THE RELATIONSHIP BETWEEN E.E.G. ACTIVITY AND HANDEDNESS

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Introduction

It has been reported by a number of investigators that some association seems to exist between differences in certain E.E.G. characteristics recorded on the right and left sides of the head and handedness (Raney, 1939; Lindsley, 1940; Cornil and Gastaut, 1947; Glanville and Antonitis, 1955; Giannitrapani, Sorkin and Enenstein, 1966).

Raney (1939), for example, suggested from his examination of the E.E.G. activity in identical twins, that there is "... a tendency for one twin to show bilateral differences which are the reverse of those found in the other twin..." and "... for the non-dominant side of the head according to behavioural indices to have a greater amount and amplitude of alpha activity in the E.E.G." However, the author also found that this tendency only occurred with certain electrode locations and that "... a definite unilateral dominance does not exist, but that first one hemisphere and then the other may dominate, but with one dominating more of the time." Since Raney gives no indication of the period of time over which such variations occur and in view of the fact that he does not describe the length of E.E.G. record per subject that he examined in his study, it is a little difficult to evaluate his findings.

In Lindsley's (1940) investigation two other E.E.G. characteristics were examined, viz: the phase relationship of the alpha waves and the amount of unilateral blocking of the alpha rhythm on the two sides of the head. He found a tendency for "... less asynchronous alpha activity in the two cerebral hemispheres in individuals who show a high degree of laterality than in those who lack a definite and complete laterality." He found little association between unilateral blocking of alpha activity and laterality, although again no indication is given in the report of the total amount of E.E.G. record examined using either criterion.

In the study by Cornil and Gastaut (1947), these authors reported that in 58% of normal subjects, they found an asymmetry of the alpha rhythm on the two sides of the head in the occipital or parieto-occipital region. This asymmetry was shown by a smaller amplitude in the dominant hemisphere, i.e., in the left hemisphere of right-handed subjects. They also reported that blockage of the alpha rhythm due to mental calculation or opening of the eyes, was more marked on the side contralateral to the preferred hand (i.e., the dominant hemisphere) and the cortical response evoked by rhythmic visual stimulation was also greater on this side. These findings were obtained from the examination of a continuous ten second length of recording from each subject and direct inspection of the E.E.G. trace.

The more recent study by Glanville and Antonitis (1955) investigated the percentage alpha activity and mean alpha amplitude in a 40 second portion of the E.E.G. record taken from each side of the head of each subject. They expressed their results in terms of ratios of the values measured on the right and left sides but found no significant correlation between either of the ratios so derived and handedness.

In the latest work by Giannitrapani, Sorkin and Enenstein (1966) the phase relationships between nine homologous brain areas on the right and left sides were investigated in equal numbers of both right and left handed children and adults. Care was taken to obtain representative E.E.G. samples over time in the sleeping and waking states from each subject and the wave patterns from the two sides were compared by means of a phase analyser. The results indicated significant differences in the phase relationships between the two sides in three of the nine head regions sampled but this was true only in the adult subjects. Furthermore, the phase relationships between the sides were opposite during sleeping from those found during the waking state.

In view of these mixed findings it was felt that further experimentation was desirable which would firstly, establish the reliability of any differences in E.E.G. characteristics which may be found between the two sides and secondly, employ more critical methods of assessing handedness than have sometimes been used previously. The present study was designed to these ends.

Material and Method

Two different methods of assessing handedness characteristics were employed. Firstly, a 31 item questionnaire was administered as described elsewhere (Provins and Cunliffe, 1972) enabling subjects to be assessed on an index ranging from + 1 (completely right-handed) to − 1 (completely left-handed). In the present investigation 20 male subjects were used half of whom had indices ranging from − 0.39 to − 1.00, while the other half were selected to give a similar (approximately rectangular) distribution of scores from + 0.45 to + 1.00. The ages of the right-handed and left-handed subjects were matched as closely as possible and ranged from 19-45 years with means of 24.3 and 27.0 years respectively. All subjects were either university students or members of the university staff apparently free from any motor or neurological abnormalities.

The second method of determining handedness characteristics employed seven different tests of motor performance: (1) a modified version of the Crawford Small Parts Dexterity Test, (2) handwriting speed, (3) throwing accuracy, (4) tapping speed, (5) speed of turning a hand-rattle, (6) hand grip-strength and (7) grip-strength endurance. These tests, which are described in detail together with the method of administration by Provins and Cunliffe (1972), were performed by all subjects using each hand in turn. Subjects were required to come to the laboratory on two separate occasions at least three days apart and to perform the whole series of motor tasks on each visit.

