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INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/21257

DOI URL: <http://dx.doi.org/10.21474/IJAR01/21257>



RESEARCH ARTICLE

ALPHA RHYTHM AND CEREBRAL SYNCHRONIZATION

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Manuscript Info

Manuscript History

Received: 18 April 2025

Final Accepted: 21 May 2025

Published: June 2025

Key words:-

Alpha Rhythm, Eeg Synchronization,
Coherence, Pearson Correlation

Abstract

The Alpha EEG rhythm, characterized by a frequency between approximately 8 and 12Hz, is an important brain rhythm associated with calmness, relaxation, and creativity. Furthermore, numerous websites associate it with the concept of “brain synchronization,” meaning that an increase in the Alpha rhythm would imply an increase in synchronization between different areas of the brain. This effect is considered very positive for people's mental and physical well-being. In this study, two groups of subjects were selected, the first High-Alpha, the second Low-Alpha, characterized respectively by a naturally high and low Alpha rhythm. The average degree of brain synchronization in the two groups was then calculated using analyses based on Fourier Transformation, Pearson's Correlation, and EEG Coherence. The results show that Low-Alpha subjects have a higher average EEG synchronization value, with the sole exception of synchronization in the frontal and occipital lobes, which is higher in High-Alpha subjects. Brain synchronization is therefore not directly related with high Alpha rhythm, as homogeneous phenomenon across the entire cerebral cortex, but depends greatly on the phase relationships between brain waves in different locations on the scalp. A method for calculating coherence is also described, which allows for better highlighting of the phase relationships between two electrodes as a function of EEG frequency.

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Introduction:-

Alpha Rhythm is the best known and most important brain rhythm discovered by Hans Berger in 1924. This rhythm is characterized by a frequency ranging from 8 to 12 Hz and occurs during wakefulness over many regions of the head, generally with a higher voltage in the occipital areas. It is also best observed with the eyes closed and in a state of physical relaxation with relative mental inactivity. In fact, Alpha rhythm is blocked or attenuated by attention, active thinking and especially visual stimulus (Halgren et al. 2019)[1].

Thus, Alpha is the dominant EEG rhythm in the occipito-parietal regions in the resting condition with eyes closed, whereas at the time of opening the eyes, or initiating an activity that requires cognitive effort, the oscillatory rhythm tends to become faster and the amplitude to decrease. All of these characteristics result from the fact that alpha is a thalamo-cortical reverberation involving the optic pathways and primary visual cortex; it also performs some types of memory scanning (Palva, 2011[2], Garcia-Rill et al. 2016)[3]. A subject with his eyes closed, in relaxation, and without performing any particular mental task, spontaneously develops his own Alpha rhythm, which, however, occurs with a high variability in amplitude and stability in different individuals.

Alpha meditation and relaxation, refer to techniques that aim to induce a higher state of Alpha brain waves, typically associated with calmness, relaxation and increased creativity. These waves can be stimulated through meditation (Katyal&Goldin, 2021)[4], deep breathing, relaxing music, binaural sounds (Shekar et al., 2018)[5], neurofeedback (Biswas&Ray, 2019)[6] and other practices.

One effect that is generally believed to be induced by increasing Alpha, is the increase in brain synchronization, that is, the value of symmetry between EEG waves of the two brain hemispheres, thus of the whole brain, believing that the EEG synchronization has very positive effects on people's mental and physical well-being. This goal is described in numerous websites that combine the concepts of Meditation, Alpha Waves and Brain Synchronization. Implicitly, it is therefore believed that the increase in Alpha waves can also induce an increase in brain synchronization. In this study, the idea that there is a positive association between the value of Alpha Rhythm and Brain Synchronization was experimentally evaluated.

Materials and Methods:-

All subjects in this study gave their consent, even if only verbal, for anonymous EEG data recording and analysis. The EEGs of about 100 normal, non-pathological subjects were recorded under simple relaxation conditions, with eyes closed, in silence, then the recorded EEGs were selected (by Fourier analysis) into two groups: the first group (29 subjects, low-alpha) had a medium-low value of Alpha rhythm, the second group (29 subjects, high-alpha) had a medium-high value of Alpha rhythm. The remaining subjects, with an intermediate Alpha rhythm value, were not included to better differentiate Low-Alpha from High-Alpha.

