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NORMATIVE SPECTRAL DATA ON ALPHA RHYTHM IN MALE ADULTS

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Although a large number of communications have appeared on alpha rhythm, relatively few of them have presented quantitative data concerning its parameters. As early as 1944 Brazier expressed the desirability for the establishment of a 'yardstick' for the normal population, against which variables found in pathological records may be measured. In collaboration with Finesinger (Brazier and Finesinger 1944) she carried out an investigation in 500 normal male adults. Since then a number of other investigations has been carried out and described extensively by Gastaut (1974). The results of a recent investigation (Hughes and Cayaffa 1977) add basically no new information.

The advent of computer analysis in EEG has created a situation in which it has become possible to produce precise quantitative data on many parameters of EEG rhythms in large numbers of subjects without too much manual labour. In our department, EEG computer analysis has been carried out routinely (Storm van Leeuwen et al. 1976) and, since we have easy access to well controlled normal subjects of different age groups, the present investigation was carried out. Our aim was to obtain objective normative data about the properties of the alpha rhythm which could be used in the discrimination between normal and pathological cases.

Methods and material

The investigation was carried out in 110 male subjects. They consisted of airplane pilots who were submitted for routine EEG examination to the EEG department of the National Aerospace Medical Centre (Soesterberg, The Netherlands). Only those subjects were used for this study in whom it was certain that no pathology was present on the basis of their anamnesis and cardiological, pulmonological and otological examinations. In addition, subjects included only those whose EEG was regarded as normal. The subjects were selected according to age groups with a width of 3 years. The distribution was as follows: 18—20 years, 21—23 years, etc., till 48—50 years. Each of the 11 groups contained 10 subjects. The time of day at which the EEG registrations started varied between 10 a.m. and 4 p.m. The records for analysis were made directly after the routine EEG registrations.

The electrodes were placed according to the 10-20 system: 4 electrodes T3, T5, P3, O1 on the left side with Fp1 as common reference, and 4 electrodes T4, T6, P4, O2 on the right side with Fp2 as common reference. We used the reference electrodes Fp1 and Fp2 because they are in the frontopolar region where no, or very little, alpha activity can be expected, in accordance with the recommendation of Cooper (1975). The EEGs were recorded by means of a 16-channel EEG apparatus and were stored on analogue tape for off-line computer analysis. The low frequencies were cut off using a time constant of 0.15 c/sec, and the high frequencies were cut off at 70 c/sec (—3 dB).

The spectral analysis was carried out over a period in which the subject had the eyes open and a period while the eyes were closed. The power spectra of the 8 derivations and the coherency functions of the left-right pairs of derivations and two pairs in the postero-anterior direction: (O1-Fp2) versus (P4-Fp2) and (O1-Fp1) versus (P3-Fp1), were calculated by means of Fast Fourier Transform. The spectra were based on 20 epochs of 5.12 sec. A convolution of the spectra with a triangular window of 3 points was performed. The result was an effective bandwidth of 0.52 c/sec and a 95% confidence interval of the power density of 14%. The power density was plotted logarithmically (0.6 dB = 1 μV^2 sec). Thus, the confidence interval was independent of the value (± 1.1 dB). The coherency was presented in values obtained by applying Fisher's z-transformation (Jenkins and Watts 1968) in order to obtain a confidence interval and bias reasonably independent of the coherency values (Storm van Leeuwen et al. 1976). The 95% confidence interval was 0.4 on the z-scale. The transformed value of 2.0 corresponds to a coherency of 0.96. In the records only few eye-blinks were present; because of their large amplitude in the EEG the remaining eye-blinks could be removed automatically.

After identifying the peaks of the alpha rhythm in the spectra, the following data were determined for each of the 8 derivations (Fig. 1A): (1) the frequency at which the power density was maximal within the peak of the alpha rhythm (peak frequency); (2) the power density (in dB) at the peak frequency (alpha peak power density); (3) the bandwidth round the peak frequency, measured as the width of the peak at a level −3 dB below peak power density (bandwidth); (4) the difference in power density (in dB) at the peak frequency between the conditions eyes closed and eyes open (reactivity).

