimulus, eye movement recording and analysis, which means that absolute values such as eye velocity cannot be compared. The variation in results may be due to the differing sample sizes, age ranges, and the use of experienced subjects in comparison to naive observers also makes the conclusions of some authors debatable. Aging changes may only become apparent in the stressed situation, when the task requires optimal neurological functioning, but tasks within the range of that performed in normal daily viewing may show no decrement. The aim of this study was to establish the normal range of both horizontal saccades and smooth pursuit movements across the full adult age range, using the Ober 2 infrared measurement system. Unlike most previous research, both saccades and pursuit eye movements were measured over a wide range of amplitudes and velocities to assess whether both systems are affected concurrently or selectively and whether age-related changes are dependent on saccadic amplitude or pursuit velocity.

METHOD

Participants

The participants were 181 healthy adults, 60 male and 121 female, aged between 17 and 78 years. All were naive to eye movement measuring techniques, with no known history of ocular pathology, neurological disorder, or psychoactive medication in the last week prior to testing. All of the older participants were healthy, independent and socially active. Visual acuity was 6/12 or better in each eye, with no manifest deviation detected at either 0.33 or 6 metres and full eye movement excursions as determined by orthoptic examination. The study was approved by the Faculty Human Ethics Committee, Faculty of Health Sciences, La Trobe University.

Instrumentation

This study used the Ober 2 infrared reflection binocular measurement system, with the stimulus being a white target subtending 0.29 degrees projected via a computer overhead projector system to a wall-mounted translucent, white screen at a testing distance of 1.5 metres. The subjects viewed the target binocularly and recordings were made of both eyes, with analysis of the data of one eye only. Eye movements were analysed using custom-designed interactive computer programs, which converted the graphical format of the Ober 2 files into eye movement measurements, via the ASCII file format.

Procedure

Prior to the eye movement measurement, the project was explained and the Informed Consent form was signed. Orthoptic assessment was then performed to determine eligibility.

The Ober 2 goggles were adjusted for the inter-pupillary distance, correctly centred and held comfortably with a velcro strap. The participants were

