Event-Related Synchronization/Desynchronization for Evaluating Cortical Response Detection Induced by Dynamic Visual Stimuli

P.J.G. Da-Silva, A.F.C. Infantosi, and J. Nadal

Biomedical Engineering Program/COPPE, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

Abstract— **In the present work, the Event-Related Synchronization and Desynchronization (ERD/ERS) index was used for evaluating the cortical response to dynamic visual stimulation in an postural control protocol. EEG signals (O1, P3, P4 and O2 derivations) of 33 healthy subjects were acquired during stabilometric test. The trials were conducted with the subject observing a white wall (WW) and a virtual scene on static (SS) and dynamic (DS) conditions. The power spectra estimates were compared using the Spectral F-Test (SFT, $\alpha = 0.05$ and Bonferroni correction) and the ERD/ERS index. The SFT results indicate no difference between the EEG power contribution of WW and SS, and decreased power within alpha band during DS for all derivations. The ERD/ERS index allowed successfully detecting above 83% of the desynchronization within the alpha band during dynamic stimulation. Moreover, it also promotes postural instability. This finding indicates the potentiality of the ERD/ERS technique in studies of postural control assessed by dynamic visual stimulation.**

Keywords— **Dynamic Visual Stimulation, EEG, Event-Related Synchronization/Desynchronization, Spectral F-Test, Virtual Environment.**

I. INTRODUCTION

Dynamic visual stimulation has been used in the study of the human orthostatic postural control in order to drive postural instability response [1, 2]. However, not all visual environmental information can be perceived and used to maintain or change the body spatial position [3]. Although theses works have used virtual dynamic visual stimulation, the evoked cortical response has not been assessed.

Usually, visual stimulation elicits evoked response, which is phase-locked to stimuli. Furthermore, it has smaller amplitude compared to the background electroencephalogram (EEG) [4]. In addition to this evoked response, paced events also result in time-locked changes of the ongoing EEG [5], i.e. occurring during the stimulation period. Such non-phase locked activity is often referred as event-related synchronization (ERS) and desynchronization (ERD), depending on whether there is increase or decrease in the EEG power spectrum. According to [6], phase-locked and non-phase-locked activities cannot be separated when they are within the same frequency band.

As it is well known, the Spectral F-Test (SFT) can be used to test whether there is a cortical response to visual stimuli. Recently, Infantosi and Miranda de Sá [6] proposed ERD/ERS indexes based on the SFT, and applied them to intermittent photo stimulation.

In the present work, a dynamic visual stimulation in a postural control protocol is investigated for assessing the cortical response. The parietal and occipital EEG signals without stimulation are compared to those acquired during static and dynamic virtual stimulation. It is carried out by statistically comparing the spectral estimates of these conditions using both the SFT and the ERD/ERS index.

II. MATERIALS AND METHODS

A. Casuistry

A casuistry of 33 healthy subjects (23 male and 10 female), age ranging from 21 to 45 years, height of 172.7 ± 9.4 cm and mass of 73.3 ± 17.3 kg (mean ± standard deviation) was used in this study. All subjects present neither historical of neurological pathologies, osseous, muscles and joints diseases nor equilibrium disorder. The anamnesis was carried out to obtain information about headache, illness, vertigo, eyestrain and the use of corrective lens or glasses. Nevertheless, subjects using lens or glasses were included. Moreover, the subjects previously gave their informed consent.

B. Experimental Protocols

The EEG and stabilometric signals were acquired simultaneously at the same environmental condition for each subject, which was upright standing in a force platform. The first trial was conducted without stimulation, with the subject observing a white wall (condition denoted as WW) at 1 m apart from the force platform for five minutes.

After three minutes of resting in a comfortably chair, a stimulation trial was performed with the subject observing a virtual scene projected with 1.52 x 1.06 m. This scene (Fig. 1), consisting of a room containing a gridded floor (similar to the reverse pattern) and a table with a chair placed in the center, were developed using IDE Delphi and OpenGL.