It is not self-evident that the measured power density at the peak frequency (point 2) is equal to the maximal alpha power density. The spectral densities in the alpha frequency band can be considered as made up of two components: the alpha rhythmic component

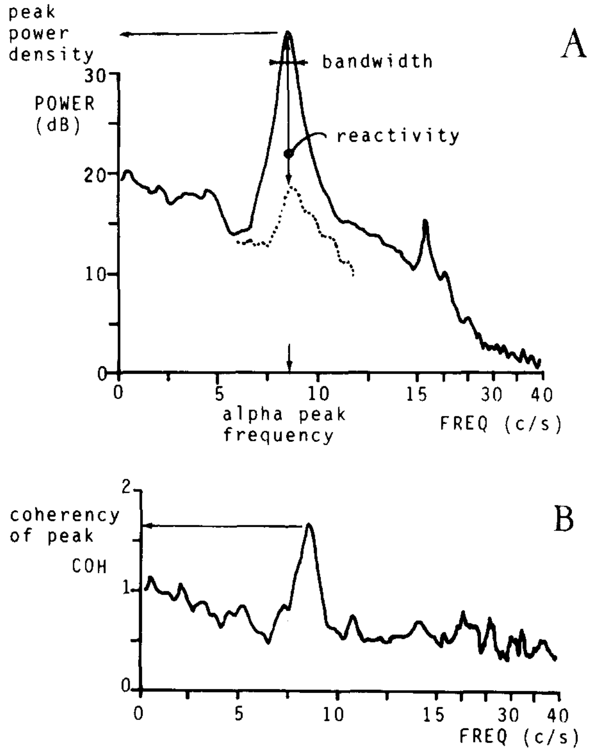

Fig. 1. A: an example of a spectrum with a clear alpha peak with eyes closed (continuous line). The spectrum with eyes open is drawn as a dotted line only near the alpha peak. The spectral parameters which were determined are indicated. See text for further explanation. Note the different linear scales of frequency below and above 15 c/sec. B: an example of the coherency function of the EEGs of two derivations with eyes closed. The coherency parameter is indicated.

and the background. However, the contribution of the background could generally be neglected in relation to the large power of the alpha rhythm. Only in about 30% of the cases did a correction have to be made. From the 6 coherency functions the maxima within the alpha peak of the spectrum were determined (Fig. 1B). This maximum will be called the alpha coherency. In the vicinity of the alpha peak frequency the coherency function of two EEG signals is determined by the coherency of the two rhythms and of the background activities and the ratios of their power densities. When the alpha peak power densities are much larger than those of the background, the coherency is almost solely determined by the coherency of the two rhythmic activities. Only in about 10% of the cases was this not true and a correction was made.

In our case the bias of the power density was less than the 95% confidence interval when the bandwidth of the alpha peak was larger than the effective bandwidth of 0.52 c/sec. The bias of the coherency of the peak values appeared to be about −0.15 to −0.20 (z-scale) on the basis of simulations. On the z-scale this value appears to be more or less independent of the value of the coherency itself. Therefore, and considering the accuracy, we did not find it necessary to make corrections for the bias in the experimental data.

Results

Frequency and bandwidth

The differences in the values of the peak frequencies of the 8 derivations appeared to be smaller than the effective bandwidth. Therefore the supposition was made that the frequencies varied mainly due to the calculation error and the average frequency of the 8 derivations was used as peak frequency. The distribution of these peak frequencies was not quite normal. The skewness (0.706) was larger than the 5% critical value for normality (0.390), the kurtosis was just on the 5% point. The mean was 9.9 c/sec and the standard deviation was 1.0 c/sec. Often for one or more derivations the bandwidth could not be established. The most common problem was that two or more peaks close to each other were present and fused more or less in the spectrum. In 8 cases 2 or 3 alpha peaks could be distinguished. The mean difference in frequency between these peaks was 1.1 c/sec in these 8 cases. Possibly two or more alpha peaks cannot be distinguished in many cases due to a small difference in frequency or a large difference in peak power density which results only in an asymmetry of the main peak. Generally the intra-individual differences in the bandwidth between the 8 derivations were not large enough in relation to the errors to reject the supposition that the bandwidth was equal in the derivations. Therefore the values were averaged, ignoring the cases which could not be computed. The mean bandwidth was 1.30 c/sec with a standard deviation of 0.55 c/sec. The distribution was more or less cut off at 0.8 c/sec, mainly due to the effective bandwidth of the spectral calculations.