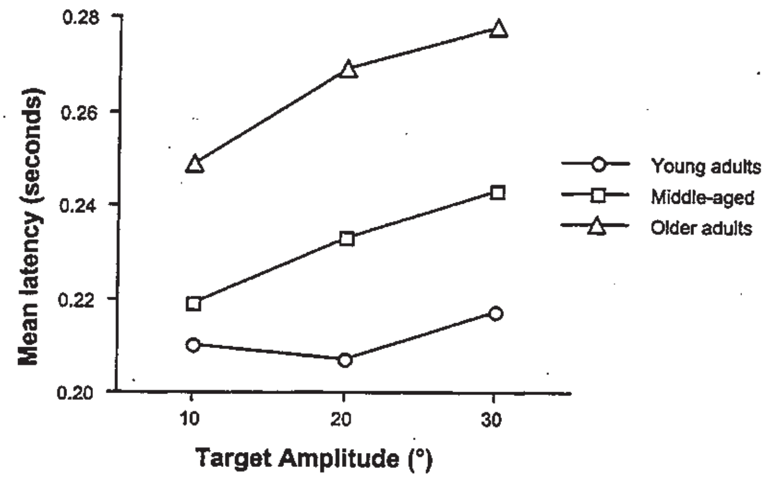

Figure 1. Mean latency values for the three groups for each target amplitude

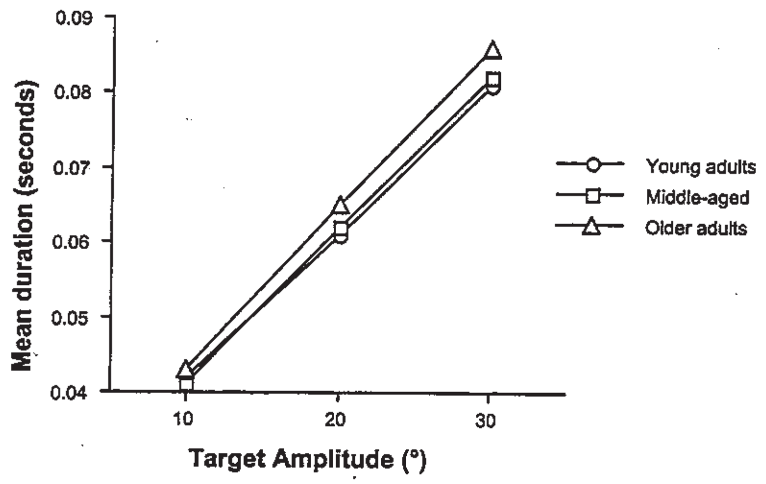

Figure 2. Mean duration values for the three groups for each target amplitude

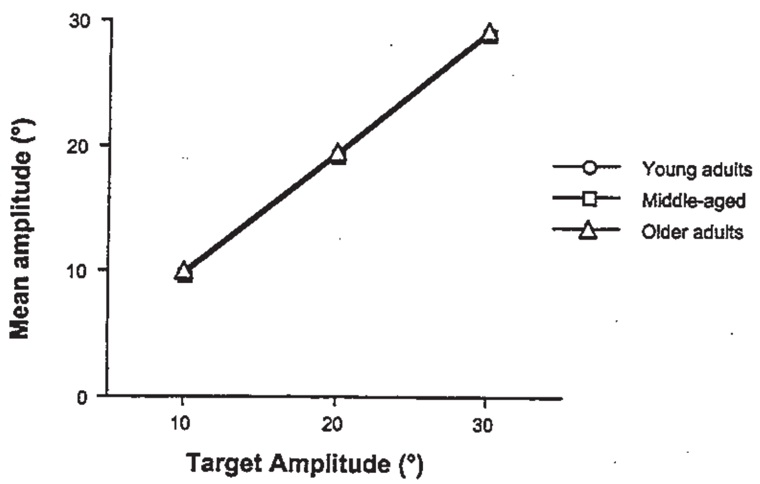

Figure 3. Mean saccadic amplitude values for the three groups for each target amplitude

seated in the darkened room, with the head stabilised by a chin rest and forehead restraint. The saccade protocol was then explained, aiming to gain the most rapid response whilst reducing the incidence of anticipatory saccades. A calibration sequence was run to assess the level of illumination required on the infrared emitters. This calibration sequence not only served the purpose of setting appropriate levels on the Ober 2, but also allowed the participants to practise the technique prior to the first recording.

Saccade stimuli were then presented in predictable sequences with a 1.5 second frequency. Predictable sequences were used with verbal instructions to wait for the target in order to avoid anticipatory saccades.[42] The cycles commenced with fixation to the left of centre, followed by a saccade to the right of centre and a return saccade to the left, so all saccades were across-centre. Five cycles were presented at each of three amplitudes; 10, 20 and 30 degrees. The sensitivity was reduced if necessary to prevent saturation. A sequence was accepted if at least 6 of the 10 saccades appeared to be without blinks or anticipation, or was repeated if this was not achieved. Following the saccade sequences, instructions were given regarding the pursuit movements, that participants were to follow the light as closely and accurately as they could. Smooth pursuit stimuli were then presented in predictable sequences with a constant velocity triangular waveform stimulus moving over an amplitude of 20 degrees, 10 degrees to each side of centre. Five cycles were presented at each velocity; 6.50, 12.99, 19.44, 25.87 and 38.56 degrees/second. These levels of target velocity were due to the constraints imposed by the quality of the computer monitor to allow an apparently smooth movement of the target. Verbal contact was maintained throughout the pursuit procedure in order to sustain attention.[31,47] The recording was again displayed after each velocity sequence to view that it was an acceptable recording. The total recording sequence usually took between 8 and 18 minutes.

Analysis

The saccadic dependent variables were mean latency, mean duration, mean and standard deviation of saccadic amplitude, and mean peak velocity. The pursuit dependent variables were mean pursuit gain, mean pursuit time (the percentage of the recorded cycle defined as smooth pursuit), frequency of catch-up saccades and mean amplitude of catch-up saccades.