The age of the subjects, of both sexes, ranged from 30 to 65 years old; some subjects had some experience with meditation techniques, but most had no specific experience. The division of the EEG data into the two groups was decided on the basis of the average amplitude of the Alpha band (8-12 Hz) using the Fourier Transform.

Instrument used

EEG recordings were made using a 14-channel Emotiv Epoch instrument, connected via its 2.4 GHz wireless connection, to a laptop computer powered by its own battery. The Emotiv Epoc is equipped with two efficient 50 Hz and 60 Hz digital notch filters against network electrical noise. The sampling rate on each channel is 128 samples/s. This frequency is sufficient to allow all EEG frequencies between 0.5 Hz and 44 Hz (Delta to Gamma) to be analyzed. In the present experiment, the 14 channels were connected to the AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 locations using a professional EEG headset from Bionen (Florence, Italy) to increase the quality of the recorded signals. The headset was connected to an Emotiv Epoc circuit using a multi-contact connector after completely disassembling the instrument, placing only the electronics in a special plastic container. The instrument thus modified is better than the original Emotiv Epoc version, because EEG signals are recorded with standard-quality Ag/AgCl electrodes. All signals were recorded with reference to the interconnected ear lobes (A1 and A2). The electrode impedance was always kept below 10 Kohms.

Analysis of EEG data

Signal quality was visually inspected, and very few areas with artifacts were entirely eliminated. The EEG signals were then analyzed by a signal pre-processing stage based on a 0.8-Hz high-pass filter to eliminate the lower frequencies deemed not useful for this study.

Then three types of analysis were performed:

1- Frequency spectrum analysis by Fourier Transform on 1-second time intervals (similar results on 2-second intervals) without overlapping, and with rectangular window, and with frequency range analyzed between 1 and 44 Hz .

Fourier analysis was performed for each channel, then averaged over the entire EEG file and individual results saved for a final analysis averaged across all subjects.

2- Calculation of synchronization between two signals by the method based on Pearson's Correlation. Several methods are described in the literature, and often the results of each method are not directly comparable because of different mathematical procedures. For reasons of simplicity and clear physical significance, we have chosen the Pearson Correlation, used for example by Šverko et al.(2022)[7], Saurabh et al. (2016)[8], Giroladini et al. (2016)[9].

In our method we have used the Pearson's correlation, defined as:

$$r = \frac{COV(A,B)}{\sqrt{var(A)*var(B)}}$$

where A(t) and B(t) are two time series of two EEG channels, COV(A, B) is the sample covariance and var(A) and var(B) are the respective sample variance. Correlation R can take any value in the range (-1, 1) and in particular a value near +1 means that the two time series (i.e. two EEG channels) are strongly in phase, a value -1 means that the two signals are in opposition of phase, and a near-zero value indicates no relationship. The Pearson's correlation was selected because the calculation of R is simple, fast, and fully independent from the absolute amplitude of the EEG signals, and then it represents only the variations of phase-correlation between two EEG channels.

Moreover, this correlation can be calculated for every band frequency or single narrow frequency. Next, we proceeded in this way:

Given 14 EEG tracks (Nc= 14 channels) the Pearson's correlation between all 14 EEG tracks was calculated (for each 1 second interval, or 2 seconds), giving in total 91 correlations between all possible pairs:

Number of Correlations = (Nc² -Nc)/2 = 91.

In the true EEG signals we find that the Pearson R value between the pairs of signals can vary from about 0.85-0.90 to about zero or also until negative values, depending on the distance between two electrodes and the phase-relation between the two signals. The average value is about 0.3 - 0.4 .

These 91 correlations can be averaged within each file (subject) and between all subjects, to obtain an overall average of all correlations.

Coherence calculation

The Coherence calculation method is described in several papers, Thatcher et al.(2008)[10], Guevara et al. (2011)[11], Lachaux et al. (1999)[12], Bowyer (2016)[13].

However in this work we used a variant, the Coherence-gw, that can be described as calculating the Pearson's correlation between two signals, for each individual frequency contained in the two EEG signals. The details of this routine, written in Visual Basic 6 language, is described in Giroladini (2025)[14] .