Power

The maximal value of the power density within the alpha peak could easily be measured. It should however be taken into account that this measure only indicates the power density at the frequency which occurs most frequently in the registration. Nevertheless, we regarded this maximum as the most reliable measure. The alpha peak power density (APPD) was very variable. For the derivations O1-Fp1 and O2-Fp2 values were ob-

TABLE I

Linear correlation coefficients r between relative alpha peak power densities of 8 derivations as indicated in the table. The reference electrode for O2, P4, T6, T4 is Fp2 and for O1, P3, T5, T3 is Fp1. Number of subjects is 108. A value of r of 0.22 or lower is non-significant with $P = 1\%$.

T5	P3	O1	← Fp1 ↓		Fp2 → ↓	O2	P4	T6
0.43	ns	ns	T3	0.39	T4	−0.28	0.30	0.23
	ns	ns	T5	ns	T6	ns	−0.26	
		ns	P3	0.39	P4	−0.24		
			O1	ns	O2			

tained between 0 dB (no alpha rhythm in two subjects) up to 32 dB (1380 μV^2 sec). For the derivations T3-Fp1 and T4-Fp2 the values varied between 0 dB (no alpha rhythm) and 20 dB (87 μV^2 sec). The linear correlation coefficients between the APPD of the different derivations were large (0.82—0.97). This was the case for the inter- as well as for the intra-hemispheric derivations. These high values suggested that the variation in the APPDs was mainly determined by the subject and less by the derivation. Therefore the APPDs were normalized by dividing them by the average of the APPDs of the 8 derivations. These ratios will be called *relative* APPDs. Table I shows the results of the inter- and intra-hemispheric correlations of the relative APPDs. None of the correlations seemed to be of great importance. The correlation of the relative APPDs with the average power density was non-significant in all cases. We concluded that we had successfully removed an amplitude factor common to each of the 8 derivations of one subject. The means of the relative APPDs indicate how the alpha rhythm is distributed over the scalp. The 8 mean values could be considered as a 'localization function' describing the relative strength of the alpha rhythm on the 8 positions of the scalp, independent of the mean strength of the rhythm (Fig. 2). The deviation of the relative APPD from the mean in a given subject and a given derivation could be considered as a more or less random factor, as the correlations between the values of the relative APPDs in different derivations were non-significant or low. The distributions of the relative APPDs were approximately normal when we removed 10 subjects with values of relative APPD clearly far outside the range of values of the other subjects. The skewness and kurtosis were calculated and are shown in Table II. When the standard deviations of the relative APPDs were corrected for the calculation errors and expressed relatively, roughly 15% was found for the occipital areas, 40% for the parietal areas, 30% for the T5-T6 derivations and 50% for the T3-T4 derivations.

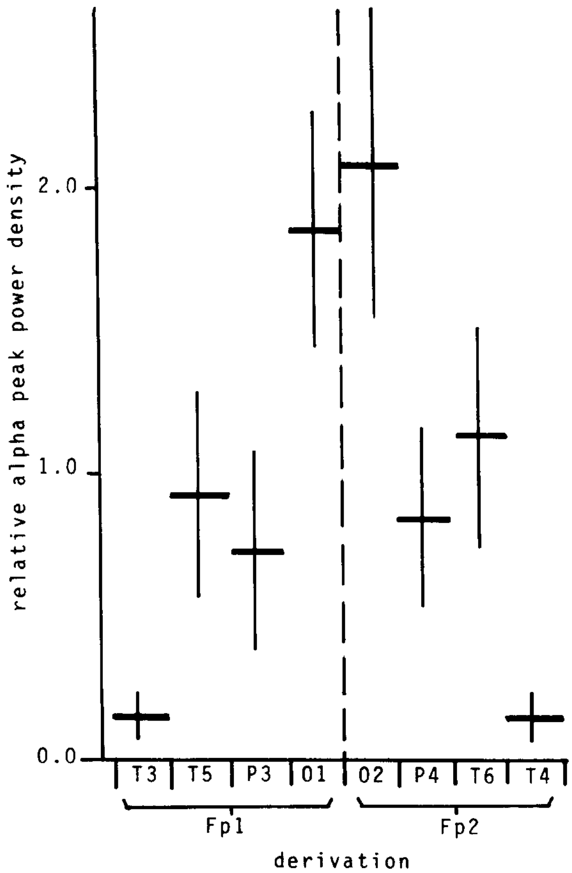

Fig. 2. Means of the relative alpha peak power densities (relative APPDs) are shown with a horizontal bar above the derivation indicated at the bottom. Plus and minus the standard deviation is shown by a line perpendicular to each bar. This is the graphical representation of the data of the first two columns of Table II.

