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Some characteristics of saccadic eye movements in children of primary school age

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Abstract. The characteristics of saccadic eye movements have been extensively studied in adults; researches have also been devoted to the saccades of preschool age children. On the contrary, for primary school-age children no data exist; we investigate the eye movements (recorded utilizing an infrared technique) of six children 7 to 11 years old. The main results indicate that the values of some parameters (for example the saccadic latency and duration) are in the same range as the values of the correspondent parameters in adults, while the values of other parameters (in particular peak velocity and mean velocity/peak velocity ratio) are distinctly different from the ones measured in adult subjects.

Introduction

Although the characteristics of saccadic eye movements in adults have been extensively studied [1–6], little research has been directed to these parameters in children [7, 8], specially in those of primary school age.

Saccadic eye movements in adults can be completely defined on the basis of few characteristics. The most important of them are the latency, the amplitude-duration and the amplitude-peak velocity relationships. The saccadic reaction time (latency) in adults is normally approximately 200 ms with a wide interpersonal variation range. The typical amplitude-duration relation can be described by a straight line over a wide range of saccadic amplitudes; the amplitude-peak velocity relation shows an exponential-like [9] or hyperbolic-like [10] trend with a saturation for amplitudes over 20 deg.

Sometimes, to get a more complete description of saccadic dynamics, other relationships such as amplitude-skewness or amplitude-K (that is the mean velocity/peak velocity ratio) are useful.

The skewness can be defined as the rise time/saccadic ratio. It characterizes the differences in the shapes of the velocity profiles. The amplitude-skewness relation shows that small saccades have a rather symmetrical velocity profile (higher values of skewness), while in large saccades the velocity profile is more asymmetrical (lower values). The skewness seems to be a useful extension of the widely used other characteristics as a tool for documenting the dynamic properties of saccades [4].

K can be considered and utilized as an index of the degree of time-optimization of the saccadic system [5]. Since it is slightly dependent on the saccadic amplitude, the amplitude-K relation is nearly constant, and it takes a value of about 0.6 in adult subjects [5, 11, 12].

The main characteristics of saccades in children of preschool age have been studied [7, 8], but the data reported by these authors do not seem totally reliable and have been strongly criticized [13, 14].

Furthermore, to our knowledge, no data about the main characteristics of saccades in children of age ranging from 6 to 18 years exist in the literature. In this report we present our data about the characteristics of saccades evaluated in children of age ranging from 7 to 11 years, being 7 the minimum age in which a correct test can be done.

Materials and methods

We recorded the saccadic eye movements in 6 healthy children (5 females and 1 male) who had neither significant refractive error, nor oculomotor disturbance. The motivation level and the alertness was maintained high by means of continuous incitement to make a good tracking. Following complete description of the procedures used in the study, informed consent was obtained from all the subjects' parents.

All tests were accomplished by means of EIREMA 1 (Eog and InfraRed Eye Movements Analyzer), an original device, built up by our group, based on a microprocessor system controlled by an Apple family PC [15].

We acquired in a single test 70 saccadic eye movements of both eyes in binocular vision. The movements were recorded by means of an infrared bichannel probe using the 'limbus tracking' technique. The signal was low-pass filtered at 100 Hz, by means of an analog 3-pole Butterworth filter, and then sampled at 500 Hz with a resolution better than 0.2 deg.

The acquisition was made in mesopic light condition, with the child sitting one meter in front of a stimulation bar constituted by a semicircular horizontal array of 255 red LEDs; the child's head was held still by a forehead stripe and a chin rest. The visual dot stimulus moved randomly in timing and position with a maximum amplitude, between two adjacent stimuli, of 30 deg in a visual range of ± 25 deg. The time interval ranged between 800 and 1400 ms. Before and after the test we recorded a calibration saccadic sequence by means of which we obtained a linearization curve used to compensate the non-linear relation between eye position and detected signal. The duration of both test and calibration phases was about four minutes, so that the fatigue was insignificant.

