Effect of Aging on Saccadic Eye Movements to Visual and Auditory Targets

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Abstract: Elderly patients with diseases of the central nervous system often show saccadic disorders. Before these disorders can be called *pathological*, they must be distinguished from the physiological effects of aging. The purpose of this study was to determine the effect of aging on visual and auditory saccadic eye movements. Ninety healthy volunteers were divided into three groups (younger than 30 years; 30–50 years; older than 50 years), with 30 volunteers in each group. Visual and auditory predictive 15-degree saccades were evoked and recorded with electrooculography. Recorded parameters were peak velocity, duration, and latency. Both stimuli showed increasing latencies with increasing age and a higher peak velocity in the middle group as compared to the oldest group. The latter result was significant only for saccades to visual targets. Duration was almost identical for both patterns and all age groups. Between the age groups, latencies were significantly shorter for the saccades to auditory targets, and no differences in peak velocity occurred. The results stress the importance of an age-related assessment for saccadic parameters. The increasing latency and decreasing peak velocity in elderly people probably result from age-related degenerative changes in central nervous system parts that are involved in the generation of saccadic eye movements. We found no indications of a different effect of aging through either the visual or the auditory pathway for saccadic parameters.

Saccadic disorders are common in many diseases of the central nervous system (e.g., Parkinson's disease and progressive supranuclear palsy) [1]. Because most patients suffering from these disorders are elderly people, age-related changes of saccadic eye movements must be differentiated from pathological changes. The specific aging process of the central nervous system (e.g., changes on neurons, synapses, and regional blood flow [2,3] and a loss of white matter [4,5]) can lead to an effect on saccades and their parameters. The results in the few studies that dealt with the effect of age on saccadic eye movements to visual targets were partly contrary. Spooner et al. [6], Warabi et al. [7], and Moschner and Baloh [8] found a decreasing peak velocity with increasing age; Warabi et al. [7] also found an increase of duration. In contrast, Henriksson et al. [9] and Abel et al. [10] did not find significant differences in peak velocity, and Sharpe and Zackon [11] reported a lower peak velocity in elderly people with prediction of the amplitude only. Latency was prolonged with increasing age [6–8,12,13]. To our knowledge, this is the first published study of saccadic eye movements in response to auditory targets and their dependence on age.

The oculomotor pathways are complex; they include the frontal and posterior parietal cortices, basal ganglia, thalamus, brainstem, and cerebellum [1]. These pathways are not understood fully, especially for the saccadic eye movements to auditory targets. Therefore, conclusions can be drawn about the involvement and influence of anatomical structures, not only through studies dealing with the effect of aging on saccades but through studies comparing saccadic eye movements to visual and auditory targets. In this study, we systematically investigated three larger populations of healthy volunteers in reference to age-related changes of the following parameters: peak velocity, latency, and duration of saccadic eye movements to visual and auditory targets.

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METHODS

Subjects

Ninety subjects, aged 17 to 75 years and without diseases of the central nervous system or of the visual, auditory, and oculomotor system, volunteered for this study. Subjects with corrected visual acuity could participate. Criteria for exclusion were use of sedative, neuroleptic, and anticonvulsant medication and alcohol. The subjects were divided into three age groups (younger than 30 years; 30–50 years; older than 50 years), with 30 subjects in each group. The mean age of all subjects was 40.1 years (standard deviation [SD] = ±16.0). The mean age in the various age groups was 24.1 years (SD = ±4.0); 36.6 years (SD = ±5.4); and 59.7 years (SD = ±7.9), respectively. Twenty-nine male and 61 female subjects were investigated; in the age groups, the male-female ratios were as follows: 6:24, 13:17, and 10:20, respectively.

Stimuli

The visual stimulus was a white light spot (0.55 minutes of arc). It was projected through a projector with an incorporated mirror (Medelec Nuovoskop 50 Jod, Medelec Inc., London, UK) onto a screen at the opposite wall. Horizontal movements of the mirror from 0 to 15 degrees to either the right or the left were possible through a computer-controlled program.