The value of the averaged alpha peak power density in the 110 subjects, used to calculate the relative APPD, varied from 0 μV^2 sec (no alpha rhythm) to 740 μV^2 sec. On a logarithmic scale the skewness (—0.385) and kurtosis (2.50) of the distribution were just within the 5% critical value for normality (2 subjects with no alpha rhythm excluded). The mean and standard deviation of this distribution were 21 dB and 6 dB.

Effects of age

The relation between age and the parame-

TABLE II

Means and standard deviations (total S.D.) of the relative alpha peak power densities of the 8 derivations when 10 subjects with 'extreme values' are excluded. In the last two columns the skewness and kurtosis of the distributions of the relative alpha peaks of the 100 subjects are shown. A value with an asterisk is within the limits of normality (P = 5%). These limits are for skewness ± 0.39 and for kurtosis 2.35 and 3.77.

Derivation	Mean	S.D.	Skewness	Kurtosis
O1-Fp1	1.87	0.42	0.38 *	2.55 *
O2-Fp2	2.10	0.55	0.41	3.03 *
P3-Fp1	0.74	0.35	0.25 *	2.42 *
P4-Fp2	0.85	0.32	0.61	3.01 *
T5-Fp1	0.93	0.36	0.25 *	2.19
T6-Fp2	1.15	0.39	0.46	2.57 *
T3-Fp1	0.14	0.082	0.46	2.66 *
T4-Fp2	0.16	0.080	0.34 *	2.79 *

ters of the spectrum was investigated by splitting up the population in 3 subgroups with a nearly equal number of subjects. These groups were: A: age 17—29 years (n = 37), B: age 29—41 years (n = 37), C: age 41—50 years (n = 34). The means of the spectral parameters in these subgroups were mutually compared, using the t test, although not all the distributions were quite normal. No significant differences were found except in the alpha peak frequency. Subgroup C (41—50 years) presented in relation to the other groups a decrease from 10.1 c/sec to 9.6 c/sec (significant at $P < 0.05$).

Interhemispheric symmetry

In normal EEGs there may be an amplitude asymmetry of 50% between the left and right hemispheres (left smaller than right). If it is supposed that the power of the rhythm is proportional with the peak power density, a voltage difference of 50% is equal to a difference of 6 dB in the peak power density. Table III gives a summary of the results.

Looking at the numbers we have to bear in mind that some subjects showed an asymmetry in more than one area. The group of 110 subjects showed, on average, an asymmetry with a larger alpha rhythm on the right side than on the left, but this holds in the 4 scalp areas in only 12 subjects. A real symmetry in 4 areas within the accuracy of measurement (± 1.1 dB) was found in 30 subjects.

It should be mentioned that there were 7 left-handed and 1 ambidextrous subject; they showed no correlation with any of these parameters. Likewise there was no correspondence between this cluster and asymmetry.

Reactivity

By reactivity we mean the difference in power density at the peak frequency between the conditions eyes open and eyes closed. It should be remarked, however, that the peak frequency values in the two conditions were

TABLE III

The ratios of the peak power densities of corresponding derivations in the right and left hemispheres (left divided by right) are indicated by the number of cases in the 5 classes shown at the top of the table. The ratios are expressed logarithmically (dB). The derivations from the left and right hemispheres are indicated in the first column with the location of one of the electrodes. The value is negative when the peak power on the right side is larger than on the left side. The total of the subjects in T3-T4 = 106.