P.D. Bamidis and N. Pallikarakis (Eds.): MEDICON 2010, IFMBE Proceedings 29, pp. 37–40, 2010.
www.springerlink.com

Fig. 1 Virtual scene

For carrying out the dynamic visual stimulation (DS), the virtual scene was randomly magnified or understated with a velocity of 200 cm/s during 250 ms interspersed by a 10 s of the static scene (SS). A set of a 100 DS (50 of each condition) was performed, with a SS preceding each DS. The SS and DS scenes were codified by a pulse width (synchronized by the start of exhibiting the scene). The sequence of pulses generates a trigger signal to be used during the signal processing.

Both visual (occipital) and associative cortex (parietal) monopolar EEG derivations (according to the International 10/20 System and bilateral references corresponding ear-lobes) were acquired using the BrainNet - BNT 36 (EMSA, Brazil) at a sampling frequency of 400 Hz. The EEG signals were then filtered by a 4th order low-pass Butterworth with cutoff frequency at 100 Hz (anti-aliasing) and 2nd order high-pass Butterworth at 0.1 Hz. In the present study, only the EEG signals of the alpha band (8 to 13 Hz) were investigated.

C. *EEG Signal Processing*

During visual stimulation, the EEG signals of SS and DS were identified and separated using the trigger signal, resulting in 100 segments for each stimulation condition. Taking the final 1 s EEG signal of each SS (just preceding a DS), the power spectra were estimated using $M = 100$ epochs for each EEG derivation. For calculating DS power spectra with the same frequency resolution, since the DS time duration segment was 250 ms, a zero padding procedure was adopted to complete 1 s. For the EEG signals in the WW condition only the first 100 s duration was processed. This segment was sectioned into $M = 100$ epochs of equal duration (1 s) and then the WW power spectra were also estimated.

The power spectra were estimated by Discrete Fourier Transform, using the Bartlett periodogram method and Hanning windows ($\tilde{P}_{xx}^{m}(f)$, frequency resolution of 1 Hz). Now, denoting the SS EEG as $y[k]$ and the DS EEG as $x[k]$, the Spectral F-Test was estimated as [7]:

$$SFT(f) = \frac{\hat{P}_{yy}(f)}{\hat{P}_{xx}(f)} = \frac{\frac{1}{M_y}\sum_{m=1}^{M_y}\left|\tilde{Y}_m(f)\right|^2}{\frac{1}{M_x}\sum_{m=1}^{M_x}\left|\tilde{X}_m(f)\right|^2} \qquad (1)$$

where f is the frequency index, M is the number of epochs, $X_m(f)$ and $Y_m(f)$, are, respectively, the Fourier Transform of the m-th epoch of $x[k]$ and $y[k]$.

Knowing that $SFT(f)$ has a central Fisher distribution F with $2\,M_x, 2\,M_y$ degrees of freedom, the null hypothesis (H_0) of same theoretical power contribution at a frequency f, the critical value can be readily obtained:

$$SFTcrit = F_{(2M_x, 2M_y, \alpha)} \qquad (2)$$

where α is the level of significance of the test. Furthermore, since there is no guarantee that the power of $x[k]$ is always higher than that of $y[k]$, a two-tailed test should be used. Thus, taking $\alpha = 0.05$, $2\,M_x = 2\,M_y = 200$ result in a $SFTcrit$ of 0.75 and 1.32 for respectively the lower and upper limits at any spectral frequency f. Therefore, H_0 can be rejected if $SFT(f) \leq 0.75$ or $SFT(f) \geq 1.32$, otherwise H_0 is accepted. For testing the power contribution in ±1 Hz around alpha peak, the Bonferroni correction (α/n, where, $n = 3$ is the number of harmonics) was applied. In this case, H_0 within this band can be rejected if $SFT(f) \leq 0.71$ or $SFT(f) \geq 1.40$.

