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THE EFFECTS OF AGE ON NORMAL SACCADIC CHARACTERISTICS AND THEIR VARIABILITY

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Abstract—Age effects on human saccadic eye movements were tested with infrared reflectance oculography in 34 subjects. In contrast to a prior report, only a slight non-significant change was observed in saccadic velocity and duration. An increase in saccadic latency comparable to that found in several previous reports was observed, however. All parameters showed considerable intersubject variability for both age groups. Decreased velocities or increased durations outside of these normal, broad ranges should be regarded as pathological for all subjects; they are not physiological effects of the aging process.

INTRODUCTION

Quantification of eye movement characteristics is both a productive method for investigation of the neural control of motor activity and a useful technique for the determination of dysfunction in a wide variety of neurologic conditions. For example, measures of saccadic latency, accuracy, peak velocity, and duration have all been studied in an effort to understand the normal ocular motor mechanisms and the ways in which they are affected in various disease states. Evaluation of abnormal response first requires accurate knowledge of what constitutes normal behavior. Previous studies (Dodge and Cline, 1901; Boghen *et al.*, 1974; Baloh *et al.*, 1975; Bahill *et al.*, 1975; Schmidt *et al.*, 1979; Bahill *et al.*, 1981) have attempted to characterize normal ranges for the parameters listed above. Disagreements exist concerning the range of normal variability. An additional problem is the significant disparity among the ages of subjects used in various normal studies as well as the ages of many of the patients seen for ocular motor evaluation. Normal subjects' ages have usually been in the range of 20–45 yr, reflecting the population most easily available in a research environment. In contrast, many patients evaluated for neurologic disorders are elderly. A logical concern has been whether the norms derived from young subjects were applicable in older patients. Sharpe and Sylvester (1978), Spooner *et al.* (1980) and Karlsen *et al.* (1981) address the effects of age upon smooth pursuit eye movements, but only Spooner *et al.* (1980) examined its effects upon saccades. Since evaluation of fast eye movements is a significant part of our ocular motor tests, we decided to investigate the effects of age on saccades more fully.

METHODS

In order to investigate the effects of age on saccadic eye movements we measured saccadic magnitude, peak velocity, duration, and latency in populations of young and old normal subjects. All were neurologically and ophthalmologically normal except for refractive error; none were taking medication, except for antihypertensive drugs in several of the older subjects. Eye movements were recorded using the infrared reflectance technique with a full system bandwidth (both position and velocity) of d.c.-100 Hz. Eye movements were displayed on a Siemens-Elema Model 803 Mingograf. Stimulus presentation and data analysis were done using a Digital Equipment Corporation MINC-11 computer. The test protocol was as follows: the subject was seated at the center of a 5 ft radius arc on which red light-emitting diodes were mounted. He was fitted with the infrared spectacles and a vertical EOG lead. A headrest and chin support were used. Using the analog recording system, the infrared system was adjusted for symmetry and linearity over the range of ±20°. Thereafter, stimuli were under computer control. Calibration lights at ±20° were presented to set the scale factors for the recording program. Data acquisition was performed in real time with A/D conversion of analog signals at a sampling rate of 200 Hz. Saccades were then elicited to and from primary position with target amplitudes of ±1°, 3°, 5°, 10°, 15° and 20°; 30° saccades were obtained by sequential illumination of the ±15° targets. Stimulus presentation order was randomized to reduce anticipation. The interstimulus interval was 3 sec. A total of 280 saccades were elicited during a session. The two eye position channels and, for blink detection, the a.c.-coupled vertical EOG lead, were digitized at a sampling rate of 200 Hz/channel. If a deflection in the EOG lead was found within the sampling period of the eye movement, those data were not stored and the trial was repeated. The subjects were given frequent verbal encouragement to maintain alertness. During the entire recording session eye movements were visually monitored on the Mingograf; if significant periods of inattentiveness were seen, the subject's data were discarded. If only a few saccades appeared grossly abnormal, they were removed using an off-line data inspection program. This was done by looking at the subject's velocity-amplitude scatter plot and deleting from the data file saccades lying far out from the rest of the points. Since isolated grossly glissadic saccades were conspicuously slow (Schmidt *et al.*, 1979), they were easily seen on scatter plots of saccadic velocity versus amplitude and could thus be identified for removal. Otherwise, all data were included for subsequent analysis, as we feel that it is important to include the entire range of normal behavior in a normal data base. A test session lasted about 35 min, depending on the number of targets repeated due to blinks; set-up consumed 15–20 min of the 35 so that the actual test took only 15 min.