In each set of 10 recordings the program calculated the measurements for each individual saccade or pursuit. The amplitude of each saccade was calibrated by measurement of the mean eye position 0.8 to 0.3 seconds prior to each stimulus presentation, in a similar manner to Wilson et al.[46] To measure regular saccades, generally in the order of 200 milliseconds latency[12] and to avoid anticipatory saccades, acceptable saccades were defined as those with a latency of 90 milliseconds or greater and an amplitude within 10% of target amplitude. Pursuit samples were calibrated by 0.5 seconds of fixation at each extreme position prior to the pursuit movement to determine amplitude of the pursuit, with velocity then calculated for each time sample. Within the pursuit recordings, when the velocity of a single time sample was greater than 79 degrees/second, these time samples were defined as saccades and removed from the pursuit velocity calculations. This detected all saccades of amplitude 1 degree or greater in a similar manner to Bahill et al.[36] With saccade time samples removed, calculation was then made of the total proportion of the trace time that was actually smooth pursuit (pursuit time).[29,48,50] Saccades or pursuits that were not acceptable, or were incorrectly identified by the computer program, were deleted from the table and the means recalculated for each set. Only the data from participants where a mean and standard deviation was calculated from at least 6 of the 10 recordings were acceptable was included in the data analysis.

The participant data was grouped into three levels, a young adult group from 17 to 29 years (N = 55, mean age = 21.6, SD 4.16 years), a middle-aged group from 30 to 59 years (N = 81, mean age = 43.8, SD 8.25 years) and an older adult group including those of 60 years and older (N = 45, mean age = 67.6, SD 4.16 years). For saccadic function the final number from which the data for all variables was analysed was 44 participants in the young, 72 in the middle-aged and 43 in the older adult group. For smooth pursuit function the final number from which the data for all variables was analysed was 51 participants in the young, 74 in the middle-aged and 34 in the older adult group.

For the analysis of saccadic eye movement function, each of the dependent variables was analysed using a two-way Age by Target Amplitude ANOVA. For the analysis of smooth pursuit eye movement function, each of the dependent variables was analysed using a two-way Age by Target Velocity ANOVA. Rejection of statistical null hypotheses was set at $p \leq 0.05$.

RESULTS

Saccades

Latency

In Figure 1 it can be seen that mean saccadic latency increased both with age and with target amplitude, and that the latency was increased for all ages for all target amplitudes. The effects for Age [F (2, 156) = 22.17, p = 0.0001] and Target Amplitude [F (2, 312) = 26.90, p = 0.0001] were significant. The interaction effect, Age by Target Amplitude, was significant [F (4, 312) = 3.44, p = 0.009] but appears to be minimal.

Duration

In Figure 2 it can be seen that the largest effect was the increase in mean duration as target amplitude increased with a significant effect for Target Amplitude [F (2, 312) = 3,536.35, p = 0.0001]. There was also a significant effect for Age but this is not particularly large [F (2, 156) = 3.80, p = 0.0244]. The duration was similar for all ages for 10 degree saccades but as target amplitude increased to 20 and 30 degrees, those in the older age group showed longer durations than those in the other groups, with a significant interaction effect [F (4, 312) = 4.03, p = 0.0034].

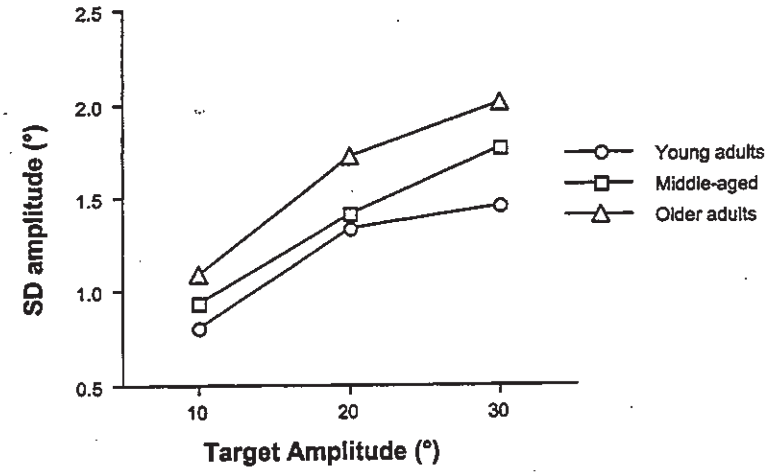

Figure 4. Mean standard deviation of saccadic amplitude values for the three groups for each target amplitude

