Correspondence Between TOVA Test Results and Characteristics of EEG Signals Acquired Through the Muse Sensor in Positions AF7–AF8

Ober Castillo [ID]**, Simy Sotomayor** [ID]**, Guillermo Kemper** [ID]**, and Vincent Clement** [ID]

Abstract This paper seeks to study the correspondence between the results of the test of variable of attention (TOVA) and the signals acquired by the Muse electroencephalogram (EEG) in the positions AF7 and AF8 of the cerebral cortex. There are a variety of research papers that estimates an index of attention in which the different characteristics in discrete signals of the brain activity were used. However, many of these results were obtained without contrasting them with standardized tests. Due to this fact, in the present work, the results will be compared with the score of the TOVA, which aims to identify an attention disorder in a person. The indicators obtained from the test are the response time variability, the average response time, and the d' prime score. During the test, the characteristics of the EEG signals in the alpha, beta, theta, and gamma subbands such as the energy, average power, and standard deviation were extracted. For this purpose, the acquired signals are filtered to reduce the effect of the movement of the muscles near the cerebral cortex and then went through a subband decomposition process by applying transformed wavelet packets. The results show a well-marked correspondence between the parameters of the EEG signal of the indicated subbands and the visual attention indicators provided by TOVA. This correspondence was measured through Pearson's correlation coefficient which had an average result of 0.8.

O. Castillo · S. Sotomayor · G. Kemper (✉)
Universidad Peruana de Ciencias Aplicadas, Av. Prolongación Primavera 2390, Santiago de Surco, Lima, Peru
e-mail: pcelgkem@upc.edu.pe

O. Castillo
e-mail: u201412884@upc.edu.pe

S. Sotomayor
e-mail: u201412287@upc.edu.pe

V. Clement
Martin-Luther University Halle-Wittenberg, Univesrtitätsplatz 010, 06108 Halle (Saale), Germany
e-mail: vincent.c.clement@gmail.com

1 Introduction

Problems of attention and concentration are the most common in the learning processes of children and adolescents. Fuster conducted a review of the different definitions of attention in which he concludes that it is a mechanism directly related to the activation and selection of cognitive processes. Attention has been divided into different types among which sustained attention is found. Sustained attention is defined as the ability to maintain the focus of attention on a stimulus or activity for a long time [1].

In this context, a tool developed to support the diagnosis of attention deficit hyperactivity disorder (ADHD) is the test of variables of attention—TOVA®. This test consists of the presentation of two types of visual stimulation on a conventional screen under certain technical specifications. These stimuli are divided into two, the target stimuli and the nontarget stimuli. Figure 1 shows the TOVA target stimuli on the left and the TOVA nontarget stimuli on the right. During the TOVA test, new stimuli are presented every 2000 ms and are flashed for 100 ms. At the end of the test, the results shown are the average response time of the correct answers (RT), the variability of the correct response times (RTV), and the indicator that relates the committed and the omitted errors (D') [2].

On the other hand, studies on the monitoring of brain activity have associated selective attention to the manifestations of brain activity in the gamma subband. [3]. Other studies provide strong results regarding the relationship of the alpha subband with changes in the attention stimuli [4]. However, very few correspond their results in standardized psychological tests.

Fig. 1 TOVA stimuli: target (left) and nontarget (right)

Therefore, this research aims to find a correspondence between the electrical activity of the brain and the results of the standardized TOVA attention variables test. Research results reveal a correspondence according to Pearson's correlation coefficient of 0.84 at electrode AF7 and 0.76 at electrode AF8 between the band $B_{\beta-H}$ standard deviation and the RT indicator of TOVA.

2 Description of the Proposed Algorithm

Figure 2 shows a block diagram of the proposed algorithm. Details of each processing stage are described in the following sections.

Stage 1. A database was built from 10 sessions of the test TOVA.

Stage 2. The TOVA test was performed with one change in the conditions mentioned above. Behind the monitor where the TOVA test was shown, a movie was projected for distracting stimulus. Seven tests were performed.

These two different conditions in the performance of the TOVA test allowed us to find the relationship between certain physiological changes in brain activity and the parameters of the TOVA test.

