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Relationship between the phase of the ongoing activity at the stimulus time and the N100 detected response using EEG recordings

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Abstract:
There are two main theories to explain the reason of the average response in the EP recorded with an EEG system. One of these theories affirms that the average response results from synchronous phase-resetting in the ongoing activity provoked by the stimulus. Testing the relationship between the phase in the ongoing EEG activity at the stimulus time and the response after the stimulus we pretend to find a relationship in accordance with this theory.
In this study, data from 19 normal subjects were recorded using an EEG recorder system. Observing the Cz channel, the phase of the ongoing activity at the time of stimulus arrival was estimated and compared with the response obtained from the same signal after applying an iterative Independent Component Analysis algorithm. Applying this algorithm, basically two kinds of EEG responses are detected for each single trial observing the N100 peak. One response follows the same pattern as the average EP and the other response follows just the opposite one. In this paper we present the relationship found between the phase and the percentage of found trials with these two kinds of responses.

Key-Words: - EEG, iterative ICA, Averaged EP, N100 peak, Single-trials analysis

1 Introduction

The analysis of cortical oscillatory activity using EEG and MEG is considered as a backbone mechanism to understand perceptual binding [1]. There are two oscillatory responses to a stimulus detected with EEG recordings. The response to a stimulus may have a constant phase relationship or may consist of a change in the amplitude in the ongoing activity without a clear phase relationship with the stimulus. The first group of responses is called phase-locked or evoked potentials and the second group is called non phase-locked or induced potentials [2].

Evoked potentials (EP) present the same latency time between the stimulus and the response. Most kinds of sensory stimulation cause evoked potentials. The recordings that will be analyzed in this report contain auditory evoked potentials (AEP). AEP present much smaller amplitude that the spontaneous activity, as in most cases of EP, and it makes necessary to perform an average process after recording several AEP in order to obtain a visible response [8].

There are two main theories to explain the reason of the average response in the EP. The first theory states that it results from the sum of low-amplitude potentials generated in each individual stimulus. The second theory affirms that it results from synchronous phase-resetting in the ongoing activity provoked by the stimulus with out any amplitude change [3-5].

Recently, a new algorithm based on independent component analysis (ICA) has been developed and provides certain information related with individual trials. The name of this algorithm is iterative ICA (iICA). Observing the N100 peak in auditory stimulation, one of the most significant findings achieved after applying this algorithm in auditory evoked potential recordings is that sometimes the obtained response for a single trial doesn't follow the expected pattern (this is, the pattern provided by the average response), but just the opposite one (see Figure 1). Those trials that follow the expected pattern are named as 'expected' responses, and those that follow the opposite pattern are named as 'aberrant' responses.