Given a pair of signals Va(x) and Vb(x) with N samples in the time, it is decomposed into the respective Real and Imaginary component using the Discrete Fourier Transform. Then using the Inverse Fourier Transform, each frequency component Fa(x) and Fb(x) can be calculated as pure signal (N samples) at the frequency F.

Then the Pearson's correlation is calculated between the two Fa(x) and Fb(x) signals. The result is a type of Coherence Coh(f) ranging from +1 to -1, where +1 means the two signals, at the frequency f, are in-phase, and -1 means they are in counter-phase. This Coherence can be interpreted as a correlation analysis of two signals in the frequency domain.

Since (as mentioned) 91 pairs of EEG signals can be calculated, Coherence can be calculated as an array of the type Coh(I, f) where I are the combinations and f the frequency between about 1 and 44 Hz. These data can then be averaged over all 91 combinations, for each second, and for each subject, and then also among all subjects.

Experimental results

Fourier transform

Fig.1 and fig. 2 show graphs of the Fourier Transform as the average of all 14 channels and all subjects in the two groups (29 subjects for both).

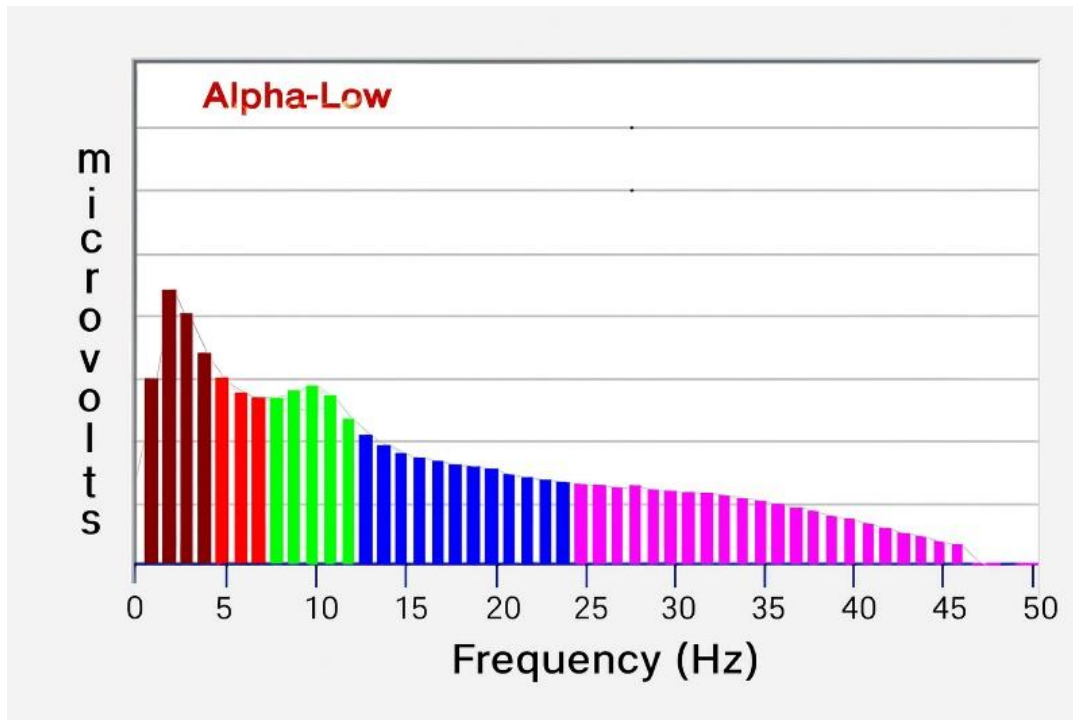


Fig. 1:- The Fourier graph of Low-Alpha subjects.

