Effect of Saccade Size on Presaccadic Spike Potential Amplitude

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Presaccadic spike potentials were recorded from electrodes placed at the inner canthus and below the eye in ten normal subjects. The responses to twenty abducting and twenty adducting saccades were back-averaged from the beginning of the eye movement, and separate waveforms were obtained for saccades of 20°, 10°, 7.5°, 5.0°, and 2.5°. The spike onset and peak latencies relative to the beginning of the eye movement and the onset–peak amplitudes were measured. Throughout the range of saccade sizes, the onset and peak occurred earlier with adduction than with abduction, but there was no consistent change in the latency values with saccade size. The amplitude, however, showed an increase with saccade size up to movements of 10°, although statistical analysis showed that these amplitude changes were not consistently significant. Comparison of the 20° saccades to the 10° saccades and the 10° saccades to the 7.5° saccades revealed no statistically significant differences in amplitudes. The difference between the 7.5° and the 5° saccades, however, was statistically significant (P < 0.05) but only at the inner electrode with abduction; comparison of the 5° and 2.5° results showed a significant difference (P < 0.01) at the inner electrode with both abduction and adduction. Comparison of the 7.5° and the 2.5° showed a significant difference (P < 0.01) at both electrode sites with abduction and adduction. These findings are discussed with respect to the previously suggested origin of the spike potential and the choice of the recording electrode site. Invest Ophthalmol Vis Sci 30:2521-2527, 1989

The recording of potentials related to saccadic eye movements, particularly the sharp spike potential (SP) that accompanies the onset of such eye movements, has gained interest recently.1-7 There has been some debate as to the nature of this spike potential; some studies have shown a large negative potential maximal in the periorbital region2,3,5,6 while other studies have reported a much smaller positive spike in the parietal region of the head.1,4,7 The difference in the spike potential recorded has been shown to be due, at least in part, to the choice of electrode montage. The small cortical potential generally has been recorded from electrodes on the parietal region of the head, P3 and P4, with linked ear references,1,4,7 while the large negative potential has been recorded from electrodes around the eyes, referred to electrodes on the parietal region of the head.2,3,5,6 The amplitude of the SP recorded from P3 and P4 has been shown to be dependent on the direction of the saccade, with a maximum amplitude recorded over the site contralateral to the saccade direction.6 This potential also has appeared to be affected by the nature of the saccade, with spontaneous saccades showing a grossly altered or absent SP.6 The negative spike potential recorded from around the eyes has not shown the same dependence on saccade direction, since its amplitude has remained constant for equal sized saccades in different directions.2,3,5 This potential has also been demonstrated to be unaffected by the nature of the saccade: voluntary saccades, saccades during reading, and the fast phases of nystagmus all have shown SPs with the same characteristics.2

Recent studies have used electrodes placed around the eyes to examine this sharp negative spike potential.2-5 Early work showed that this presaccadic spike potential begins 15.0–30.0 msec before the onset of the eye movement and reaches a peak approximately 7.5 msec before the eye movement.2 More recent recordings have placed the onset at 4.4–12.0 msec before the saccade, with the peak occurring between the beginning of the eye movement and 7.8 msec afterwards.3 These latencies have been similar at all electrode sites, although the onset and peak have occurred earlier with adduction than abduction.3 The recorded onset–peak amplitude for 20° saccades has been between 32 and 47 μV regardless of the recording site or the saccade direction,5 and initial work suggested that the SP amplitude remains unaltered with saccades of different sizes between 10–40°.5 More recently, it has been found that the amplitude...
increases with saccade size for movements of up to approximately 8–10°, after which further increases in saccade size do not lead to any change in SP amplitude.4 The latter results were found in a small group of subjects in whom only abducting saccades were recorded from an electrode at the outer canthus and for whom no statistical analysis of the amplitude changes were made. A similar relationship has also been demonstrated for the parietal spike potential: an increase in the amplitude for saccades between 2.5° and 10° has been recorded with no change in the amplitude for larger saccades.7 It must be noted, however, that the maximum amplitude recorded in this study for 20° saccades was approximately 9 µV, in contrast to values of between 32 µV and 40 µV for the same size eye movement recorded from the orbital region.