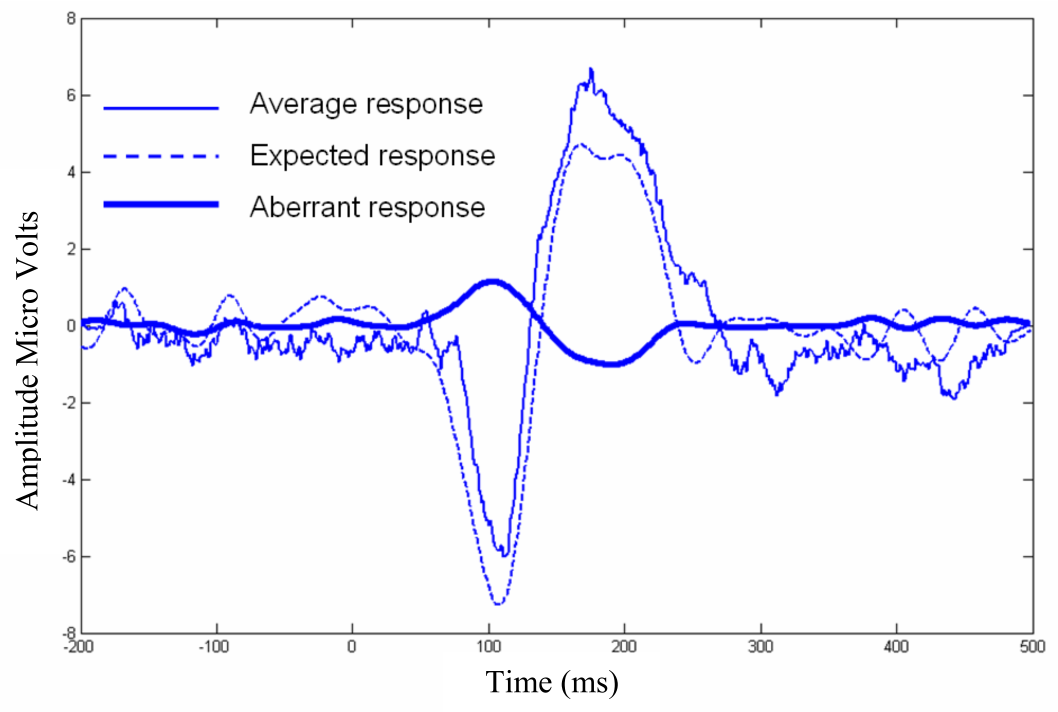

Figure 1 Example of aberrant and expected responses. The continuous thin line corresponds with the evoked potential average response. The other two lines correspond with two examples of single trials filtered using the iICA algorithm. The discontinuous thin line is an expected response (shows the same polarity as the averaged at the N100 peak) and continuous thick line is an aberrant response (shows the opposite polarity than the averaged at the N100 peak). The time axis is set to zero when the stimulus is applied.

In this study, we have analyzed the relationship between the evoked responses obtained for single trials after applying the iICA focusing our attention on the relationship between the aberrant or expected response of each trial and the phase of the ongoing rhythms at the stimulus time.

2 Subjects and Methods

Data from 19 normal subjects between 23 and 42 years were recorded with a whole-head, 256-channel, dense array EEG (dEEG) scanner, using an electrode cap covering the entire head (BioSemi Active Two EEG system). All subjects were volunteers and gave written informed consent to the studies.

The stimuli consisted of 1-kHz tones with duration of 40 msec, and 10 msec rise and fall times. Stimuli were delivered binaurally at the rate of 1.1 stimuli per second. The data were referenced to the linked mastoids [6].

A total of 200 trials were collected for patient in each recording session, but subsequent removal of artifacts, e.g., eye blinks, eye movement, muscle activity, with absolute amplitude greater than 75 µV, resulted in each set having between 50 and 200 trials. Data were segmented into 700 ms epochs, each containing 200 ms prestimulus and 500 ms poststimulus activity before further processing (see Figure 1). Data from only the Cz channel were used for the analysis.

The phase of the ongoing activity at the time of stimulus arrival was estimated. In order to determine the phase angle of the ongoing activity at the time of stimulus arrival, 100 msec of prestimulus and 100 msec of poststimulus activity were smoothed with a zero-phase 13 Hz lowpass filter; this way all the frequencies down to beta were preserved. The two extrema, one before (ta) and one after (tb) the stimulus time (ts), were determined by computing the product of the first derivative at two consecutive points [7]. A negative value would indicate an inflection point. The amplitudes of the inflection points (Va and Vb, respectively) were also computed. Then, a sine wave was fitted to the data and finally the phase angle (φ) was computed as follows,

$$\varphi = \frac{ts - ta}{tb - ta}\pi + \frac{\pi}{2}$$

If Vb > Va, then the value of φ was increased by π, and if $\varphi > 2\pi$, it was decreased by 2π. Figure 2 depicts the values defined on a single trial EP that are necessary to determine the phase angle of the ongoing EEG activity at the time of stimulus arrival.

The range of 360^0 degrees presented by the phase was divided into 8 regular intervals of 45^0 degrees. This way, the first interval covered from 0^0 to 45^0, and so on.

The iICA method was applied separately for each subject obtaining in this way the filtered trials with the expected and aberrant responses. Those trials were binary labeled as 0 or 1 if they presented and aberrant or expected response, respectively.

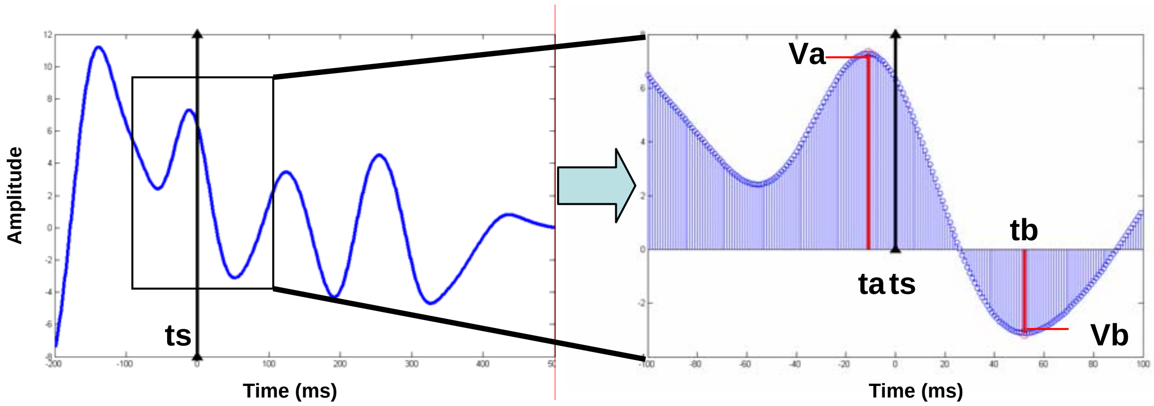

Figure 2 Illustration of the procedure followed to obtain the phase of the ongoing activity at the stimulus arrival