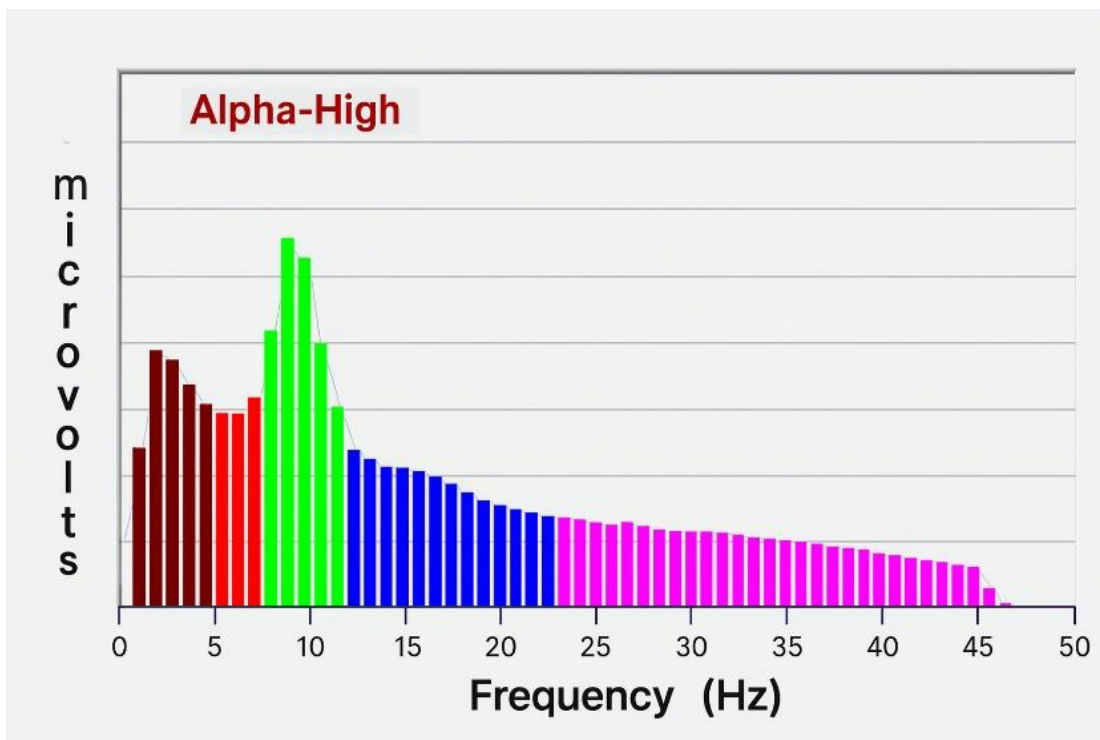


Fig. 2:- The Fourier graph of High-Alpha subjects.

The Fourier Transform is shown in amplitude (not as the power of the signals), and besides the obvious difference in Alpha amplitude, there is also a slight excess of Beta activity (25-46Hz) in subjects with little Alpha ($P= 0.03$), the other Delta and Theta bands have no significant differences.

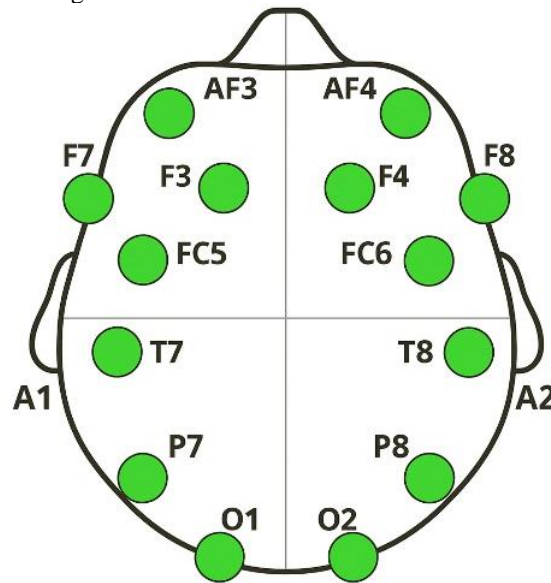


Fig. 3:- Arrangement of the 14 electrodes on the scalp.

Calculation of synchronization between pairs of signals using Pearson's Correlation, yields (as mentioned) 91 values that can be calculated as an overall average and also divided into three other groups, depending on the location of the electrodes (Fig. 3)

- 1- Synchro between the two hemispheres (41 combinations, example AF3-AF4, F7-F4 etc.)
- 2- Synchro in the left hemisphere (21 combinations, example T7-P7 etc.)
- 3- Synchro in the right hemisphere (21 combinations, example F4-P8 etc.)