The auditory stimulus was a 1,000-Hz pure tone from three 11.3-cm-diameter loudspeakers (Monacor Corp., Bremen, Germany) at the opposite wall at 0, 15 degrees to the left, and 15 degrees to the right. A computer-controlled signal permitted a change of the tone between either 0 degrees and 15 degrees left or 0 degrees and 15 degrees right. When the first tone had ended, the next tone started immediately (Fig. 1).

Experimental Design

The experiments were performed in a darkened room with sound absorption. Subjects were seated in a slightly reclined chair with a headrest to prevent head movements. The distance from the head to the 15-degree positions of the light spot and loudspeakers, respectively, was 210 cm. Eye movements were recorded by direct-current electrooculography with silver-silverchloride electrodes connected binocularly, horizontally (outer canthi of the eyes) and monocularly, and vertically (above and under the left eye); a ground electrode was placed on the left ear. The electrooculography signal was amplified (Amplifier Toennies, Toennies Corp., Würzburg, Germany), and a 10-Hz filter was used.
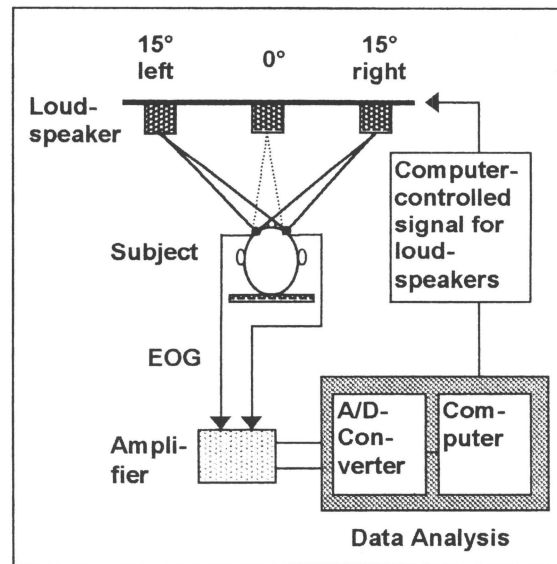

Figure 1. Schematic of the experimental apparatus used to record saccadic eye movements to auditory targets. (A/D = analog-digital; EOG = electrooculography.)

Calibration of the eye movements started after 10 minutes' dark adaptation of the subjects. Before every experiment, subjects were informed of the beginning, the type and the direction of the stimulus, and the number of saccades. They were asked to follow either the light spot or the change of the tone as accurately and rapidly as possible with saccadic eye movements. First, at intervals of 2 seconds, five visually evoked saccadic eye movements were introduced from 0 to 15 degrees left, then from 0 to 15 degrees right. They were followed, at intervals of 2 seconds, by five auditorily evoked saccadic eye movements from 0 to 15 degrees left and then from 0 to 15 degrees right.

To prevent fatigue, a break of at least 30 seconds was introduced between each experiment and, again, the subjects were asked to perform the experiments as accurately and rapidly as possible. The duration of one entire session lasted approximately 4 minutes. Each subject engaged in two sessions, with a break of approximately 5 minutes.

Data Analysis

The data were recorded with an A/D converter and were stored for analysis using a semiautomatic program [14]. Parameters were peak velocity, latency (time of target presentation to onset of eye movement), and duration (eye position different from starting position at 0 degrees and target position at 15 degrees). To exclude either anticipatory saccades or saccades with prolonged latency due to inattention, only saccades with a latency

of between 100 and 400 msec were included. The registration of the experiments of the two sessions, corresponding in direction and kind of stimulus, were compared visually by the investigator, and the five most accurately shaped saccades were chosen.

Mean values and SDs were calculated with Excel 5.0 (Microsoft Corp., USA); SPSS for Windows 6.0 (SPSS Inc., USA) was used for the statistical analysis. At first, mean values and SDs of the saccadic parameter peak velocity, latency, and duration were calculated for each of the three age groups and the four experiments. The next analysis was performed separately for every age group. As no statistical differences were seen between right and left of the visual and auditory responses in the paired Student's t-test ($p < .05$), the data of either the visual or the auditory experiments were pooled, and mean values and SDs were calculated again. Then two statistical analyses followed, the first between saccades to visual and auditory targets with the paired Student's t-test ($p < .05$), and the second between the age groups with the Student's t-test ($p < .05$).