The SP recorded from the orbital region is thought to originate in the extra-ocular muscles—from the motor units,2,5 or more precisely, from the ocular motoneurones that innervate the muscle units.7 The SP has been described as resembling the compound muscle action potential: it may be brought about by a synchronous volley of action potentials generated in the brain stem nucleus and causing nearly simultaneous activation of the muscle fibers of several motor units, which produces the spike potential.8 The reported observations of the effects of saccade size on SP amplitude have been used to support these suggested origins.1,3 It has been suggested that this large negative orbital potential could in fact be responsible for the synchronous positive potential recorded posteriorly, with current flow around the head producing a reversal in polarity around the scalp, maximal at Pz.2

The current study was undertaken to confirm the reported changes in the orbital SP amplitude with saccade size in a larger group of subjects and with statistical analysis of the results. It is important that the reported changes are supported statistically since amplitude is known to be a variable parameter in evoked potential studies, as has been shown to be the case with SP recordings.5 The other SP parameters and onset and peak latencies must also be investigated to determine if their values are affected by saccade size. Since differences have been found between the SP parameters recorded with abducting and adducting saccades, the two movements must be analyzed independently; this analysis should show if any changes found with differently sized saccades are consistently found with both types of movement. Finally, by using electrodes at the inner canthus and below the eye, it can be established whether or not the reported changes are due simply to the choice of electrode recording site.

Materials and Methods

Ten subjects with no known ophthalmologic or neurologic defects and ranging in age from 23–30 yr (mean 25.6 yr) were examined. Informed consent was obtained from each subject prior to the commencement of the investigations. In each subject recordings were made from either the right or the left eye, chosen randomly to give a group of ten eyes, five right and five left. Two electrode sites (at the inner canthus and below the eye) were chosen, with Pz as the reference in accord with previous investigations.1,2,4 The subjects were seated with their heads held steady by a chin and forehead rest. Visually triggered saccades of different sizes were initiated by two horizontally separated, alternately flashing, red light-emitting diodes (LEDs). Separate recordings were made for eye movements of 20°, 10°, 7.5°, 5.0°, and 2.5° in size and the responses to 40 saccades (20 abducting and 20 adducting) were recorded with eye position monitored by electro-oculography (EOG).

The individual eye position traces and the SPs were recorded on separate channels of a Nicolet Pathfinder II (Nicolet, Madison, WI) with a time sweep of 500 msec and a bandpass filter of low cut off 0.50 Hz and high cut off 100 Hz. Each eye position trace and SP were stored on hard disc and, after the recordings, the traces obtained for each individual saccade were recalled and the beginning of the eye movement identified manually with the averager’s internal cursor. This visual examination of the eye position data allowed accurate identification of the beginning of the EOG deflection and hence the beginning of the saccade; if this point could not be identified easily the data was rejected. The computer then back-averaged the SP recordings from the beginning of the eye movements and, for display purposes, aligned the beginning of the saccades at a predetermined and fixed latency. Thus, the latencies of the onset and peak of the spikes relative to the beginning of the saccades could be determined. The results for abducting and adducting saccades were averaged separately. From the averaged traces the following parameters were measured using the averager’s internal cursor: the latencies of the onset and peak of the SP relative to the beginning of the saccade (a negative value indicating a latency prior to the onset of the saccade and a positive value a latency after the onset of the saccade) and the amplitude from the onset to the peak.