In recording the E.E.G. activity of subjects, three electrode locations were used. For each subject the distance from the glabella to the inion was measured over the top of the head and a similar distance measured between the external auditory meatus on each side so that the two lines of measurement intersected at their mid-points. One electrode (posterior parietal) was then placed a quarter of the distance from the intersection towards the inion in the mid-sagittal plane and a second electrode (right parietal) positioned a quarter of the distance from the intersection towards the right ear. The third electrode (left parietal) was symmetrically located a quarter of the distance down from the intersection towards the left ear. A ground electrode was taped to the skin behind one ear. Bipolar E.E.G. recordings were made from electrode pairs on the right and left sides, the right parietal and posterior parietal electrode providing one channel and the left parietal and posterior parietal lead forming the other.

Silver/silver chloride hat electrodes were used (9 mm diam.) fixed in place on the head with collodion. The scalp was first degreased with alcohol and lightly abraded with a dental drill before applying the glue. Cambridge electrode jelly was then inserted through a hole in the electrode and care taken to ensure that the resistance between any pair of electrodes was always less than 3 kΩ before connecting the subject to the E.E.G. A Grass Model 7A recording polygraph was used for this purpose connected to a two-channel San-Ei frequency analyser.

When the E.E.G. was recorded, the subject was placed by himself in an air-conditioned and sound insulated room and seated in an easy chair. All the associated recording equipment was located in an ante-room with facilities for two-way intercommunication with the subject as required. Each subject's E.E.G. was recorded for a four minute period under each of three different conditions: (1) relaxed with his eyes closed, (2) relaxed with his eyes open and gazing forwards without head movement, and (3) reading silently from a book while avoiding head movement. In each instance, the E.E.G. record was taken on the right and left sides simultaneously and the frequency analyser output integrated over five second epochs was superimposed on the same record corresponding to the appropriate time period. To ensure comparable records on the right and left sides, the filters of the frequency analyser were carefully matched and both channels of the analyser and polygraph calibrated to give an equal output to the same input signal at the beginning of each recording session.

The E.E.G. recording in each condition for each subject within each session was carried out in two parts. After the first two minutes recording of the E.E.G. in a given condition, the right and left channels of the entire recording and analysing system were transposed for the second two minutes. As a check on the ultimate reliability of the E.E.G. data, all subjects were required to complete the whole series of recordings on each of two separate visits to the laboratory at the same time of day at least three days apart, as for the motor tasks.

Results

The detailed results of the motor performance tests have been reported elsewhere (Provins and Cunliffe, 1972). Suffice it to say here that the performances of the preferred hand were significantly better than those of the non-preferred hand on each task, but that these differences were significantly reliable from one occasion of testing to another for only the handwriting and tapping tasks.

The E.E.G. records were analysed by taking the output from the frequency analyser for 10 corresponding five second epochs on the right and left sides for the first two minutes of each recording run and a further 10 epochs during the second two minutes in each condition. These 20 epochs were obtained from artifact-free records and care was taken to avoid using successive five-second periods — usually alternate epochs were used in deriving the data. From each epoch the amount of activity in each of the five frequency bandwidths (2-4, 4-8, 8-13, 13-20, and 20-30 Hz) was obtained for the right and left sides separately. These figures were then summed over the 20 epochs to give an assessment of the total amount of activity in that condition for each side. The data for the 8-13 Hz bandwidth on each side were also expressed as a percentage of the total amount of E.E.G. activity recorded during that period. The data for the 13-20 Hz bandwidth were similarly treated so that for each of the three conditions examined, three different measures of E.E.G. characteristics were derived for the right and left sides, viz: total amount of E.E.G. activity, % alpha and % beta.

Product-moment correlations were carried out on the data for the two different occasions of recording and the test-retest results for the right and left sides for the three different conditions of testing on each criterion are summarized in Table I. Similar results are also presented for correlation tests of the differences in E.E.G. activity on the right and left sides between the two occasions. It will be seen that while all correlations between sessions are positive and highly significant (at $p < 0.01$ or better) in the comparisons using the results for each side independently, they are all low and insignificant except one in the comparisons involving differences between the sides. The same picture is presented if instead of using the data for the right and left sides, calculations are based on differentiating the sides either in terms of that showing the greater versus that showing the lesser amount of E.E.G. activity, or in terms of the side contralateral to the preferred hand (as determined by the questionnaire) versus the side ipsilateral to it. Nevertheless, in case there was a tendency for the side of greater activity to be consistent from Trial 1 to Trial 2 irrespective of the amount of the difference between sides on each occasion, a sign test for correlated samples (Ferguson, 1966) was carried out for total activity, % alpha and % beta between trials separately for each condition. However, none of the nine comparisons gave significant chi^2 values, again confirming the lack of consistency in the E.E.G. differences between sides from one occasion to another.

