# Simples Coherence vs. Multiple Coherence: A Somatosensory Evoked Response Detection Investigation

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*Abstract*— **In this work the performance of two techniques useful for detecting the somatosensory evoked potential (SEP), namely the Magnitude-Squared Coherence (MSC or Simple Coherence) and its multivariate version, the Multiple Coherence (MC), was compared. Electroencephalographic (EEG) signals during somatosensory stimulation were collected from forty adult volunteers without history of neurological pathology using the 10-20 International System. All leads were referenced to the earlobe average. The stimulation was carried out throughout current pulses (200 µs width) applied to the right posterior tibial nerve (motor threshold intensity level) at the rate of 5 Hz. The response detection was based on rejecting the null hypothesis of response absence ($M = 100$ epochs and significance level $\alpha = 0.05$). The MSC was applied to the derivations [Cz], [Fz], [C3] and [C4], usually employed in the SEP recordings when bipolar derivations are used. The MC was applied to the pairs [Cz][Fz] and [C3][C4]. The results indicated that if two derivations are available, it should be better to use the MC applied to both leads than the MSC applied to each one.**

*Keywords*— **Somatosensory evoked potential, Magnitude-Squared Coherence, Multiple Coherence, Objective Response Detection.**

## I. INTRODUCTION

The somatosensory evoked potential (SEP) is useful for neurological assessment for both clinical and intra-operative monitoring purposes. The application of statistical methods known as Objective Response Detection (ORD) Techniques has been widely investigated to overcome the subjective component of the morphological (visual) analysis made by the specialist. These techniques allow inferring about the presence (or absence) of a stimulus response with a maximum false-positive rate defined a priori, which is the significance level of the statistical test applied.

However, the probability of detecting stimulus response using ORD techniques applied to EEG with fixed signal-to-noise ratio is only achieved by augmenting the recording time [1] and, hence, the exam duration. Nevertheless, this should be avoided, especially for intra-operative monitoring, when the speed of detection is critical.

In order to overcome this limitation, many works [1-4] studied the possibility of augmenting the probability of detection by using information from more than one EEG derivation. Therefore, in an ORD approach, multivariate extensions of the ORD techniques (MORD) should be employed.

In this work, we compare the performance of Simple and Multiple Coherence applied to EEG during somatosensory stimulation.

## II. MATERIAL AND METHODS

### A. Multiple Coherence (MC)

The MC between a periodic signal and a set of $N$ random ones ($y_j[k]$, $j = 1..N$) is given by [2]:

$$\hat{\kappa}_N^2(f) = \mathbf{V}^H(f)\hat{\mathbf{S}}_{yy}^{-1}(f)\mathbf{V}(f)\big/M \qquad (1)$$

where $\mathbf{V}(f) = \left[\sum_{i=1}^{M} Y_{1i}^*(f) \quad \sum_{i=1}^{M} Y_{2i}^*(f) \quad \cdots \quad \sum_{i=1}^{M} Y_{Ni}^*(f)\right]^T$.

$H$ and $T$ superscript mean, respectively, Hermitian and the matrix transpose; and the $p^{\text{th}}$-row, $q^{\text{th}}$-column element of $\hat{\mathbf{S}}_{yy}(f)$ is $\hat{\mathbf{S}}_{yp\,yq}(f) = \sum_{i=1}^{M} Y_{pi}^*(f) Y_{qi}(f)$.

The critical value for a significance level $\alpha$, $M$ epochs and $N$ signals can be expressed as [2]:

$$\hat{\kappa}_{N\,crit}^2 = \frac{F_{crit\,\alpha,2N,2(M-N)}}{F_{crit\,\alpha,2N,2(M-N)} + [M-N]/N} \qquad (2)$$

The detection is identified based on the rejection of the Null Hypothesis ($H_0$) of Response Absence, which is achieved when the estimate values exceed the critical value ($\hat{\kappa}_N^2(f) > \hat{\kappa}_N^2 crit$).

### B. Magnitude-Squared Coherence (MSC) or Simple Coherence

The MSC represents the parcel of the squared-mean value of the measured EEG that can be explained by the stimulation. The MSC for a discrete-time, finite duration and windowed signal can be estimated as described by [5].

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For the case of a periodic stimulus, the MSC estimate depends only on the measured EEG and can be expressed as:

$$\hat{\kappa}^2(f) = \left|\sum_{i=1}^{M} Y_i(f)\right|^2 \Bigg/ M\sum_{i=1}^{M}\left|Y_i(f)\right|^2 \qquad (3)$$

where "^" superscript denotes estimation, $Y_i(f)$ is the Fourier Transform of the i$^{\text{th}}$ window of EEG and *M* is the number of epochs used for the estimates calculation. (See [6] for further details about the MSC interpretation).