The final numerical results are summarized in Table 1

The significance of the differences between the two groups of 29 subjects, was calculated by one-tailed t-test, sd is the Standard Deviation.

Type	High-Alpha	Low-Alpha	Probability
Synchro between emispheres	30.7 sd=8.7	37.0 sd=10.5	$P < 0.01$
Synchro left	40.2 sd=10.5	46.5 sd=11	$P < 0.015$
Synchro right	38.6 sd=7.6	47.9 sd=8.9	$P < 0.0005$
Global synchro	34.7 sd=8.0	41.7 sd=9.8	$P < 0.0025$

Table 1:-

It clearly appears that High-Alpha subjects have lower mean synchronization than Low-Alpha subjects. Another way to illustrate this result is to calculate the average of each of the 91 combinations and then sort them decreasingly in a graph.

It is observed that the value of synchronizations varies from about 0.75 (75 %) to a value around 0.1 (10%) in Low-Alpha, while it can take negative values in High-Alpha. In fact, individual subjects may show very negative values that stand for the fact that in some electrode combinations the EEG signals are in counterphase (opposition of phase)

Figure 4 represents this result.

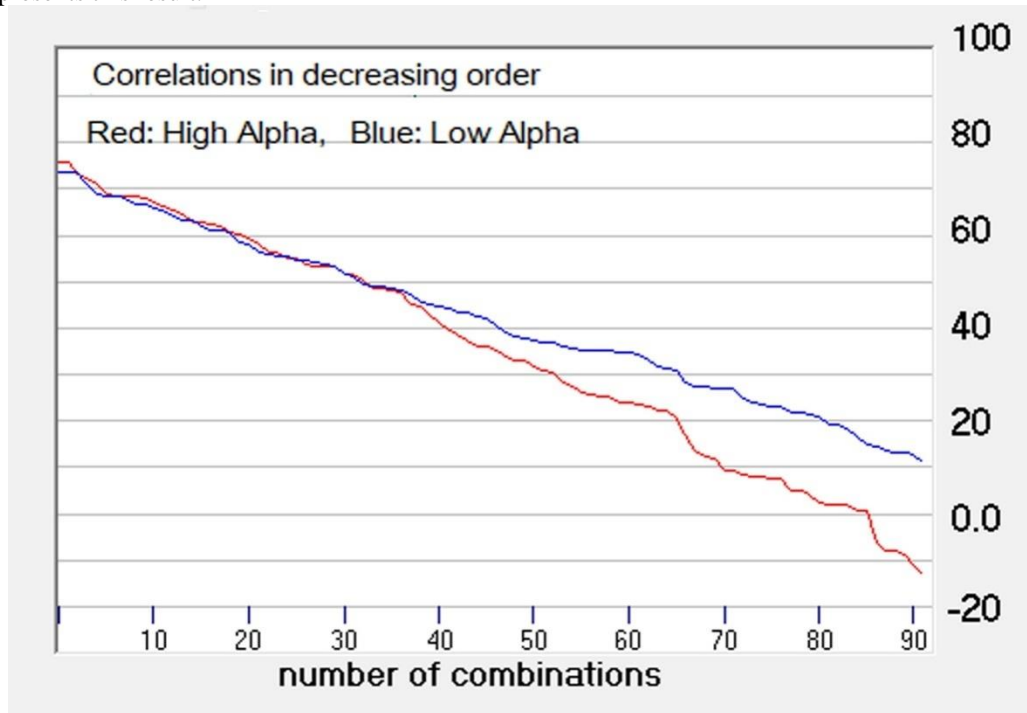


Fig. 4:- Graph of the 91 correlations (multiplied x 100) in descending order between the two groups.

Coherence-gw

Coherence concerns the calculation of synchronization along each frequency. If we calculate the overall Coherence of all subjects, in the two groups, we get a graph like the one in fig.5 .