2.1 EEG Signal

The signal used in this investigation was provided by the electroencephalogram device Muse version 2016, developed by Interaxon Inc. This device has four electrodes in the positions TP9, AF7, AF8, and TP10, according to the international system for the electrode placement 10/10 [5, 6]. The device connects to the PC via Bluetooth 4.0 and delivers 12 bits per sample at a sampling rate of 256 Hz. The brain's electrical activity is classified in different frequency bands. These frequency signals are encountered from 0.1 Hz up to roughly 100 Hz. According to this, the EEG device needs to enable at least twice the maximum frequency to be analyzed (100 Hz) to match the sampling theorem [7].
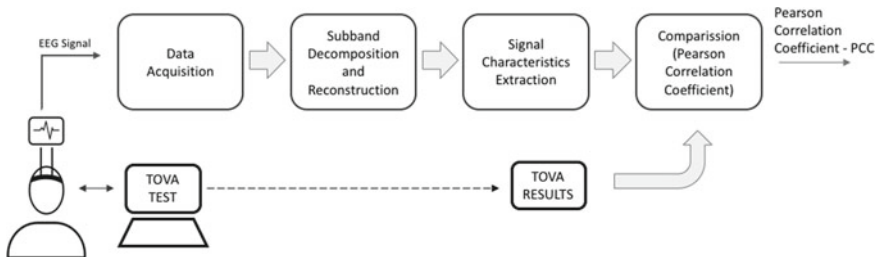

Fig. 2 Block diagram of the proposed algorithm

2.2   Data Acquisition

The signal was acquired for 21.6 min, the duration of the TOVA test. Due to the sampling frequency (256 Hz), 331,776 samples of raw data were obtained for each session and for each electrode. Studies of ADHD reveal that in most cases the characteristics of attention disorders are the product of damage in the prefrontal cortex. This is why the two front electrodes of the Muse (AF7 y AF8) were used [1].

On the other hand, both for the generation of the database (Stage 1) and for the subsequent tests (Stage 2), suitable space for the realization of these tests was prepared and a TOVA test was coded following the specifications that are available in the test manual. Some of these considerations are the size of the stimulus, that should be found in between 15 and 30% of the monitor's size (this is measured diagonally), the displayed stimuli, that should be placed at eye level to the subject, and an eye to monitor the distance of 75 cm [8].

2.3   Subband Decomposition Filtering and Reconstruction

In this stage, the acquisition signal of the EEG is separated into four main subbands that were needed in the identification of a correspondence between the TOVA and the EEG signals. These were obtained from the decomposition of the signal in 18 subbands 4 Hz wide as shown in Fig. 3 [9]. For this, a subband decomposition algorithm was developed with the objective of eliminating the bands where the artifacts signals were located and then proceed to the reconstruction of the bands of interest: $B_{\beta-L}$, $B_{\beta-M}$, $B_{\beta-H}$, $B_{\gamma-L}$, $B_{\gamma-M}$ y $B_{\gamma-H}$ whose description is in Table 1.

Due to the instability of the EEG signals, and their non-stationary characteristics, it is recommended to use the wavelet packet transform. A wavelet transform is a mathematical tool that allows the extraction of information both in time and frequency. The families of this type of filters that are used for decomposition come from a single function known as "mother wavelet" and its use has been shown to effectively remove the different noises on non-stationary signals [10]. For this investigation, the Daubechies 9 ("db9") family was used, which shows a great correlation with the EEG signal according to Akkar and Hassim, 2017 [11].

