SPECTRAL F-TEST POWER EVALUATION IN THE EEG DURING INTERMITTENT PHOTIC STIMULATION

Antonio Mauricio F. L. Miranda de Sá[1], Mauricio Cagy[2], Vladimir V. Lazarev[3], Antonio Fernando C. Infantosi[4]

ABSTRACT - Intermittent photic stimulation (IPS) is an important functional test, which can induce the photic driving in the electroencephalogram (EEG). It is capable of enhancing latent oscillation's manifestations not present in the resting EEG. However, for adequate quantitative evaluation of the photic driving, these changes should be assessed on a statistical basis. With this aim, the sampling distribution of spectral F test was investigated. On this basis, confidence limits of the SFT-estimate could be obtained for different practical situations, in which the signal-to-noise ratio and the number of epochs used in the estimation may vary. The technique was applied to the EEG of 10 normal subjects during IPS, and allowed detecting responses not only at the fundamental IPS frequency but also at higher harmonics. It also permitted to assess the strength of the photic driving responses and to compare them in different derivations and in different subjects.

KEY WORDS: EEG, intermittent photic stimulation, photic driving, Spectral F test, quantitative analysis.

Avaliação do teste-F espectral do EEG durante fotoestimulação intermitente

RESUMO - A fotoestimulação intermitente (FEI) é um importante teste functional, que pode induzir o fotorecrutamento no eletroencefalograma (EEG), sendo capaz de realçar manifestações latentes de oscilações não observadas no EEG de repouso. Entretanto, para uma análise quantitativa adequada do fotorecrutamento, tais alterações devem ser avaliadas com base estatística. Assim, a distribuição de probabilidade do teste-F espectral (TFE) foi investigada. Neste sentido, limites de confiança para a estimativa do TFE puderam ser obtidos para diferentes situações práticas, nas quais a razão sinal-ruído e o número de épocas usadas na estimação podem variar. A técnica foi aplicada ao EEG de 10 sujeitos normais durante FEI, e permitiu a detecção de respostas não somente na freqüência fundamental da FEI como também em seus harmônicos. Além disso, permitiu avaliar o grau de fotorecrutamento entre derivações distintas e entre diferentes sujeitos.

PALAVRAS-CHAVE: EEG, fotoestimulação intermitente, fotorecrutamento, teste-F espectral, análise quantitativa.

Intermittent photic stimulation (IPS) is considered as one of the most important functional neurophysiological tests that can induce photic driving in the electroencephalogram (EEG). It is capable of enhancing the latent oscillations' manifestation including pathological alterations, which are not observable in the EEG of the resting state[1-4]. However, for an adequate quantitative evaluation of the photic driving these changes should be assessed on a statistical basis[5].

Spectral F-Test (SFT) is a statistical test for assessing whether two sample spectra are from populations with identical theoretical spectra, and has been applied in objectively detecting somatosensory[6] and auditory evoked responses[7]. It can be applied either to investigate two different spectral estimates over the same frequency band or to test samples from the same spectral density over two different frequency bands[8]. On this basis, SFT was applied to the EEG during IPS and showed to be sensitive in detecting spectral changes related to the stimulation[4]. SFT allows ascertaining whether photic driving occurs according to statistical criteria. Since SFT sampling distribution is known under the null hypothesis of same theoretical spectra (H_0), critical values can be readily ob-

tained. They constitute thresholds above which statistical difference between the estimates can be accepted.

However, in order to evaluate the power of SFT, i.e. the probability of correctly identifying spectral differences (previous and during IPS), its sampling distribution should be investigated for the alternative hypothesis (H$_1$)[9]. Furthermore, on the basis of such distribution, the strength of the EEG driving response to the stimulation could be compared (e.g. through the confidence limits) in different cortical regions as well as in different subjects including patients versus control group. Thus, the investigation of the sampling distribution of SFT under H$_1$ would broaden the applicability of the technique to the EEG during IPS. This issue is exploited in the present work, where the power of SFT is assessed theoretically. The methodology proposed was applied to the EEG of normal subjects during IPS.

