Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Using Component Synchrony Measure for somatosensory evoked potential detection

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Abstract—**The Multiple Component Synchrony Measure (MCSM), a Multivariate Objective Response Detection (MORD) technique in the frequency domain, was applied to EEG signals during somatosensory stimulation of the right posterior tibial nerve collected from derivations [Fpz'-Cz'] and [C3'-C4'] of 10 adult volunteers. Stimuli were applied at the rate of 4.91 Hz and at the motor threshold intensity level. Detection was identified based on the null hypothesis of response absence rejection – when the estimates exceed the critical values (significance level $\alpha = 0.05$ and $M = 100$, 400 and 800 epochs). For these three M values, detection was obtained in at least 80% of the volunteers for the frequency range from 34.3 to 54.0 Hz, within the gamma band. With M =400, however, response could be detected in all subjects for this frequency range. Similar performance was observed for $M = 800$. These findings indicate that MCSM is capable of objectively identifying stimuli response.**

I. INTRODUCTION

THE EEG during sensory stimulation is a non-invasive, low-cost exam that has been widely used for neurological diagnosis as well as for prognosis and surgery monitoring. This exam consists of the visual inspection of coherent averages of EEG epochs during stimulation (epochs synchronized with the stimulus) which is called Evoked Potential (EP).

The somatosensory evoked potential (SEP) is elicited by electrical stimulation. Encouraging results have been found for it as an evolution predictor in cases such as intracranial hypertension [1], coma [2] and neuromotor development in preterm newborns [3]. Moreover, it has been applied during spine surgeries [4] (lumbar, thoracic or cervical) and vascular surgeries [5], since the SEP is sensitive to neurological insults. Additionally, this potential is important during the post-operative period for late neurological impairment detection [6].

Although the SEP analysis has become unquestionably useful for neurological assessment, the visual analysis methodology is known to introduce a subjective bias, since it depends on the observer expertise and attention status. Furthermore, many confusing factors such as baseline EEG quality, anaesthesia regimen and inter-patient variability can affect the inspection [7]. Besides the subjective bias, during surgery monitoring, the SEP important changes are assessed by very informal criteria [8], such as amplitude decrease from 30% to 50% of the pre-operative level or latency increase from 5% to 10%, or a combination of both.

On the basis of this drawback, Dobie & Wilson [9] suggested the application of mathematical methods, the Objective Response Detection (ORD) techniques, which could allow inferring about the absence of stimuli response with a constant false alarm rate defined *a priori*. However, the detection rate of these techniques is limited by the signal-to-noise ratio (SNR) and the length of the collected signal [10]. For a fixed data length, the higher the SNR, the better the detection probability. Moreover, the greater the number of EEG epochs considered in the techniques calculation, the better the probability of detecting the stimuli response if such is present. Thus, for a fixed SNR-value, detection can only be increased at the expense of using more EEG data.

In this scenario, the use of Multivariate Objective Response Detection (MORD) has been recently suggested by Miranda de Sá *et al.* [10] as an attempt to increase the detection rate for a fixed data length by including more EEG signals in the detector. These techniques are N-dimension extensions of the ORD techniques that use, in a synergic way, information of more than one derivation. It is particularly relevant in noisy environments such as hospitals and ICU, where the SEP is an important tool and the probability of response detection is critical.

In this work, we applied the Multivariate extension of Component Synchrony Measure (CSM) to EEG during somatosensory stimulation in order to evaluate its performance for detecting evoked responses. Additionally, the number M of epochs used to evaluate the CSM is varied and its effects, observed.

Manuscript received April 3, 2006. This work was supported by CAPES, CNPq and FAPERJ.

