Saccadic Velocity Characteristics: Intrinsic Variability and Fatigue

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Saccadic eye movements exhibit a characteristic peak velocity vs. amplitude relationship. As with all quantifications of biological function, there exists an associated intra- and intersubject variability of this relationship. This paper documents this variability and demonstrates both the absence of a predictable short-term "muscle fatigue" effect and the presence of a generalized "mental fatigue" (i.e. tiredness) effect.

A PREVIOUS STUDY from this laboratory of the velocity-amplitude relationships of saccades from 5°-30° in 15 normal subjects uncovered considerable intra- and intersubject variability in peak velocity at each amplitude (2). Bahill and Stark (1) found little intra- and intersubject variability and attributed the observations in our previous study to eye muscle or mental fatigue. They concluded that fatigue occurred during repetitive refixations and caused slowing of saccades. "Fresh," unfatigued saccades were said to fall along a curve of narrow range designated the "main sequence."

The determination of the lower limits of velocities as well as intra- and intersubject variability is extremely important for the clinical diagnosis of pathologically slow saccades and to monitor improvement. For such determinations, it is imperative that the recording system be of sufficient bandwidth, stable over the recording time of each subject, and repeatable over periods of time which, for some patients, may be months or years.

This short study documents by specific examples the inherent variability present in the normal population and the absence of predictable short-term "muscle fatigue" effects on saccadic velocities—it shows rather an overall slowing due to generalized "mental fatigue" (i.e. tiredness).

MATERIALS AND METHODS

Six normal subjects, four males and two females ranging in age from 8-38, were investigated. All subjects were mentally alert and none had taken any drugs which might affect ocular motor performance. One subject was also recorded when tired. Eye movements were recorded by an infrared reflection device mounted on spectacle frames. The electronics had a total system bandwidth of DC-100 Hz. Velocities were obtained by electronic differentiation of the eye position signal. The infrared system was linear within the ±20° range of eye movements used in this study. Drift was negligible during each recording and, even if it were not, would not have affected velocity measurements. Calibration was done for each eye individually, while the other was occluded. The system used has been reliably providing the accuracy and repeatability necessary to enable us to study hundreds of patients over the past 6 years. Many of these have been tested at intervals years apart, and the repeatable demonstration of subtle waveform peculiarities is evidence of the stability of the measurement system over time. The subjects were seated in a modified dental chair with head brace and chin rest. Targets viewed were red light-emitting diodes subtending 1′ of arc mounted on an arc 1.14 m from the subject. Recordings were carried out in subdued light.

Fifteen refixations were made for 5°, 10°, 15°, 20°, 25°, 30°, 35°, and 40° *across-the-center* in both directions. Records were analyzed for saccadic velocity in both eyes in relation to the corresponding amplitudes of the actual saccades made. There is no difference in the peak velocity of an 18° saccade made towards a 20° target, a quite normal occurrence, and one accurately made to an 18° target. The peak velocity (PV) points used to determine the group mean curve represent an average of 75 movements; for each individual's curve, the average of 10 movements.

RESULTS

The best fit ($r^2=0.95$) curve for the mean data (Fig. 1) for all subjects was $PV=134.6A^{0.38}$. For the overall fastest subject, the best fit was $PV=129A^{0.46}$ ($r^2=0.98$) and for the slowest, $PV=50.7A^{0.56}$ ($r^2=0.92$) (Fig. 2a). The standard deviations for both the fastest and slowest subjects were smaller than those of the other subjects. These individual curves are not only significantly dif-

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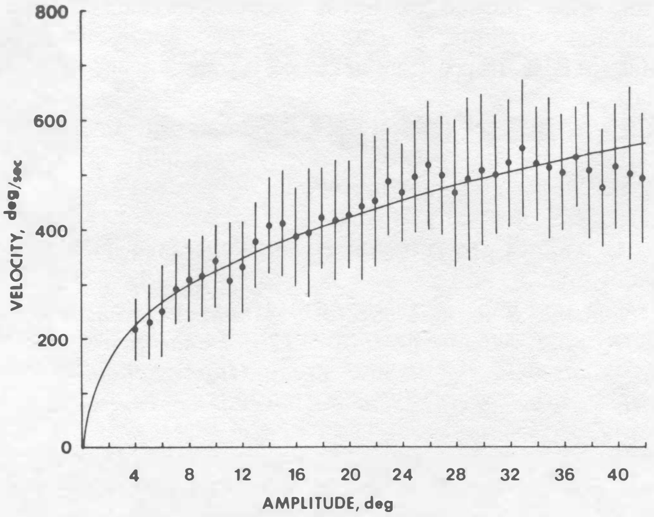

Fig. 1. Mean saccadic peak velocity (PV)-amplitude (A) relationship for six normal subjects. Bars indicate ± 1 S. D. Best mean-square fit curve ($r^2=0.95$) $PV=134.6A^{0.38}$.

