Changes in oculomotor behaviors with aging were studied in normal young and elderly subjects. Saccadic eye movements induced by presentation of a visual target were analyzed. Elderly subjects commonly showed an elongation of the time to locate the target, accompanied by an increase in reaction times (mean increase, 100 ms) and a decrease in saccadic velocities. The decrease in the velocity was particularly notable when a large-amplitude saccade was executed. In spite of the slowed motor responses, most elderly subjects preserved the function necessary to execute a correct saccade toward the visual target. The saccadic slowing was accompanied by an increase in saccade duration. Although a longer time was necessary for elderly subjects to locate the target, the accuracy of the initial saccades was not different from that of young subjects. One group of elderly subjects showed extremely long reaction times. These subjects, displaying no abnormal neurological symptoms, were not able to locate the visual target with initial saccades. They had to execute multistep saccades typically seen in patients with degenerative neurological diseases.

Systemic neurological diseases commonly found in aged patients are frequently accompanied by various oculomotor disorders. Abnormal ocular movements have been reported in patients with olivopontocerebellar atrophy, Parkinson's disease, and progressive supranuclear palsy [6, 8, 12, 15, 23]. In evaluating such patients it is necessary to discriminate abnormal ocular movements caused by a degenerative brain disease from those caused by nonpathological changes in brain tissue associated with aging. Recent studies of the effects of aging on saccadic eye movement have shown a decrease in saccadic velocities [17] and an increase in their reaction times [1]. These studies were, however, primarily concerned with limited variables of individual saccades, and factors such as the accuracy of initial saccades in target location or the effectiveness of corrective saccades have not been evaluated [1, 17]. The present study provides a more detailed description of nonpathological changes in oculomotor behaviors associated with aging. An effort was made to characterize not only the motor behavior of saccades, but also the quality of visually guided saccades, for example, the effectiveness of the initial saccade in target location.

Methods

Visually guided saccades were recorded from 8 young, healthy subjects whose ages ranged from 19 to 26 years, and 24 elderly subjects whose ages ranged from 59 to 82 years. The 24 elderly subjects had no history of any neurological disorders and possessed good visual acuity (better than 0.5) with or without correction. Subjects had no restriction of lateral or upward gape (no Parinaud's sign).

Four elderly subjects were given either hydrochlorothiazide or furosemide because of moderate hypertension. One subject had been treated with isoniazid (INH) and rifampin for inactive pulmonary tuberculosis. Neither sedatives (such as diazepam) nor anti-convulsants were given to any subjects during the examination, however.

Eye movements were recorded in a dark room by using a DC electro-oculograph with an upper frequency limit of 100 Hz after subjects were dark adapted for 15 to 20 minutes. Three silver-silver chloride electrodes were attached to the internal and external canthi of the right eye and the forehead. Visually guided saccades were induced by five light-emitting diodes, which were placed at 10-degree intervals horizontally from left 20 degrees to right 20 degrees on a tangent screen 1.7 m in front of the subject's eyes. After head immobilization subjects were instructed to fixate a visual target. The light-emitting diode target was presented at varying positions in irregular sequences at variable frequencies. As an additional paradigm, the visual target was turned off for 500 ms immediately after a goal-directed saccade had occurred, creating a situation in which the visual feedback signal usable for correcting the final eye position was eliminated. These examinations were finished within 20 minutes to prevent fatigue in the subjects.

Signals of eye position, eye velocity, and visual target positions were stored on magnetic tapes. On analysis, the data signals were played back on a polygraph and a digital memory

From the Departments of *Neurosurgery and Neurology and †Ophthalmology, Hokkaido University School of Medicine, and ‡Nishimaruuyama Hospital, Sapporo, Japan.

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Address reprint requests to Dr Warabi, Department of Neurosurgery and Neurology, Hokkaido University School of Medicine, Kita 15, Nishi 7, Kita-ku, Sapporo, Japan.