3 Results

Finally, all the trials were checked observing each trial's phase at the stimulus time and the binary response's label (0 or 1). Two counters were established for that. These counters consisted of two vectors of eight cells each one (one cell per interval). The first counter registered the number of expected trials found in each angle interval, and the second counter registered the number of aberrant responses found for each angle interval.

Table 1 contains the information about the number of aberrant trials found for each patient along the different intervals.

Table 1 Number of aberrant trials found for each patient along the different intervals

		Aberrant trials per Interval								
		Interval Range in Degrees								
Subject Number	**Number of Accepted Trials**	**0-45**	**45-90**	**90-135**	**135-180**	**180-225**	**225-270**	**270-315**	**315-360**	**Percentage of Aberrant Trials**
1	200	1	4	11	3	9	9	1	5	**22%**
2	195	10	7	8	5	7	9	7	6	**30%**
3	188	5	6	6	2	0	1	0	5	**13%**
4	198	1	2	1	1	0	0	1	1	**4%**
5	186	1	2	1	2	1	1	3	0	**6%**
6	170	1	2	2	3	0	1	3	6	**11%**
7	85	1	5	4	2	3	3	0	2	**24%**
8	50	1	3	2	1	1	0	0	2	**20%**
9	69	0	1	0	0	0	0	1	1	**4%**
10	117	0	0	0	0	0	1	0	1	**2%**
11	65	1	1	1	0	0	1	0	0	**6%**
12	74	2	1	0	0	3	0	1	3	**14%**
13	146	5	3	2	3	0	1	1	4	**13%**
14	186	7	10	6	1	1	1	0	4	**16%**
15	75	0	0	0	0	1	0	1	0	**3%**
16	84	0	3	3	4	1	2	1	2	**19%**
17	70	0	0	0	0	1	0	0	1	**3%**
18	190	5	5	5	4	2	2	6	1	**16%**
19	198	2	6	8	12	5	3	7	2	**23%**
Total	**2546**	**43**	**61**	**60**	**43**	**35**	**35**	**33**	**46**	

The column headed as 'Number of Accepted Trials' shows the number of accepted trials per patient after the preprocessing method described in section 2. The number of accepted trials ranges from 50 for patient 8 to 200 for patient 1. The total number of accepted trials is 2546.

The number of aberrant trials found along the different intervals oscillates between 33 for the range 270º-315º to 61 for the range 45º-90º. Different patients present different percentage of aberrant trials varying between 2% for patient 10 to 30% for patient 2. The mean value of the percentage of aberrant trials per patient is 13% ± 8.

Table 2 presents the number of expected trials found in the different intervals and the valance with respect to the number of aberrant trials found in each interval.

The number of aberrant trials found along the different intervals oscillates between 226 for the range 135º-180º to 352 for the range 225º-227º, and the total number of trials ranges from 269 to 387 presenting an average of 318 ± 34.

Table 2 Comparison between the number of expected and aberrant trials found in the different intervals.

	Interval Range in Degrees							
	0-45	45-90	90-135	135-180	180-225	225-270	270-315	315-360
Total of Expected Trials	272	248	248	226	261	352	293	290
Total Number of Trials	315	309	308	269	296	387	326	336
% of Aberrant Trails	14%	20%	19%	16%	12%	9%	10%	14%
STD	13	15	17	16	13	9	9	10

The percentage of aberrant trials found in each interval is obtained relating the number of aberrant trials with the total number of trials found for that interval. The low part of Table 2 shows the numerical values. We found a maximum in the interval 45º-90º (20%) and a minimum in the interval 225º-270º (9%). The separation from these two intervals is 180º which means that these intervals are in opposite phases, and the evolution of the rest of values present an smooth sinusoidal progression, as it is shown in Figure 3.