All of the programs used in this study were written entirely in Fortran IV and run under the RT-11 operating system on the MINC. The stimulus presentation and data acquisition program stored the digitized saccade and 0.125 sec of the record on either side of the saccade (the beginning and end of the saccade were defined at the points at which eye velocity exceeded and dropped below 5 deg/sec, respectively). The program also computed and stored the saccadic latency. The data were stored in two floppy disk files, one for each eye.

An off-line analysis computed the saccadic magnitude, velocity and duration. These data were stored in four files; one for each eye in each direction. The algorithm used to compute the velocities required that the data be digitally filtered at 1/4 the sampling rate, which served to further filter the data (Bahill *et al.*, 1981) so that the saccadic velocities were computed at an effective bandwidth of 50 Hz. This bandwidth is lower than optimal but the resulting velocities were comparable to those measured at 100 Hz using analog techniques, since it has been shown that most of the energy of a saccade lies below 50 Hz (Abel, *et al.*, 1979).

The four files created by the analysis program in turn served as the input to various statistical and graphics programs. These enabled us to examine the saccadic characteristics of individual subjects and of various subject groups. The resulting comparisons provide the basis for the remainder of this report.

RESULTS

Of the 40 individuals recorded in this study, 23 were included in the "young" group (18–37 yr old, mean = 2.57, SD = 4.7 yr) and 11 in the "old" group (59–87 yr old, mean = 72.0, SD = 7.9 yr). Three subjects' ages fell between these two groups; the remaining subjects were excluded from the study on the basis of grossly abnormal eye movements (e.g. severe and consistent hypometria) or obvious signs of pronounced fatigue (e.g. repeated failure to make saccades in response to target movement, long periods of greatly slowed saccades, self-reports by the subjects of falling asleep). No age trends were seen in the subjects who were excluded.

In agreement with the results previously reported by this laboratory and others (Boghen *et al.*, 1974; Schmidt *et al.*, 1979; Ishikawa and Terakado, 1973; Jürgens *et al.*, 1981), a wide spectrum of saccadic characteristics was seen in the normal population. As has been previously found, individual subjects recorded on separate occasions show reproducible saccadic velocity-amplitude profiles. The range of responses seen in both the young and old populations, however showed great variability. This is well illustrated by examination of the saccadic velocity-amplitude relationship. An example of a scatter plot produced by a typical subject is shown in Fig. 1. The curve shown is a best mean-square fit of an equation of the form VEL = $V_{\max}$ [1-exp($-$AMP/C]. Where VEL = velocity, AMP = amplitude, $V_{\max}$ = asymptotic velocity, and C = a constant. $V_{\max}$ and C were varied to find the minimum error, using a brute-force method. Curves of this form were found by Baloh *et al.* (1975) to provide the best fit to saccadic velocity-amplitude data. To illustrate the wide variability of both age groups, the curves for the fastest and slowest young and old subjects are shown plotted together in Fig. 2. It is interesting to note that for saccades less than 17° our fastest subject was 79-yr old. Coincidently, the slowest young and old subjects' data were best fitted by the same curve. The wide spread of velocities for saccades of a given amplitude is readily apparent.