Taking the usual ERD/ERS index definition as the calculation of the percent power difference between the DS EEG and SS EEG stimulation (reference signal), the ERD/ERS can be re-written as [6]:

$$ERD/ERS(f) = 100 \times \left[\frac{\sum_{i=1}^{M}\left|Y_i(f)\right|^2}{\sum_{i=1}^{M}\left|X_i(f)\right|^2} - 1\right] = 100 \times \left[SFT(f) - 1\right] \qquad (3)$$

A negative value in (3) indicates a power decrease during the dynamic stimulation and hence a desynchronization (ERD). Otherwise, in case of synchronization, (3) is positive (ERS). Based on $SFTcrit$ values, the lower and upper critical values of (3) are -25 and 32, respectively. Therefore, for detecting the dynamic stimulus at a frequency f, ERD should be lower than -25.

Considering $y[k]$ as the EEG background (WW) and $x[k]$ as one of the EEG during visual stimulation, the Spectral F-Test was also estimated by (1). In both cases, the ERD/ERS was calculated using (3).

III. RESULTS

Figure 2 depicts the power spectra before and during stimulation, the application of both the SFT and the ERD/ERS index, and the rate of ERD detection for the subject # 7 in the O1, P3, P4 and O2 derivations. Firstly, for all such derivations, it can be noted that the EEG spectra in WW and SS conditions behaves similarly, showing an increased magnitude in the alpha peak at 11 Hz (Fig. 2a).

The SFT results (Fig. 2b) indicate that there is no statistical difference ($0.71 < SFT(\Delta f) < 1.40$, $\alpha = 0.05$) between WW and SS power spectra neither in occipital nor parietal derivations (therefore, the null hypothesis was not reject). In this case, the eq. (3) tends to zero, hence *ERD/ERS(f)* are not shown. On the other hand, the decreased power contribution in DS is observed within the alpha band of all derivations ($SFT < 0.71$), implying in rejecting H_0 when DS is compared to both WW and SS conditions.

The negative mean index ($ERD/ERS < -25$, Fig. 2c, black circles) achieved for all derivations indicate desynchronization. However, the 95% confidence limits of the *ERD/ERS* index indicate that some dynamic visual stimulation does not evoke cortical response. For this subject (#7), the rate of ERD detection was higher than 85% within the alpha band (Fig. 2d), and above 95% at the peak (11 Hz).

The total power contribution around the alpha peak (grey area in Fig. 2a) in WW, SS and DS conditions for all 33 subjects show significant differences (Wilcoxon sign rank test, $\alpha = 0.05$), excepting between WW and SS (Table 1). Furthermore, ERD rate detection during dynamic stimulation varies from 83 to 88% for the occipital and parietal EEG derivations (Fig. 3).