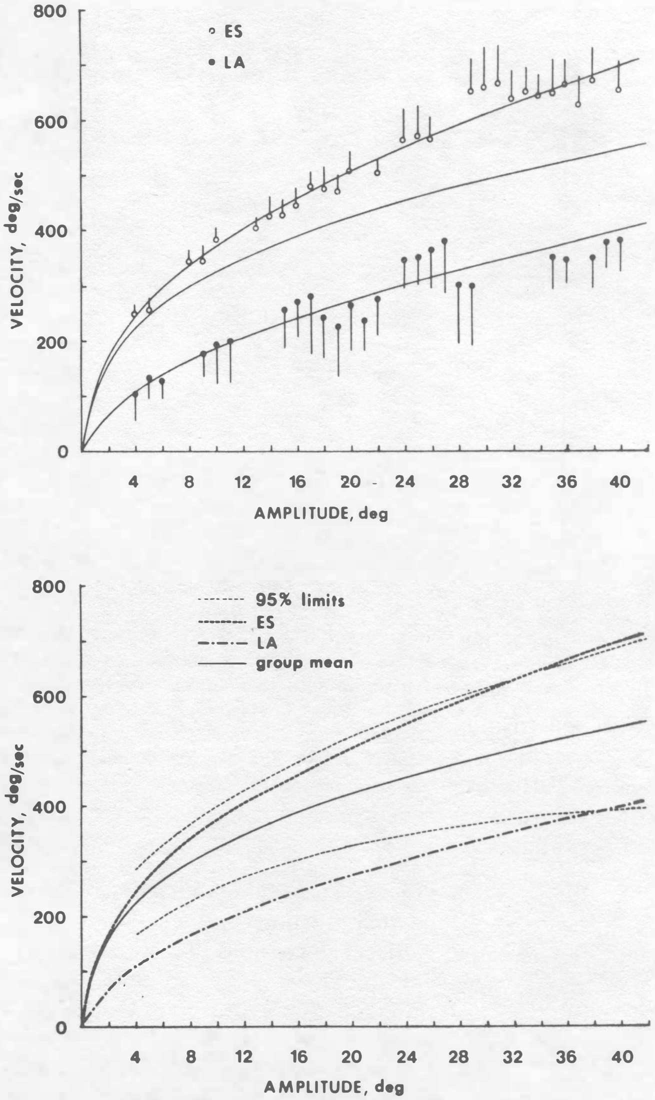

Fig. 2. a. Mean curve shown with data for overall fastest and slowest subjects. Bars indicate ± 1 S. D. Curve for fastest subject ($r^2=0.98$) $PV=129A^{0.46}$; for slowest ($r^2=0.92$) $PV=50.7A^{0.56}$. b. Curves for fastest (ES) and slowest (LA) subjects shown with mean curve and its ±95% limits.

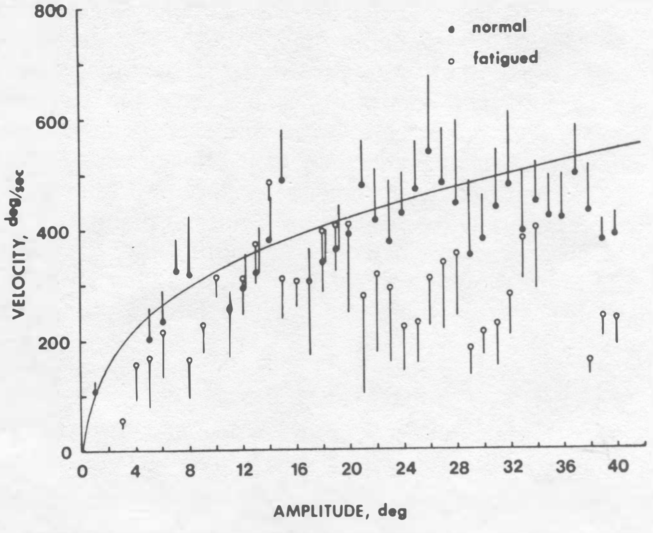

Fig. 3. Data for subject DS taken when he was either mentally tired or alert. Curve is group mean curve; bars indicate ± 1 S. D.

ferent from each other but also from the group mean (Fig. 2b).