In order to compare the behavior of the two age groups, saccades were grouped in 1° bins, with means and standard deviations calculated for velocity and duration of each bin. The results are shown in Fig. 3, with curves fitted to the two means. The younger group was only slightly faster than the older; only for one bin were the differences significant at the 0.05 level for velocities below 20° (Student's two-tailed *t*-test). Similarity, comparison of group saccadic durations showed no significant ($P < 0.05$) differences. For saccadic latency, values for all saccades for the two age groups were pooled. The mean for the young subjects was 229.8 msec (SD = 62.5 msec) and for the old subjects 275.2 (SD = 74.7 msec). This difference *was* significant at better than the 0.05 level (Student's 2-tailed *t*-test).

DISCUSSION

Our most notable finding is that, although there is a decrease in overall saccadic velocity with age, it is

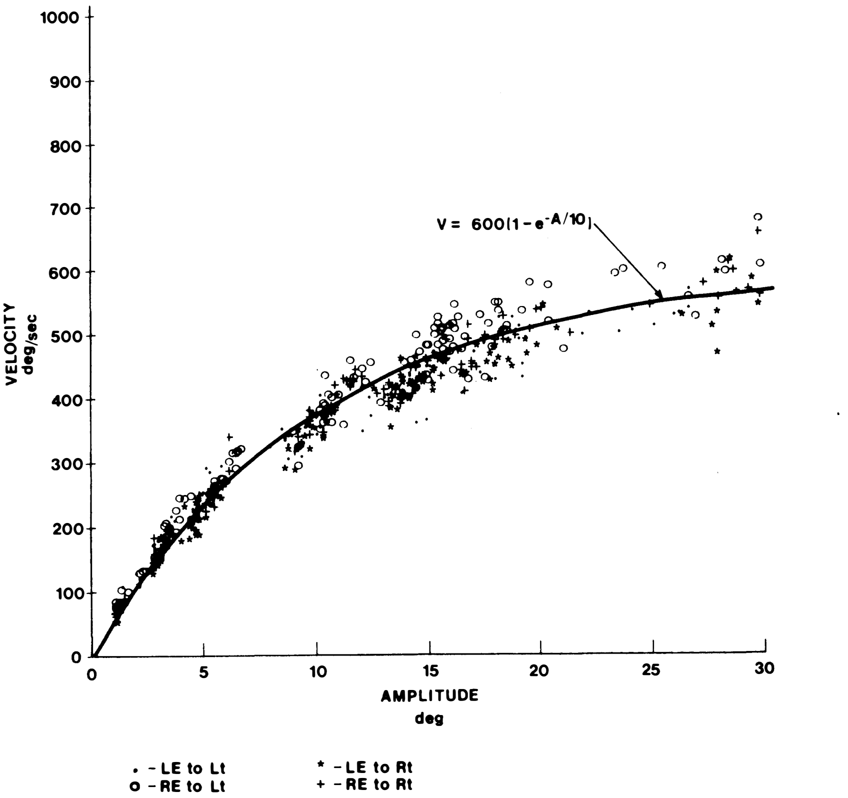

Fig. 1. Typical velocity-amplitude plot and best mean-square fit curve for a 37-yr old subject.

very small. This can be seen both in the degree to which the curves in Fig. 3 overlap and in the similarity between the coefficients of the curves fitted to the pooled data for the young and old groups. A similar condition holds for saccadic duration. The virtual absence of statistically significant differences between the averaged data for the two age groups further reinforces the point. The small systematic difference seen in the curves of Fig. 3 (young subjects being slightly faster than old and having slightly smaller standard deviations) is of no practical importance, since the two groups overlap to such a degree. The only possible discrimination that could be made from these data is that a very slow young subject would possibly be suspect. However, since this study includes several normal individuals whose data lie more than one standard deviation from the group mean, even this is of minimal relevance. The expected inference, that a slower norm would be appropriate for eldrely patients, cannot be drawn.

