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EVALUATION OF PARAMETERS USED AS SYMPTOMS TO EEG ANALYSIS

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Abstract. *Electroencephalography (EEG) is the study of the graphical register of electric currents developed in the brain, performed by electrodes applied to the scalp, the brain surface, or even within the brain. The physics spend a large time in neurological exams analysis and most of all are not an anomaly. To assist the specialist, we want to choose which statistical parameters (symptoms) best represent the brain signals, in order to classify them into signs with and without anomalies. To do this, an available database of Bern-Barcelona are used, which consists of signs with and without the presence of ictal (signal event caused by an epileptic seizure). The parameters used as symptoms were RMS Level, Peak Value, Peak to Peak Value, Asymmetry, Curtosis, Crest Factor, k4 estimator and k6 estimator, applied to signals that underwent signal treatments, such as filtering processes, envelope analysis, Continuous Wavelet Transform, Intrinsic Modes Functions in conjunction with K-NEO low frequency peak evaluation metrics, Hilbert-Huang transform and entropy calculation, resulting in 1180 possible symptoms. A qualitative, visual analysis was performed through the boxplot evaluation of 100 pairs of focal and non-focal signals. The most frequent parameters were RMS Value, Crest Factor and kurtosis, with 15, 14 and 10 occurrences respectively.*

Keywords: *Electroencephalography, Statistical Parameters, epilepsy, focal and non-focal signals*

1. INTRODUCTION

Biological signal is defined as a variable measured in living organisms, at continuous time or in periodic samples and these may be electrical or bioelectric (ECG-measured cardiac signals, EEG-EEG synaptic signals, eye movement electro-oculogram, muscle tone measured by electromyogram), mechanical (blood pressure, muscle contraction strength), chemistry (PH, glycemia, blood alcohol content), thermal, magnetic (cardiac signals measured by magnetocardiography and synaptic signals measured by Magnetoencephalogram) among others (Gomes, 2003).

Electroencephalography (EEG) is the study of the graphical register of electric currents developed in the brain, performed by electrodes applied to the scalp, the brain surface, or even within the brain. Currently, five types of brain waves are recognized: delta (0.5 to 4 Hz), theta (4 to 8 Hz), alpha (8 to 13 Hz), beta (13 to 30 Hz) and gamma (above 30 Hz), with different characteristics, voltage ranges and frequencies. Delta waves usually occur when in deep sleep, ranging from 75 to 200 mV, since theta is rarely present in humans. Alpha waves are when the person is awake, beta waves with increased alertness and alertness and the gamma wave for voluntary movements of the body (Blinowska and Durka, 2006).

The medicine spends a long time in the analysis of exams that mostly do not present any anomaly. For the case of the neurologist, more than 80% of the analyzed tests are considered good, without anomalies. Electroencephalogram (EEG) signals will be used in this work due to the great need of programs to aid in its diagnosis, besides the specialist spending a long time to analyze hours of records (Travessa, 2006).

The objective of this work is to involve the largest number of parameters that may be candidates for the detection of focal signals (signal that detected the first event as an epileptic crisis) and non-focal, through EEG analysis, and with that, to evaluate effectiveness. For this, a statistical analysis was performed through the visual analysis of the box diagrams for each parameter studied, in order to define the best parameters to be used as symptoms for the classification of the pairs of signals in focal and non-focal. To do this, an available database of Bern-Barcelona are used, which consists of signs with and without the presence of ictal (signal event caused by an epileptic seizure).

2. METHODOLOGY

To develop this work, the Bern-Barcelona database described in Andrzejak, Schindler and Rummel (2012) were used. The signs used by the authors are intracranial EEG recordings of five epilepsy patients. Importantly, all patients had longstanding drug-resistant temporal lobe epilepsy and were candidates for epilepsy surgery. The signals were acquired at 512 Hz and 1024 Hz. As preprocessing, all signals were filtered by a fourth-order Butterworth bandpass filter between 0.5 and 150 Hz. All signals acquired at 1024 Hz were re-processed and sampled for the frequency of 512 Hz (Andrzejak, Schindler and Rummel, 2012).

The parameters used as input data for the classification procedures were: RMS Level, Peak Value, Peak to Peak Value, Asymmetry, Curtosis, Crest Factor, k4 estimator and k6 estimator.