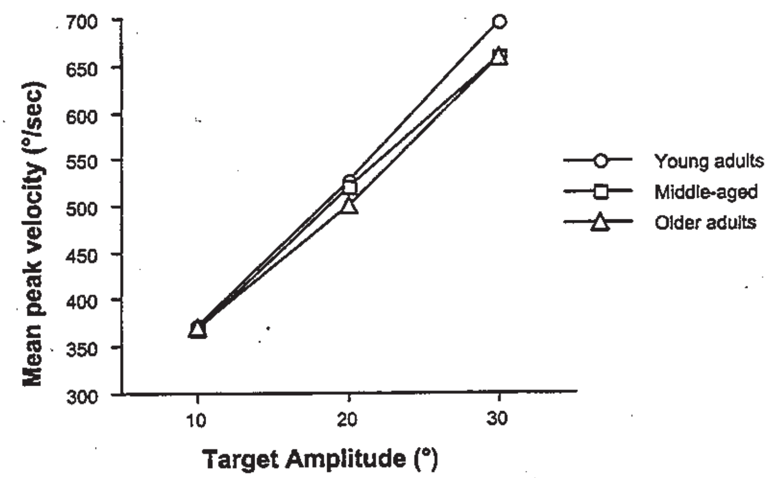

Figure 5. Mean peak velocity values for the three groups for each target amplitude

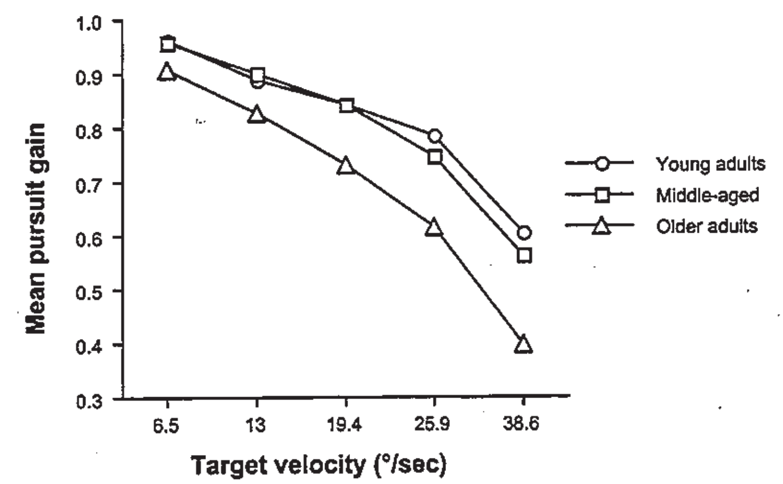

Figure 6. Mean gain values for the three groups for each target velocity

Amplitude

Because the measured variable was mean saccadic amplitude the main effect of Target Amplitude was expected to be large [F (2, 312) = 39,502.84, p = 0.0001] and therefore was of no interest. While the Age effect was significant, it can be seen in Figure 3 that it was only small [F (2, 156) = 4.02, p = 0.0198] and there was no interaction effect [F (4, 312) = 0.20, p = 0.9363]. The individual standard deviations of saccadic amplitude showed significant effects for both Age [F (2, 156) = 5.05, p =0.0075] and Target Amplitude [F (2, 312) = 85.69, p = 0.0001], with no significant interaction effect [F (4, 312) = 1.04, p = 0.3881], displayed in Figure 4. This measure of saccadic accuracy demonstrated that even though the mean saccadic amplitude showed minimal variation with increasing age, the variance around this mean increased with age.

Peak saccadic velocity

Figure 5 shows that mean peak velocity [F (2, 156) = 774.10, p = 0.0001] significantly increased with increasing target amplitude. There was no significant Age effect [F (2, 156) = 1.16, p = 0.3159], nor any interaction effects [F (4, 312) = 1.60, p = 0.1754].