After digital compensation of the phase lag introduced by the analogue filter, the eye velocity was evaluated by EIREMA 1 by means of a zero-phase digital filter [16]. A semiautomatic identification of saccade starting and ending times, based on a velocity threshold (fixed to 10 deg/s), was performed by EIREMA 1. Then the amplitude (A), the latency (L), the peak velocity (Vp), the duration (D), the skewness and K were automatically evaluated. Finally, a statistical analysis was performed and the results were plotted on a printer.

The best-fit curve for the amplitude/duration relation was calculated as a linear regression. For the amplitude/peak velocity relation the fitting curve was derived [16] from the following function:

$$\mathrm{Vp} = \frac{1}{\left(\alpha + \frac{\beta}{\mathrm{A}}\right)} .$$

Notice that Vp saturates for $\mathrm{A} \to \infty$ (with a value $\mathrm{Vp} = 1/\alpha$) and decreases for $\mathrm{A} \to 0$ (with slope $= 1/\beta$). All the above reported characteristic were evaluated separately for rightward and leftward saccades.

Results

Latency. The latency mean values $\pm$ 1 SD of the rightward and leftward saccades of each subject are reported in Table 1. The mean intersubject latency value is 204 $\pm$ 47 msec for rightward saccades and 193 $\pm$ 42 msec for leftward saccades (the global mean value is 199 $\pm$ 45 msec). We notice a slight increase of the latency for increasing saccadic amplitude, with little differences among our subjects.

Amplitude-duration relation. A typical amplitude-duration relation, obtained from one of our subjects, is shown in Fig. 1. The values of the intersection with the duration axis (D0) and the slope (D1) of the linear regression curve in all the subjects are reported in Table 2, for rightward and leftward saccades. The regression coefficient (R), which is a measure of data spread, shows high values and thus a small data spread. It should be

Table 1. Latency mean values ± 1 SD

Subject	Age (years)	Latency (ms)	
		Rightwards	Leftwards
DG	7	208 ± 36	195 ± 50
FF	9	196 ± 30	193 ± 46
PP	9	230 ± 64	193 ± 32
TM	9	254 ± 77	231 ± 58
KI	10	173 ± 27	188 ± 36
DA	11	165 ± 24	156 ± 11

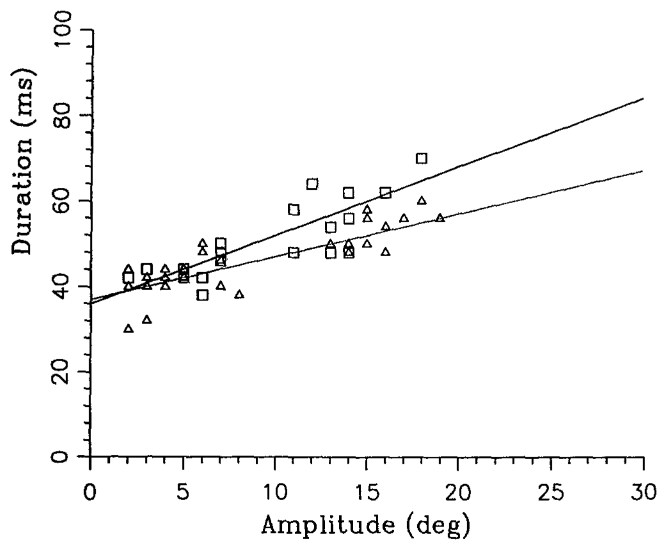

Fig. 1. Typical amplitude/duration relations and their corresponding rightward (square and solid line) and leftward linear regression curves (triangle and thin line). (Subject DG)

noted that D0 is nearly constant both among the subjects and for rightward and leftward movements; the D0 mean values ± 1 SD are 36 ± 2 ms for rightward saccades and 36 ± 3 ms for leftward saccades. Regarding the D1 values, we can observe differences between rightward and leftward movements which increase for greater data scattering (as suggested also by the regression coefficient). Furthermore a wide intersubject variability is present. The D1 mean values ± 1 SD are 2.1 ± 0.4 ms/deg for rightward saccades and 1.9 ± 0.6 ms/deg for leftward saccades.