The 300 data sets used in this work underwent signal treatments, such as filtering processes, envelope analysis, Continuous Wavelet Transform, Intrinsic Mode Functions in conjunction with K-NEO low frequency peak evaluation metrics, Hilbert Transform -Huang and calculation of entropy (28 parameters applied to MFIs taken from Sharma, Pachori and Acharya, 2015). In addition, treatments were applied for both unipolar and dipole arrangements. For the filtered signals, the values of the non-normalized and normalized parameters (by the mean and standard deviation) were used. For the other treatments, only the normalized signals were used. Thus, the symptoms for each treatment were calculated, which resulted in 1180 symptoms that were used to classify the pairs in focal and non-focal.

It is important to note that in the filtering processes Butterworth filters with six poles were used, and the filter bands were chosen according to the wave types found in the EEG. The filters used were:

- Total: filtered signal with low pass filter at 256 Hz;
- Delta: filtered signal with low pass filter at 4 Hz;
- Theta: filtered signal with bandpass filter from 3 to 7 Hz;
- Alpha: filtered signal with bandpass filter from 7 to 13 Hz;
- Beta: filtered signal with band pass filter of 13 to 30 Hz;
- Range: filtered signal with high pass filter of 30 Hz;
- User: filtered signal with bandpass filter from 8 to 245 Hz.

In order to guarantee the convergence of the IIR type filters, it was necessary to pre-filter and re-sample the frequencies of 64 Hz for the Delta and Beta filters and 32 Hz for the Teta and Alpha filters.

The combination of the filters (Total, Delta, Theta, Alpha, Beta, Gamma and User) with the normalized unipolar and dipole signal pairs resulted in the symptoms from 3.1 to 3.224. The application of the envelope technique in the unipolar and dipole normalized signs resulted in the symptoms 3.225 to 3.336.

The next set of symptoms is given by the application of continuous Wavelet Transform, with base function dB4. The scales were chosen to contemplate the frequency bands of theta, alpha, beta and gamma. Since there are infinite possibilities for the scales, a study was made to determine which scales would best discriminate ValorRMS, VP, VPP, Sk, Kx, FC, k4 and k6 symptoms.

This study consists of: given the range of scales of interest and the Xfocal and Xnfocal data set of each symptom, the objective function presented by Eq. (1). The assumption was made for the hypothesis that populations have a constant variance, that is, they are homozygous.

$$Obj = max\left(\frac{\left\|\overline{X_{focal}} - \overline{X_{nfocal}}\right\|}{S^2_{focal} + S^2_{nfocal}}\right) \quad (1)$$

where: $\overline{X_{Focal}}$ is the mean of the focal set, $\overline{X_{nFocal}}$ is the mean of the non-focal set, S^2_{Focal} is the variance of the focal set and S^2_{nFocal} is the non-focal set variance.

Based on the eight objective functions (one for each parameter studied), an optimization procedure based on GA was used to determine the best scales for each objective function, and then it was chosen the scales that maximized the greatest number of objective functions. After this procedure, the WT applied on the unipolar and standardized dipole signals resulted in the symptoms of 3.337 to 3.416.

The envelope modulus of the signals in which WT was applied resulted in the symptoms from 3.417 to 3.496. On the other hand, the symptoms of 3.497 to 3.700 are results of the application of the MFI, and include the orthogonality index, the first six intrinsic modes and respective residues, for both the unipolar signals and the dipolar signals.

The symptoms of 3.701 to 3.892 are the result of the application of HHT in the first six MFIs, and respective residues, for unipolar and dipole signals. The 13 parameters of the K-NEO (Liu et al, 2013) were calculated for a limit of 2 seconds and a peak width of 20 to 65 milliseconds, with a spacing of 5 milliseconds. For each signal pair, a maximum of ten peaks were identified. The use of the maximum and average values of each pair results in 260 symptoms, from 3.893 to 3.1152.

Finally, the entropy values (Sharma, Pachori and Acharya, 2015) applied to the first six MFIs and their respective residues resulted in the symptoms from 3.1153 to 3.1180.

A statistical analysis was performed to evaluate the parameters as possible symptoms for the classification of the focal and non-focal pairs populations from the database used. The analysis was only qualitative, visual, and was performed by evaluating the boxplot of 100 pairs of focal and non-focal signals, chosen at random from 3750 pairs.

Visually, the best symptom candidates should have well-separated focal and non-focal parameters, and the third quartile of one sample should be smaller than the first quartile of the other sample. Not intersecting the upper limit of one sample with the lower limit of the other sample is strongly indicative of samples from different populations.

3. RESULTS AND ANALISYS

It was desired to do a visual inspection of the symptoms related to the eight basic parameters (ValorRMS, VP, VPP, Sk, Kx, FC, k4 and k6) calculated on the Total, Delta, Theta, Alpha, Beta and Gamma filtered signals. For the analysis, it was used the symptom boxplot calculated for the first 50 sets of signals (focal and non-focal) in the database. Due to the occurrence of very outside symptom values, the presentation of results was limited to two interquartiles.