	Negative more than 6 dB	Negative 1—6 dB	—1 dB; 0; +1 dB	Positive 1—6 dB	Positive more than 6 dB
O1-O2	1	25	77	7	0
P3-P4	6	23	66	15	0
T5-T6	2	39	56	12	1
T3-T4	2	28	58	17	1

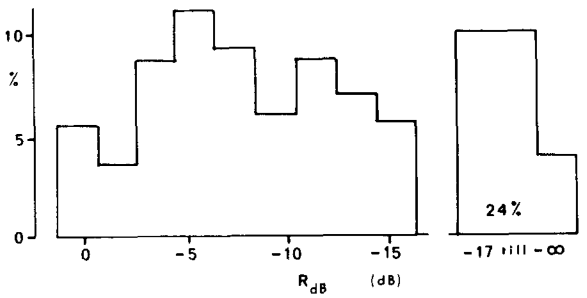

Fig. 3. Histogram of the logarithmic reactivity: logarithm of the ratio of the power densities in eyes open and eyes closed conditions. Values less than —16 dB are grouped in one block. Vertical axis: percentage of cases in the occipital derivations.

not always the same. In about 30% of the cases a difference of more than 0.5 c/sec was found. It may be questioned whether the peak frequency differences correspond to a real shift in frequency due to the two conditions: eyes closed and eyes open, as described by Kawabata (1973). In the histogram the power density differences at the peak frequency of the eyes closed condition were used.

Since in this study a logarithmic power scale was used, the reactivity was also expressed logarithmically, i.e., as the logarithm of the ratio of the power in the eyes-open and eyes-closed conditions. This quantity was always negative as the power with eyes open was smaller than with eyes closed. If the alpha rhythm vanished entirely, the reactivity on the logarithmic scale was minus infinity. In the majority of the cases the error in the logarithmic reactivity was about +3 dB and —4 dB. The results for the 108 subjects are shown in the histogram of Fig. 3. A reactivity of more than —16 dB is very large and is considered to approximate a reactivity of —∞. No systematic difference between the two derivations (O1-Fp1) and (O2-Fp2) was noticed, so they were combined in the figure. The correlations between the reactivities of the different derivations were larger than 0.80 and therefore no important other conclusions were suspected.

Coherency

The coherency of the alpha rhythm was determined by taking the maximum of the coherency function within the spectral alpha peak in the eyes closed condition. This maximum is likely to be the best measure of the coherency of the alpha rhythm. In many cases a peak in the coherency function associated with the alpha rhythm could not be distinguished. The difference from the background coherency was apparently too small. In such cases the background coherency averaged over the alpha band was taken as the alpha coherency. For the derivations (O1-Fp1) and (O2-Fp2) this was carried out in 39% of the cases. It was clear that the shape of the histogram of alpha coherency was influenced in the vicinity of the values of the background coherency, in this case 1.0—1.6. The effect led to a concentration of the cases in the intervals in which the background coherencies fell, at the cost of the neighbouring intervals. The histograms of alpha coherency of the 6 pairs of derivations are shown in Fig. 4. The alpha coherency appeared to vary from the level of the background coherency to more than 2.0 on the z-scale (0.96 linear).

Bearing the above effect in mind, we see that the left-right alpha coherency decreased from the occipital regions to the T3-T4 regions (means 1.6 and 0.9, z-scale), and that the postero-anterior coherency was larger than even the occipital left-right coherency. The common electrode in the postero-anterior pairs of derivations would not have enhanced the alpha coherency, given that the alpha rhythm does not spread to the Fp1 and Fp2 electrodes.

Relations

An indication of the relations between the measured quantities can be found in the correlation coefficients. The most interesting relations were those between the peak frequency, bandwidth, alpha peak power density and alpha coherency. The reactivity was uncorrelated with each of the mentioned quantities. The Spearman correlation coefficients

