A SECOND SURVEY WITH ELECTRO-OCULOGRAPHY*

BY

B. SHACKEL AND J. R. DAVIS

Psychological Research Laboratory, EMI Electronics Ltd., Hayes, Middlesex

A survey of the EOG potential level and other basic parameters of electro-oculography in 126 subjects has been reported by Shackel (1960). This paper reports a second survey made 10 months later on the same subjects. For convenience the first survey will be referred to as Ganges I and the second as Ganges II. The basis of EOG is the detection of the standing potential difference between the front and the back of the eyeball; with known eyeball rotations the level of this potential can be assessed in terms of the potential detected by peri-orbital electrodes. The definitions of various terms used, details of the apparatus, and illustrations of typical recordings were given in the report on Ganges I.

The specific purposes of the second survey were:

1. To find the test-retest correlation of EOG potential level over a long period of time.
2. To find whether the positioning of the electrodes within the limits of this test had any significant effect on potential level.
3. To find the general distribution and scatter of potential levels for vertical eye movements, and to evaluate a formula relating uniocular and binocular potential levels for 30° of eye rotation.
4. To check correlations of EOG potential with height, weight and age, and also with changes in height and weight.

The subjects, apparatus, and methods used in this survey will be described first, and then each particular section of the investigation, with its results and discussion, will be treated separately.

Subjects

The subjects were drawn from No. 103 recruitment of H.M.S. Ganges, and were the same subjects who had been used in Ganges I. Of the 126 used in the first survey only 97 were available; ten of the original subjects were older boys from an earlier recruitment, and by October, 1957 (the time of this survey), had left the training establishment. Others who were not available for this survey had been transferred to different establishments, and the remainder were absent sick.

* Received for publication July 10, 1959.
Apparatus

A portable version of the electronic system developed for measuring eye movements (Shackel, Sloan, and Warr, 1958) was used as in the first survey.

The target consisted of a perspex cross, the arms of which were $17\frac{5}{8}$ in. long by 1 in. wide. At the end of each arm and at the centre of the cross was a cheese-head screw, painted black, to serve as a fixation point, so that the target, which was rotatable about the centre, could be aligned with the plane through the horizontal electrodes, by viewing through the siting jig. The siting jig consisted of a piece of aluminium mounted 18 in. from the table top, in which was a small peephole $\frac{1}{2}$ in. in diameter. At the other end of the mounting was a small spike at the same distance from the table, so arranged that when the observer looked through the peep-hole he could align the spike and the central point of the target to the mid-point between the subjects’ eyes. The target could then be rotated to ensure that the engraved line through the centre was on a plane through the horizontal electrodes (Fig. 1).

Fig. 1.—Target, biting bar, and siting jig for aligning the target accurately with the subject.
A wooden spatula was mounted as a biting-bar to prevent head movements for the duration of the test. The bar was exactly 30 in. away from the target giving an angle of eyeball rotation of 30° from the centre to the fixation points.

The same type of electrode (Shackel, 1958) was used as previously. After the electrodes had been removed from each subject, a small perspex rule, marked in tenths, was used to measure the distance, in the horizontal frontal plane, between the centre of the electrode position and the centre of the pupil. It was considered unnecessary for this experiment to drill the skin (Shackel, 1959) as any drifts occurring in the short time of this test could easily be compensated by interpolating a zero datum-line between the zero levels recorded.

Method

On entering the experimental room each subject was seated for 3 minutes while his temperature was taken and the skin was cleaned around the eyes and behind the right ear where the electrodes were to be placed. The electrodes were then filled with 1 per cent saline jelly and applied to the skin above and below the right eye for vertical eye movement recording, at the outer corners of the left and right eye for horizontal eye-movement recording, and behind the right ear for the earth connection (Fig. 2).

The subject was then seated at the testing table, and the height of the biting bar was adjusted for comfort. The sitting jig was used to align the subject and the target.

Recordings were made, simultaneously on both channels, of eye fixations in the following sequence (L = Left; R = Right; U = Up; D = Down):

\[
\begin{align*}
0 & - L30° - 0 - R30° - 0 - L30° - 0 - R30° - 0 \\
0 & - U30° - 0 - D30° - 0 - U30° - 0 - D30° - 0 \\
0 & - D30° - 0 - U30° - 0 - D30° - 0 - U30° - 0 \\
0 & - R30° - 0 - L30° - 0 - R30° - 0 - L30° - 0 
\end{align*}
\]

While the subject was being tested his pulse was taken. At the end of the test the recording was calibrated with a known input voltage.