As an example, Fig. (1) shows the boxplot graphs of the calculated RMS value for unnormalized, non-standard signals with the Total (Symptom 3.1), Delta (Symptom 3.2), Theta (Symptom 3.3), Alpha (Symptom 3.4), Beta (Symptom 3.5) and Gamma (Symptom 3.6). Box 1 represents the focal signal sets and box 2 the non-focal signal sets.

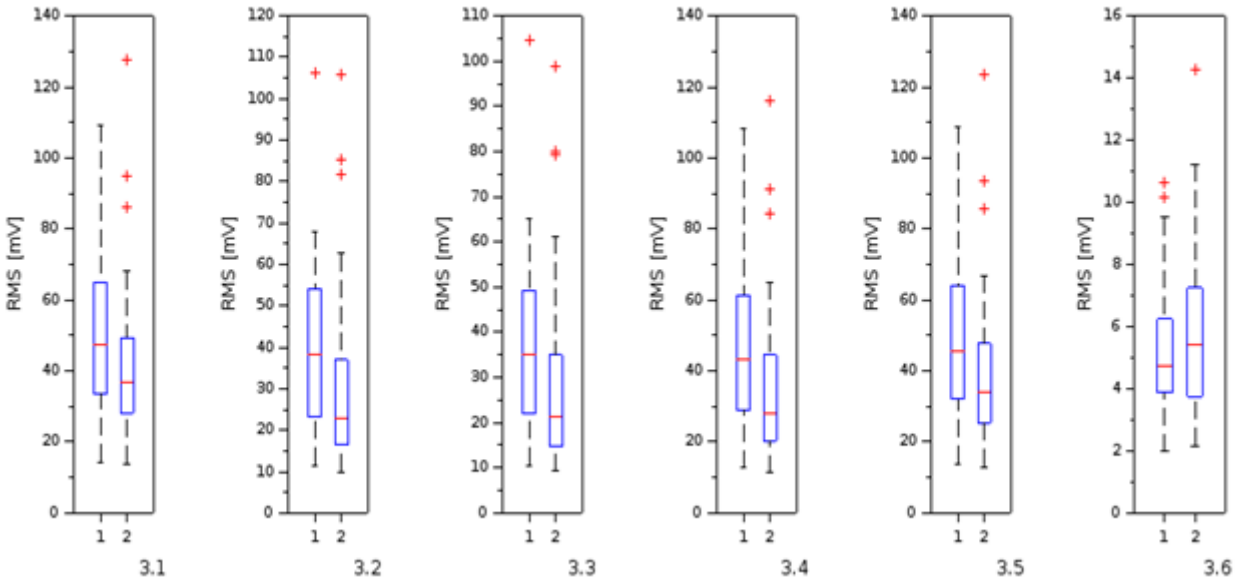


Figure 1. Boxplot diagram for RMSValue parameter.

From the analysis of Fig. (1), it can be seen that the third quartile of symptoms with delta (Symptom 3.2) and theta (Symptom 3.3) filters, for non-focal signals, are below the median of focal signals. For the gamma filter (Symptom 3.6) there is an inversion in the magnitude of the medians. Due to the visually analyzed results, it was desired to obtain an optimized frequency band that would result in the best results for the analyzed estimators.

In doing so, it was observed the need to obtain an optimized frequency band that would result in the best results for the analyzed estimators.

Initially, a t-test, with 99% confidence, was used as the objective function to compare population means with 500 signals (without repetition), with peaks of epilepsy and without peaks of epilepsy, randomly chosen from the 3750 data available at the bank. Because it has symptoms values that are far from the central tendency, parametric statistics were not feasible as an objective function. To illustrate this statement, Fig. 2 shows the box diagrams for the Gamma and PV (unipolar mounting) filter. Doing the t-test for mean difference resulted in a P-value of 2.5.10-5 indicating that the two populations are different. However, when analyzing Fig. 2, it is observed that this statement of different populations does not proceed, since the boxes are practically the same.