Effect of Aging on the Accuracy of Visually Guided Saccadic Eye Movement

Tateo Warabi, MD,* Manabu Kase, MD,† and Takamasa Kato, MD‡
Fig 1. Reaction times of subjects in groups a, b, and c. The mean reaction times and their standard deviations in individual subjects are represented by dots and horizontal bars, respectively. Group means of the reaction times for subjects in groups a, b, and c were 235, 337, and 468 ms, respectively. Note that the reaction times and their variations in subjects in group c were particularly large.

![Reaction Times Diagram](image)

**Fig 2.** (A) Accuracy of visually guided saccades in subjects in groups a, b, and c toward visual target angles of 10, 20, 30, and 40 degrees. The degree of accuracy is expressed by metrics, which are the ratios between the saccade amplitude and the target angle. Note that the metrics values and their standard deviations are almost identical in groups a and b. The metrics values of group c declined when a large angle to the target was used. (B, C) Amplitude distributions of the initial saccades in response to 40-degree target displacements in subjects in groups a, b, and c. The saccade amplitudes were sampled from ten to fifteen saccades of all the subjects of corresponding groups and are expressed as percentages. Note that there was no significant difference in the amplitude distributions between groups a and b, whereas group c subjects showed numerous saccades that were far smaller than 40 degrees.

The reaction times were significantly different among the three groups (t test; p < 0.001).
placements. Note the smaller initial saccades

degrees and did not increase with a larger target angle (b, 2).
The average metrics were 0.95 with a 10-degree target

to target angles of 20 degrees followed by multiple corrective saccades.

Signals

(Ci

Fig 3. (A,B) Responses of a group a subject and a group b subject
to target angles of 10, 20, 30, and 40 degrees. Eye position signals (1) and eye velocity signals (2) are superimposed. Note that the saccade of the group b subject reached its peak velocity at 20 degrees and did not increase with a larger target angle (b, 2).

(C) Responses of a group c subject to two 40-degree target displacements. Note the smaller initial saccades of about half the target angle followed by multiple corrective saccades.

these saccades often fell short of the target by roughly 10% of the target angle. For instance, when the target jumped 40 degrees, most saccades fell between 35 and 41 degrees in groups a and b (see Fig 2 B,C). The amplitudes of saccades in group c were smaller than those of groups a and b, however. This difference was more prominent when a larger target angle was used. The average metrics were 0.95 with a 10-degree target angle but 0.78 with 20-degree, 0.61 with 30-degree, and 0.52 with 40-degree target angles. The standard deviations in group c were always larger than those in the other groups (see Fig 2). When the target jumped 40 degrees, initial saccades in group c ranged widely, from 3 to 41 degrees (see Fig 2C). Figure 3C shows typical examples of saccades of a subject in group c in response to a 40-degree target angle. The target was located by two saccades of about half the target angle followed by two or three smaller corrective saccades.

Velocities and Durations

Changes in the maximum velocities during saccades of different amplitudes are shown in Figure 3. In group a the maximum velocity increased when a larger saccade was executed (Fig 3A). Interestingly, however, in 8 elderly subjects belonging to group b, a maximum velocity of 400 degrees per second was reached during 20-degree saccades, as shown in Figure 3B, and the maximum velocity did not increase any further in association with saccades of larger amplitudes. The velocity during larger-amplitude saccades formed a plateau rather than a peak, as seen in the example of velocity curves in Figure 3B, graph 2. Figure 4A shows amplitude/velocity curves in groups a and b. The average velocities in saccades to 10, 20, and 40 degrees of target angle and their standard deviations in the two groups are shown. The means and standard deviations of the maximum velocities for 10-, 20-, and 40-degree saccades were 306 ± 51, 408 ± 57, and 508 ± 76 degrees per second, respectively, in young subjects. In contrast, those in aged subjects were 300 ± 63, 391 ± 65, and 464 ± 89 degrees per second. For 10-degree and 20-degree saccades, there was no significant difference in the maximum velocities of the two groups (t test; p > 0.05). For 40-degree saccades, however, the maximum velocities in group b were significantly smaller than those in group a (p < 0.001). The maximum velocities were significantly smaller in group b even when smaller saccades (36 to 38 degrees) toward 40-degree target displacements were compared (group a, 514 ± 60 degrees per second; group b, 461 ± 89 degrees per second; p < 0.001). This finding is due to the contribution of a group of subjects whose maximum saccadic velocity reached a plateau during saccades larger than 20 degrees.