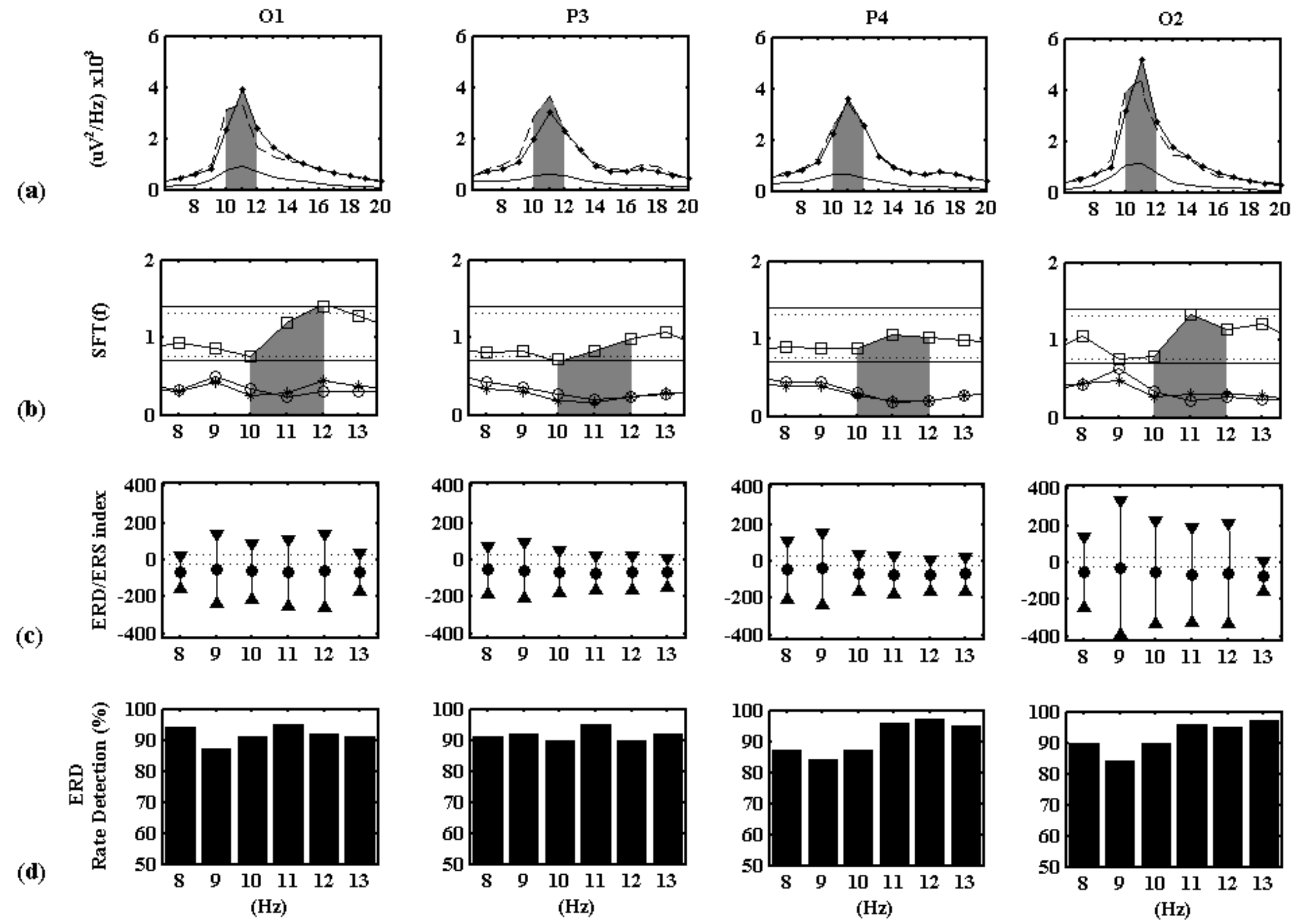

Fig. 2 Power spectra before and during stimulation (a), the application of the SFT (b) and ERD/ERS (c), and the rate of ERD detection (d) obtained in O1, P3, P4 and O2 derivations for the subject #7. The gray areas in (a) and (b) indicate the total power contribution of the ±1 Hz frequency around alpha peak. In (a), the dashed, dash-dot and solid lines represent the power spectra of WW, SS and DS, respectively. In (b), the squares, circles and stars represent the SFT between WW and SS, WW and DS, and between SS and DS, respectively. In (c), the mean ERD/ERS indexes and the 95% confidence limits of the ERD/ERS distribution are indicated with circles and triangles, respectively. In (b) and (c), the SFT and ERD/ERS critical values are shown in horizontal dotted line. The horizontal solid line in (b) represents the SFT critical values (two-tailed, $\alpha = 0.05$) after the Bonferroni correction

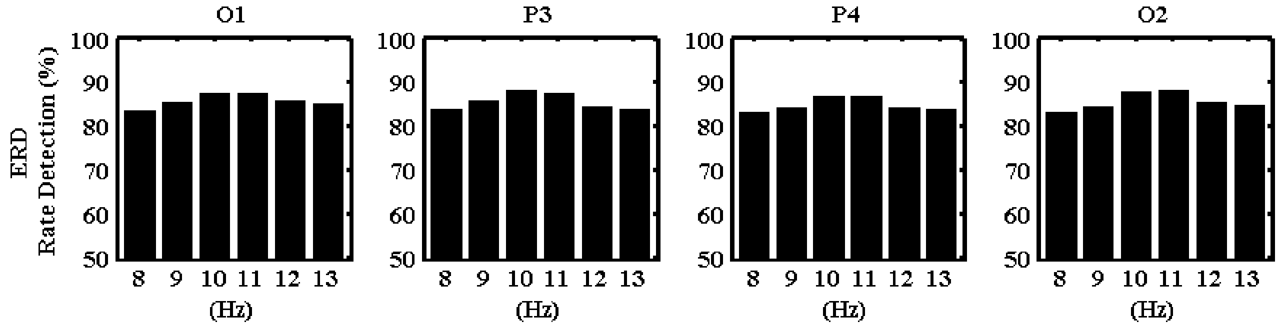

Fig. 3 The ERD rate detection after dynamic stimuli for 33 subjects, in alpha frequency band (derivations O1, P3, P4 and O2)