Since these results appear to be unreliable, it was considered unjustifiable to attempt the intended comparison between handedness

TABLE I

Values of Product-Moment Test-Retest Correlations between Trial 1 and Trial 2 for Each Experimental Condition and Criterion of E.E.G. Activity

Experimental Condition	Right-posterior parietal channel			Left-posterior parietal channel			Difference between sides (LPP-RPP)		
	Total activity	% alpha	% beta	Total activity	% alpha	% beta	Total activity	% alpha	% beta
1. Eyes closed	+ 0.96***	+ 0.90***	+ 0.90***	+ 0.93***	+ 0.89***	+ 0.83***	+ 0.32	+ 0.29	+0.32
2. Eyes open	+ 0.93***	+ 0.63**	+ 0.76***	+ 0.88***	+ 0.72***	+ 0.81***	+ 0.46*	+ 0.25	+ 0.32
3. Reading	+ 0.95***	+ 0.85***	+ 0.87***	+ 0.90***	+ 0.76***	+ 0.92***	+ 0.22	— 0.02	+ 0.34

* significant at $p < 0.05$
** significant at $p < 0.01$
*** significant at $p < 0.001$

(assessed by differences in motor performance between hands) and E.E.G. characteristics (assessed by differences between the two sides). Only the highly reliable activity of each side by itself has therefore been employed in further analysis.

Subdividing the data further according to the handedness of the subjects concerned, revealed marked differences between subject groups, and the mean values for Trial 1 and 2 for the total E.E.G. activity recorded on each side separately are presented in Table II. The results of paired comparison 't' tests show that the differences between subject groups are significant (at $p < 0.05$ or better) in four of the six instances. Similar comparisons between subjects for the % alpha activity gave significant 't' values in all four tests in conditions 1 and 2 but no significant differences in condition 3. There were no significant differences between the right and left-handed subjects in any of the three conditions for % beta activity.

TABLE II

Mean Values for Trials 1 and 2 of Total E.E.G. Activity (in Arbitrary Units) Recorded in the Right and Left Posterior Parietal Channels in Each Experimental Condition by Subject Groupings

Experimental condition	Subject group	Right P.P.			Left P.P.		
		Mean	S.D.	t	Mean	S.D.	t
1. Eyes closed	R.H. L.H.	3679.2 1952.1	1073.3 688.9	4.29***	3580.1 2074.9	1158.5 682.8	3.53**
2. Eyes open	R.H. L.H.	2673.8 1697.4	1016.8 577.7	2.64*	2630.7 1812.3	1116.1 546.4	2.08
3. Reading	R.H. L.H.	2554.3 1770.8	999.1 583.4	2.14*	2441.9 1870.9	1050.7 560.5	1.51

* significant at $p < 0.05$
** significant at $p < 0.01$
*** significant at $p < 0.001$

Examining the data for the two subject groups averaged over both trials for the right and left sides separately, the total amount of the E.E.G. activity recorded decreased significantly (at $p < 0.01$ or better) from the eyes closed condition to either of the other two conditions (Table III). No significant difference was found between the two conditions in which the subjects had their eyes open. The main reason for the significant difference between conditions where they occurred appears to be the smaller amount of alpha activity recorded in the eyes open runs since similar comparisons between conditions for % alpha show significant effects (at $p < 0.01$ or better) in all instances with no significant change in % beta across these conditions. In addition, a significant decrease in % alpha activity (at $p < 0.05$ or better) was recorded (for both handedness groups and on both sides of the brain) in the reading situation (condition 3) compared with condition 2 although again there was no significant difference in % beta activity registered between these two conditions.

TABLE III

Comparisons of the Total E.E.G. Activity Recorded in each Experimental Condition According to Subject Grouping and Brain Area. (related samples 't' test)

Conditions compared	Right P.P.		Left P.P.	
	R.H.	L.H.	R.H.	L.H.
1. Eyes closed 2. Eyes open	7.99***	5.07***	6.74***	4.55**
1. Eyes closed 3. Reading	6.72***	2.89*	7.03***	2.85*
2. Eyes open 3. Reading	1.38	2.18⧺	2.64*	1.34

* significant at $p < 0.05$
** significant at $p < 0.01$
*** significant at $p < 0.001$
⧺ mean value for condition $3 > 2$ (see Table II)

Discussion

The very highly reliable results recorded for the various E.E.G. measures taken separately on each side provide reasonable grounds for believing that the methodology used in this investigation was satisfactory. Yet these findings are in marked contrast to the lack of significant consistency in the differences in E.E.G. activity recorded between the right and left sides of the head in eight cases out of nine. In fact, only just over half of the subjects (between 10 and 13 depending on the experimental condition) favoured one side consistently (e.g., in terms of greater total E.E.G. activity) from one occasion to the other. However, since this agrees fairly well with Cornil and Gastaut's (1947) estimate that 58% of subjects display an asymmetry of the alpha rhythm between the two sides, these 10 to 13 subjects of the present investigation were examined more closely. Product-moment test-retest correlations (using only the data from these subjects) were carried out on differences between the favoured and non-favoured sides for each experimental condition and using each of the three E.E.G. measures, but all nine of the correlation values were very low and none approached significance (at $p < 0.05$).

