Waveform of EOG is dependent on the direction of movement

H. Eskola[1], H. Aalto[2], I. Rimpiläinen[3], V. Jäntti[4], V. Häkkinen[5]
[1] Ragnar Granit Institute, Tampere University of Technology,
P.O. Box 692, FIN-33101 Tampere, FINLAND
[2] University Hospital of Helsinki, P.O.Box 220, FIN-00029 HUS, Helsinki, FINLAND
[3] Huddinge University Hospital, 14186 Huddinge, SWEDEN
[4] Oulu University Hospital, P.O.Box 22, FIN-90221 Oulu, FINLAND
[5] Tampere University Hospital, P.O Box 2000, FIN-33520 Tampere, FINLAND

Abstract: *The relation of the electro-oculogram (EOG) and eyeball orientation was studied for saccadic eye movements. The special target of the study was the origin of the asymmetry between signals from movements towards the EOG electrode and away from it. A set of experiments was made, where both the eyeball orientation and the EOG were simultaneously recorded. A simulated EOG signal was reconstructed from the orientation signal by using a geometrical model. Comparison of the this signal to the real EOG produced very similar waveforms, giving rise to the assumption that the asymmetrical saccadic movements explain the different amplitudes in forth-and-back EOG recordings.*

INTRODUCTION

Electro-oculogram (EOG) is a signal, which is associated with the rotation of the eyeball. It can be easily recorded and is thus widely used as a polygraphic signal in EEG and sleep studies. Depending on the application, its is either a source of information or interference. The utilization of EOG is restricted, because it does not contain a straightforward relation to the orientation of the eyes.

In our earlier studies (Häkkinen et al. 1993) we used monopolar EOG recordings and found a statistically significant dependence of EOG amplitude on the direction of the horizontal saccadic movement. Movements to the electrode (outwards) produced higher amplitudes than movements from the electrode. A review of waveforms in this and other articles containing monopolar DC recordings shows that not only the amplitudes, but also the waveforms seem to be very different (Jäntti 1982, Häkkinen et al. 1993). Similar asymmetrical waveforms can also be obtained from magnetic recordings (Jousmäki et al. 1996). In AC recordings the outward movement produce an asymmetric triangular waveform, while the inward signal is seen as a smooth wave with smaller maximum amplitude.

The purpose of this study was to give an explanation for this phenomenon. We decided to study whether the asymmetry can be obtained in the basic signals, the eye position and EOG recorded as DC signals. By applying a volume conductor model these two signals can be compared to evaluate whether the asymmetry is originated in the movement itself or if the EOG signal is contaminated by other signal sources.

METHOD

A healthy 37 years old male subject served as the subject for the study. He was sitting in a chair in relaxed position, situated between two circular transmitter coils with the diameter of 100 cm. A contact lens containing a circular receiver coil was attached on the cornea of the left eye. Four disposal Ag-AgCl electrodes were applied: two active electrodes 1 cm laterally from both eye canthi, the reference electrode on the inion and the grounding electrode on the forehead.

The three desired gaze directions (left: -30°, forward: 0°, right: +30°) were indicated by black markers on white target plane. After a training period several recordings of 30° forth-and-back saccadic eye movements were performed, each recording lasting 30 seconds. Five of the movements within one recording session were between left and forward directions and five between right and forward directions.

A magnetic field was applied between the transmitter coils by feeding current in the windings. This system for recording the angle of rotation (Juhola et al. 1995) was calibrated beforehand.

The EOG and the rotation angle signals were averaged over each group of five repetitions. A simple electrical model was constructed, where the eyes were represented by two rotating dipoles located 15 mm from the surface of a semi-infinite volume conductor. This geometry gives finally the following approximation for calculating the EOG potential V as the function of the rotation angle α in respect to the forward direction:

$$V = k * \cos(\alpha + g), \qquad (1)$$

where k is a proportionality constant (depending on the recording distance) and g is the angle between the forward and electrode directions (in our case about 60 degrees). When deriving this formula it was shown that the signal from the contralateral eye is negligible.

Application of formula (1) to the magnetically recorded eyeball direction produces a simulated EOG signal that is free of artifacts and non-ocular electrical sources.
The real and simulated EOG signals were also filtered digitally to imitate the traditional AC recordings made by EEG equipment.

RESULTS

The recorded EOG signals were asymmetrical so that the waveforms were steeper when the gaze was turned towards the electrode from the forward direction than in movements away from the electrode. The same phenomenon was also found in simulated EOG signals that were calculated from the eyeball orientations. Converted to AC recordings the real and simulated EOG signals have clearly steeper waveforms and higher amplitudes for eye movements towards the electrode than in movements away from it.

The simple volume conductor model showed that the sensitivity of EOG is highest when the eyeball is orientated temporally, and nearly zero at nasal orientation. This results in differences between the gaze direction and the corresponding EOG signal.

DISCUSSION

We have managed to replicate the asymmetrical EOG recordings reported in earlier papers. With simultaneous recording of real eyeball direction signal we could study the mechanism of generation of this phenomenon.

A simple explanation to the asymmetry is that the eyeball has different velocity profile in outwards than inwards movements. If this is the case, the slower inward movement is strongly filtered in AC recordings and results thus in lower amplitude. In most practical EOG applications the asymmetry is not visible because the signal is usually recorded as the potential difference between the two electrodes locating on both eye canthi.

The pure velocity profiles of saccadic eye movements have been studied by various groups (Thomas et al., Baloh et al., Boghen et al.). One conclusion in these papers is that symmetrical eye movements directed temporally are faster than saccades directed nasally. On the other hand, saccades directed to the mid-position are faster than movements from midpoint to nasal or temporal directions. And finally, high variation between subjects and the eyes has also been reported.

The purpose of this paper is not primarily to study the velocity profiles of saccadic eye movements, but to investigate the dependence of EOG signal on the velocity profile. On the basis of studying four types of movements separately for both eyes of one test subject we state that the EOG signal seems to follow the gaze direction. The asymmetry and differences in the waveforms have their origin in different velocity profiles, but are modified by the sensitivity function.

REFERENCES

[1] R.W. Baloh, H.R. Konrad, A.W. Sills, V. Honrubia, "The saccade velocity test," *Neurology*, vol. 25, pp. 1071-1076, 1975.

[2] D. Boghen , B.T. Troost, R.B. Daroff, L.F. Dell'Osso, J.E. Birkett, "Velocity characteristics of normal human saccades," *Invest. Ophthalmol.*, vol. 13, pp. 619-623, 1974.

[3] V. Häkkinen, K. Hirvonen, J. Hasan, M. Kataja, A. Värri, H. Eskola, "The effect of small differences in electrode position on EOG vigilance data," *Electroenceph. Clin. Neurophysiol.*, vol. 86, pp. 294-300, 1993.

[4] V. Jousmäki, M. Hämäläinen, R. Hari, "Magnetic source imaging during a visually guided task," *Neuroreport*, vol. 7, pp. 2961-2964, 1996.

[5] M. Juhola, I. Pyykkö, H. Aalto, K. Setälä, "Using magnetic coil signals with EOG signals in computer analysis of vestibulo-ocular reflex," *Acta Otolaryngol.*, vol. 520, suppl., pp. 279-281, 1995.

[6] V. Jäntti, "Spike artefact associated with fast eye movements in electronystagmography and its importance in the automatic analysis of saccades," *ORL J. Otorhinolaryngol. Relat. Spec.*, vol. 44, pp. 216-225, 1982.