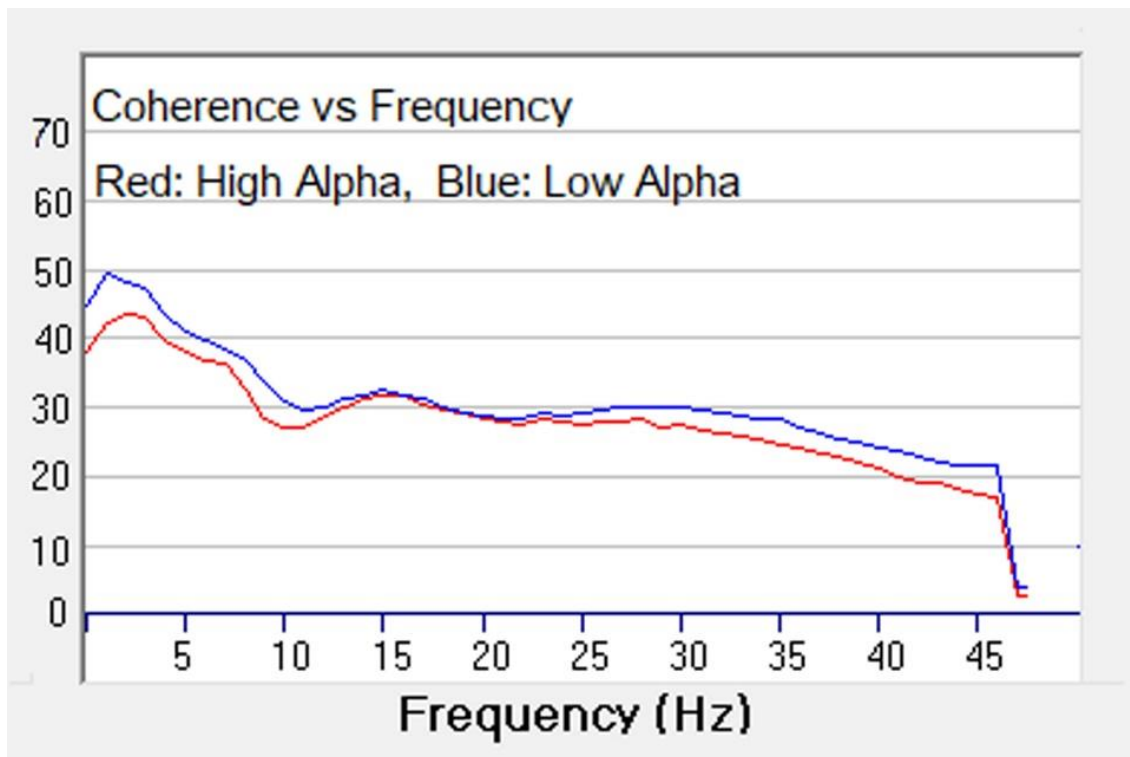


Fig. 5:- Coherence of the two groups of subjects.

Once again the High-Alpha subjects show lower values in several EEG bands.

The lowering of the curve at about 10 Hz is due to several pairs of counterphase signals in the Alpha band. With reference to figure 3, the Coherence of some pair of electrodes is shown in fig. 6