The analytic critical values for the coherence estimate can be calculated from the distribution obtained in [7] as described in [8]:

$$\hat{\kappa}^2_{\text{crit}} = 1-\alpha^{\frac{1}{M-1}} \qquad (4)$$

The detection is based on rejecting of the null hypothesis ($H_0$) of response absence, which is reached when the estimate values exceed the critical value ($\hat{\kappa}^2(f) > \hat{\kappa}^2 crit$).

### *C. EEG Acquisition*

The electroencephalogram (EEG) during somatosensory stimulation was collected from forty adult volunteers aging from 21 to 41 years old (mean±standard deviation: 28.6±4.6 years) and without history of neurological pathology. The signals were collected using the EEG BNT-36 (EMSA, Brazil, www.emsamed.com.br) according to the 10-20 International System and all leads were referenced to the earlobe average. The volunteers were laid down in the supine position with eyes closed. The stimuli were applied by means of current pulses (200 µs width) to the right posterior tibial nerve using the Atlantis Four (EMSA). The stimulus was applied at the motor threshold intensity level and at the rate of 4.80 Hz (nominal frequency: 5 Hz). The ground electrode was positioned on the poplitea fossa. Surface silver and gold electrodes were used, respectively, for recording and stimulation. The local ethics committee (CEP-HUCFF/UFRJ) approved this research and all volunteers gave written informed consent to participate.

### *D. Pre-processing*

First, the signals were band-filtered within 0.5 – 100 Hz and digitized with BNT-36 (16-bits resolution) at the sampling rate of 600 Hz. The EEG signals were segmented into epochs of 207 ms, synchronized with the stimulation (i.e. windows of one inter-stimulus duration were used), resulting in spectral resolution of 4.8 Hz. The first 5 ms after each stimulus were set to zero in order to avoid the stimulus artifact, which produces distortion in the frequency domain. Additionally, the final 5 ms were zero padded to ensure window symmetry. Furthermore, a Tukey window with 7 ms rising (falling) time has been applied to each epoch to ensure that the late components of the artifact were also attenuated. Noisy epochs were next discarded through a semi-automatic artifact rejection algorithm. (See [6] for further details about the windowing and the artifact rejection). $\hat{\kappa}^2_N(f)$ and $\hat{\kappa}^2_{N\,crit}$ were calculated for the acquired signals using expressions (1) and (2) with $N = 2$, $\alpha = 5\%$ and $M = 100$. These values were also used to calculate $\hat{\kappa}^2(f)$ and $\hat{\kappa}^2{}_{crit}$ (expressions (3) and (4)). The MSC was applied to the derivations [Cz], [Fz], [C3] and [C4], usually employed in the SEP recordings when bipolar derivations are used. The MC was applied to the pairs [Cz][Fz] and [C3][C4].

In order to evaluate the overall result for response detection, the percentage of volunteer for whom it was possible to detect de stimuli response with each technique was calculated for each frequency. Then, the performance of MSC and MC was compared based on the detection percentages by means of the proportion test [9].

## III. RESULTS

The detection rates for $\hat{\kappa}^2$ [C3], $\hat{\kappa}^2$ [C4] and $\hat{\kappa}^2_2$ [C3][C4], are drawn in the Figure 1, for the calculated estimates with $M = 100$ epochs. Considering only the frequencies within the band from 20 to 60 Hz (referred from now towards of maximum response band or optimum band of SEP as suggested by [6]), $\hat{\kappa}^2$ [C3], $\hat{\kappa}^2$ [C4] and $\hat{\kappa}^2_2$ [C3][C4] presented detection rates varying, respectively from 10 to 32.5%, 10 to 62.5% and 27.5 to 75%. Without considering the edge frequencies (20 and 60 Hz), the rates for $\hat{\kappa}^2$ [C4] vary from 30 to 62.5%. Clearly, $\hat{\kappa}^2$ [C3] presents the worst result between the three estimates.

The frequencies for which were found significant difference between the detection rates of the MC and the MSC are shown in Table 1. As it can be seen, the MC surpassed the MSC applied to C3 in the whole maximum response band. On the other hand, the MC exceeded the MSC applied to C4 in only four frequencies from nine of this band.