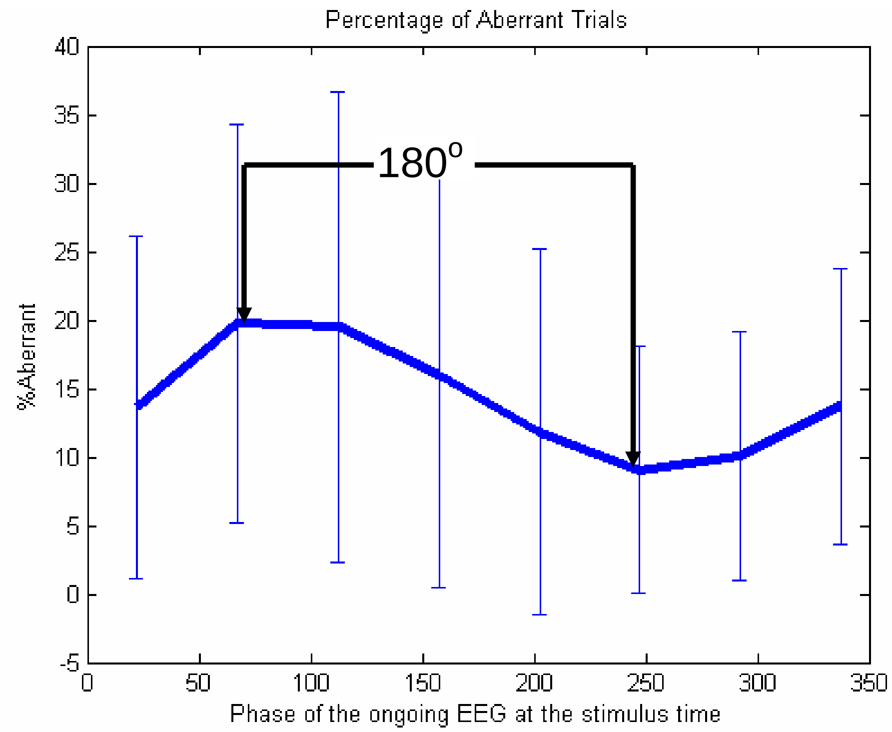

Figure 3 Graphical representation of the percentage of aberrant responses along the different intervals (wide continuous line) and the standard typical deviation for each interval (vertical lines)

This information suggests that it is more likely to obtain an aberrant response when the phase of the ongoing EEG has a certain angle (in this case close to 75°). In this way, the response of the brain could be related with a phase-resetting in the ongoing activity provoked by the stimulus as suggested the second theory presented in the introduction.

As we said before, the total number of trials found for each interval has a very narrow range (318 ± 34). This could balance the data in one or another direction, because some intervals have much more trials than others. The process was remade so that randomly an equal number of trials per interval were selected, but this made not be an important factor as the results before described were consistent.

The main concern about the confidence of these results is the next. The vertical bars mark the range determined by the standard deviation. This bars shows an improvement in the consistency of the results around 250^0 in comparison with the results obtained around 75^0; this is, more patients present a 10% of aberrant response around 250^0 phase than 20% around 75^0. And in both cases, the relationship between the standard typical deviation and the mean value is not very good, as the range between the minimum and maximum value on the percentage of aberrant responses is 11% and the minimum value for the standard deviation is 9.

4 Discussion

The relationship between the evoked response obtained for single trials after applying the iICA algorithm and the phase of the ongoing rhythms at the stimulus time on the original signal has been analyzed. Some phases down the beta range looked more likely to produce aberrant responses in the global analysis over 19 patients. The difference between the angles that most likely produce aberrant responses and the angles that less likely do is 180^0 and the rest of the phases keep a smooth sinusoidal progression.

This relationship between phase and response is in accordance with the theory that the phase on the ongoing activity at the stimulus time plays an important role in the evoked response of the brain.

The main concern for the verification of these results is that the relationship between the standard typical deviation and the mean value is not very good.

The same relationship were tried to be found using the beta and gamma range, but only the down to beta range presented the pattern described in this paper.

Finally a parameter to relate the phase and the response was tried to be found. Two other relationships between the ongoing activity and the response have been tested using the single trials obtained by mean of the iICA algorithm. The first association under study was the relation between the amplitude of the ongoing activity at the stimulus time and the aberrant/expected response of the single trial. The second association was the relationship between the power and phase of the ongoing activity with the aberrant/expected response. This last experiment has been taken out for the different bands (from delta to gamma) obtaining a 3D representation of the percentage of aberrant responses as a function of power and phase of the ongoing activity. But any significant relationship was appreciated both in the case of the amplitude as in the case of the power analysis.

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