RESULTS

The statistical analysis first was made separately for every age group. Because analysis revealed no significant differences between right and left of corresponding stimuli, the data of the corresponding experiments of one age group were pooled.

Comparison Between Age Groups

Comparison between age groups was conducted using the Student's t-test; differences were considered statistically significant at the level $\alpha < .05$.

Peak Velocity

Peak velocity was lowest in the oldest age group for both the visually and the auditorily evoked saccades (Table 1). It was slightly higher in the youngest age group and highest in the middle age group. There was a

Table 1. Mean Values and Standard Deviations of Peak Velocity

| Age (yr) | Visual (degrees/sec) | | Auditory (degrees/sec) | |
	Mean	SD	Mean	SD
<30	387.7	38.5	385.9	30.9
30–50	397.7	41.1	397.6	42.9
>50	372.3	34.2	378.2	36.8

Note: Results after pooling the data of both directions.

Table 2. Mean Values and Standard Deviations of Latency

| Age (yr) | Visual (msec) | | Auditory (msec) | |
	Mean	SD	Mean	SD
<30	196.6	21.3	175.8	22.0
30–50	202.9	17.1	183.0	18.8
>50	231.6	25.5	215.1	29.3

Note: Results after pooling the data of both directions.

significant difference only for the saccadic eye movements to the visual targets between the middle and oldest age group ($p = .012$). All other differences for the saccades to visual and auditory targets were not statistically significant between the age groups.

Latency

With increasing age, latency of the saccadic eye movements was longer in response to both the visual and the auditory targets (Table 2). The difference between the youngest and the middle-aged group was not significant for both kinds of stimuli. However, the increase of latency between the youngest and the oldest and the middle-aged and the oldest age group, respectively, was highly significant for both stimuli ($p = .0001$).

Duration

The results for duration were quite similar in all age groups (Table 3). No significant differences were observed in the duration among the age groups.

Comparison of Saccadic Eye Movements to Visual and Auditory Targets

Comparison between saccadic eye movements in response to visual targets and those in response to auditory targets was conducted using the paired t-test; differences were considered statistically significant at the level $\alpha < .05$.

Peak Velocity

The same age groups exhibited no significant differences in peak velocity of saccades to visual targets as compared to saccades to auditory targets (see Table 1).

Table 3. Mean Values and Standard Deviations of Duration

| Age (yr) | Visual (msec) | | Auditory (msec) | |
	Mean	SD	Mean	SD
<30	82.9	6.1	82.3	6.1
30–50	82.2	6.9	82.5	7.3
>50	83.2	6.2	82.8	5.5

Note: Results after pooling the data of both directions.

Latency

In saccades both to visual and auditory targets, latency increased with increasing age (see Table 2). In a comparison of visual with auditory saccadic eye movements in the age groups, latency was significantly shorter for the saccades to auditory targets ($p = .0001$).

Duration

The difference in duration for both stimuli in the age groups, with values between 0.3 msec and 0.6 msec, was very small (see Table 3). Therefore, no significant differences were seen between saccadic eye movements to visual and auditory targets.

DISCUSSION

Age and Saccadic Eye Movements to Visual Targets

Latency

For saccadic eye movements to visual targets, latency increased with increasing age. This became statistically significant in comparing the youngest and the middle-aged groups to the oldest age group. The comparison of published studies [7,8,11–13] always showed an increase in latency with increasing age, beginning in early adulthood, in nonoverlapping age groups. However, this increase was significant only in strictly distinct age groups [7,8] or, as in the study of Sharpe and Zackon [11] and our study, in those in which the borderline between the age groups was 60 and 50 years, respectively. Likewise, the study of Carter et al. [12] showed a clear increase in latency only from the fifth decade onward. These studies indicated only a slight increase in latency by the age of 50–60 years for saccadic eye movements to visual targets; thereafter, the increase of latency seems to become much stronger. In contrast to these studies, Munoz et al. [13] found the shortest latencies for subjects aged 18–22, younger and older subjects had significantly longer latencies, and latency seemed to increase almost steadily with age from 20 years on.