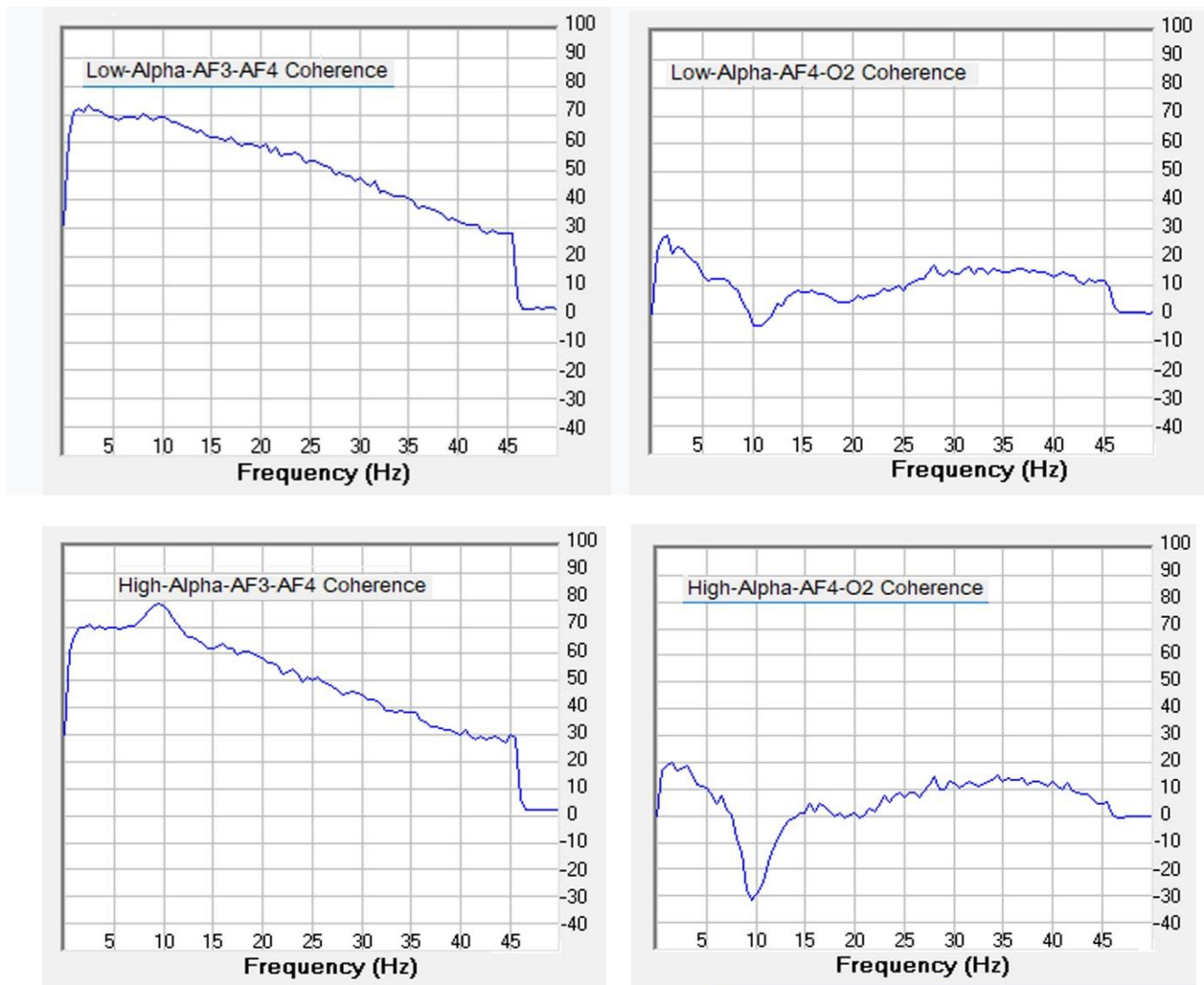


Fig. 6:- Average Coherence (29 subjects) in AF3-AF4 (frontal lobes) and AF4-O2 (frontal vs occipital). The High-Alpha show higher coherence around 8-12 Hz (alpha) in frontal lobes and lower coherence between frontal vs occipital lobes. The drop of curves around 46Hz is due to the band-pass of the EEG amplifiers and signal digital filtering.

Subjects with high Alpha Rhythm value show increased synchronization in frontal and occipital lobes, and a marked tendency to negative values (counterphase) in the relationship between frontal and occipital lobes. The same observation was made by H.Suzuki (1974)[15] with accurate measures of phase-synchrony over distance.

When Alpha waves are large enough, they are more in-phase in frontal and occipital lobes, and partially in counterphase between several different pairs of electrodes, and thus for this reason, the overall synchrony in High-Alpha subjects tends to be lower than in Low-Alpha subjects.

Figure 7 shows this concept.