Smooth pursuit

Pursuit gain

In Figure 6 it can be seen that mean pursuit gain steadily decreased as the target velocity increased, with a significant effect for Target Velocity [F (4, 624) = 583.36, p = 0.0001]. The older group had a pursuit gain value less than the other groups at all target velocities, with the middle-aged group showing a decrease only at the faster velocities of 25.9 and 38.6 degrees/second. Pursuit gain in the older group was only minimally less than the other groups at the slowest velocity of 6.5 degrees/second but this difference increased as velocity increased, demonstrated by a significant Age effect [F (2,156) = 13.63, p = 0.0001] and interaction effect [F (8, 624) = 6.83, p = 0.0001].

Pursuit time

In Figure 7 a decrease in mean pursuit time was demonstrated as target velocity increased, with a significant effect for Target Velocity [F (4, 624) = 1,203.24, p = 0.0001]. Pursuit time was minimally decreased from the young to the middle-aged group with a larger effect observed for the older group, particularly for the target velocities of 19.4 degrees/second and faster, with significant Age [F (2, 156) = 17.48, p = 0.0001] and interaction [F (8, 624) = 8.71, p = 0.0001] effects.

Saccadic frequency

In Figure 8 it can be seen that generally there was a decrease in the number of saccades recorded in the five cycles of the pursuit trace from target velocites of 6.5 to 13.0 degrees/second with an increase towards the faster velocities, then a decrease again at the fastest target movement of 38.6 degrees/second. This was demonstrated by a significant Target Velocity effect [F (4, 624) = 4.04, p = 0.0001]. The frequency of saccades within the pursuit trace increased with age, with the more marked difference being at the slowest velocity, with only a minimal difference at the fastest velocity, demonstrated by a significant Age effect [F (2, 156) = 10.98, p = 0.0001] and interaction effect [F (8, 624) = 4.04, p = 0.0001].

Saccadic amplitude

Figure 9 presents the results of mean saccadic amplitude and demonstrated that saccadic amplitude increased as target velocity increased, with a significant Target Velocity effect [F (4, 624) = 408.51, p = 0.0001]. It can be seen that there was only a minimal increase from the young to the middle-aged group but a more marked increase for the older group. There was no difference between the groups at the slowest velocity but the older group demonstrated increasingly larger saccades as the target velocity increased, with a significant effect for Age [F (2, 156) = 9.56, p = 0.0001] and a significant interaction effect [F (8, 624) = 8.18, p = 0.0001].

DISCUSSION

Saccades

Latency

Mean latency of 20 degree saccades increased from 207 milliseconds in the young to 233 milliseconds in the middle-aged and 269 milliseconds in the older adult group (see Figure 1), so giving an apparently steady increase with age, consistent with that reported in the literature.[8,10,15] The latency was longer in the older group than the younger group by 39, 62 and 61 milliseconds for 10, 20 and 30 degree saccades respectively, showing a differential effect in that the variation with amplitude was more apparent in the middle-aged and older than the younger adult groups. Though this study used predictable targets, these latencies were within the range of previous studies,[7-9,11,14,23,27,45,54] most of which used random sequences.

It has been suggested that this increase in latency is not unexpected with age due to the involvement of the entire visual and ocular motor systems, a long and complex pathway, and therefore an increased neural conduction time associated with aging[8,10] and that this is consistent with the increased reaction time for other motor tasks in the elderly.[23] Abel and colleagues[23] suggested it was a result of deterioration of the higher centres involved in programming saccades and Sharpe and Zackon[9] further hypothesised that increased latency may be associated with frontal lobe changes, with parietal lobe deficits resulting in a delayed shifting of attention, or with a general cognitive decline.

Duration

The small but statistically significant increase in duration with age and the more marked increase with saccade amplitude, with duration in the young adult group increasing from 42 to 81 milliseconds and in the older adult group from 43 to 86 milliseconds for 10 and 30 degree saccades respectively (see Figure 2), were consistent with most other studies.[12,17,20] The results of this study also demonstrated a differential aging effect with increasing amplitude, with a similar duration for all ages for 10 degree saccades and a