Increasing age leads to aging processes of the central nervous system, which usually result in a decrease of weight and volume of the brain, especially of the frontal lobe [2,4,15]. This decrease probably is due to a loss of neurons [16] and a decline of white matter [5]. Moreover, changes of neurotransmitter systems [17] and the regional blood flow [2,3] occur. These age-related structural changes of the central nervous system could lead to generally slowed central processing. This outcome would explain the prolonged motor reaction time and, therefore, the increase of latency in saccadic eye movements often occurring in elderly people [18].

Peak Velocity

In our study, the peak velocity of the predictive 15-degree saccades in the oldest age group was significantly lower than that in the middle-aged group. The peak velocity for the youngest group lay in between, without any significant difference relative to one or the other group. This could be either an indication that the fastest human saccades occur between the ages of 30 and 50 years or an accidental dispersion. Hainline et al. [19] and Muñoz et al. [13] did not find differences of peak velocity of saccadic eye movements to visual targets in infants and children as compared to adults. Our study also reinforces the results of Sharpe and Zackon [11] that, with prediction of target amplitude and direction, significant age-related differences of peak velocity already occur at small amplitudes, whereas in studies with randomized saccades, larger amplitudes seem to be necessary to receive a significant age-related difference of peak velocity [7,8]. Muñoz et al. [13] evoked randomized 20-degree saccades; this outcome might explain why they did not find significant differences in peak velocity. These studies indicated that effects of age on peak velocity become more evident with prediction of target amplitude and direction; this is stressed through anatomical and neurophysiological findings. Thus, high activity of the burst neurons of the pulse generator in the paramedian pontine reticular formation with following activation of the ocular motoneurons is needed for a high peak velocity of horizontal saccades. Neurons of the higher centers (e.g., the frontal eye fields and basal ganglia) control the burst neurons. Age-related changes of neurons or synapses in one of the involved structures could lead to a decrease in burst neuron or motoneuron activity and could, therefore, result in a reduced peak velocity. The age-related decrease of weight and volume of the brain and the loss of neurons of the central nervous system affect the frontal cortex particularly, which is important for predictive saccades [2,4,5,15,16,20]. This could be the reason why aging effects are more easily detected by using the predictive-saccades setting in studies.

Duration

Warabi et al. [7] and Meienberg [21] found, with increasing age, a strong decrease of peak velocity, with a simultaneous slight increase of duration, for either visual 40-degree or 30-degree saccades. Our study showed a decrease of peak velocity with a minimum, insignificant increase of duration. What should be noted, however, is that because of larger amplitudes, the peak velocity in the studies of Warabi et al. [7] and Meienberg [21] was much higher than in our study. Meienberg also showed that for older subjects, the decrease of peak velocity is lower in small saccades than in large saccades. It is possible, therefore, that in our study, the

peak velocity—which is lower anyway because of the smaller amplitudes—leads to the even smaller, statistically insignificant differences in duration. This finding could be an indication that effects of aging on dynamic saccadic parameters in smaller amplitudes are described more reliably through peak velocity than through duration. Again, the findings of Muñoz et al. [13] differ somewhat. Muñoz's group found a significant increase of duration but no changes in peak velocity with increasing age, especially from 60 years on.

Age and Saccadic Eye Movements to Auditory Targets

Latency

Increasing age resulted in an almost parallel increase of latency for saccadic eye movements to visual and auditory targets. Parallel to the saccades to visual targets, only the increase between the youngest and the middle-aged groups was not significant. We also found in all three age groups a longer latency for the visually evoked saccades as compared to those auditorily evoked.

Studies that compared the latency of visual and auditory horizontal saccadic eye movements seemed to prove a decrease in latency of saccades to auditory targets with increasing amplitude of the target position, as defined through the change of the eye position [22–28]. In contrast to this, a slight increase in latency occurred for the saccades to visual targets with increasing amplitude. These findings were significant in the studies of Zahn et al. [23], Zambarbieri et al. [25], and Yao and Peck [28]. Engelken and Stevens [26] did not find a correlation between the increase in latency and amplitude. The size of the amplitude, where the saccades to visual targets had a slightly shorter latency than the saccades to auditory targets, varied between 15 degrees [26] and 35 degrees [25].