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II. METHODS

A. Multiple Component Measure Synchrony

According to [11] it is possible to measure the synchronization of the ith-window Fourier transform of N EEG derivations ($y_1[k]$, $y_2[k]$,…, $y_N[k]$) due to a rhythmic stimulation only by considering its mean phase angle, $\bar{\theta}_i(f)$. This MORD technique, called Multiple Component Synchrony (MCSM), can be used for EP detection and can be mathematically defined as:

$$\hat{\rho}_N^2(f) = \left[\frac{1}{M}\sum_{i=1}^{M}\cos\left(\bar{\theta}_i(f)\right)\right]^2 + \left[\frac{1}{M}\sum_{i=1}^{M} sin\left(\bar{\theta}_i(f)\right)\right]^2 \qquad (1)$$

and the asymptotic critical value can be expressed as:

$$\rho_N^2 crit = \frac{\chi_2^2 crit,\alpha}{2M} \qquad (2)$$

where $\chi_2^2 crit,\alpha$ is the critical value of the chi-squared distribution with 2 degrees of freedom for a significance level α and M is the number of epochs used in the estimation. The mean phase can be calculated as:

$$\bar{\theta}_i(f) = \begin{cases} \tan^{-1}\left(\bar{S}_i/\bar{C}_i\right) & if \quad \bar{C}_i \geq 0 \\ \tan^{-1}\left(\bar{S}_i/\bar{C}_i\right) + \pi & if \quad \bar{C}_i < 0 \end{cases}$$

where

$$\bar{C}_i = \frac{1}{N}\sum_{j=1}^{N}\cos\theta_{ij}(f) \quad \text{and} \quad \bar{S}_i = \frac{1}{N}\sum_{j=1}^{N}\sin\theta_{ij}(f)$$

The detection is obtained based on the rejection of the null hypothesis (H_0) of response absence, which is reached when the estimates values exceed the critical values ($\hat{\rho}_N^2(f) > \rho_N^2 crit$).

B. EEG Acquisition

EEG during somatosensory stimulation was collected from two scalp regions corresponding to the somatosensory cortex. Surface gold electrodes were positioned in the derivations [Fpz'-Cz'] and [C3'-C4'], as is usual for SEP monitoring. Fpz' is the mid-point between Fpz and Fz (International System 10-20) and Cz', C3', C4' are located 2 cm posterior to Cz, C3 and C4, respectively. The signals were obtained from ten adult volunteers aged between 23 and 45 (mean: 27.6, standard deviation: 6.8 years) with no symptoms of neurological pathology and with normal SEP. The volunteers were lied down in the supine position with eyes closed. The stimuli (current pulses of 200 µs width) were applied to the right posterior tibial nerve with the MEB 9102 (Nihon Koden) at the rate of 4.91 Hz in order to avoid responses at 60 Hz and harmonics. The intensity used was the lowest that produced feet interior muscle involuntary contraction, namely the motor threshold level. The ground electrode was positioned on the poplitea fossa. Surface gold electrodes were used for both recording and stimulation. The local ethics committee (CEP-HUCFF/UFRJ) approved this research.

C. Pre-processing

First, the signals were band-filtered within 1 – 1000 Hz with the bioamplifier Opti-Amp V. 8000D (Intelligent Hearing System) and digitized with a 12-bits analog-digital converter (DaqPad1200 of National Instruments) at the sampling rate of 3000 Hz.

The EEG signals were segmented in epochs of 203 ms (spectral resolution of 4.93 Hz) by using the stimulus as the fiducial (synchronization) point. In order to avoid the stimulus artifact, which produces distortion in frequency domain MORD techniques, since it is wide-band and stimulus synchronized, the first 3 ms were set to zero. Also, the final 3 ms were zero padded to ensure window symmetry. Moreover, a Tukey window with a 7 ms rising (falling) time has been applied to each epoch. This procedure is in accordance with Tierra-Criollo & Infantosi [12] who reported the influence of the stimulus artifact is more evident up to 5 ms post-stimulus.

Next, epochs with low signal-to-noise ratio were rejected by using a semi-automatic rejection artifact algorithm [13]. This procedure is based on twenty seconds of background EEG visually considered noisy-free. The standard deviation (*sd*) of the selected data is taken as reference and epochs with over than 5% of continuous samples or over than 10% of any samples exceed ±3 *sd* (threshold containing approximately 99.5% of samples assuming EEG amplitude as normally distributed) are rejected.

Then, $\hat{\rho}_N^2(f)$ and $\rho_N^2 crit$ were calculated for the acquired signals using (1) and (2) with $N = 2$, $\alpha = 5\%$ and $M = 100$, 400 and 800.