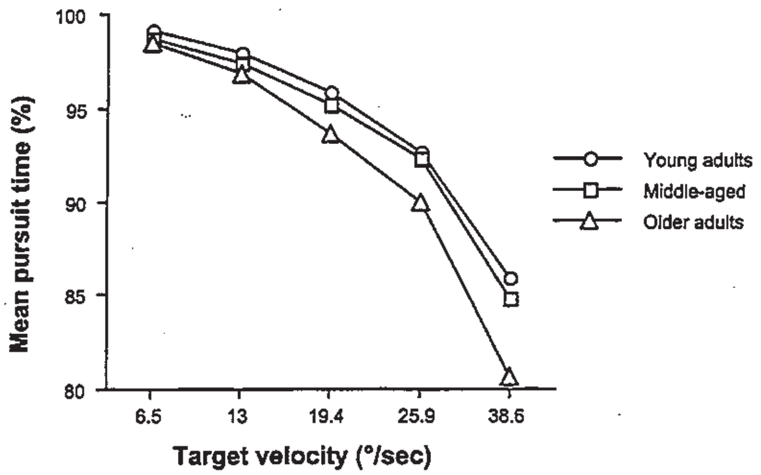

Figure 7. Mean pursuit time values for the three groups for each target velocity

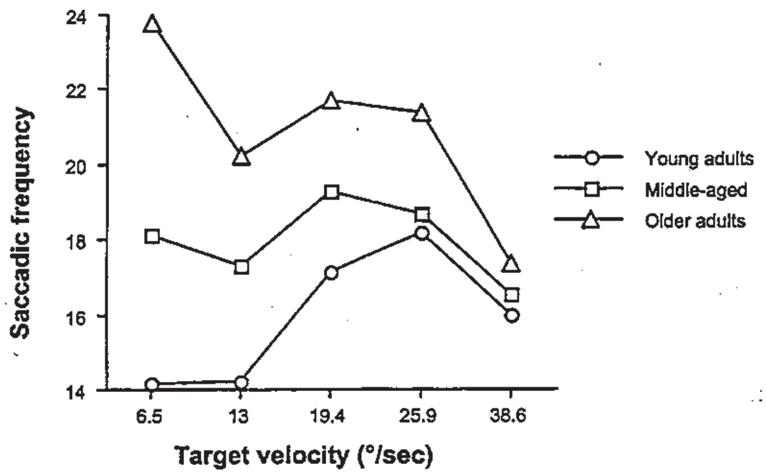

Figure 8. Mean saccadic frequency values for the three groups for each target velocity

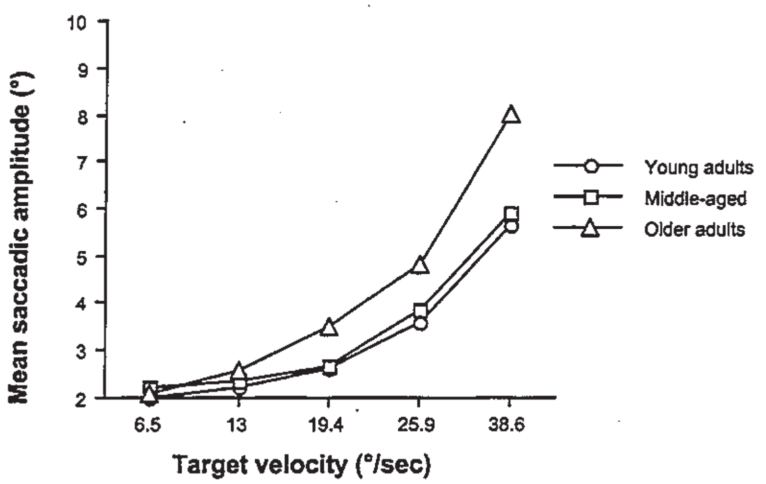

Figure 9. Mean saccadic amplitude values for the three groups for each target velocity

larger increase for the 20 and 30 degree saccades for the older adult group than the other two groups.[11,14]

It might be suggested that the increased saccadic duration is linked with the increased neural conduction time associated with aging in the same way that latency is increased, with an increase in reaction time reflecting the increased processing time required to build up a more accurate premotor command.[11] This would suggest that the increased latency is linked to the increased duration as a compensatory mechanism.