Because of our experimental setting, only 15-degree saccades were elicited; in all three age groups, the latency was longer for the visual than for the auditory saccades. A comparison of the latencies among the different studies clearly demonstrates wide variability; latencies in our study were some of the shortest. In contrast, as described, differences occurred in the size of the amplitude, with values between 15 and 35 degrees, and the saccades to visual targets had a shorter latency than did the saccades to auditory targets. Seemingly, methodical differences in the experimental design are responsible for this and, to some extent, explain the shorter latencies in our study of saccades to auditory targets. This aspect is interesting but is not the subject of this study. For that reason, prediction, attentiveness, number of subjects, kind of starting stimulus, gap or overlap experiment, and visual target control are mentioned only as examples of methodical differences.

Peak Velocity

For saccades to auditory targets, peak velocity also was highest in the middle-aged group and lowest in the oldest group. Though these differences were not statistically significant, they could indicate a trend. The data for the youngest group, again, were between those of the other two age groups.

A lower peak velocity was found for auditorily evoked saccades than for visually evoked saccades [22,24,26,27]. In the studies of Zahn et al. [22] and Zambarbieri et al. [24], the peak velocity of the saccades to auditory targets was lower, although the initial fixation point for the visually (as for the auditorily) evoked saccades consisted of a light-emitting diode. Engelken and Stevens [26] varied the experimental design for saccades to auditory targets and did not find differences in peak velocity but, with regard to saccades to visual targets, found a lower peak velocity. In contrast to these findings is our study: No significant differences were found for the peak velocity between visual and auditory 15-degree saccades in any of the three age groups. The auditory saccades had a weak visual target control. With regard to saccades to visual targets, Becker and Fuchs [29] were able to show that saccades in the dark or in a homogeneous illuminated visual field toward a remembered target had a lower peak velocity than those with a clearly visible target. As the saccades to auditory targets in the studies of Zahn et al. [22] and Zambarbieri et al. [24] were performed in darkness, the light-emitting diode being the fixation point, our result could indicate that for saccades to auditory targets, the illumination of the room is also important, and a visual target control might lead to a higher peak velocity. Therefore, these studies seem to indicate that peak velocity of the saccades to auditory targets is independent of the kind of starting stimulus but rather depends on the kind of target stimulus. In contrast to this is the study of Engelken and Stevens [26], who found no differences in peak velocity for saccades to auditory targets with or without additional light-emitting diodes at the target positions.

Duration

For the saccades to auditory targets, the duration with values between 0.5 msec lay within a very small range; no longer duration resulted from lower peak velocity. Because of the small amplitude similar to the saccades to visual targets, peak velocity was low. In a comparison of older and younger subjects, analogous with visually evoked saccades, if the auditorily evoked saccades at smaller amplitudes were to cause a slighter decrease in peak velocity, the values for the duration (with only a slight decrease of the lower peak velocity) would lie in a range where no differences in duration could be found. This will have to be proved through other studies.

It seems also that for saccades to auditory targets, peak velocity is a much more sensitive parameter than is duration for age-related changes at small amplitudes.

CONCLUSION

Altogether, for all three parameters of the saccadic eye movements to auditory targets, changes for the saccadic eye movements to visual targets were similar. This could imply an almost identical influence of aging on saccades to auditory and visual targets and, if age-related changes of the central nervous system are responsible for the differences of the saccades to visual targets, would mean an involvement of the same anatomical structures for the saccades to auditory targets. Seemingly, either the visual pathway and the auditory pathway both are subject to age-related effects with the same influence on saccadic parameters or the age-related influence on saccadic parameters is so small that different aging processes of either the visual or auditory pathway lead to no (or almost no) alteration of the saccadic parameters. As far as we know, no other studies have addressed the effect of aging on saccadic eye movements to auditory targets. Therefore, further investigation is required to elucidate this issue further.

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