The relation between saccade duration and maximum velocity was analyzed for both young and aged subjects. The inverse relationship between those two variables was similar in these two groups, and, when plotted on a scatter diagram, the data points obtained from the two groups overlapped along a regression line (Fig 4B). Regression lines for 20-degree saccades and 40-degree saccades were γ = -4.14x + 686.4 (r = -0.94) and γ = -2.75x + 813.9 (r = -0.96), respectively. The elderly subjects of group b were classified into two age groups, younger than 69 and older than 69. The mean maximum velocity and saccade duration in response to 40 degrees of target shift calculated from the 7 subjects less than 69 years of age were 499 degrees per second and 113 ms, respectively. They were not significantly different from those of young subjects (p > 0.3). The maximum velocity and duration obtained from the 13 subjects in group b more than 69 years old were 428 degrees per second and 141 ms, respectively. They were significantly different from those in the other two groups (p < 0.001), showing that the saccade velocity was smaller and duration greater in this group. As already described, the visually guided saccades were severely impaired in the subjects in group c, indicated by the long reaction times and low metrics values. The relationship between velocity and duration was

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within the range of that found in other elderly subjects, however. In Figure 5 the maximum velocity/amplitude relationships for subjects in groups b and c are plotted together. There was no difference in the distributions of these values in the two elderly groups.

**Corrective Saccades and Final Eye Position**

When the initial saccades fell short of the target angle, corrective saccades followed with latencies of 130 to 230 ms in groups a and b. In group c these intersaccadic intervals between the initial and the corrective saccades were much more variable, ranging from 60 to 1,200 ms. Half the intervals were longer than 230 ms. The intervals between saccadic onsets, for both initial and corrective saccades, were longer than 200 ms in 85% of cases.

In both groups a and b, after a target was attained with saccades, fixation was steadily maintained in most cases regardless of the presence or absence of the visual target after the saccade (Fig 6A,B). In group c, however, the eye position drifted toward the primary position following the saccades, with constant velocities of about 6 degrees per second, when the target light was turned off (Fig 6C,D). Similar drift was sometimes observed in groups a and b; in these cases the eyes drifted with a variable velocity of less than 2 degrees per second, less than the drift speed of group c. In group c the continuous eye drift persisted throughout the darkness, although corrective saccades occurred when the target was turned on again (see Fig 6C).

**Discussion**

Most elderly normal subjects (except those in group c) asked to look at a visual target presented in a dark room were able by the initial saccades to bring the image of the target as close to the fovea as were young subjects. The metrics [5, 11, 14, 19], the ratio between saccade amplitude and target angle, were not different from those of young subjects. It appears, therefore, that the fundamental functions necessary for programming the appropriate size of a saccade are well preserved in the elderly subjects. There were subjects (group c), however, who had great difficulty in locating the target with the initial saccades. Particularly when a large-angle saccade (for example, 40 degrees) was required, several saccades of about 15 degrees and smaller corrective saccades were repeated until the target was located. The metrics were, therefore, extremely small and variable. Even when the target was successfully located, these subjects showed difficulty in maintaining the peripheral eye position in the darkness, and the eyes drifted toward the primary position at a fairly constant velocity, suggesting a lack of absolute target position information in space [10, 16, 20].

The multistep saccades of these subjects (group c) were not due to fatigue, because the intervals between the successive saccades were in most cases longer than 200 ms and the saccades were not the so-called double
saccades that are known to appear as a result of fatigue [2, 3]. The results were identical even when tests were conducted on different days. These subjects were 67 years old or older and showed normal findings, not only in physical and neurological examinations, but also on computed tomographic scannings. The multistep saccades have been seen in patients with Parkinson's disease, progressive supranuclear palsy, and olivopontocerebellar atrophy [6, 8, 12, 15, 23]. The present study suggests that these abnormal eye movements can occur in subjects without any signs of neurological disease. It is possible, however, that the oculomotor symptom may be the first sign of a latent degenerative neurological disease. In considering nonpathological changes in oculomotor behaviors in association with aging, it appears more appropriate to deal only with the subjects of group b in the following discussion.