To reduce the influence of blinks on the acquisition signal, the averaging filter, the median filter, and the elimination of the band containing more energy during the blink were tested. It was noted that the best method to eliminate intrusive signals in brain activity is to eliminate the band that contains the most components of the signal to be removed. The results of the filters are observed below. Figure 4a shows that the average and median filter affect the entire signal; and, although they reduce the peaks produced by the blinking, much information is lost from the part not affected by these blinks, unlike Fig. 4b, where greater reduction is observed during the blinking and conservation of the signal not affected by them. The bands where the highest energy were produced by the artifacts was removed from the reconstruction process, as shown in Fig. 4; these bands correspond to a bandwidth of de 0–12 Hz, and these are components of the alpha and delta band of brain activity that, for purposes of this paper, they are not of interest in the search of the state of attention.
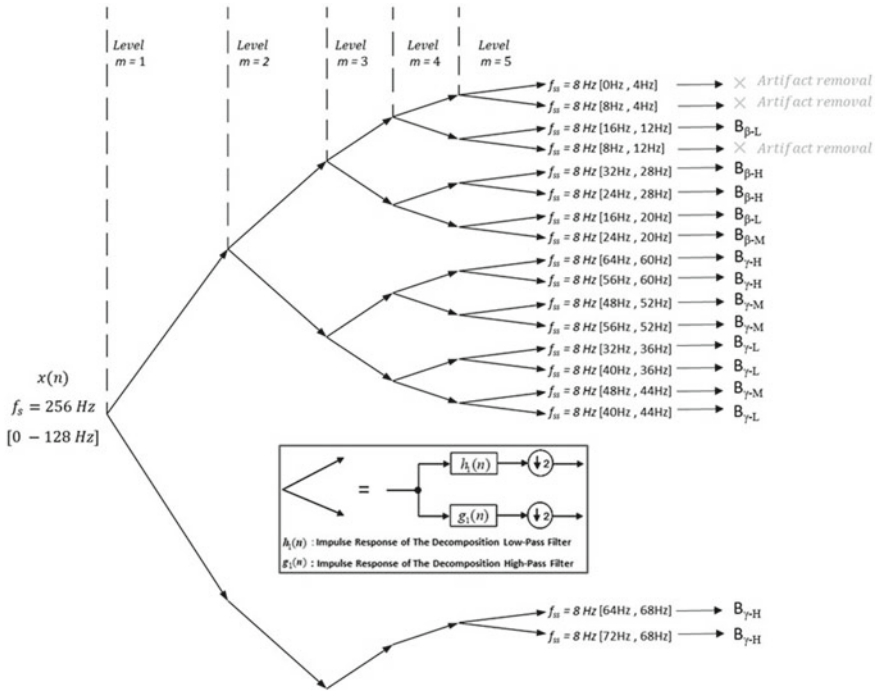
Fig. 3 Wavelet packet decomposition tree used in the proposed method

Table 1 Frequency bands association

Subband	Hz	i	Subband	Hz	i
$B_{\beta-L}$	12–20	1	$B_{\gamma-M}$	44–56	6
$B_{\beta-M}$	20–24	2	$B_{\gamma-H}$	56–72	7
$B_{\beta-H}$	24–32	3	B_{β}	12–32	8
$B_{\gamma-L}$	32–44	4	B_{γ}	32–56	9

2.4 Signal Characteristics Extraction

In this stage, the signal characteristics of each subband indicated in Table 1 were extracted. The characteristics extracted were:

Temporary mean power (P). To calculate, the vector x_i was taken, where i describes the corresponding subband and N_i the number of elements contained in the vector of the subband i; the absolute values added to the square of the N_i elements contained in the vector were summed to finally divide it by the size of the vector.
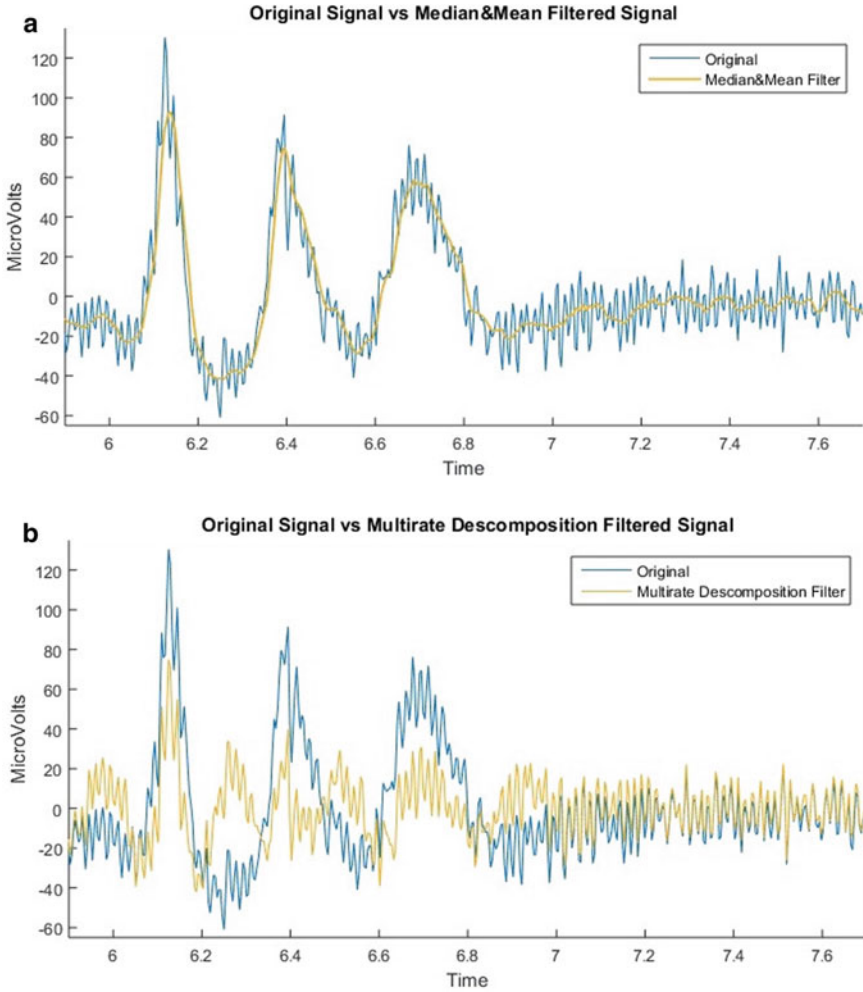
Fig. 4 **a** Original signal compared to the median and mean filtered signal. **b** Original signal compared to the original signal without B_α

$$P_i = \frac{1}{N_i} \times \sum_{n=1}^{N_i} |x_i(n)|^2 \tag{1}$$

Temporary standard deviation (σ). To calculate, the sum of the difference between each element and its mean μ_i squared was made. Finally, it was divided by the number of elements contained in x_i.

$$\sigma_i = \sqrt{\frac{\sum_{n=1}^{N_i} (x_i(n) - \mu_i)^2}{N_i}} \tag{2}$$

Table 2 Mean TOVA results summary

	Optimal TOVA test	Non-optimal TOVA test
RTV	63.60	104.74
RT	344.13	426.18
d'	4.55	4.07

The exposed characteristics were applied to all the rebuilt subbands during the performance of the TOVA both for the obtaining of the database (Stage 1) and for the tests TOVA under distracting conditions (Stage 2).

From these results, it was possible to identify the bands in which there was a greater change between the two stages. Within this analysis, the band $B_{\beta-H}$ was chosen and it was also decided to integrate a new band (B_Σ) defined in Eq. 3.

$$B_\Sigma = B_{\beta-L} + B_{\beta-M} + B_{\beta-H} + B_{\gamma-L} + B_{\gamma-M} \tag{3}$$

2.5 Comparison

To compare the results of the EEG, the following TOVA parameters were extracted: response time (RT), this parameter reflects the average time required for a correct response to a target stimulus. Response time variability (RTV) corresponds to the variability of the correct response times. D Prime score (d') indicates the accuracy to discriminate a target stimulus and a nontarget stimulus. This score can be interpreted as "perceptual sensitivity" [12]. Table 2 shows a summary of the results obtained from the TOVA test. The second column corresponds to the average of the tests performed under optimal conditions and the third column, to the average of the tests performed under distracting stimuli.

Each of these parameters was contrasted with the characteristics of the bands selected in the previous point to find some correspondence between both groups.