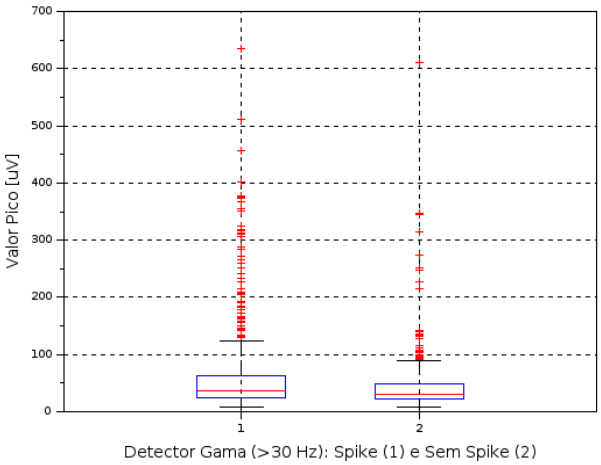


Figure 2. Unpolarized, non-standard Gamma Filtered Vp Boxplot Diagram.

A nonparametric test applied to two independent samples, which can be considered a nonparametric version of the t test to compare two populations, the Mann-Whitney U test, also known as the Wilcoxon-Mann-Whitney test (Salkind, 2010). This test was proposed by Frank Wilcoxon in the 1945s for samples of the same size, and HB Mann and DR Whitney extended their application in 1947 to samples of different sizes, also providing probability values for the U distribution, that is, the statistics of the test (Salkind, 2010).

The test U has as null hypothesis that the groups have the same distribution, with 99% confidence. For the calculation of U, values are assigned to the samples in order to construct a ranking, given by Eq. (2), where n_1 and n_2 are the sample sizes and R_1 and R_2 are the sum of the rows of observations for each sample (Salkind, 2010).

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$
$$U_2 = 1 n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2 \quad (2)$$

The statistic is defined as the minimum between U_1 and U_2, and is very useful for small samples, but for large samples, the U distribution tends to a normal distribution with mean and standard deviation given by Eq. (3).

$$\mu = \frac{n_1 n_2}{2}$$
$$\sigma = \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}} \quad (3)$$

When using this test, however, as for large samples it tends to a normal distribution, the same problems encountered for the t test appeared, since the variance of the estimator tends to the population variance divided by the sample size, implying that , for very large samples, the sample means have very small variances and any difference in the sample means result in tests of hypotheses indicating different populations (low P-values).

Therefore, to find an objective function, the metric used in this work consisted of:

1. Perform 100 tests of equality of means by calculating the P-value for the U-test. In each test 20 values of the focal and non-focal data set are used;
2. Calculate the mean and sample variance for each test;
3. Use the Taguchi's Less-is-Best quality function for the construction of the objective function z, given by Eq. (4).

$$z = \bar{x}^2 + s^2 \quad (4)$$

Once the objective function was defined, Genetic Algorithm was used to minimize z as a function of the limited frequency band between 8 and 245 Hz. The population size was 100 individuals. The minimum value obtained for the objective function was 0.0016, for the frequency band between 19.68 and 188.03 Hz.

The statistical parameters for unipolar unipolar signals filtered in the optimized band were then calculated, resulting in symptoms 3.49 for ValorRMS, 3.50 for Vp, 3.51 for VPP, 3.52 for Sk, 3.53 for Kx, 3.54 for k4, 3.55 for FC and 3.56 for K6. Figure (3) shows the box diagrams for these symptoms, as an example. The same analysis was made to all the symptoms.

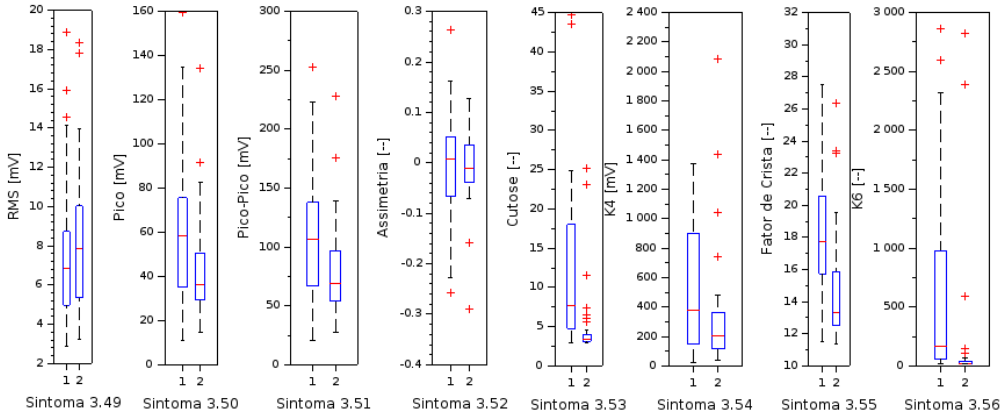


Figure 3. Boxplot Diagram for the filtered parameters in the optimized band.