Influence of Fatigue: Subject DS was tested twice under different states of mental fatigue. The first investigation was in the afternoon after he had been tested for about 2 h and felt mentally tired. The PV increased slightly for small-amplitude saccades until an amplitude of about 20° was reached. A distinct decrease in velocity then occurred, so that a 38° saccade showed nearly the same PV, with a very small standard deviation, as a 4° saccade (Fig. 3). The second recording, made in the morning when the subject was rested, showed an increasing velocity-amplitude relationship with variable velocities until a plateau beginning at approximately 22° was reached.

To examine the possible effects of short-term muscular fatigue upon saccadic velocity-amplitude relationships, data for the first and last five saccades of each of five amplitudes were averaged for all subjects (Fig. 4). One subject (LA) showed a distinct slowing of saccades at all amplitudes. Another (ES) *increased* in velocity, particularly at 20° and 30°. The group mean varied between decreasing and increasing velocity, depending upon the amplitude.

DISCUSSION

The intersubject variability of saccadic velocity in this study could not be attributed to fatigue since all subjects were mentally alert and followed the same experimental protocol. The data for our slowest subject (LA, Fig. 2) dramatically demonstrates the need to recognize the range of normal variation in saccadic velocities. He has been recorded repeatedly over a 2-year period and has always exhibited the same velocity-amplitude relationship, which is along the lower edge of normal variation that we have found over the years. He has no ocular motor abnormalities discernable by any known clinical tests.

Only in one subject could intrasubject variability be

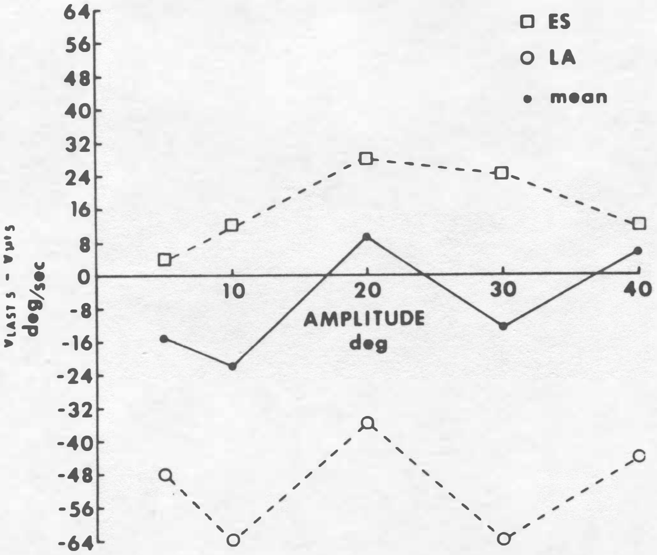

Fig. 4. Difference between average PV of first five and last five saccades of sequence. One subject (LA) consistently became slower; another (ES) became faster; the group showed no consistent trend.

attributed to muscular fatigue (Fig. 4). He had slower velocities at all amplitudes after repetative refixations. The overall group varied with amplitude; no consistent effect of muscle fatigue was demonstrated. If short-term muscle fatigue was a factor in the variability of saccadic velocities, a positive difference in velocities should have been found for all subjects at all amplitudes. The variation in the magnitude and direction of the differences shown for the group in Fig. 4 was evidence that if this type of fatigue was a factor at all, it was an nth order effect obscured by the major factor: intrinsic variability about a long-recognized characteristic curve. It is important to realize that even the Bahill and Stark data, obtained with careful attention at avoiding fatigue effect, when plotted on linear coordinates (3) showed definite variability; the use of log-log coordinates created a false impression of a very tight cluster of the data.

Thus, we feel that muscle fatigue is not the major explanation for saccadic velocity variability. We did demonstrate that mental fatigue (tiredness) could be responsible for marked slowing of all saccadic velocities in a subject with pronounced slowing at larger amplitudes (Fig. 3).

The velocities in this study of normals were higher than that of our previous investigation (2). In the earlier study, we used electro-oculography (EOG) and utilized a calibration curve which only partially corrected for the lower bandwidth necessitated by the EOG. Our present study with infrared recording and a 100-Hz bandwidth still showed slower velocities than that of Bahill and Stark (1), who used a 1000-Hz bandwidth. The differences in velocities cannot be attributed entirely to bandwidth, since Bahill and Stark claimed slower saccades were caused by fatigue and deleted them from consideration thereby skewing their data upwards. The optimal bandwidth is between 100 and 1000 Hz; we have calculated, using Bahill and Stark's data, that 100 Hz yields velocities within 3% of those measured using a 1000-Hz system and that a modest increase in bandwidth to 150 Hz would eliminate any differences.

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