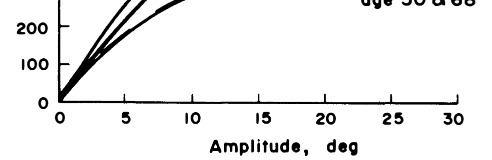

Fig. 2. Best-fit curves for our fastest and slowest young (heavy lines) and old (light lines) subjects.

This is in marked contrast to Spooner *et al.* (1980) who found a considerable decline in saccadic velocity with age. This discrepancy is all the more striking because the methodological differences between the two studies were such as to have made the present one more sensitive to an age effect. Our subject groups were non-overlapping and much farther apart in mean age. Each of our subjects made four times as many saccades. We used infrared reflectance instead of the less stable and less precise bitemporal EOG. All of these differences would have led us, *a priori*, to expect that our study would have been more likely to detect a dependence of saccadic velocity upon age. The reason for the disagreement between the two studies remains undetermined. Our results agreed with Henriksson *et al.* (1980), who found no consistent variation of saccadic velocity with age; as in our study, they also had elderly subjects who made faster saccades than their young ones.

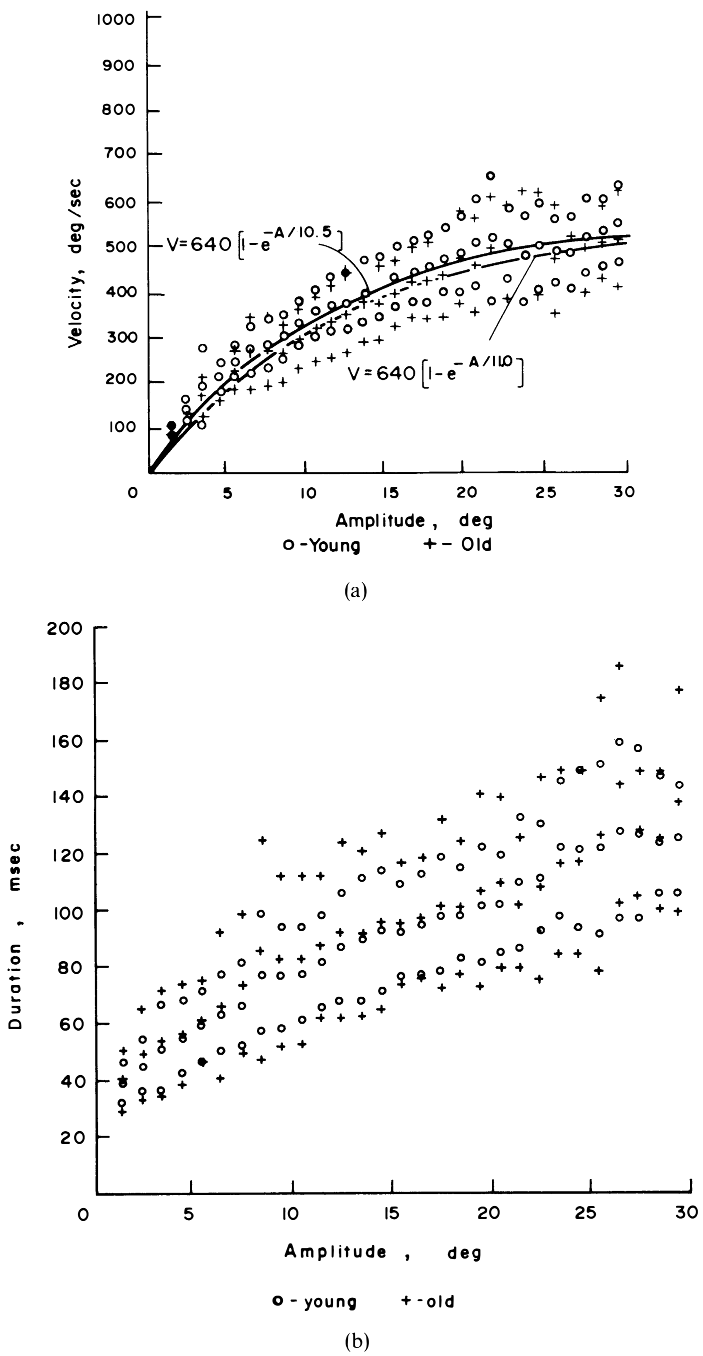

Fig. 3. (a) Group means and 1 SD for the velocities for the two age groups. Curves fitted to the two sets of means are shown. (b) Group means and 1 SD for durations.