Figure 2 shows the percentages of detection for $\hat{\kappa}^2$ [Cz], $\hat{\kappa}^2$ [Fz] and $\hat{\kappa}^2_2$ [Cz][Fz], which varied, in the optimum frequency band, from 2.6 to 84.6%, 5 to 45% and 17.9 to 89.7%. Considering only the frequencies from 25 to 55 Hz, these percentages vary from 33.3 to 84.6%, 10 to 45% and 48.7 to 89.7%, respectively, that is, the minimum rates are higher for this frequency range. Moreover, $\hat{\kappa}^2$ [Fz] shows

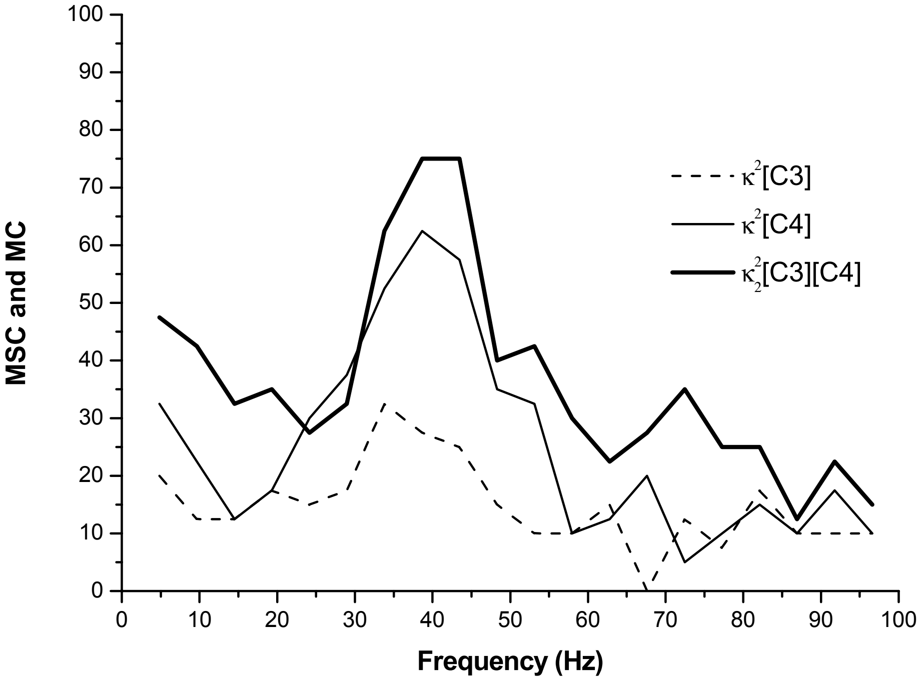

Fig. 1 Detection rates for $\hat{\kappa}^2$ [C3], $\hat{\kappa}^2$ [C4] and $\hat{\kappa}_2^2$ [C3][C4]

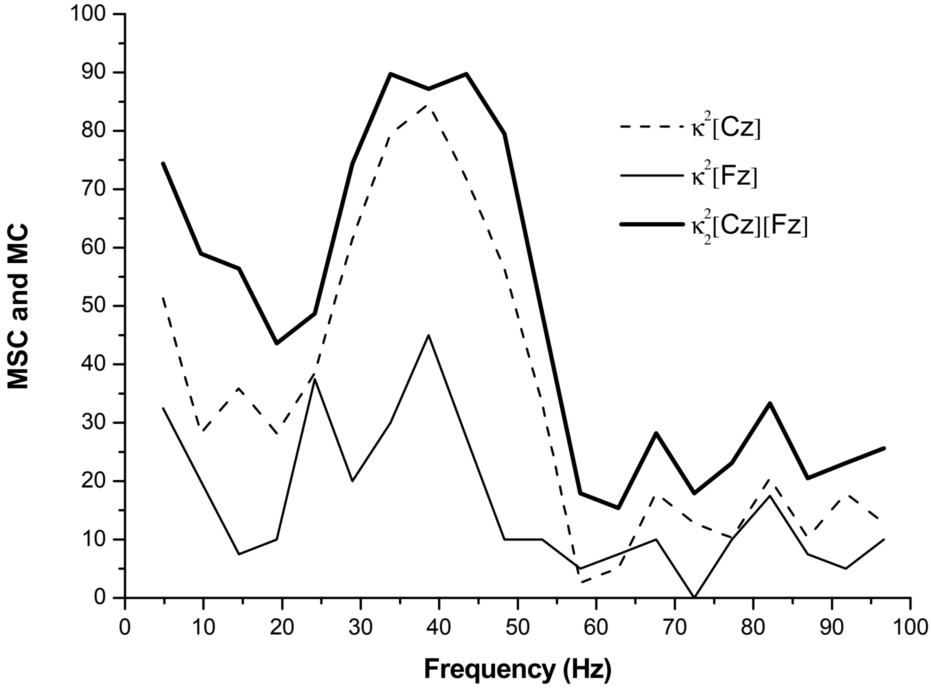

Fig. 2 Detection rates for $\hat{\kappa}^2$ [Cz], $\hat{\kappa}^2$ [Fz] and $\hat{\kappa}_2^2$ [Cz][Fz]. For derivation Cz, it was only possible to obtain 100 artifact-free epochs for 39 from the 40 volunteers, hence, the percentage of detection for $\hat{\kappa}^2$ [Cz] and $\hat{\kappa}_2^2$ [Cz][Fz] were calculated over 39

the lowest rates. It can also be noted that the rates found for these derivations are higher than that found for [C3] and [C4].