Analyzing Fig. (3), it can be observed that the parameters of kurtosis, crest factor and k6 are good candidates for symptoms for the classification of the signs, once sample 2 is not intersecting the upper limit with the lower limit of the sample 1 and the third quartile of sample 2 is smaller than the first quartile of the sample 1, these are strong indicators that sample 1 belongs to a different population from sample 2. It is important to note that the K4 estimator is influenced by ValorRMS, which has a median for the non-focal signals greater than the median for the focal signals.

From this point on, only the results with the most significant sample differences will be presented, since a pre-analysis has already been made corroborating how the choice is made.

Symptoms calculated from 3.57 to 3.112 have the same metrics as symptoms from 3.1 to 3.56, but now the signal has been normalized by its means and standard deviations. From this symptom block, in making a visual analysis of the diagrams, the Gamma filtered signals and optimized filtered band, titled here as User, had the best candidates for the symptom. It was observed that the kurtosis, K4, K6, FC and peak estimators are repeated in both bands, and that they were also considered good candidates for the symptoms of non-normal signs. Now with normalized signs, PV was expected to be a good candidate, since the peaks for epilepsy signs are quite characteristic, which did not happen.

The next set of symptoms are the signals treated by dB4-based Continuous Wavelet Transform. The scales were chosen to include theta, alpha, beta and gamma frequency bands. For the delta band, considering normalized unipolar signals, the scales are worth 160.84 for the valueRMS symptom, 91.45 for VP, 90.50 for VPP, 120.63 for Sk, 329.75 for Kx, 91.43 for K4, 348.27 for FC and 327.83 for K6. Scales spanning the delta band range from 90 (≈ 4 Hz) to 350 (≈ 1 Hz). Although a considerable distance is observed between the medians of the ValorRMS, VP, VPP and K4 parameters when analyzing interquartis and mustaches, no clear separation between focal and non-focal samples can be observed.

The delta band optimized scales, considering normalized dipolar signals, are 115.30 for the RMSV value, 159.53 for VP, 61.81 for VPP, 108.16 for Sk, 231.16 for Kx, 155.41 for K4, 241.01 for FC, and 315.10 for K6. From these symptoms, it is observed that the valueRMS parameter is a good symptom candidate, since the interquartiles are well separated.

Symptoms from 3,353 to 3,360 refer to the statistical parameters for the theta band optimized scales, considering the unipolar signals. The scales are 118.76 for the ValorRMS symptom, 87.36 for VP, 83.97 for VPP, 73.14 for Sk, 56.21 for Kx, 76.69 for K4, 83.71 for FC and 55.19 for K6. Scales covering the theta band range from 120 (≈ 3 Hz) to 55 (≈ 7 Hz). With this set of symptoms, there was no significant visual separation to choose from potential candidates.

Considering now theta band normalized dipolar signals, the scales are 115.07 for the ValorRMS symptom, 112.95 for VP, 119.34 for VPP, 57.95 for Sk, 119.40 for Kx, 55.96 for K4, 82.08 for FC and 120.00 for K6. A good distance between the medians of some symptoms and a good separation between the interquartiles of the ValorRMS symptom was observed.

Symptoms from 3,369 to 3,376 refer to the statistical parameters for the alpha band optimized scales, considering the unipolar signals. The scales are valid for 28.18 for the RMS Value symptom, 30.72 for VP, 29.18 for VPP, 31.62 for Sk, 31.62 for Kx, 31.40 for K4, 28.11 for FC and 37.68 for K6. Scales spanning the alpha band range from 28 (≈ 13 Hz) to 55 (≈ 7 Hz). From these symptoms, one can observe the tendency of population separation for the Crest Factor and K6 parameters.

For the alpha band, now considering the normalized dipole signals, the scales are 28.71 for the ValorRMS symptom, 31.85 for VP, 31.02 for VPP, 54.07 for Sk, 28.53 for Kx, 35.50 for K4, 28.81 for FC and 32.53 for K6. In addition to

the parameters already observed for the unipolar signal, it was also noticed that the ValorRMS parameter is a good symptom candidate, since the interquartiles are well separated, as well as the kurtosis.

For the beta band, for normalized unipolar signals, the scales are 16.27 for the ValorRMS symptom, 12.48 for VP, 12.70 for VPP, 12.47 for Sk, 27.60 for Kx, 12.51 for K4, 12.89 for FC and 27.69. For this beta band, the ranges covering it range from 228 (≈ 13 Hz) to 12.15 (≈ 30 Hz). Of this band, the best candidate for the symptom is the CF, where it was observed that the third quartile of non focal signs is smaller than the first quartile of focal signs.