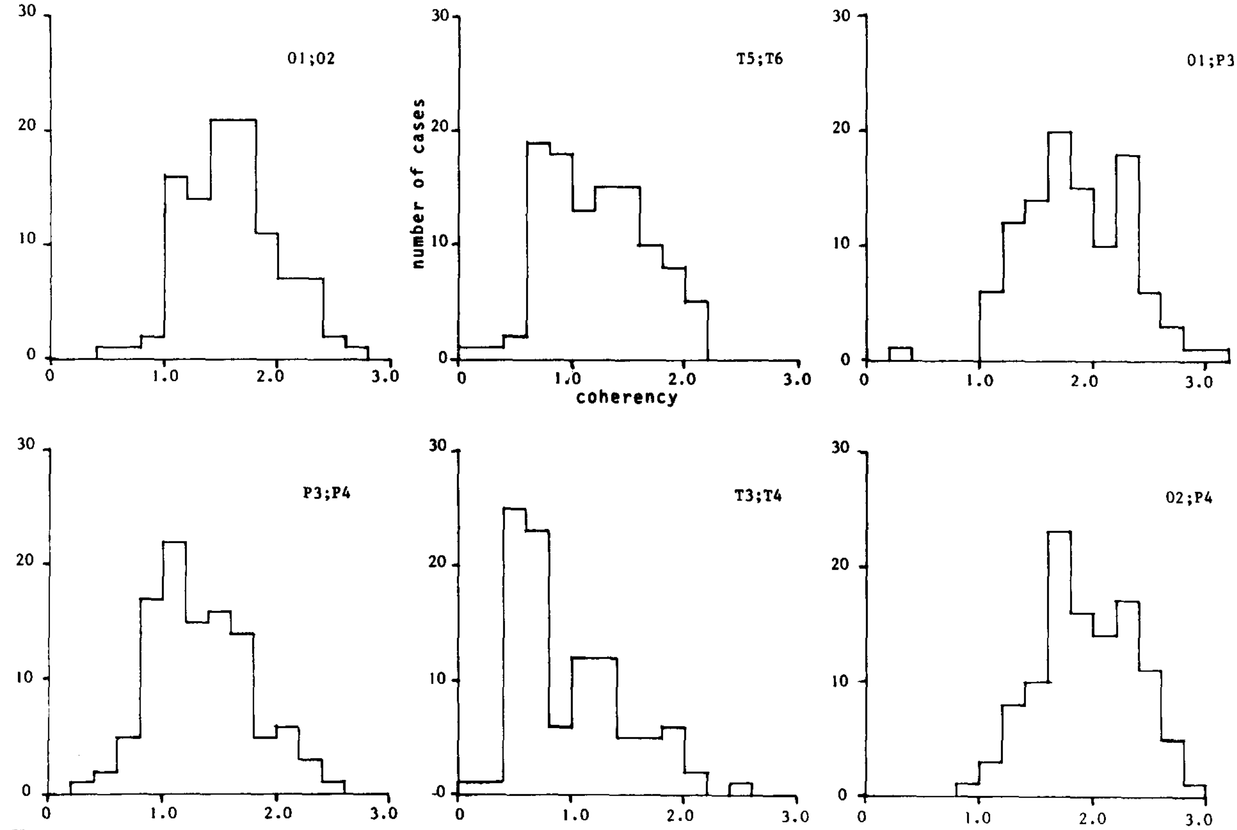

Fig. 4. Histograms of the alpha coherency of all the pairs of derivations investigated. The pair of derivations is indicated in each figure by the non-reference electrodes. The coherency on the horizontal axis is the Fisher z-transformed coherency. The number of cases is shown on the vertical axis.

for the occipital area are shown in Table IV. The correlations appeared to be rather low, but they were all above the 1% confidence level. The correlations showed that, on average, a low alpha peak frequency was coupled with a small bandwidth, a large peak power density and a high coherency. But it should be stressed that these relations were weak.

TABLE IV

Spearman correlation coefficients between alpha peak frequency (1), bandwidth (2), alpha peak power density (3) and alpha peak coherency (4) for the occipital area.

	2	3	4
1 Frequency	+0.61	−0.52	−0.48
2 Bandwidth		−0.69	−0.53
3 Power density			+0.33
4 Coherency			

Discussion

The results concerning the mean frequency (namely 9.9 c/sec) are in accordance with the findings of most authors. So is the slight decline in middle age, with the restriction that in our material there were no subjects older than 50 years of age. The slight positive correlation between the frequency and the bandwidth and the slight negative correlation between the frequency and the power density, underline one of the conclusions of the investigation of Brazier and Finesinger (1944).

A positive correlation between mean alpha frequency and bandwidth and a negative correlation between mean alpha frequency and alpha peak amplitude were also reported by Wouda and Lopes da Silva (1976). However, they found a much smaller value for the former correlation coefficient; this may be because we used the peak frequency whereas these authors used the mean frequency as the parameter.

The well-known inter-hemispheric asymmetry of amplitude, with the left hemisphere showing a lower voltage, was confirmed in our study. 73% of the cases showed an amplitude asymmetry in one or more areas. Cornil and Gastaut (1947) reported an asymmetry in 58% of normal subjects, with lower voltages in the dominant hemisphere. The difference between these percentages may be caused by a difference in the criteria used. In our group 7 subjects were left-handed, according to their own report. The left-right asymmetries found in this group were not significantly ($P < 0.01$) different from those of the whole group.