Results

For each saccade size the group means and standard deviations (SD) for the latencies and amplitudes were calculated; the data from each electrode site and with abduction and adduction were analyzed sepa-
rately. Figures 1 and 2 show the onset latency (±1 SD) and the peak latency (±1 SD), respectively, plotted against saccade size. The graphs show a clear trend between the onset and peak of the SP and saccade direction. In all recordings the onset and peak of the SP occurred earlier with adduction than with abduction. Two-way analysis of variance was performed on the latency raw data for each saccade size, with saccade direction (abduction or adduction) as the first treatment and electrode site (inner canthus or below the eye) as the second treatment. The difference in the SP onset with saccade direction was found to be significant for all saccade sizes except one, the 2.5° amplitude (20° $F_{1,9} = 2.17$, not significant; 10° $F_{1,9} = 23.16$, $P < 0.001$; 7.5° $F_{1,9} = 42.88$, $P < 0.001$; 5° $F_{1,9} = 8.42$, $P < 0.025$; 2.5° $F_{1,9} = 7.88$, $P < 0.025$). The difference in the peak of the SP was also found to be significant for all saccade sizes except one, the 2.5° amplitude (20° $F_{1,9} = 16.31$, $P < 0.01$; 10° $F_{1,9} = 20.12$, $P < 0.01$; 7.5° $F_{1,9} = 19.9$, $P < 0.01$; 5° $F_{1,9} = 44.74$, $P < 0.001$; 2.5° $F_{1,9} = 4.70$, not significant).

Plotting the onset–peak amplitudes against saccade size also revealed a consistent relationship between the two parameters. Figure 3 shows that the amplitude increased with saccade size for eye movements of up to 10° at both electrode sites with abduction and adduction. Increasing the saccade size to 20° resulted in minimal changes in the amplitudes, with the exception of the lower electrode during adduction, where a further small increase was evident. Investigating these amplitude changes statistically was difficult with parametric statistics since, as shown in Figure 3, the variance of the data changed with saccade size; the standard deviations varied with SP ampli-

Fig. 1. The latency of the onset of the SP (±1 SD) plotted against saccade size. A negative value indicates an onset before the beginning of the eye movement, and a positive value indicates an onset after the beginning of the eye movement. The onset occurs earlier with adduction than with abduction across the range of eye movement sizes, but there is no consistent change in the latency with saccade size.
Fig. 2. The latency of the peak of the SP (±1 SD) plotted against saccade size. A negative value indicates a peak before the beginning of the eye movement, and a positive value indicates a peak after the beginning of the eye movement. The peak occurs earlier with adduction than with abduction across the range of eye movement sizes, but there is no consistent change in the latency with saccade size.

The change in onset-peak amplitude with saccade size could be seen in the group average SP responses, shown in Figure 4. The SP waveform is maintained throughout the recordings with different eye movement sizes; the change is one simply of amplitude reduction. Figure 4 also shows the consistency in amplitude and tended to be smaller with the lower amplitude values. A Wilcoxon's rank sum t-test was used to compare the amplitude data for the different sized saccades at each electrode site and for both abduction and adduction. Comparison of the 20° to the 10° saccades and the 10° to the 7.5° saccades showed no statistically significant amplitude differences at either electrode site during both abduction and adduction. Comparison of the 20° to the 7.5° saccades showed no statistically significant amplitude difference except at the lower electrode with adduction (n = 10, t = 6; P < 0.05). Comparing the 7.5° to the 5° saccades did show a statistically significant difference in amplitude but only at the inner electrode with abduction (n = 10, t = 5; P < 0.05). Comparison of the 5° to the 2.5° saccades showed a statistically significant difference at the inner electrode with both abduction (n = 10, t = 0; P < 0.01) and adduction (n = 10, t = 4; P < 0.01) but no significant difference at the lower electrode. A significant difference at both electrode sites was found in the comparison of the 7.5° to the 2.5° saccades: at the inner electrode with abduction and the lower electrode with adduction, n = 10, t = 0; P < 0.01, while at the inner electrode with adduction, n = 10, t = 4; P < 0.01, and at the lower electrode with abduction n = 10, t = 2; P < 0.01.
Fig. 3. The amplitude of the onset-peak of the SP (± 1 SD) plotted against saccade size. There is a consistent increase in the amplitude with saccade size up to 10° but little change from 10° to 20°, with the exception of the lower electrode on adduction, which shows a small increase with 20° movements.