Why should E.E.G. differences between the sides lack consistency? There appear to be two important possible explanations. In the first instance, it was reported by Adrian and Yamagiwa (1935) that the alpha activity is at a maximum in the occipital region of the skull but that from time to time the focus shifts both laterally and vertically. These authors also pointed out that... "the shift is not necessarily symmetrical on either side, and as the potentials are often greater on one side than the other it is probable that the active areas may be unequal"... while they found that there may be appreciable differences in the lability of the focus from one subject to another. They further suggested that the apparent waxing and waning of alpha activity, if recorded from one pair of electrodes, may be due mainly to the movements of the focus which may shift considerably during a long period of recording. Since in the present experiment, the E.E.G. activity has been recorded from the same anatomical locations by one pair of electrodes on each side of the head on each occasion of testing, it seems quite possible that the variation from time to time in the E.E.G. differences between the sides is simply a result of the shifting focus of activity reported by Adrian and Yamagiwa. However, relatively long samples of record were analysed in each of the three experimental conditions in the current investigation and yet the test-retest reliability of the differences between sides was similar for each condition.

Secondly, the new explanation for the origin of the alpha rhythm proposed by Lippold (1970) and Ennever, Lippold and Novotny (1971) in place of the traditional view that the waves reflect the activity of cortical neurones beating in unison seems to have particular application to the present findings. Lippold and his colleagues have provided cogent evidence for their belief that the alpha rhythm is generated by the tremor of the extra-ocular muscles modulating the corneo-retinal potential of the eye on each side and have shown that the alpha activity of the right and left occipital regions is dependent upon the visual fixation of the eye *on the same side of the head*. If indeed the alpha rhythm which constitutes such a high proportion of the E.E.G. activity (approximately 20-40% of the total recorded on each side in the present experiments) is primarily affected by the visual stimulation of the eye on the same side and then albeit indirectly by virtue of the extent to which visual fixation occurs, then some of the findings reported here become a little more understandable. Certainly, the high reliability of the E.E.G. activity on each side by itself but not the difference between the sides seems to be more easily explained on this hypothesis than if the alpha in each occipital region is dependent on the activity of cortical neurones stimulated by the visual input from the right and left eyes equally. This new explanation could perhaps also account better for the significantly smaller % alpha activity recorded in the present experiment with the eyes open when subjects were continuously fixating on the book they were reading (condition 3) than when they were presumably just as alert and subject to the same level of illumination but viewing the less detailed although not exactly featureless wall on the far side of the laboratory (condition 2).

But the result which is perhaps most puzzling to account for is the large difference in E.E.G. activity recorded between subjects grouped according to handedness. Why should the right handed subjects demonstrate significantly more total E.E.G. activity and % alpha than left handed subjects irrespective of the side of the head from which the records are taken? There seems to be no obvious explanation. The time of day at which subjects attended the experimental sessions was approximately matched for the two handedness groups but since no personality measures were taken, it is possibile that the differences recorded here are the result of personality variables rather than handedness characteristics. Certainly the present findings need to be confirmed on a larger sample of subjects before the effect can be considered to be a real association between brain activity and handedness.

Summary

The E.E.G.s of ten right-handed and ten left-handed normal male subjects (matched for degree of handedness and age) were recorded in order to compare differences in E.E.G. between the right and left parietal

areas in each subject with differences in their performances between the right and left hands on a range of motor tasks. Three measures of E.E.G. activity were obtained for the right and left sides separately, viz: total E.E.G. activity, % alpha and % beta under three conditions of testing (eyes closed, eyes open and eyes open, reading) on each of two occasions at least three days apart.

It was found that while the E.E.G. activity on each side was very highly reliable from one occasion of testing to the other, the differences between sides were not. However, significant differences in E.E.G. activity were found between the right-handed and left-handed groups of subjects irrespective of the side of the brain considered.

It is suggested that the lack of reliability of E.E.G. differences between the two sides of the head may best be sought in terms of the recently proposed explanation of the origin of the alpha rhythm (Lippold, 1970; Ennever et al., 1971). The differences in E.E.G. activity between the right and left handed groups of subjects are considered tentative and may be due to the influence of some concomitant variable such as personality or anxiety level.

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