In contrast to the relative independence of velocity from age, we found, as have many investigators (Spooner *et al.*, 1980; Pirrozolo and Hansch, 1981; Iacono *et al.*, 1981), that saccadic latency increases with age. Our difference of 45 msec between age groups agrees well with the changes reported in these studies. This increase in saccadic latency is consistent with the lengthened reaction times for other motor tasks found in the elderly (Potvin *et al.*, 1980).

Another finding of interest was that both young and old populations showed wide ranges of response. This can be seen in the illustration of the fastest and slowest subjects for the two groups (Fig. 2) or in the standard deviations of the group mean velocity data (Fig. 3). This variability has been a consistent feature of every normal study undertaken in this laboratory (Boghen *et al.*, 1974; Schmidt *et al.*, 1979), and is in agreement with the range of responses found by most other investigators (Baloh *et al.*, 1975; Jürgens *et al.*, 1981; Ishikawa and Terakado, 1973). Indeed, given the variable nature of biological processes in general, it would be surprising if saccadic velocity was somehow uniquely standardized for all individuals. Reports showing a tight clustering of saccadic velocities (Bahill *et al.*, 1975) have used different graphic presentations (e.g. log-log instead of linear plots) and have involved different criteria for inclusion of data (Bahill *et al.*, 1975; Bahill *et al.*, 1981). In our studies we have only excluded the occasional extreme outliers found for a few subjects' peak velocity plots; this usually indicated that the subject had ceased attending to the task. Otherwise, all saccades were included, as they reflected the normal variety of outputs of the ocular motor system (Jürgens *et al.*, 1981). Even a perfectly functioning brainstem produces saccades with slight pulse-step mismatches. Given the vast number of saccades normally made in the course of a day, the response variations seen in a study such as the present one do not reflect true, neuromuscular fatigue of the ocular motor system. They are, rather, reflections of the idiosyncratically variable nature of this biological system. Some individuals' saccades were virtually all alike; others' were of a wide range of velocities. Other investigators have been concerned about fatigue (Bahill and Stark, 1975). An example of what effect mental fatigue ("tiredness") has on saccades may be seen in Schmidt *et al.* (1979). The wide range of saccadic velocities seen in both young and old subjects cannot be ascribed to apparently slow saccades in fact being composed of two closely spaced, smaller saccades as has been suggested by Bahill *et al.* (1981). Inspection of the records of several of our slower subjects (including the subject discussed by Bahill *et al.*, 1981) showed only occasional instances of such closely-spaced saccades at 30° and none at 20° or less, the amplitude under discussion. That our recording system is fully capable of resolving such movements is evidenced by our identification of multiple, closely-spaced saccades in ocular myasthenia (Schmidt *et al.*, 1980a; Schmidt *et al.*, 1980b). There simply exist some normal individuals who make fast saccades and some who make slow ones.

This latter fact, coupled with the very weak effect that aging has on saccadic velocity or duration, means that an omnidirectional slowness of saccades can be considered to be a likely indicator of pathology only in extreme cases; a more certain sign of dysfunction is a directional asymmetry of velocity. This point has been made by Spooner *et al.* (1980) for the elderly; we wish to stress that it holds as well for the young.