Table 1 The *p*-value of the Wilcoxon sign rank test ($\alpha = 0.05$) applied between the distributions of the total power contribution around the alpha peak in WW, SS and DS conditions

Derivations	WW x SS	WW x DS	SS x DS
O_1	0,4052	<< 0,0001	0,0004
P_3	0,7138	<< 0,0001	0,0003
P_4	0,7243	<< 0,0001	0,0005
O_2	0,4132	<< 0,0001	0,0004

IV. Discussion and Conclusion

The dynamic stimulation caused a reduction in the power spectra estimates around the alpha peak (±1 Hz), when compared to both the background EEG (WW) and the static scene stimulation (SS). The change in amplitude spectrum is expected to occur since evoked responses are phase-locked to the stimulation [4].

The similarity observed between EEG from WW and SS conditions suggests that the static virtual scene can be used as spatial reference for the body sway control in promoting the postural stability. Furthermore, applying SFT allows detecting significant spectral changes due to DS in all frequencies of the alpha band. The ERD/ERS index allowed to successfully detecting above 83% of the desynchronization within the alpha band during dynamic stimulation. This finding is in accordance with Infantosi and Miranda de Sá [6].

In our study, moving the visual surround was carried out to induce the perception that the body is also in movement, but as pointed out by [1, 2], in an opposite direction of the stimulus. Hence, there is the need for compensating it, that is, a compensatory adjustment in the same direction of the surround motion is required.

In summary, by using the ERD/ERS index it was possible to distinguish the evoked cortical response of stimulating with a static and dynamic scene. The dynamic stimulation causes desynchronization within the EEG alpha band and also promotes postural instability. Therefore, the ERD/ERS technique can be useful in studies of postural control assessed by dynamic visual stimulation.

Acknowledgment

This work received the financial support from the Brazilian Research Council (CNPq).

References

1. Streepey J W, Kenyon R V, Keshner E A (2007) Field of view and base of support width influence postural responses to visual stimuli during quiet stance. Gait & Posture 25:49–55 DOI 10.1016/j.gaitpost.2005.12.013
2. Dokka K, Kenyon R V, Keshner A (2009) Influence of visual scene velocity on segmental kinematics during stance. Gait & Posture 30:211–216 DOI 10.1016/j.gaitpost.2009.05.001
3. Patla A E (1997) Understanding the roles of vision in the control of human locomotion. Gait & Posture 5:54–69 DOI 10.1016/S0966-6362(96)01109-5
4. Chiappa K H (1997) Evoked Potentials in Clinical Medicine, 2., Raven Press, New York
5. Pfurtscheller G and Lopes da Silva F H (1999) Event-related EEG/MEG synchronization and desynchronization: basic principles. Clin Neurophysiol 110: 1842-1857 DOI 10.1016/S1388-2457(99)00141-8
6. Infantosi A F C and Miranda de Sá A M F L (2007) A statistical test for evaluating the event-related synchronization/desynchronization and its potential use in brain-computer-interfaces. IFMBE Proc. vol 18, IV Latin American Congress on Biomed Eng, Isla de Margarita, Venezuela, 2007, pp 1122–1136.
7. Shiavi R (1999) Introduction to applied statistical signal analysis. Academic Press, London

Author: Paulo José Guimarães da Silva
Institute: Biomedical Engineering Program (COPPE/UFRJ)
Street: P. O. Box 68.510
City: 21941-972 - Rio de Janeiro - RJ
Country: Brazil
Email: guima@peb.ufrj.br