After the test the electrodes were removed and the skin was wiped clean of saline jelly. The distance of the centre of each electrode position from the centre of the eyeball was measured with the perspex rule held squarely in front of the subject’s face. The height and weight of each subject was measured immediately before or after each test. As before, the average time required for testing each subject was about 6 minutes.
Results

(1) Stability of EOG Potential over 10 Months

Fenn and Hursh (1937) have reported constancy of potential for individuals over time, but subsequent workers (Miles, 1939b; Mackensen and Harder, 1954; Kris, 1957) have reported significant differences in the potential levels for the same individuals on different occasions; however, all experimenters have noted large inter-individual differences in EOG potential level (Fenn and Hursh, 1937; Miles, 1939a,b; Leksell, 1939; Mackensen and Harder, 1954; Shackel, 1960).

As the evidence is somewhat conflicting and deals only with small samples, it was decided to test a sample of boys on two occasions at an interval of approximately one year. The testing situation for both tests was as nearly identical as possible and the same experimenter applied the electrodes, etc., throughout both series.

The mean and standard deviation of the binocular EOG potential levels for 30° lateral rotation were not significantly different for Ganges I and Ganges II (Table I).

<table>
<thead>
<tr>
<th>Test Series</th>
<th>Ganges I</th>
<th>Ganges II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>580 µV</td>
<td>562 µV</td>
</tr>
<tr>
<td>S.D.</td>
<td>146 µV</td>
<td>147 µV</td>
</tr>
<tr>
<td>Median</td>
<td>560 µV</td>
<td>533 µV</td>
</tr>
<tr>
<td>N</td>
<td>126</td>
<td>97</td>
</tr>
<tr>
<td>Age Range</td>
<td>15 yrs to 17½ yrs</td>
<td>15 yrs 10 mths to 17 yrs 2 mths</td>
</tr>
</tbody>
</table>

To find the correlation between the voltage levels on the two occasions a Pearson product moment test was applied to the uncorrected scores.

**Correlation Test I with Test II**

\[ r = +0.66 \text{ (97 subjects)} \]

\[ (P = <0.001; \text{both regressions linear}) \]

It was thought that the only major variable likely to affect the result was the time of day at which each subject was tested on the two occasions. To eliminate this variable it was decided to correlate the scores of those subjects for whom the time of testing on the two occasions did not differ by more than one hour.
A SECOND SURVEY WITH ELECTRO-OCULOGRAPHY

CORRELATION TEST I WITH TEST II; TIME HELD CONSTANT

\[ r = +0.83 \text{ (27 subjects)} \]
\[ (P = <0.001; \text{both regressions linear}) \]

These correlations indicate that the EOG potential is relatively stable over long periods of time, supporting the work of Fenn and Hursh (1937). This does not necessarily disprove the results of those workers who have found significant changes for subjects on successive testings; it seems evident from some more recent studies by the present authors (Davis and Shackel, 1959), that the potential maintains a steady mean level, but that there are marked, short-term fluctuations around this level. The size of the present population sample reveals the general tendency for constancy of potential level despite the individual variations.

(2) The Effect of Electrode Position

It is impossible for any experimenter to place electrodes at identical distances from each eye owing to anatomical differences and sighting errors, even when a locating jig is used. Various experimenters in this field have recorded widely different mean levels of potential, and it is probable that these differences are due to the positioning of the electrodes, *i.e.* the nearer the electrodes are to the outer canthus the greater will be the potential (*e.g.* Mackensen and Harder, 1954; Cohn, 1957). However, no results have been reported relating electrode distance to potential level by a precise function. The data from the tests reported here cannot provide this function; simultaneous recording from several different electrode positions on the same subjects will be necessary. However, it was thought that a discrepancy between left and right potentials found in Ganges I, *i.e.* that the potential given by movement to the right was greater, might have been due to a difference in the distance of the left and right electrodes respectively from the eyes. To test this possibility the electrodes were placed *“by eye”* in this survey in exactly the same manner as in Ganges I, but the distance from the eye was measured with a perspex rule at the end of each test.

It was found that the right electrodes were significantly nearer the right eye than were the left electrodes to the left eye (mean difference in distance Left to Right = 0.13 in., significantly different from zero *P* = < 0.001). However, the significant difference between potentials for left and right eyeball rotations of 30°, which had been found in Ganges I, was not found in Ganges II, where the differences were evenly distributed about zero. This may be due to the fact that the positioning of the midline of the subject’s head, and of the electrodes, with regard to the target was not so carefully controlled in the first survey; the positioning there may have been slightly biassed to the left owing to the experimenter’s visual sighting errors. These errors would be greatly reduced in the second survey by the use of the siting jig.
The standard deviation of the differences between potentials recorded for equal right and left excursions was calculated:

S.D. R to L = 9.7 μV

From this standard deviation it is possible to determine the accuracy with which the potentials for either left or right excursions can be predicted from each other. In a normal distribution 95 per cent. of all measurements fall within ±2 standard deviations, so that in predicting from left to right, or vice versa, 95 per cent. of the predictions will be within ±19.4 μV. From the two surveys it is evident that for the average subject, with the electrode positions used, one degree of eye movement is equal to 19 μV; on average, therefore, 95 per cent. of the predictions from left to right or vice versa will be accurate within ±1 degree.