METHOD

The spectral F test (SFT) for the discrete-time signals $y[k]$ (here assumed to represent an EEG lead during intermittent stimulation) and $x[k]$ (EEG signal immediately before stimulation) can be defined as[8].

$$\hat{\phi}_{yx}(f) = \frac{\sum_{i=1}^{M}|Y_i(f)|^2}{\sum_{i=1}^{M}|X_i(f)|^2}$$

where f is the frequency index, "^" superscript denotes estimation, and $X_i(f)$ and $Y_i(f)$, are, respectively, the Fourier Transform of the i-th epoch of $x[k]$ and $y[k]$, which have been partitioned into M disjoint segments each for carrying out the spectral estimation.

The case when no driving response occurs in the EEG leads $x[k]$ and $y[k]$ to be independent, Gaussian-distributed signals pertaining to populations with same theoretical spectra. This reflects the null hypothesis H$_0$, under which $\hat{\phi}_{yx}(f)$ is known to be distributed as[8]

$$\hat{\phi}_{yx}(f)\big|_{H_0} \sim F_{2M,2M}$$

where $F_{2M,2M}$ is the F- (Fisher) distribution with $2M$ and $2M$ degrees of freedom. Thus, for a given significance level if $\hat{\phi}_{yx}(f)$ is greater than the critical value of the F-distribution in (2) the hypothesis of absence of cortical response can be rejected.

Nevertheless, one cannot ascertain that the driving response has indeed occurred. This can be tested by using the alternative hypothesis (H$_1$) of presence of the driving response. In this case, the numerator of (1) is now the response but added to the spontaneous EEG. Hence, the F distribution in (2) should be altered (not proved here) and the sampling distribution of $\hat{\phi}_{yx}(f)$ under H1 can be expressed as:

where $F_{2M,2M}$ is non-central F distribution, λ is the non-centrality parameter (SNR is the signal-to-noise ratio). A complete proof of λ expression is provided in[10]. It can be also derived with some further manipulations on the classical results of Akaike[11] and Brillinger[12].

$$\hat{\phi}_{yx}(f)\big|_{H_1} \sim F'_{2M,2M}(\lambda = 2M \cdot SNR)$$

In order to evaluate the performance of SFT in detecting driving responses, the power of the test should be established for distinct experimental conditions, i.e., different M and SNR values. The probability of detection (PD) is the area under the distribution of $\hat{\phi}_{yx}(f)$ when response occurs (expression 3) for abscise values greater than the threshold for the detection (critical value for testing the absence of response, expression 2). This process is illustrated in Figure 1A for M=24 epochs, where PD is the shaded area. As can be noted, SNR=2 results in PD-value greater than that for SNR=1. Figure 1B displays PD for different number of epochs (M=6, 12, 24, 48 and 96) as a monotonically increasing function of SNR. It can be observed that if SNR is fixed, PD increases as M is augmented. The SNR-values that provide 95% of detection are also indicated by arrows. The PD behaviour with M and SNR is due to the fact that the non-central F distribution is shifted to the right as λ (=2M.SNR) increases, leading to greater probability of detecting responses. This can be easily seen in Fig 1A.

EEG data collection and pre-processing – The SFT was applied to EEG signals obtained from 10 normal children and adolescents (age range: 3-17 years) with no symptoms of neurological pathology and with normal visual evoked potential. None of them had a history of neurological, psychiatric or drug related illness. The local ethics committee approved this research.

EEG signals were recorded during a state of relaxed wakefulness (initial background, 2-3 min duration) and then over a period of 20-30 seconds during flash stimulation at the frequency of 6 Hz. The subjects kept eyes closed throughout the examination. The multichannel EEG was acquired using the Nihon Kohden polygraph (EEG-4418) with 0.3 s time constant, 70 Hz high frequency filter (anti-aliasing) and 15 μV/mm sensitivity. Fourteen scalp monopolar derivations (according to the International 10/20 System) with unilatereral references to the corresponding earlobes were utilized in the EEG recording. In the present study, only symmetrical occipital (O$_1$ and O$_2$) and parietal (P$_3$ and P$_4$) leads were used. The instants of the stimulation signal were also acquired in a separate channel in order to be used as a reference when applying the signal processing techniques.