III. RESULTS

The application of the Multiple CSM to the EEG during stimulation with 15.6 mA is illustrated in Figure 1 for the volunteer #8. In this case, $\hat{\rho}_2^2(f)$ for $M = 100$ indicates the response detection in the frequencies 9.8-19.6, 34.4-54.0,78.6-83.5, 98.0-112.9, 147.3-152.2, and 157.1 Hz (using $\alpha = 0.05$ in (2) results $\rho_2^2 crit = 0.0300$). For the same volunteer but $\hat{\rho}_2^2(f)$ for $M = 800$, Figure 2 shows that the rejection of the null hypothesis ($\rho_2^2 crit = 0.0037$) occurs for almost all frequencies within the range 9.8-108.0 Hz. It is important to note that the estimate values are similar ($\hat{\rho}_2^2(f)$ from 0 to about 0.08) for both M, and are even higher for $M = 100$ (e.g.: at the frequency 83.5 Hz). However, a better detection rate was achieved with $M = 800$, since it implies improving the signal to noise ratio and decreasing the critical value (from 0.0300, with $M = 100$, to 0.0037, with $M = 800$).

The number of volunteers for whom it was possible to detect stimuli response for the multiples of the stimulation frequency from 3 to 15 is presented in Figure 3. For $M = 100$, the detection is higher that 70% within 7th to 11st multiples, leading to full detection at 44.2, 49.1 and 54.0 Hz. For $M = 400$, detection rate was found to be greater than 80% within 3rd to 13rd (14.7 to 63.8 Hz, except at 19.6 Hz), and equal to 100% from 7th to 11st multiples of the stimulation frequency. Similar results were obtained for $M = 800$, with full detection at the multiples 5, 7-9 and 11 (24.6, 34.3-44.2, 54.0 Hz).

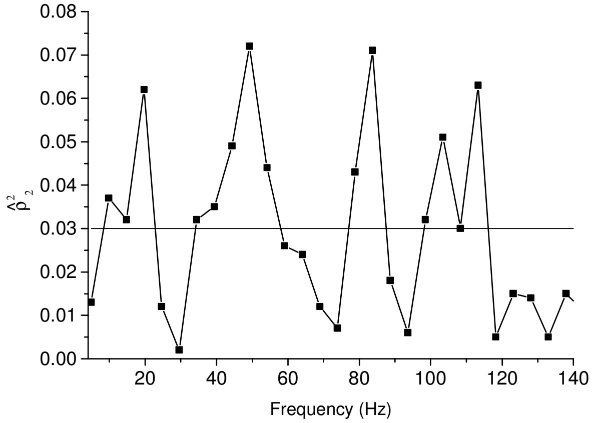

Figure 1: For volunteer #8, stimulated with 15.6 mA, $\hat{\rho}_2^2(f)$ and $\rho_2^2 crit$ = 0.0300 (thick horizontal), for $M = 100$, α = 0.05.

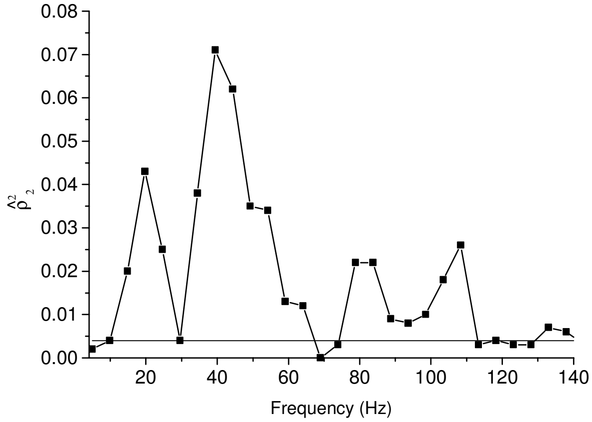

Figure 2: Idem Figure 1, but $\rho_2^2 crit$ = 0.0037 (thick horizontal), for $M = 800$, α = 0.05.