It is noteworthy, for the practical use of EOG as a recording technique for eye movements, that, even without using an electrode locating jig, and with quite a large average discrepancy (0.13 in.) between the distance of the left and right electrodes from the respective eyeballs, there is nevertheless no significant difference in a large sample of subjects between the potentials recorded for left and right eyeball displacements, and that for any individual the difference in potential has only a 5 per cent. chance of falsely indicating a discrepancy of more than one degree of eyeball rotation. Calibrating the record separately with left and right rotations will of course minimize this error considerably.

(3) Vertical Movements

Distribution of Potential Levels for 30° Vertical Rotation.—The monocular EOG potential levels for 30° vertical rotation are shown in Fig. 3.
For comparison a histogram of the binocular potential levels for 30° lateral rotation is shown on the same figure; this latter histogram is substantially the same as that reported for Ganges I.

### Table II

| General Distribution of EOG Potential Levels for 30° Vertical Eyeball Rotation |
|---------------------------------|------------------|------------------|
| Mean                            | 371 µV           | 99 µV            |
| S.D.                            |                  | 97               |
| N                               |                  |                  |

The grand mean and standard deviation of the vertical potential levels of all subjects are shown in Table II.

**Relation between Horizontal and Vertical Potential Levels.**—The correlation between horizontal and vertical potential levels for 30° eyeball rotation was calculated. Only 92 of the 97 subjects were used for this test; five subjects showed an “abnormal” effect, in that they produced a larger potential monocularly for the vertical movement than binocularly for the horizontal movement. At present no explanation is available; it is to be expected that the potential from two eyes in series would be greater than that from a single eye, but this apparently is not always the case.

**Correlation Between Vertical and Horizontal Potential Levels**

\[ r = +0.73 \] (92 “normal” subjects)

\[ P = < 0.001; \text{ both regressions linear} \]

However, in spite of this high correlation, prediction from one plane to the other, by means of the regression equations, was found to have little practical significance because the standard errors of estimate were 60 µV from vertical to horizontal and 100 µV from horizontal to vertical. These large standard errors, together with the results of the five “abnormal” subjects, indicate that only a rough formula, of the type given in the next section, is warranted to make comparisons. The surprisingly large scatter of the data is presumably due to individual differences in anatomical structure and in tissue and bone conduction.

**Relation between Binocular and Monocular Potential Levels.**—Miles (1939a) has deduced a formula relating monocular to binocular potential levels:

\[ \frac{L_1 + L_2}{2} = \frac{3}{2}L_3. \]

\( L_1 \) and \( L_2 \) are leads from two single eyes, \( L_3 \) is the lead from two eyes in series. Using the mean of the potential levels, a formula of a similar nature was found from the present experiment:

\[ \frac{L_1 + L_2}{2} = \frac{3}{2}L_3. \]

This formula is qualitatively similar to that of Miles, in that more voltage is
produced by two single eyes than by two eyes in series, but the quantity of the difference varies in the two formulae. This may well be due to the fact that the method used by Miles of measuring the monocular potential was of two leads across one eye in the horizontal plane, whereas the method used here was of two leads across one eye in the vertical plane.

(4) **Age, Height, and Weight Correlations**

Although only age had been found to be significantly related to potential level in the first survey, it was decided to test again for a relation between potential level and age, height, weight, temperature, and pulse, and also between potential levels, from both Ganges I and II, and changes in height and weight (Table III).

<table>
<thead>
<tr>
<th>Test Series</th>
<th>Ganges I</th>
<th>Ganges II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>$r = -0.33^*$</td>
<td>$r = -0.12$</td>
</tr>
<tr>
<td>Height</td>
<td></td>
<td>$r = 0.14$</td>
</tr>
<tr>
<td>Change in Height</td>
<td>$p = 0.12$</td>
<td>$p = -0.13$</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td>$r = 0.15$</td>
</tr>
<tr>
<td>Change in Weight</td>
<td>$p = 0.07$</td>
<td>$p = 0.15$</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td>$r = 0.24^+$</td>
</tr>
<tr>
<td>Pulse</td>
<td></td>
<td>$r = 0.15$</td>
</tr>
</tbody>
</table>

* Significant at $P < 0.01$.  
† Significant at $P < 0.05$.