3 Results

Finally, Pearson's correlation coefficient of the TOVA test with the selected EEG signals was calculated. Ten sessions of Stage 1 and seven sessions of Stage 2 were performed. From there, we needed to remove three sessions on electrode AF7 and one session on electrode AF8 due to an accumulation of values that were far above from the mean. A correlation coefficient was observed between the temporary standard deviation of the $B_{\beta-H}$ band with the TOVA RT of -0.8824 for the AF7 electrode and -0.8071 para the AF8 electrode, as shown in Fig. 5a.
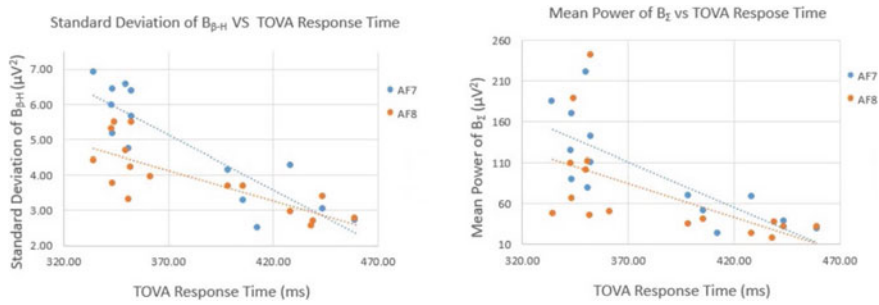
Fig. 5 **a** Correlation between $B_{\beta-H}$ and TOVA response time. **b** Correlation between B_{Σ} and TOVA response time

A correlation coefficient between the temporary mean power of the band B_{Σ} and the TOVA RT of -0.7817 for electrode AF7 and -0.5154 for electrode AF8 is also observed in Fig. 5b.

The x-axis shows the TOVA response time in which a higher value corresponds to the slower response toward a stimulus, indicating a lower attention state [12]. The y-axis shows the value of the characteristics extracted from the band obtained in the TOVA tests performed, being the temporary standard deviation in Fig. 5a and the temporary mean power in Fig. 5b. It was found that tests performed in Stage 1, with optimal conditions, tend to have an EEG response of high mean power and standard deviation, and tests performed in Stage 2, with the distracting stimulus, tend to have lower mean power and lower standard deviation.

4 Discussion

The existence of a relationship is between the behavior of the physiological activity of the brain and the TOVA results as evidenced by the good correlation between the average response time of the TOVA and the standard deviation of the band $B_{\beta-H}$, and this relationship shows that greater response times are manifesting, in inverse proportion, into greater standard deviation of the power in the band $B_{\beta-H}$. However, it is important to continue taking data to reinforce this correlation and find other parameters that could also meet this relationship.

For the continuation of this investigation, an analysis will be carried out in smaller window times in the EEG signal to observe in more detail the behavior of the signals throughout the test and, in this way, determine the existence of a greater correlation between the EEG signals and other TOVA parameters.

Furthermore, the AF8 electrode signal shows more reliability in seeking the correspondence between the parameters specified above. This asymmetrical performance between AF7 and AF8 electrodes may be due to not so accurate EEG positioning or degraded electrode. Due to this behavior, AF7 electrode presented samples that were

far above from the mean in three sessions, so they were removed from the analysis: two correspond to a stage 1 session and one to a stage 2 session.

This research allowed us to identify the brain activity band where sustained attention manifests in relation to standardized TOVA test. In the same way, we can build now a characteristic vector in order to feed a neural network for classifying the attention state. The final goal of this research is to develop a neurofeedback therapy device of the attention state.

It is important to indicate that the framework used in this study corresponds to the unique case approach because we attempted to determine a correlated behavior between two parameters. Thus, ethical approval for the experiment in this study was deemed unnecessary by the university, since the research was designed to develop a computational framework. For this, all the data presented were acquired from the first author of this research and did not involve human participation. Additionally, for this study, we use a commercial EEG non-invasive sensor with dry surface electrodes that do not represent any health risk. The activities undertaken in this research do not pose risks greater than those ordinarily encountered in daily life, as well as affecting the preservation of the anonymity.

The goal of these recordings was a concept and preliminary study for later applications, where tests with several persons will be regulated by the respective ethical committee.

5   Conclusions

The research carried out shows that sustained attention is manifested in the temporary standard deviation of the $B_{\beta-H}$ band. This relationship has a behavior inversely proportional to the response time of the TOVA. A lower level of sustained attention corresponds to a longer average response time to the objective stimulation of the TOVA test.

With the results obtained, a behavior of brain activity has been identified during the state of sustained attention, so a K-means classifier will be implemented to develop a neurofeedback therapy that will be used as a tool in psychology studies.

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