In their normative studies Gibbs et al. (1943) gave a percentage of circa 11% in which there was no or little alpha rhythm. They drew their conclusions from a study of 1000 adult subjects (male and female) older than 20 years of age. Their results are not comparable with ours (we found no alpha rhythm in circa 2%) because we selected normal individuals and their group included pathological cases.

Coherency

The alpha coherency can be considered as a quantification of the synchrony of the alpha rhythm. Although this quantification was used in 1952 by Brazier and Casby, few investigations on this point have been published since then. A comparison of the values mentioned in the literature and the values we found is difficult because the dependence of the coherency on the pairs of electrodes used. We found alpha coherency values from 0.70 to 0.98 (linear scale) which are in the same range as those which Lopes da Silva et al. (1973) found (0.67—0.87) in the dog, but are larger than the values from 0.4 to 0.6 reported by Hord et al. (1974). The differences can be due to the distance between the electrodes and the localization or the condition of the subjects. Generally it is important to realize that, for example, the alpha coherency in the pair of derivations (O1-Fp1), (O2-Fp2) can only be interpreted as the bilateral occipital coherency of the alpha rhythm when the alpha rhythm is absent at electrodes Fp1 and Fp2. In many subjects the alpha rhythm is clearly not completely coherent in all the derivations. This finding is in accordance with the idea that several alpha generators exist which are more or less independent (Lopes da Silva and Storm van Leeuwen 1978). Noteworthy is the fact that the correlation between the effective bandwidth and the alpha coherency was low (—0.40). In some cases with an effective bandwidth smaller than 1.0 c/sec the occipital coherency appeared to be 0.76, which is about the lowest value we found in this study. Apparently a small spectral peak did not necessarily involve a high synchronization of the alpha generators.

Technical aspects

The results describe in a quantitative way a number of properties of the alpha rhythm as revealed by the power spectrum. These data of a normal population can be useful in the clinic as a reference for data of patients. In this respect it is advantageous that we found so many normal or approximately normal distributions. A comparison with simple parametric statistical methods is possible in that case. However, it is necessary that a logarithmic power density scale and a Fisher z-transform for the coherency be used. This fact reinforces the technical arguments for the use of these scales.

The parameters of the spectral analysis: the effective bandwidth and the variance of the power density, were chosen a priori on the basis of experience of EEG examination without spectral analysis. With the results of this study we can verify whether the choice was adequate. If the criterion is used that the histograms had to be found with sufficient accuracy, it is plausible to look at the ratio of the standard deviation due to the spectral calculation and the total standard deviation. It appeared that in the histograms of the absolute and relative power densities and the coherencies this ratio was respectively about 1/7, 1/3 and 1/4. These values seemed sufficient to us. However, the influence of the background activity on the low alpha coherencies should be less when the calculation error decreased. The effective bandwidth of 0.52 c/sec limited the possibility to detect differences in peak frequency between cortical areas (Pfurtscheller et al. 1977) as well as to measure the smallest bandwidth which, according for example to Wennberg and Zetterberg (1971), could be under 0.7 c/sec. Probably a decrease of the effective bandwidth to about 0.3 c/sec is necessary to determine these details. Such a decrease has as a consequence that the duration of the primary analysis epoch (5.12 sec) should be increased to about 10 sec. The total period of analysis (20 epochs) should also increase from about 100 to 200 sec in order to maintain the same variance of the power density. We must stress that in clinical practice larger variances and a large effective bandwidth may be sufficient to distinguish pathological cases from normal ones.

Summary

Spectral analysis of the EEGs of 110 normal male subjects was carried out in order to obtain objective normative data on the alpha rhythm. The parameters of alpha rhythm extracted from the spectra and coherency functions were: the frequency and bandwidth, maximum power density, interhemispheric symmetry, reactivity, coherency and their interrelationships.

Résumé

Données spectrales de référence pour le rythme alpha chez des adultes mâles

L'analyse spectrale des EEG de 110 sujets mâles normaux a été effectuée afin d'obtenir des données objectives de référence pour le rythme alpha. Ces paramètres du rythme alpha déduits des fonctions spectrale et de cohérence ont été: la fréquence et la largeur de bande, la densité de puissance maximale, la symétrie inter-hémisphérique, la réactivité, la cohérence et leurs interrelations.

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