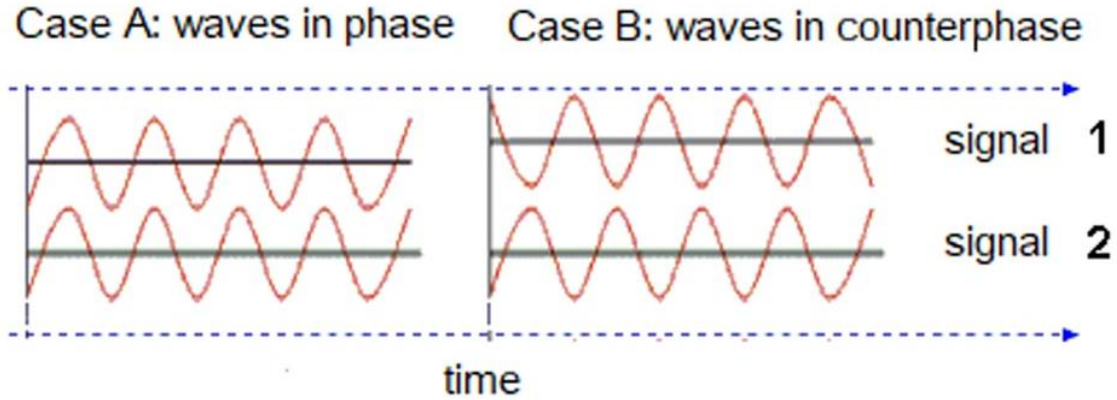


Figure 7:- Description of the concept of phase and counterphase of waves of any type.

Conclusions and Discussion:-

In this study, no positive association was found between Alpha Rhythm value and Brain Synchronization, but on the contrary High-Alpha subjects show (on average) lower EEG synchronization than Low-Alpha subjects. However in the frontal and occipital locations there is an increase in synchronization in High-Alpha subjects, all other electrode combinations give lower results.

This result strictly depends on the type of mathematical algorithm used to calculate EEG synchronization. The method based on Pearson's Correlation is independent of the amplitude of the two signals and depends only on the phase between them. Other algorithms used by different authors may lead to different results because each algorithm has a different physical meaning, although each is proposed as a method of calculating EEG Synchrony. For example, A.P.Kulaichev (2021)[16] expresses doubts about the reproducibility and significance of different methods of coherence calculation, and proposes a method based on correlation between the envelope of two signals, described in fig.7.

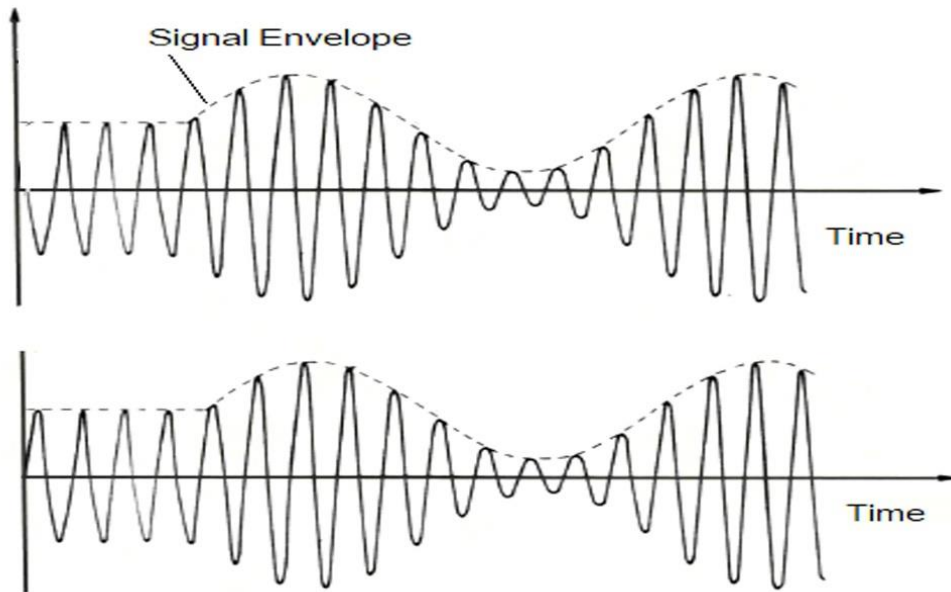


Figure 7:- Example of envelope of two signals and correlation between the two envelopes.

Figure 7 shows two signals that are in counterphase with each other, but their time envelope is significantly in phase. Pearson's correlation would give a very negative value between the two signals, and very positive between the

envelopes. This method (based on the envelopes) is part of an alternative proposal by Kulaichev. The conclusion is that EEG synchrony must be perfectly defined as an identical algorithm in order to compare the results of different experimental works. In addition, this Author thinks it is very important to assign a clear physical meaning to each mathematical algorithm, otherwise the meaning of the results obtained is unclear.

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