Symptoms from 3,393 to 3,400 refer to the statistical parameters for the beta-band optimized scales, now considering the dipolar signals. The scales are 17.67 for the ValorRMS symptom, 12.41 for VP, 12.57 for VPP, 16.27 for Sk, 25.99 for Kx, 12.38 for K4, 16.31 for FC and 27.21 for K6. The diagrams of these symptoms are similar to those of unipolar signs.

For the gamma band, considering the unipolar signals, the scales are 12.00 for the ValorRMS symptom, 2.19 for VP, 2.32 for VPP, 4.41 for Sk, 12.05 for Kx, 4.64 for K4, 11.43 for FC and 1.50 for K6. Scales spanning the gamma band range from 12.15 (≈ 30 Hz) to 1.462 (≈ 250 Hz). For these symptoms, it was possible to observe good results for asymmetry, kurtosis and crest factor.

Symptoms 3,409 to 3,416 refer to the statistical parameters for the gamma-optimized scales, considering the dipolar signals. The scales are 12.00 for the ValorRMS symptom, 2.19 for VP, 2.32 for VPP, 4.41 for Sk, 12.05 for Kx, 4.64 for K4, 11.43 for FC and 1.05. For dipolar signs, only for the Crest Factor symptom, a difference in the mean of the two populations is observed.

Subsequently, an envelope analysis was applied to WT treated signals, resulting in symptoms 3,417 to 3,496, which are the functions 3,337 to 3,416 applied to the signal envelope modules. The main indicators for the assertion that populations are different were observed in symptoms 3,425 (normalized dipolar signal db4 RMS value - scale 115.30); 3,441 (RMS value of db4 normalized dipole signal - scale 115.07); 3,457 (Normalized dipolar signal db4 RMS value - scale 28.71); 3,468 (Sk value of db4 of normalized unipolar signal - scale 17.47); 3,471 (Normalized unipolar signal db4 HR value - scale 12.89); 3,473 (Normalized dipolar signal db4 RMS value - scale 17.61); 3,476 (Sk value of db4 of normalized dipolar signal - scale 16.27); 3,484 (Sk value of db4 of normalized unipolar signal - scale 4.41); 3,485 (Normalized unipolar signal db4 Kx value - 12.05 scale); 3,487 (Normalized unipolar signal db4 HR value - scale 11.43); 3,492 (Db4 Sk value of normalized dipolar signal - scale 2.43); and 3,495 (HR value of db4 of normalized dipolar signal scale - 12.08). Except for symptom 3,457, where the first quartile of the non-focal sign was greater than the third quartile of the non-focal sign, all other symptoms had the third interquartile of the focal set smaller than the first interquartile of the non-focal set.

Symptoms 3,497 to 4,700 sequentially involve the first six empirical modes (EMD), associated with the first six MFIs with the following mode setting:

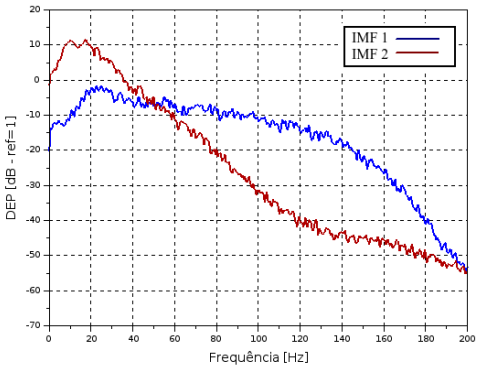
1. Mode i orthogonality index for the unipolar signal;
2. The eight parameters of mode i for the unipolar signal;
3. The eight parameters of the mode i residue for the unipolar signal;
4. Mode i orthogonality index for the dipolar signal;
5. The eight parameters of mode i for the dipole signal;
6. The eight parameters of the mode i residue for the dipolar signal.

The use of the first six empirical modes is justified by the analysis of Fig. (4), where estimates of power spectral densities (PSD) for the first six empirical modes using 100 focal data blocks with a frequency resolution of 0.5Hz.