Amplitude

The results of the present study showed no real difference in mean saccadic amplitude with age, but individual variance as measured by the mean of individual standard deviations, significantly increased with increasing age (see Figures 3 & 4). This measurement demonstrated that saccadic accuracy decreased with increasing age even though the mean saccadic amplitude was not markedly affected. A reduction in accuracy has been reported by some studies,[9,10,23] but contradicted by others.[7,11,14,42] Interestingly, Moschner and Baloh[7] reported no decline in accuracy with age, stating that the mean accuracy did not decrease with age but that there was a significant aging effect for intrasubject variability based on individual variances, which finding is replicated by the present study. It has been suggested that deterioration in the higher centres of eye movement control such as the frontal lobes or cerebellum may be responsible for the decrease in accuracy.[9,10]

Peak velocity

The results of the present study (see Figure 5) found, as all others, that peak velocity increased with increasing saccadic amplitude.[12,14,17-22] An aging effect was not found for peak velocity, similar to previous studies.[11,23,25,42] It appears that the aging effect for peak velocity is not strongly demonstrated by other studies except for larger amplitude saccades in the order of 25 degrees or greater,[10,14] and in subjects aged 70 years or older.[7,9,14] On observation of the raw data it was noticed that the peak velocities of those subjects aged 70 years and older did show an apparent decrease compared to those subjects aged in their 60s for saccades of 20 and 30 degree amplitudes, however the number of subjects in the older group was too small for separate analysis.

It has been suggested that the strong effect on latency and the small effect on velocity with age indicate that the higher centres involved in programming saccades deteriorate with age, but that the brainstem saccadic generator is relatively unaffected.[7,9,10,23,43,44] Due to the resistance to aging of the PPRF, significant changes in peak velocity may be an indicator of pathological change rather than aging in anyone under 70 years.

Smooth pursuit

Pursuit gain

The findings of a decrease in mean pursuit gain with increasing velocity (see Figure 6) agree with previous studies.[28-33,35] Pursuit gain also decreased with increasing age. At the target velocity of 6.5 degrees/second there was only a minimal difference in gain between the younger and older adult groups, with mean gain of 0.96 and 0.91 respectively which agrees with previous studies, most of which demonstrated an aging effect when target velocity is in the order of 10 degrees/second or greater but not at slower velocities.[27,32,34,35,47-51] At increasing velocities there was minimal difference between the younger and the middle-aged adults, whereas the older adults demonstrated an increasing difference as target velocity increased, with mean gain being 0.61 and 0.40 for the younger and older groups respectively at the target velocity of 38.6 degrees/second.

Pursuit time

The decrease in the proportion of time of the pursuit cycle that was actually defined as smooth pursuit movement is concomitant with the decrease in mean pursuit gain (see Figure 7). The most marked decrease in pursuit time occurred only at the highest velocity in the younger adult group, from 92.6% to 86.0%, with the middle-aged adults demonstrating similar results, whereas the older adults showed a steady decrease at the slower velocities and dropped to 80.7% at the highest velocity.

Saccadic frequency

In Figure 8 it can be seen that the findings agree with previous reports regarding the increased frequency of catch-up saccades as pursuit velocity increased.[28,29] In the present study the relationship between the frequency of saccades and aging in pursuit movements demonstrated an interesting pattern, where the older adult group demonstrated a much greater saccadic frequency at 6.5 degrees/second target velocity than at 13.0 degrees/second. Kaufman and Abel[49] reported that the elderly showed more distraction than the young at the slower pursuit velocity of 5 degrees/second, compared to a faster velocity of 20 degrees/second. At 38.6 degrees/second target velocity there was minimal difference between the three groups, as was also reported by Sharpe and Sylvester[28] who found no difference between age groups at velocities greater than 40 degrees/second.

Saccadic amplitude

This study demonstrated a significant increase in saccadic amplitude as pursuit velocity increased, from a mean of 2.0 degrees to 5.7 degrees at target velocities of 6.5 and 38.6 degrees/second respectively (see Figure 9), agreeing with the study by Schalen.[29] Saccadic amplitude also increased with aging as reported previously.[28,32] There was only a minimal difference between the saccadic amplitudes of the young and middle-aged group, with the older adults showing a marked increase in amplitude at velocities of 19.4 degrees/second and greater, concomitant with the decrease in pursuit gain.

These four measurements of smooth pursuit combine to give a complete description of the smooth pursuit eye movement, demonstrating a decrease in pursuit gain in the older adult group which was adequately compensated by larger and more frequent saccades than those performed by the younger group.