The EEG signals digitized at a sampling frequency of 256 Hz, before and during stimulation, were sectioned into M=10 epochs of equal duration (2 s). The power-spectra of the EEG before and during stimulation were estimated using the periodogram of Bartlett based on the Discrete
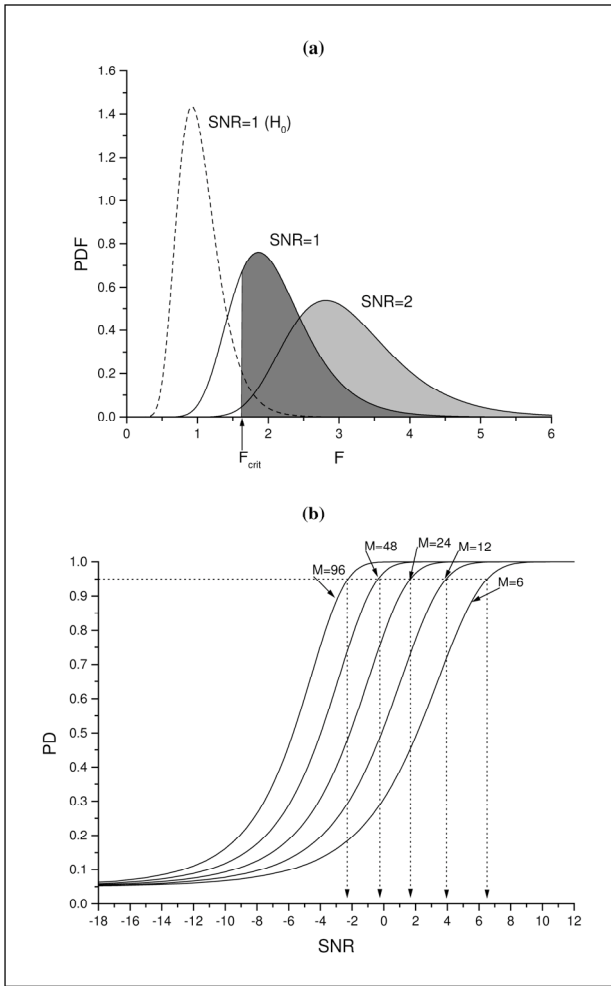
Fig 1. A) Illustration of the PD calculation as the shaded areas under the probability density function (PDF) of the non-cen - tral F-distribution defined in expression (3) (continuous line) for M=24 and for both SNR=1 (dark grey-shaded area) and SNR= 2 (light grey-shaded area). The distribution under the null-hypothesis of no response (H_0) is also shown for M=24 in dashed line. The critical value from this latter (F_{crit} - indicated by an a rrow) is taken as the inferior limit for the integral evaluation, which results in the shaded area. B) Probability of detection (PD) with $\hat{\phi}_{yx}(f)$ as a function of the signal-to-noise ratio (SNR expressed in dB, i.e. $(SNR)_{dB}=10 \cdot log(SNR)$) for diff e rent number of epochs (M=6, 12, 24, 48 and 96). SNR-values that lead to 95% expected detection rate are indicated by arrows.