The only significant correlation found in Ganges I (for age and EOG level), although still negative on Ganges II, has dropped to a non-significant level. This may be because the ten oldest subjects in the first survey were not available for the second survey, which gave a much reduced age range. A second explanation might be that bodily changes undergone during the pubertal years may affect the voltage; if this is so it could be postulated that over the 10 months between tests most of the boys had passed this critical stage, so that the effect of age on voltage was no longer obvious. Alternatively it is possible that the correlation of $r = -0.33$ was an artifact, although significant at $P = 0.01$. The only significant correlation in Ganges II with EOG potential level was that of temperature ($r = 0.24$).

In general, temperature, pulse rate, age, and body surface area (related to weight and height) seem to be correlated with basal metabolic rate (Du Bois, 1936; Kleitman, 1939). It has been suggested that EOG is related to metabolic factors (Miles, 1939c; Kris, 1957). If this is so, a relationship would be expected between EOG and the measures correlated with basal
metabolic rate, but no clearcut relationship was found in this experiment. This may be due to the possible inadequacy of the measures taken as indicators of basal metabolic rate, and further experimentation is required to find out if in fact EOG is in any way related to metabolic processes.

(5) Effect of Time of Day on Potential

Kris (1957) has reported a diurnal rhythm in EOG potential, of a similar nature to the diurnal metabolic pattern, with a tendency to a peak at about 3 to 4 p.m. In order to find the effect of the time of day on EOG potential level it was decided to correlate the scores of both Ganges I and Ganges II with the times at which each test was made. The time range was divided into hours so that all tests made within each hour were regarded as having been made at the same time. In order to test Kris's hypothesis the ranges were then regrouped about a maximum at 3 to 4 p.m.; thus the potential levels of those tested between 2 to 3 p.m. and 4 to 5 p.m. formed one group, and the levels of those tested between 1 to 2 p.m. and 5 to 6 p.m. formed another group, and so on. The correlation coefficients between potential levels and both types of time grouping, hour by hour and about a 3 to 4 p.m. maximum, are given in Table IV.

<table>
<thead>
<tr>
<th>Test Series</th>
<th>Normal Time Range</th>
<th>Time Range with Peak at 3–4 p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ganges I</td>
<td></td>
<td>( r = -0.095 )</td>
</tr>
<tr>
<td>Ganges II</td>
<td></td>
<td>( r = -0.2^* )</td>
</tr>
</tbody>
</table>

\( ^* \) Significant at \( P = 0.05 \).
\( ^\dagger \) Significant at \( P = 0.01 \).
Regression of time on voltage is linear.
Regression of voltage on time is non-linear.

The results shown in Table IV are somewhat conflicting. If the times for Ganges I are grouped, the correlation becomes significant (increasing from \(-0.095\) to \(-0.2\)). By grouping the times for Ganges II, the correlation is reduced from \(-0.43\) to \(-0.38\), although this is still significant. It is possible that, in grouping, the range of the regression line has been reduced without a corresponding reduction in the scatter, thereby obscuring the result which would be expected if the hypothesis of grouping of times is correct.

It should be noted that all the correlations obtained are negative, which is the converse of the result expected on the basis of Kris's work.

Recent work by the present authors (Davis and Shackel, 1959) seems to indicate that there is no general diurnal pattern for EOG fluctuations, but
that there may perhaps be several different types of pattern. This possibility would explain the conflicting results of Table IV and the increase in correlation between Ganges I and II when the time of testing was held constant, and also might explain the divergent results found by different workers with regard to stability of EOG.

Summary

A survey was carried out on the EOG potential levels of 97 boys from \textit{H.M.S. Ganges}, who had been tested 10 months previously. It was found that there was a correlation of \( r = +0.66 \) between the levels of the subjects on the two occasions, indicating that the EOG potential has a long-term stability.

When the data were selected from subjects tested at the same time of day on the two occasions, the correlation increased to \( r = +0.83 \). However, no clear-cut correlation was found between actual times of testing and potential levels, giving conflicting evidence as to the effect of time on EOG potential level.

It was found that, although the right electrode was on average nearer the right eye by 0.13 in. than was the left electrode to the left eye, the potentials recorded for left and right eye rotations did not differ, in 95 per cent. of the cases, by more than the equivalent of one degree of rotation. Even this discrepancy can of course be corrected by calibrating left and right rotations separately.

A general distribution was found for vertical movement potentials and the relation between vertical and horizontal movements was determined. An approximate formula was evolved for the relation of monocular vertical to binocular horizontal levels of EOG.

As with the previous study, this survey would have been impossible without the extensive assistance of the Officers and Ratings at \textit{H.M.S. Ganges}, for which we are most grateful. We also thank the Directors of E.M.I. Electronics Ltd. for continued support in this work.

REFERENCES


(1959). \textit{Amer. J. Psychol.}, 72, 114.