Amplitude-peak velocity relation. A typical amplitude-peak velocity relation is shown in Fig. 2. The saturation values for the peak velocity ($1/\alpha$), evaluated by means of the best fit curve, and the slope of the same curve ($1/\beta$) for saccades of small amplitudes are shown in Table 3. When we evaluate in the same subject the values of $1/\alpha$, separately for rightward and

Table 2. Mean values of the intersection (D0), of the slope (D1) and regression coefficient (R) of the linear regression curve of the amplitude/duration relation

Subject	D0 (ms)		D1 (ms/deg)		R	
	Rightwards	Leftwards	Rightwards	Leftwards	Rightwards	Leftwards
DG	36	37	1.6	1.0	0.81	0.83
FF	35	31	1.7	2.0	0.67	0.87
PP	36	35	2.3	2.3	0.90	0.82
TM	35	42	1.9	1.1	0.77	0.65
KI	33	35	2.9	2.5	0.89	0.71
DA	39	36	2.1	2.3	0.73	0.91

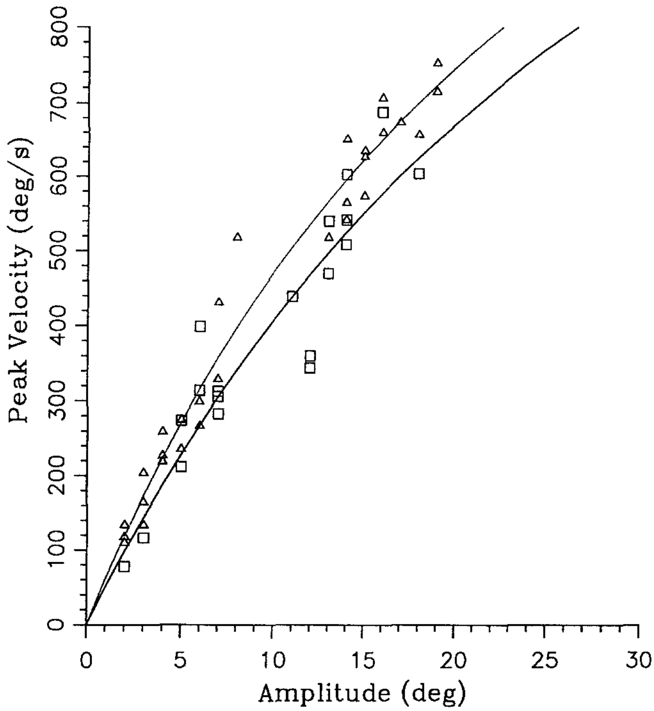

Fig. 2. Typical amplitude/peak velocity relations and their corresponding rightward (square and solid line) and leftward best-fit curves (triangle and thin line). (Subject DG)

leftward saccades, they do not show significant differences between the two directions, while there is a large intersubject variability (Table 3). The same happens for the values of $1/\beta$, but with a small intersubject variability. The mean values of this factor are $61 \pm 10\,s^{-1}$ for the rightward saccades and $66 \pm 8\,s^{-1}$ for the leftward ones.

Amplitude-K relation. The K mean values ± 1 SD of rightward and leftward saccades of each subject are reported in Table 4. The values of K range between 0.42 and 0.49 with a mean value of 0.46 ± 0.07 for both rightward

Table 3. Saturation ($1/\alpha$), slope ($1/\beta$) and regression coefficient (R) of the best-fit curve of the amplitude/peak velocity relation

Subject	$1/\alpha$ (deg/s)		$1/\beta$ (s^{-1})		R	
	Rightwards	Leftwards	Rightwards	Leftwards	Rightwards	Leftwards
DG	1887	1786	52	64	0.54	0.84
FF	1124	901	70	78	0.63	0.78
PP	847	826	63	66	0.86	0.82
TM	2500	2778	54	51	0.34	0.38
KI	617	789	79	62	0.89	0.71
DA	1299	885	50	72	0.56	0.79