The combination of a small effect of aging upon velocity and a stronger one upon latency may indicate that the brainstem saccadic generator is relatively unaffected by age but that the higher centers involved in programming saccades to deteriorate somewhat. Additional support for this comes from the impression gained from viewing the scatter plots: the younger subjects as a group made more accurate saccades than the elderly. This question is the subject of further study in this laboratory.

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REFERENCES

Abel L. A., Bahill A. T. and Troost B. T. (1979) Frequency characteristics of the human electro-oculographic response. *Soc. Neurosci. Abs.* **5**, 64.

Bahill A. T. and Stark L. (1975) Overlapping saccades and glissades are produced by fatigue in the saccadic eye movement system. *Expl Neurol.* **48**, 95–106.

Bahill A. T., Clark M. R. and Stark L. (1975) The main sequence: a tool for studying human eye movements. *Math. Biosci.* **24**, 191–204.

Bahill A. T., Brockenbrough A. and Troost B. T. (1981) Variability and development of a normative data base for saccadic eye movements. *Invest. Ophthalmol. visual Sci.* **21**, 116–125.

Baloh R. W., Sills A. W., Kumley W. E. and Honrubia V. (1975) Quantitative measurement of saccade amplitude, duration and velocity. *Neurology* **25**, 1065–1070.

Boghen D., Troost B. T., Daroff R. B., Dell'Osso L. F. and Birkett J. E. (1974) Velocity characteristics of normal human saccades. *Invest. Ophthal.* **13**, 619–623.

Dodge R. and Cline T. S. (1901) The angle velocity of eye movements. *Psycholol. Rev.* **8**, 145–157.

Henriksson N. G., Pyykkö, Schalen L. and Wennmo C. (1980) Velocity patterns of rapid eye movements. *Acta otolar* **89**, 504–512.

Iacono W. G., Tuason V. B. and Johnson R. A. (1981) Dissociation of smooth pursuit and saccadic eye tracking in remitted schizophrenics. *Archs gen. Psychol.* **38**, 991–996.

Ishikawa S. and Terakado R. (1973) Maximum velocity of saccadic eye movement in normal and strabismic subjects. *Jap. J. Ophthal.* **17**, 11–21.

Jürgens R., Becker W. and Kornhuber H. H. (1981) Natural and drug-induced variations of velocity and duration of human saccadic eye movements: Evidence for a control of the neural pulse generator by local feedback. *Biol. Cybernet.* **39**, 87–96.

Karlsen E. A., Hassanein R. S. and Goetzinger C. P. (1981) Age and sex variables in smooth-pursuit eye movements. *E.N.T. J.* **60**, 13–21.

Pirrozolo F. J. and Hansch E. C. (1981) Oculomotor reaction time in dementia reflects degree of cerebral dysfunction. *Science* **214**, 349–351.

Potvin A. R., Syndulko K., Tourtellottte W. W., Lemmon J. A. and Potvin J. H. (1980) Human neurologic function and the aging process. *J. Am. Geriat. Soc.* **28**, 1–9.

Schmidt D., Abel L. A., Dell'Osso L. F. and Daroff R. B. (1979) Saccadic velocity characteristics: intrinsic variability and fatigue. *Aviat. Space Environ. Med.* **50**, 393–395.

Schmidt D., Dell'Osso L. F., Abel L. A. and Daroff R. B. (1980a) Myasthenia gravis: I. Saccadic eye movement waveforms. *Expl Neurol.* **68**, 346–364.

Schmidt D., Dell'Osso L. F., Abel L. A. and Daroff R. B. (1980b) Myasthenia gravis: II. Dynamic changes in saccadic waveform, gain, and velocity. *Expl Neurol.* **68**, 365–377.

Sharpe J. A. and Sylvester T. O. (1978) Effect of aging on horizontal smooth pursuit. *Invest. Ophthal. visual Sci.* **17**, 465–468.

Spooner J. W., Sakala S. M. and Baloh R. W. (1980) Effect of aging on eye tracking. *Archs Neurol.* **37**, 575–576.