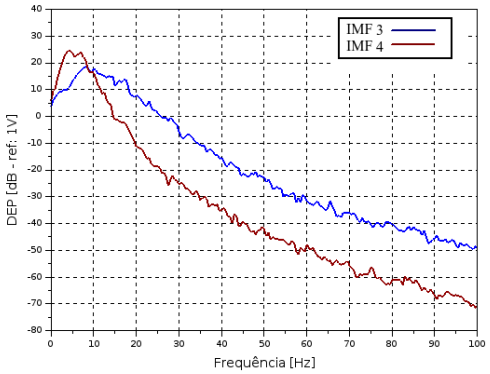
From the analysis of Fig. (4), it is observed that, compared to the other spectra, the PSD of IMF 1 covers the 15 to 200 Hz band (Fig. (4a)), that is, it covers the optimized frequency band, here called User Rating (19.68 to 188.03 Hz); The frequency range of the PSDs of IMF 2 and IMF 3 is approximately equal to the Beta filter range (13 to 30 Hz); IMF 4 PSD (Fig. (4b)) is equivalent to Alpha filter PSD (7 to 13 Hz band pass); and in Fig. (4c), it is observed that the PSDs of IMF 5 and IMF 6 are equivalent to Delta (4 Hz low pass) and Theta (3 to 7 Hz band pass) filters, respectively.

The PSD of the six MFI residue has a frequency band of 0 to 2 Hz, and it is also observed that the non-focal signal IMF PSDs have the same behavior as the focal signal PSDs. To exemplify this statement, Fig. (5) shows the PSDs of IMFs 1 and 2 of 100 non-focal signal blocks. When comparing Figs (4a) and (5), one observes the same frequency ranges being contemplated.

The best results for the EMDs were the symptoms: 3,540, which is the RMSV of the second mode residue for the unipolar signal, 3,549 is relative to theRMSV and involves the normalized second dipolar mode signals, 3,566 concerns the third unipolar mode. , RMSValue, and symptom 3.583 is the third mode RMSValue for the dipolar signal. It is important to highlight that for all the DIPolar SignalRMSRs, there was an inversion in the diagram and for 3.466.



(a)



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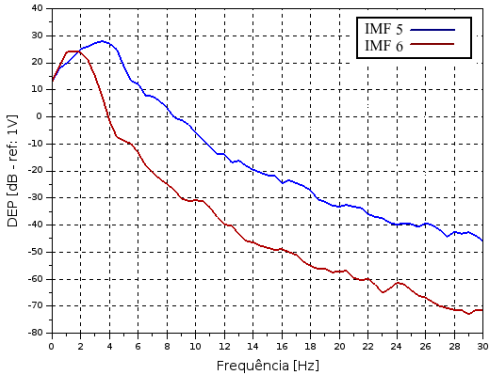

(c)

Figure 4. PSD of the first six intrinsic modes for the focal signal.

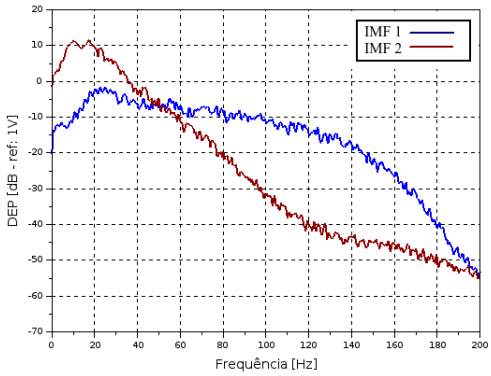

Figure 5. Power Spectral Density of the first intrinsic modes for the non-focal data set

Symptoms 3,701 to 3,892 sequentially involve HHTs using the first six empirical modes (EMD). The same settings used for EMD symptoms were used in this symptom block. The best symptoms using HHT for the first empirical mode of normalized unipolar signals were asymmetry, kurtosis, CF and K6. For the normalized dipolar signals in the first mode, only asymmetry proved to be a good candidate for discrimination between the two populations. It is noteworthy that, when analyzing the boxplot, the interquartiles do not cross, with the non-focal signal interquartile always below the focal signal interquartile.

When applying the HHT for the second mode, good parameters were observed for both the mode and its residue, all related to the calculation of the RMS value for both unipolar and dipolar signals.

Symptom candidates from 3,893 to 3,152 refer to the thirteen k-NEO symptoms, with peak widths ranging from 20 to 60 milliseconds and 25 to 65 milliseconds using a 10 millisecond interval for both cases.

From the box diagram analysis for the k-NEO parameters, 12 symptom candidates were obtained: one Dur_AP, four Dur_PB, four Dur_spike, one Amp_AP and two Slope_PB. Of these 12, Fig. 6 shows the best results obtained which were the symptoms: 3,986 which is the Amp_AP for the 60 ms interval; 3.1037 which is Dur_PB for the 35 ms range; 3.1038 which is Dur_spike for the 35 ms range; 3,960 which is Dur_spike for the 40 ms range and 3,985 which is Dur_spike for the 60 ms range. Those names of entropy parameters are the same used by the authors Sharma et al in

their work.