Table 4. Mean values ± 1 SD of the mean velocity/peak velocity ratio (K) of each subject

Subject	Mean K (–)	
	Rightwards	Leftwards
DG	0.48 ± 0.05	0.45 ± 0.05
FF	0.47 ± 0.07	0.47 ± 0.06
PP	0.49 ± 0.07	0.46 ± 0.07
TM	0.42 ± 0.08	0.43 ± 0.07
KI	0.47 ± 0.07	0.49 ± 0.08
DA	0.44 ± 0.05	0.43 ± 0.06

and leftward saccades. A typical K-amplitude relation is shown in Fig. 3; K appears clearly independent of the amplitude. We observe that K values vary in a wide interval for all the saccadic amplitudes; its values range from 0.29 to 0.65 among all the subjects, attesting that saccades of the same amplitude can also be realized with different mean velocity/peak velocity ratios.

Amplitude-skewness relation. In each subject we find a large variability of the skewness values for every amplitude, showing higher values for small amplitudes and lower values for large amplitudes. We do not find significative differences in the asymmetry values between rightward and leftward saccades, probably due to the great data variability.

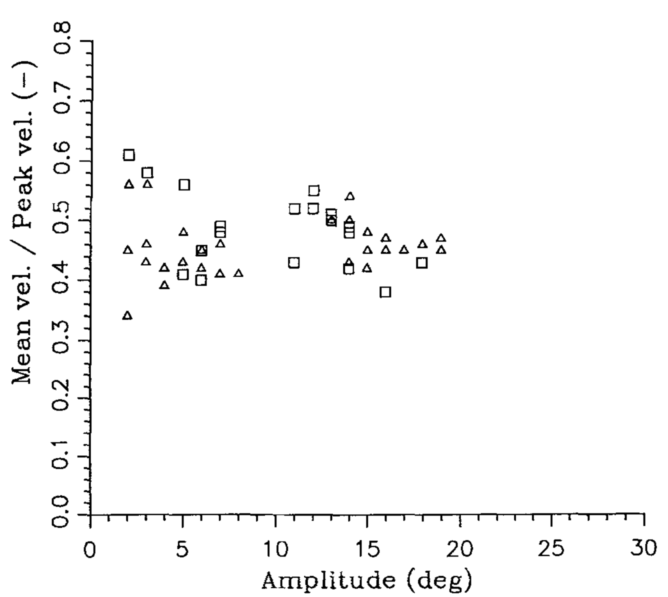

Fig. 3. Typical amplitude/K relations: rightward (square), leftward (triangle). (Subject DG)

Discussion

Almost all the saccadic movements are about of the same amplitude (within 10%) of the target jump, both pointing out no fatigue and a high attentive level in our recordings. In our subjects we find latency values similar to those reported in adults by other authors [17, 18], with a mean value of about 200 ms. Moreover, the latency differences between rightward and leftward saccades are similar to those we found in adult subjects [19]; we reported mean values of 202 ± 37 ms for rightward saccades and 198 ± 35 ms for leftward saccades, with a global mean value of 200 ± 36 ms for the same stimulation pattern. Even the slight increase of the latency for increasing amplitude is in agreement with our previous data [19] and with the data reported by Findlay [20].

In Fig. 4 the mean amplitude/duration relationship, obtained in our subjects and compared to the same relationship reported by other authors [3, 6, 9, 21, 22] in adults, is shown. Our data are well fitted by the linear function: $D = 2^{*}A + 36$ ms (with A in degrees); moreover, when compared to the mean value of adults, the mean value of the intercept with the duration axis (D0) in children occupies an intermediate position, but with a lower slope (D1) than the one reported by other authors, with the exception