Fourier Transform of the 2 s duration epochs (frequency resolution of 0.5 Hz). The SFT was calculated using the EEG power-spectrum during stimulation in the numerator of e x p ression (1) and that of the EEG before stim ulation, in the denominator[13]. The critical value for the null hypothe-sis of absence of response was determined by setting a 5% pe rcentage of significance (α) in the sampling distribution of (2). This leads to critical value for $\hat{\phi}_{yx}(f)$ equal to 2.12[13]. In order to test the alternative hypothesis (H_1) of the pres-ence of a driving response, based on (3) the confidence lim-its (95%) were determined.
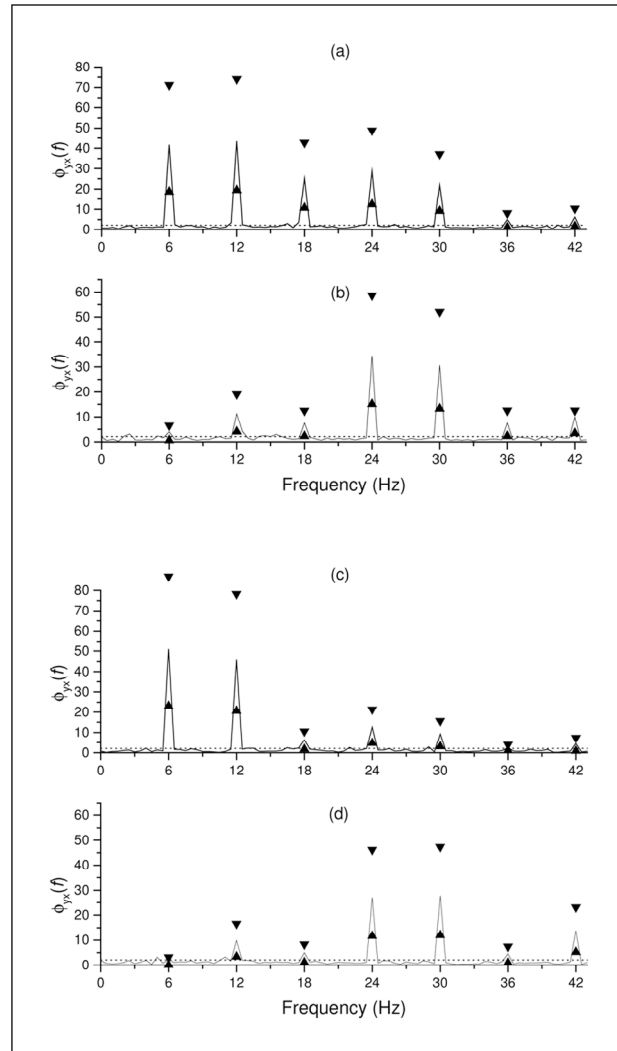

Fig 2. $\hat{\phi}_{yx}(f)$ (obtained according to expression (1) with M=10 epochs) for subject #8 stimulated with stroboscopic flash at 6 Hz in the derivations: A) O1, B) P3, C) O_2 and D) P4. The criti - cal value (α=5%) is shown in horizontal dotted lines. It consti - tutes a threshold upon which the driving responses can be assu - med to have occurred. The 95% confidence limits for such res - ponses are indicated with triangles.

RESULTS

Figure 2 illustrates the application of the SFT tech-nique to the EEG from subject #8. It can be noted in both occipital and parietal leads that $\hat{\phi}_{yx}(f)$ exceeds the critical value (shown as a horizontal dotted line) at the stimulus frequency (6 Hz) and harmonics, even in the beta-2 and in the lower gamma bands. In addi-tion, the responses, as measured by $\hat{\phi}_{yx}(f)$, are stro n-ger in O_1 (O_2) than in P_3 (P_4), which is in accordance with the literature on the EEG photic driving[2,4]. Such d iff e rences can be assessed through the comparison of the 95% confidence limits (indicated with trian-gles), which also indicate that the strength of the EEG
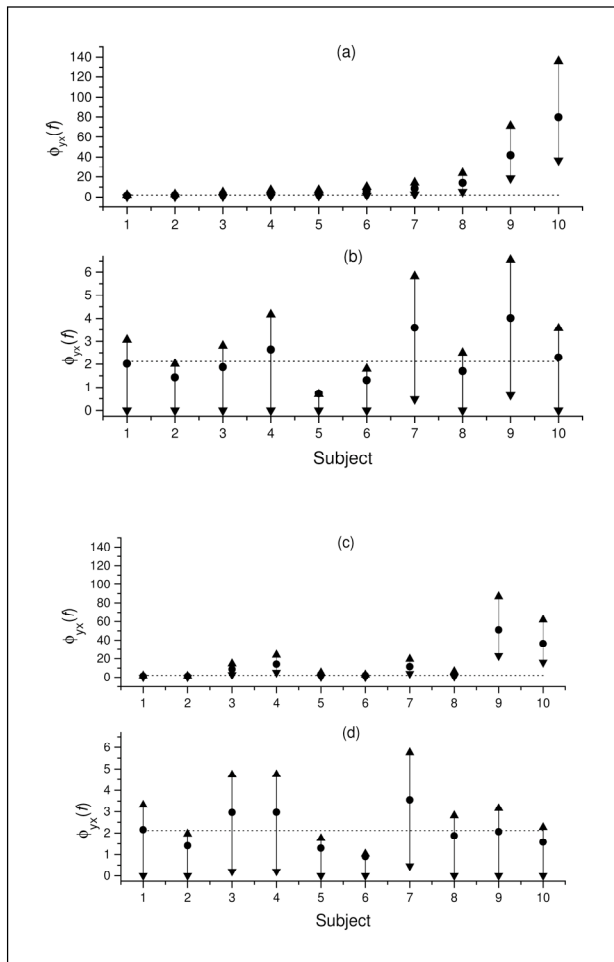
Fig 3. $\hat{\phi}_{yx}(f)$ *(obtained according to expression (1) with M=10 epochs) at the frequency of stimulation (6 Hz) is indicated by a circle and the 95% confidence limits are indicated with tri- angles for each of the subjects in the derivations: A) O1, B) P3, C) O2 and D) P4. Critical values (α=5%) are shown in horizon- tal dotted lines.*