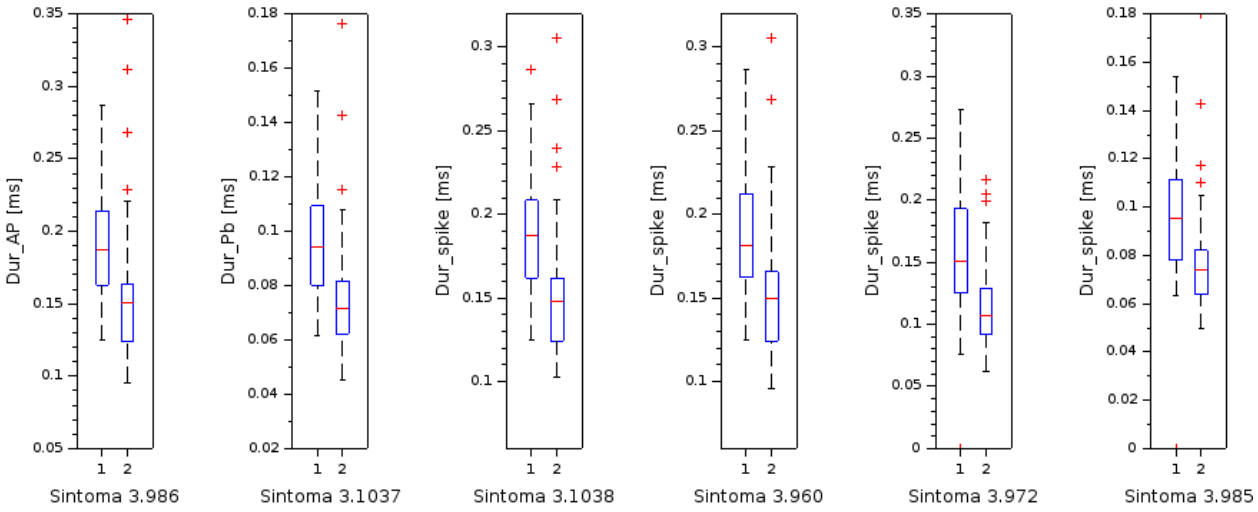

Figure 6. Best observed parameters for k-NEO analysis.

By analyzing Fig. (6), it is observed that the best symptom candidates are the mean values related to both peak and half peak wave durations, with k values chosen for periods longer than 35 ms.

Within the block of 50 datasets used for the analysis using k-NEO, 21 signals with a waveform following a peak were found for the focal set. For the non-focal set, only nine occurrences were observed. This difference, and the low frequency for the non focal set, explains the fact that there are no slow wave related metrics (Dur_slowwave, Amp_slowwave, and Area_slowwave) as possible candidates for this dataset.

For symptoms from 3.1153 to 3.1180, the RenEnAvg, ShEnAvg, ApEnAvg, and SampEnAvg entropy values for the first six intrinsic modes and their respective residues were calculated. The best results were observed for peak to peak values and asymmetry of the first empirical mode.

In summary, the number of symptom candidates, related to each of the eight statistical parameters analyzed in this study (ValorRMS, Peak, Peak to Peak, Asymmetry, Curtosis, K4, Crest Factor and K6) are shown in Tab. (1).

Table 1. Number of symptom candidates for each of the eight parameters analyzed.

Parameter	Times that symptom was candidate
ValorRMS	15
VP	3
VPP	3
Sk	9
Kx	10
K4	3
FC	14
K6	8

When analyzing Tab. (1), it is observed that the parameters that were most repeated were ValorRMS, FC and Kx, with 15, 14 and 10 occurrences respectively. It was expected that ValorRMS would be a good parameter since the set of focal signals has more energy, depending on the peaks. The same goes for FC and kurtosis, which measure off-center excursions, also related to focal peaks. This does not mean that, when associated with other symptoms for sorting through optimization algorithms and sorting procedures, these will present the best results, since there is a combination between them.

4. CONCLUSIONS

For the case under study, that is, for the analysis of brain signals obtained through electroencephalography, and considering the database used Bern-Barcelona, the main conclusions obtained in this work were:

- when calculating intrinsic modes, agreement was observed with the characteristic frequency bands of the brain signals, delta, alpha, theta, beta and gamma, and also with the optimized frequency band;
- the parameters that were most frequently repeated as possible symptoms were ValorRMS, FC and Kx,

with 15, 14 and 10 occurrences respectively. It was expected that ValorRMS would be a good parameter since the set of focal signals has more energy, depending on the peaks. The same thing is true for FC and kurtosis, which measures off-center excursions, also related to focal peaks.

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6. RESPONSIBILITY NOTICE

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