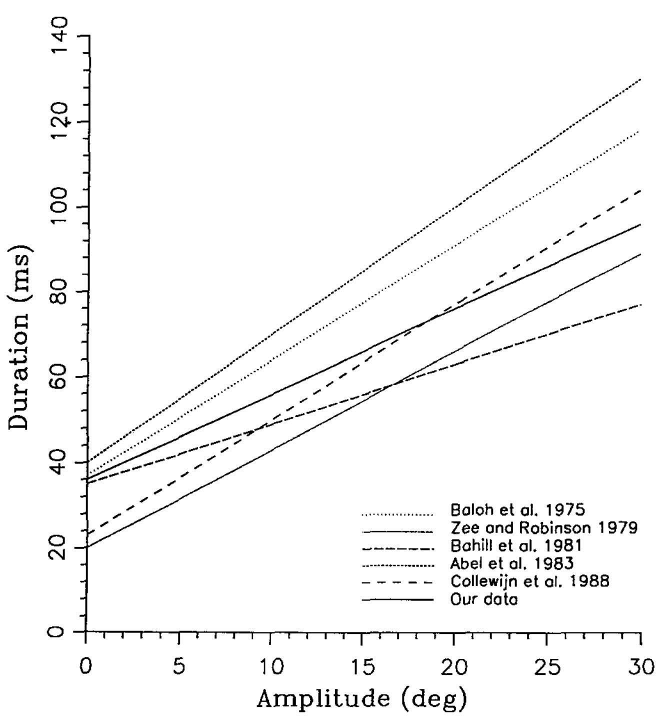

Fig. 4. Comparison of the amplitude/duration relation between adults (reported by other authors) and children (our results).

of Bahill et al. [22]. Concerning the amplitude/peak velocity relationship our data are well fitted by the function

$$Vp = \frac{1}{\left(739E-6+\frac{156E-4}{A}\right)} \text{ deg/s}.$$

In Fig. 5 our best-fit curve is compared to the ones reported by other authors in adults [1, 3, 4, 6, 9, 22]. We find in children a higher initial slope ($1/\beta$) and a higher value of the peak velocity saturation ($1/\alpha$) than in adults, with the exception, relatively to $1/\beta$, of the results reported by Bahill et al. [22] which, as already point out by Collewijn et al. [6], substantially differs from those of all the other researchers.

The mean values of K in our subjects are smaller than those measured in adults by other authors. Baloh et al. [11] report a mean K of 0.6, Inchingolo et al. [5] a mean K ranging from 0.5 to 0.6, van Opstal & van Gisbergen [4] 0.61, and Pelisson & Prablanc [12] 0.63.

Moreover, our data, with respect to the skewness (as previously reported in adults by other authors [5, 6]), show a reduction of the asymmetry for increasing amplitude, but with a much larger data spread.

We notice that the values of some parameters of saccadic eye movements in children (latency and absolute duration values) are totally identical to the

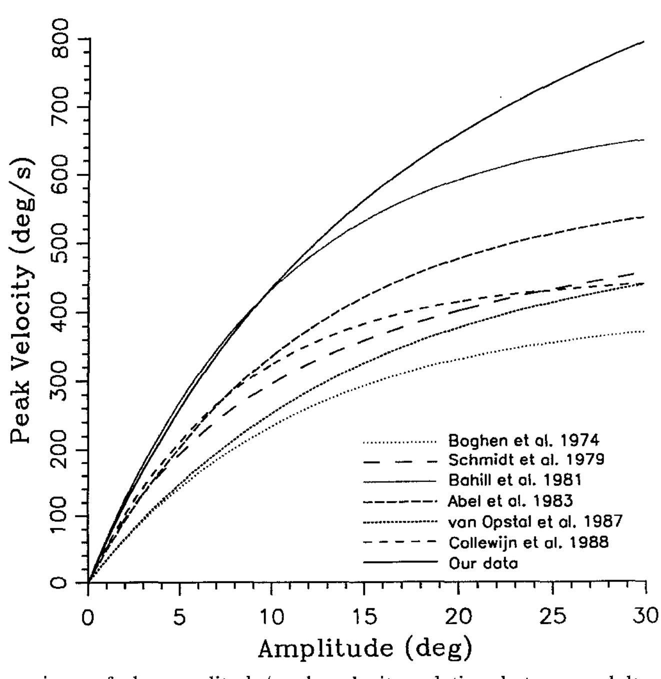

Fig. 5. Comparison of the amplitude/peak velocity relation between adults (reported by several authors) and children (our results).

adult ones, while we find a strong increase in the peak velocity values at every considered amplitude, and a lower slope for the amplitude/duration relationship with respect to the adult ones. Finally, K values in children are lower than in adults and the skewness presents a wider data spread than in adults.