Similar to the hypotheses concerning the decline of saccadic function with aging, it has been suggested that the decline in pursuit function with age may be due to incipient degenerative processes, such as cerebral cortical atrophy, degeneration of the nigrostriatal pathway and loss of cerebellar Purkinje cells.[7,28,32,35,40,47,51] It has been proposed that there is an age-dependent deterioration in attention to visual targets and visuo-motor tasks and that this may be a reason for the decline in pursuit gain.[7,34,48,49,55,56] Morrow and Sharpe[47] suggested that the sensory limitations of target motion signals were a contributing factor.

CONCLUSION

The results of this study have shown age-related decrements in both horizontal saccadic and smooth pursuit eye movements, with the changes in smooth pursuit more marked than those in saccades. This finding agrees with other studies which reported that the changes in pursuit function were more marked than those in saccadic function.[7,39,53] The decrease in pursuit function occurred predominantly in the older group with minimal differences between the young and the middle-aged groups. In contrast, the changes in saccadic function showed a gradual aging effect across the middle-aged range. It was also demonstrated that the age-related decrement in pursuit function was certainly velocity dependent, with more marked differences as pursuit velocity increased, whereas saccade changes were less amplitude dependent.

The greater effects on pursuit function may be due to the greater reliance of the smooth pursuit eye movement system on the afferent visual system, the closed-loop system which is dependent upon the recognition of retinal slip and target motion and the conversion of afferent information to efferent signals. The many aging changes that occur in the afferent pathway such as senile miosis, cataract development, reduced visual acuity, reduced contrast sensitivity, along with the cerebral cortical changes may all contribute to this greater effect on smooth pursuit than on saccadic function. The prolonged neural conduction time resulting in increased saccadic latency was not amplitude dependent but was apparent as an aging effect even at the smallest target amplitude and across all age groups. The lesser effect on peak saccadic velocity appears to be related to the fact that the brainstem integration centres, such as the PPRF, which are responsible for the pulse of saccade innervation and so primarily peak saccadic velocity, are more resistant to aging changes than other structures involved in saccade function.

A further explanation of the different aging effects of saccade and smooth pursuit function may be the fact that pursuit eye movements are not regularly exercised in the same way as saccades, particularly in the way in which they are clinically examined. In the normal viewing situation the smooth pursuit system is more involved in retinal image stabilisation in combination with the vestibulo-ocular reflex to maintain fixation in the presence of either head, body or target movement, rather than in the following of a moving target with the head and body completely stabilised.

This study raises two other areas for further research. First, the question of differentiating senescence, or normal aging, from pathological changes as raised by Versino and colleagues.[50] As these authors suggested, a study with a large number of older adults is required to measure eye movement function, assess neurophysical and neuropsychological function and document morphological changes to differentiate normal aging from pathological aging. This may be particularly evident in the age group of 70 years and older, where some studies have found a subgroup of subjects who appeared to be different from the rest of the subjects in this age group and suggested that this may be a sign of pathological change rather than normal aging.[38,39] A study of this nature may connect decrement of eye movement function more clearly with degenerative aging changes.

The second question to be resolved is that of the functional implications of the decline in ocular motor function found with aging. This study has found changes in some of the measured variables of saccadic and smooth pursuit function with increasing age, but it is not known to what extent this decrease in ocular motor function can be translated into changes in actual visual activities or even everyday activities. Some of the previous studies have suggested that this decline, along with the reduction in visual sensory systems that occurs, may be quite disabling in the everyday function of elderly people.[15,41] However others, particularly those who assessed a wide range of neurological functions, suggested that the eye movement changes did not cause any substantial difficulty and did not interfere with everyday tasks.[38-40] Again, a large study which measured eye movement function and assessed certain aspects of neuropsychological function may determine the effects of reduced ocular motor function on some aspects of everyday living such as reading and mobility.

ACKNOWLEDGEMENTS

This research was assisted by two grants, a La Trobe University Central Starter Research Grant and a Faculty of Health Sciences Postgraduate Research Project Grant. Thanks are extended to Alison Pitt, my supervisor, during this thesis, for her assistance and encouragement. Also, thankyou to the many participants in this project.

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