Discussion

The results show that the differences in SP parameters previously found between adducting and abducting movements were maintained across the range of saccades used in the current study, with the onset and peak occurring earlier with adduction than with abduction. However, these latency differences did not show any consistent change with saccade size. The parameter that did vary with eye movement size was the onset-peak amplitude, which showed the trend of increasing with increasing eye movement size from 2.5° to 10°; this increase did not appear to be maintained with saccades of 20°. Statistical analysis, however, showed that the increase in SP amplitude with saccade size was not always statistically significant; results from the inner electrode with abduction showed the most consistent relationship. The reason for this consistency is not clear, but it could have been related to the position of the electrode, which was close to the fellow eye. When one eye abducted, the other adducted and approached the inner electrode of the abducting eye; this electrode, therefore, also may have recorded signals from the contralateral eye. Previous workers commented on the complications that could be caused by the interaction of the SP with the SP generated by the muscles of the contralateral eye. The interaction is likely to be greater with larger saccade size, an effect that may exaggerate the general trend of increasing amplitude with increasing saccade size.

onset and peak latency values relative to the beginning of the eye movement with different sized saccades.
size. Conclusions on such interaction effects are only tentative, however, since the SPs recorded from the inner electrode were generally not greater in amplitude when compared to the lower electrode and since those obtained with abduction were not larger than those obtained with adduction (Fig. 3). These findings would have been unexpected if the signals from the contralateral eye had been contributing to any great extent to the potential recorded from the inner electrode. The graphic findings support a previous investigation into changes in SP amplitude with saccade size, but show that careful statistical analysis of the results is necessary before any firm conclusions can be reached.

The amplitude values found in this study were considerably larger, for all saccade sizes, than the indicated amplitude values in the earlier study of the effect of saccade size on the cortically recorded spike potential. The smallest mean SP amplitude for 2.5° saccades in the current study was 12.6 μV, while the largest SP amplitude for 20° saccades for the cortical recorded SP was approximately 9 μV. As discussed earlier, Thickbroom and Mastaglia have suggested that the large negative spike may be involved in the production of the posterior cortical potential, and Becker et al. have reported that bipolar recordings in a sagittal line from the chin through the nasion, midfrontal, vertex, and neck show a reversal of potential.

Fig. 4. The SPs recorded at the lower and inner electrodes during adduction and abduction for progressively smaller saccades. The onset and peak latencies and the waveform of the SP are relatively unaffected by the eye movement size, but amplitude clearly decreases with decreasing saccade size. O = the beginning of the eye movement.
between the nasion and midfrontal and another more diffuse reversal between the vertex and the neck. This led the latter workers to suggest that the large negative potential found between the nasion and midfrontal probably has an intraorbital origin. The orbitally and cortically recorded potentials have been given the same name, but in view of the different recording montages used and the large differences in the amplitudes found, it would seem unwise to make any comparisons between these two potentials until their respective origins are better known.

The results of the current study can be used to support the hypothesis of the origin of the SP if the general trend for an increase in amplitude with saccade size up to about 10° is accepted and if the results are compared to the known extraocular muscle activity that precedes saccades. Information about this activity in humans is sparse; Sindermann et al. used electromyography to record the activity of ocular motoneurones from single motor units in the medial and lateral rectus muscles during these movements. The first discharge of the motor units was found to precede the onset of the eye movement by a few milliseconds, and the latency of this initial discharge relative to the beginning of the saccade was found to remain unchanged with different sizes of saccade. In addition, these workers found that the first phase of firing of a motor unit consisted of a burst of rapid discharges, the peak frequency of which occurred at the onset of the burst. This peak frequency was found to increase with increasing saccade size up to approximately 15°, with saturation in the discharge rate thereafter. These findings can be related to our findings that the SP latencies are constant regardless of saccade size while there is a trend for the amplitudes to increase with increasing saccade size up to 10°, with little change thereafter. Such comparisons may support the hypothesis that the origin of the SP lies in the motor units of the extraocular muscles; the SP latency, particularly that of the onset, may reflect the onset of the motor unit discharge that precedes saccadic movements, while the amplitude may reflect the frequency of the motor unit activity at the onset of the burst. Whether the activity reflects that of the motor neuron or that of the muscle fibers cannot, however, be hypothesized from these results.

Whatever the source of the SP, the current results show that future investigations must carefully examine, with statistics, any results before firm conclusions can be drawn and must consider the choice of electrode recording site.

Key words: saccade, amplitude, latency, presaccadic potentials, motoneurone

References