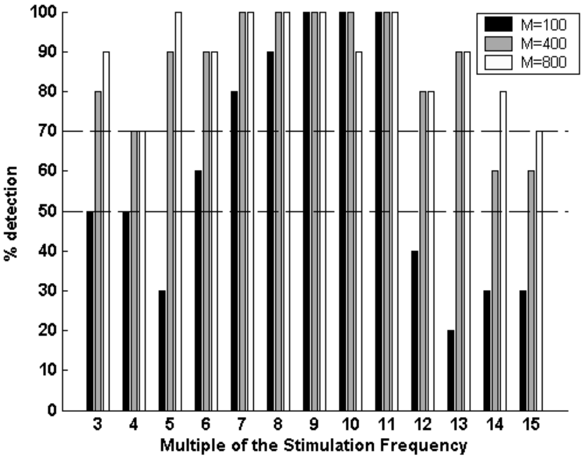

Figure 3: Percentage of volunteers for whom the stimuli response was detected for $\hat{\rho}_2^2(f)$ with different M values. Horizontal dashed lines represent detection for 50 and 70 % of volunteers.

IV. DISCUSSION

By comparing the results obtained in this work with those from a previous one [14], $\hat{\rho}_2^2(f)$ seems to present inferior performance than Multiple Coherence ($\hat{\kappa}_2^2(f)$) for $M = 100$ epochs. In fact, our results agree with Felix *et al.* [15] who reported, using simulation, that the probability of detection is higher for $\hat{\kappa}_N^2(f)$ than the obtained for $\hat{\rho}_N^2(f)$, using $N = 2$. However, for larger M values such as 400 or 800, response could be detected with $\hat{\rho}_2^2(f)$ in all volunteers within the range 34.4 to 54.0 Hz. In fact, the performance observed for $\hat{\kappa}_2^2(f)$ with $M = 100$ is reached by $\hat{\rho}_2^2(f)$, but only with $M \geq 400$. Moreover, the frequencies for which one can obtain the best detection rate in both [14] and this work are the same – i.e. 7th to 11st multiples of the stimulation frequencies (34 to 58 Hz), which are within the gamma band Furthermore, this finding is in accordance with [12] that reported the gamma range as the maximum response band, i.e., the frequencies that better characterize the SEP and to which special attention during SEP monitoring should be given.

Although 400 (or 800) epochs could be considered a large M value, it is worth noting that the SEP morphology analysis, carried out for monitoring purposes, can involve averaging up to M=2000 epochs [16]. Hence, $\hat{\rho}_2^2(f)$ is advantageous in comparison with the traditional methods.

It was reported in [11] and [15] that the use of more than one derivation does not guarantee a monotonically increase in the detection rate. Sometimes, this rate could present an oscillatory behavior by augmenting the number N of derivations. According to these authors, the increase of the detection rate is only expected if the SNR of the derivations used in MORD techniques does not differ too much. Although this could be expected for visual evoked potential, studied in [11] and [15], on the basis of the interhemipheric symmetry [17] this cannot be guaranteed for SEP, since there is no *a priori* evidence that Fpz'-Cz' and C3'-C4' have similar SNR.

V. CONCLUSION

The Multiple Component Synchrony Measure, $\hat{\rho}_2^2(f)$, showed to be capable of identifying somatosensory stimuli response at the motor threshold, especially for $M = 400$ or 800. The frequencies from 34 to 55 Hz, within the gamma band, are of particular interest, since the detection occurred at least for 80% of the volunteers for the three M-values used. Hence, it should be considered for monitoring purposes.

Although $\hat{\rho}_2^2(f)$ has lead to encouraging results, its performance should be compared, in more details, with other MORD techniques and even with its ordinary version ($\hat{\rho}^2(f)$ with $N = 1$), for different M-values. Furthermore, the assumption of similar SNR for SEP derivations should be clarified in order to have a better insight about the results obtained with MORD methods.

These results should be extended to a large number N of derivations and a wider casuistry, which would allow establishing it as statistically significant and generalizing the results for EEG during somatosensory stimulation.

ACKNOWLEDGMENT

To CAPES, CNPq and FAPERJ for the financial support and to the Military Police Central Hospital of Rio de Janeiro for providing infrastructure support.

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