The most prominent change in saccades in group b was elongation of time to acquire target, which resulted from an increase in reaction times and a decrease in saccadic velocities. The reaction times of elderly subjects were, on the average, 100 ms longer than those of younger subjects. This value is larger than that (45 ms) reported by Abel and colleagues [11]. We attribute this discrepancy to the difference in the angles of saccades tested [9, 18]. We sampled the data only from 20-degree saccades selected from among those of various angles tested in random sequences. The data of Abel and colleagues [1] are based on all successive saccades of different angles smaller than or equal to 30 degrees.

The elongation of saccades in group b subjects was always accompanied by a decrease in the maximum velocities of saccades. There were, however, young subjects whose saccadic velocities were slower than those of group b. There were also subjects 80 years old or older whose maximum velocity almost corresponded to the fastest speed of the young subjects. Allowing for all these variations in individual subjects, the curves of the saccadic velocities of elderly subjects overlapped those of young subjects (control) whose values were almost comparable to those reported by other authors [4, 9, 13, 14]. When the target angle was 20 degrees or less, the distribution of the maximum saccadic velocities of group b did not differ significantly from those of group a. This finding is in agreement with the results of Abel and colleagues [1]. When the saccade angle was 40 degrees, however, the velocities of group b were significantly smaller than those of group a (p < 0.001). This finding agrees with the data of Spooner and co-workers [17]. A significant difference in the maximum saccade velocity of elderly subjects became prominent only when a large saccade (40 degrees) was induced. Despite the marked decrease in velocity, the accuracy of the initial saccade, expressed by the values of metrics, was well preserved in the elderly subjects. In both young and elderly subjects, the maximum velocities and the accompanying durations were inversely related, relationships expressed by fairly straight lines when the saccades were directed to the same visual target (see Fig 4B). The slowing of saccades was accompanied by an elongation of the du-

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**Fig 5.** The maximum velocity/saccade amplitude relationships in groups b and c. The data points represent individual saccades of a group b subject (circles) and a group c subject (triangles). Note that the distributions are almost identical in groups b and c.

**Fig 6.** The target light was blacked out for 500 ms from the onset of the initial saccades. Five executions of saccades by a group b subject are superimposed in (A) and (B) (A, eye position; B, eye velocity). Corrective saccades always occurred following the reappearance of the target. Two multistep saccades by a group c subject are superimposed in (C) and (D) (C, eye position; D, eye velocity). Centripetal eye drifts, indicated by straight lines in C, took place following saccades, and corrective saccades occurred after the reappearance of the target.
ration, resulting in a normal-size saccade, which was seen in the young subjects. This finding indicates that the function of the brain that programs the appropriate size of the saccade, a function necessary to bring the target image on the fovea, is relatively well preserved in the elderly subjects. It indicates also that the central nervous system, by utilizing internal feedback mechanisms [21, 22], can lengthen the duration of the saccade to bring it on target even though its velocity is decreased. Changes in the saccade velocity/duration relationship observed in group b are considered to be an outcome of a distinct age-dependent plastic process, but one within the realm of physiological saccadic functions.

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References

Correction
In the letter "Aphasia/Apraxia and Familial Aggregation in Alzheimer's Disease" published in the June 1984 issue (Ann Neurol 15:614–615, 1984), two of the three authors' names were not given. The authors are John C. S. Breitner, MD, Diane Powell, MD, and Marshal F. Folstein, MD.

Correction
In "Measurements In Vivo of Parameters of the Dopamine System," by A. M. Friedman et al, which appeared in "Research Issues in Positron Emission Tomography," a supplement to the April issue (Ann Neurol 15 (suppl):S66–S76, 1984), an error appears in equation 6, page S67. The equation should read:

\[ Y_a = \frac{1}{1 + \frac{1}{K_a(A_0 - X)} + \frac{(B_0 - Z)K_b}{K_a(A_0 - X)}} \]