The observation that peak velocity values in children are very high, though duration values are identical to the adult values, induce to suppose the presence of different morphologies in the velocity profiles at the two ages.

This statement is supported by the analysis of saccadic movement morphology in adults (our unpublished data) and in the six children we tested. Especially in the latter group, after an initial phase of the movement, marked by an extremely lower acceleration than in adults, the velocity profile is very narrow, with a much larger slope in the rising phase of the saccade (Fig. 6).

Thus, the duration of this higher-velocity interval is smaller than in adults, also because a final saccadic phase marked by a smaller deceleration is often present. This trend in the morphology of the velocity profile of saccadic eye

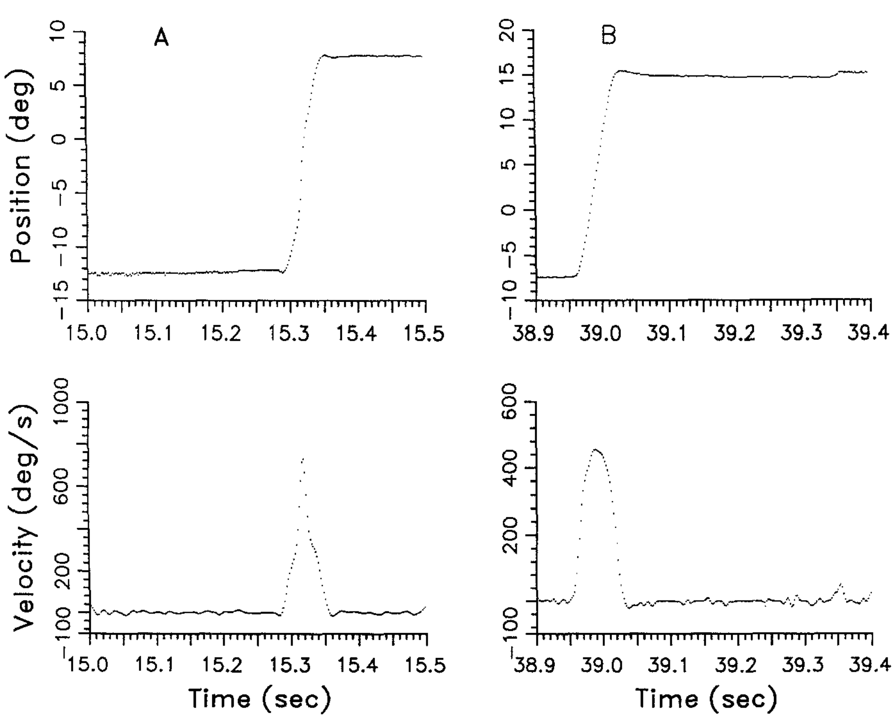

Fig. 6. Saccadic position (top panels) and velocity (bottom panels) profiles in a child (A) and in an adult (B). The morphological differences (low initial acceleration and narrow peak-velocity profile in child) can explain the differences found between the characteristics in the two considered ages.

movements in children, more evident in the subjects (DG, TM, FF, DA) who reached the highest peak velocity values, could probably be due to the morphological and functional differences of the plant.

Summing up our results, the above presented findings show that many characteristics of saccadic eye movements in normal children of age ranging from 7 to 11 years are very similar to the same characteristics in adults; on the other hand we must emphasize the presence of some differences in amplitude/peak velocity relation and in K values.

It must be observed that notwithstanding a certain intersubject variability, the obtained results are homogeneous in their behaviour with respect to adults' characteristics. This fact validates the results themselves even if a small sample was considered.

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