driving response at 6 and 12 Hz in O_1 (O_2) are signi- ficantly higher than those at 36 and 42 Hz. On the other hand, for derivation P_3 (P_4) the strongest driv- ing response occurs at 24 and 30 Hz.

In Figure 3 $\hat{\phi}_{yx}(f)$, is depicted for the first harmon- ic of the stimulation frequency of 6 Hz in both occip- ital and parietal leads for all 10 subjects. It can be no- ted that there are substantial diffe rences in detect- ing response ($\hat{\phi}_{yx}(f)$>2.12) between occipital and pari- etal leads. While O_1 (O_2) demonstrates a 100% detec- tion, in P_3 (P_4), only 40% of the subjects show such estimate higher than the critical value. Small differen- ces were found however between homologue leads which would indicate inter-hemispheric symmetry. For the occipital leads, considering the 95% confiden- ce limits, one can state that the strength of driving

response in subjects # 9 and 10 is significantly high- er than that for the other subjects. It is also noted that for both subjects the photic driving response is higher in P_3 than in P_4.

DISCUSSION

The application of the Spectral F-Test allows de- tecting responses not only at the fundamental IPS frequency of 6 Hz but also at higher harmonics inclu- ding the frequencies within the upper beta and low- er gamma bands. Moreover, using the alternative hy- pothesis of the presence of response and the 95% confidence interval it is possible to apply this statis- tical technique as an indicator of the strength phot- ic driving response. Thus, SFT can be used to compa- re the strength of the driving response in distinct brain regions, at diffe rent frequencies in the same location and in diffe rent subjects, e.g. controls and patients. This capacity (ability) can give certain advan- tage to SFT over spectral peak amplitude measure- ment[4] since the former in contrast to the latter deals with changes based on statistical criterion (significan- ce level).

The curves obtained for the probability of detect- ing a spectral change (which should reflect photic driving in the EEG during IPS) can provide import a n t information in clinical application, such as the mini- mum data stretch necessary for a 95% detection rate in a signal with a given signal-to-noise ratio. Thus, for SNR close to zero, i.e. response and background with close amplitude-values, a minimum of 48 epochs should be used to provide 95% detection. On the o- ther hand, for SNR close to –2 dB (which reflects am- plitude response nearly 1.6 times smaller than that of background EEG), this number should be doubled to maintain the same detection rate.

All these findings show a broad potential of the SFT application to the estimation of the EEG photic driving reactions, particularly in special experimen- tal and clinical conditions which demand a finer sensi- tivity of the EEG characteristics to the functional sta- tes of the brain. It looks promising in the topograph- ic approach to the study of the driving effects in the brain ontogenetic development, in the study of func- tional alterations in neurological and psychiatric dis- eases, for instance, etc. where it can improve a diag- nostic value of the IPS functional test.

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