The performance of $\hat{\kappa}_2^2$ [Cz][Fz] exceeds $\hat{\kappa}^2$ [Fz] and $\hat{\kappa}^2$ [Cz]. However, the detection trace profile of $\hat{\kappa}^2$ [Cz] is more similar to that obtained for the MC. This result can be confirmed in Table 2 that indicates the significant difference between $\hat{\kappa}_2^2$ [Cz][Fz] and $\hat{\kappa}^2$ [Fz] for the whole maximum response band and between $\hat{\kappa}_2^2$ [Cz][Fz] and $\hat{\kappa}^2$ [Cz] for about half the frequencies within this band.

Table 1 Frequencies for which it was observed significant difference between the performance of MC and MSC

| $\hat{\kappa}^2$ **[C3] vs** $\hat{\kappa}_2^2$ **[C3][C4]** | $\hat{\kappa}^2$ **[C4] vs** $\hat{\kappa}_2^2$ **[C3][C4]** |
|---|---|
| 20-60 | 20, 50-60 |

Table 2 Idem Table 1

| $\hat{\kappa}^2$ **[Cz] vs** $\hat{\kappa}_2^2$ **[Cz][Fz]** | $\hat{\kappa}^2$ **[Fz] vs** $\hat{\kappa}_2^2$ **[Cz][Fz]** |
|---|---|
| 20, 25, 50-60 | 20-60 |

## IV. Discussion and conclusions

The MC presented higher detection rates than the MSC, both for derivations [C3] and [C4] and for [Cz] and [Fz], for at least three frequencies of the maximum response band. Each pair of EEG channels has one lead with lower signal-to-noise ratio, that is, [C3] and [Fz]. Even in this case, the use of additional information from them resulted in better percentages of detection with the Multiple Coherence. This result agree with those found by [1], who indicated, using simulation, the possibility of performance improvement of the MC even when the second EEG derivation presents signal-to-noise ratio lower than that for the first available derivation.

In a previous work [3], we have also reported better performance of the MC when compared with the MSC, but applied to the bipolar derivations commonly used in the tibial nerve SEP recording, [C3'-C4'] and [Cz'-Fpz']. These results are similar to those found by [1] and [2], who employed these techniques for detecting the visual evoked response recorded in the leads O1 and O2. In these studies, the authors pointed out higher detection rates for the MC.

Based on these results, if two derivations are available, it should be better to use the Multiple Coherence than the Magnitude-Squared Coherence applied to each lead.

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## References

1. Miranda de Sá AMFL, Felix LB (2002) Improving the detection of evoked responses to periodic stimulation by using multiple coherence – application during photic stimulation. Med Eng Phys 24(4):245-252.
2. Miranda de Sá AMFL, Felix LB, Infantosi AFC (2004) A matrix-based algorithm for estimating multiple coherence of a periodic signal and its application to the multichannel EEG during sensory stimulation. IEEE Trans Biomed Eng 51 (7): 1140-1146.
3. Infantosi AFC, Melges DB, Miranda de Sá AMFL, Cagy M. (2005) Uni- and multi-variate coherence-based detection applied to EEG during somatosensory stimulation, IFMBE Proc. vol. 11, 3rd. European Medical & Biological Engineering Conference, Czech Republic, 2005, pp. 1-4.
4. Felix LB, Miranda de Sá AMFL, Infantosi AFC, Yehia HC. (2007) Multivariate objective response detectors (MORD): statistical tools for multichannel EEG analysis. Ann Biomed Eng 35(3):443-452.
5. Miranda de Sá AMFL, Infantosi AFC, Simpson DM. (2002) Coherence between one random and one periodic signal for measuring the strength of responses in the EEG during sensory stimulation. Med Biol Eng Comput 40:99-104.
6. Infantosi AFC, Melges DB, Tierra-Criollo CJ. (2006) Use of magnitude-squared coherence to identify the maximum driving response band of the somatosensory evoked potential. Braz J Med Biol Res 39:1593-1603.
7. Miranda de Sá AMFL. (2004) A note on the sampling distribution of coherence estimate for the detection of periodic signals. IEEE Signal Process Lett 11(3): 323-325.
8. Miranda de Sá AMFL and Infantosi AFC. (2007) Measuring the synchronism in the ongoing Electroencephalogram during intermittent stimulation – a partial coherence-based approach. Med Biol Eng Comput 47(7): 443-452.
9. MOORE D. (2005) A Estatística Básica e sua prática. LTC Editora, Rio de Janeiro.

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