Determination of EEG Power For Individuals During Memory usage Based on Personalized Frequency Bands

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Abstract— **Despite of many researches done about memory and it's relation with brain signal, yet there is disagreement on rhythm selection. The reasons of this disagreement are complexity of memory structure and different cognitive factors such as spirit, intelligence level and attention to memory. In this paper, we consider power variations of different bands in fz and oz channel from 3 persons during memory usage. We observed that power of lower 1 alpha, lower 2 alpha and upper alpha band decreases and power of SMR band increases.**

Keywords-memory; EEG; power spectrum,wilcoxon exam.

I. INTRODUCTION

Working memory has been a major topic of cognitive research during last 25 years. Many studies proved that working memory plays an important role in learning, calculating, reasoning and verb comprehension of cognitive processing. Working memory tasks are known by changing functional connectivity [1].Working memory is variously defined as a set of linked and interacting information processing components that maintain information in a short-term store (or retrieve information into that store) for the purpose of the active manipulation of the stored items [2].

The human electroencephalograph (EEG) has proven to be a useful tool in the examination of the brain's functioning. Quantitative electroencephalography (qEEG) and coherence provide additional sources of information about the topography of synchronous oscillation activity and potential cortico-cortical interactions during cognitive testing [1].

Many researches have been performed about brain signal and memory working relations. Relations between memory and different brain signal rhythms have been evaluated during period of recall and memorization. Theta rhythm was related to memory in many studies [3-5]. For example in one study performed by sarenthin et all [5], increase of synchronization in theta band between prefrontal and back of head during memory usagehave been observed. In some studies, gama [6-9] and SMR [10] rhythms were related to memory. For instance, Howard et all [6] showed that gamma band activity increases during transient memorization of letters in working memory. Haarmannet all [10] also reported that there is increased synchronization among frontal and back regions while repeating words in working memory. Moreover, alpha rhythm has been related to memory in many studies [7, 11-13]. Klimesch [12] showed that alpha rhythm is specially related to semantic memory so that alpha activity had been decreased after semantic excitation display.

As it has been seen, despite of many researches performed about memory and it's relation with brain signal, there is disagreement on cores padding rhythm selection yet. This disagreement reasons are memory structure complications and different cognitive factors such as spirit, intelligence level and attention of persons to memory.

Moreover, there is no precise definition for brain signal rhythms until now. For example in many studies, alpha rhythm is considered 8-12 Hz [14,15], but in several studies this band ranges is 8-13[13,7] , 7.5-12.5 [16,17], 7.5-13 [18] and 8-12.5 [19] Hz. Klimesch [12] also showed that alpha rhythm is different from one person to another based on different parameters such as age, brain disease, intelligence and memory quality. To solve this problem, klimesch proposed using individual alpha frequency (IAF) for each person.

Finding appropriate relation between memory and brain signal frequencies according to personalization attitude of brain bands and disagreement about rhythms which are related to memory is essential. So, in this paper we consider designing an appropriate experiment to extract personal bands related to memory.

In Section III, power estimation method for memory evaluation and individual alpha extraction is introduced. In section III, we introduce the experimental setup and the protocol under which the experiments are conducted. The results of implementation are mentioned in section IV. Finally, conclusion and discussion of work are given in section V.

II. POWER SPECTRUM DENSITY

A. Basic Idea

In a physiological sense, EEG power reflects the number of neurons that discharge synchronously. Because brain volume and the thickness of the cortical layer is positively correlated with intelligence, it is tempting to assume that EEG power too, is a measure that reflects the capacity or performance of cortical information processing. Although it will be argued that this is in principle the case, it must be emphasized that power measurements are strongly affected by a variety of unspecific factors such as the thickness of the skull or the volume of cerebrospinal fluid, by methodological and technical factors (such as interelectrode distance or type of montage) but also by more specific factors such as age, arousal and the type of cognitive demands during actual task performance [12].

B. Methods of Simulation

Power spectral density (PSD) estimation is a balance between smoothing and frequency resolution. Obtaining representative spectra is challenging due to the large data sets and the computational complexity. A periodogram is a description of the signal power as a function of frequency. For small signal sequences, this can be obtained by performing a DFT on the X(k) data series. As a practical matter, the entire set may be quite long, or continuous, whereby a direct calculation is not possible. For these cases, smaller intervals are selected and DFT taken:

The resulting PSD has larger frequency spacing, but the result of averaging many such spectra together returns an average, particularly if zero-padding is used in the DFT [21].

In general, PSD estimates using a limited number of samples tend to be quite poor. In order to produce a smoother, well-behaved PSD estimate, many independent periodograms are averaged together, as proposed by Bartlett. Bartlett's method is a popular approach, which divides the long sequence into L non-overlapping sub-sequences, having length M. To create the Bartlett sub-sequence; the data is effectively multiplied by a rectangular function, or time-windowed. This window, when finally convolved with the signal spectrum, distorts the original by smearing the narrow spectra components, possibly eliminating them. Improvement is possible by careful selection of windows, which all have the basic tradeoff between main lobe width, and sidelobe suppression.

Similar to Bartlett's method, Welch computes periodogram of length M and averages the spectra. However, two additional parameters permit the use of overlapping segments, and freedom to use any window. The result is control over the amount of smoothing as well as improving resolution by reduction energy leakage from excessive sidelobes.

$$\hat{p}_d(f) = \frac{1}{MU}\left|\sum_{n=0}^{M-1} x_d(n)w(n)e^{-j2\pi fn}\right|^2 \quad (1)$$

And U is a normalization factor:

$$U = \frac{1}{M}\sum_{n=0}^{M-1}|w(n)|^2 \quad (2)$$

So the power of signal in wlech method is:

$$\hat{p}_{welch}(f) = \frac{1}{L}\sum_{i=0}^{L-1}\hat{p}_d(f) \quad (3)$$

The PSD of EEG signal was approximated by means of Welch's averaged modified periodogram [19] with 2-sec epochs (0.5-Hz frequency resolution), 50% overlap, and a Hanning window. Relative power was computed based on the following formula:

$$Pr(f) = \frac{Pa(f)}{\sum Pa(f)} \quad (4)$$

Where Pr(f) is a relative power at frequency f, Pa(f) is an absolute PSD at the same frequency and Σ is a sum of the power over the all bandwidth.

C. Determination of Individual Frequency Band

Then, The PSD of EEG baselines in both open and closed-eye conditions were computed. Then, individual alpha peak (IAF) frequency was calculated for each subject according to the formula:

$$IAF = \frac{\sum_{f=f_1}^{f_2} Pr(f)\times f}{\sum_{f=f_1}^{f_2} Pr(f)} \quad (5)$$

Where Pr (f) is the PSD estimate of closed eyes EEG baseline at frequency f and the index of summation is in the range of f1–f2. The frequency window f1–f2 was the range of alpha peak which was determined individually for each subject. For determining the frequency window f1–f2, the PSD of EEG baseline was plotted with open and closed eyes together. By visual inspection, the bandwidth of the frequency window f1–f2 was determined. f1 marks the beginning of the ''ascent'' and f2 the end of the ''descent'' of the alpha peak for closed eyes PSD, compared to open eyes PSD (figure 1).

Also in [10], EEG power spectrum in rest situation was compared with power spectrum during brain activity. The location which 2 spectrum are intersected is called "transition frequency (TF)" between alpha and theta band.

After computing IAF and TF for each subject, we defined TF-2 Hz to TF Hz as an individual theta frequency band and TF Hz to IAF-2 Hz as an individual Lower 1 Alpha frequency band, IAF-2 Hz to IAF Hz as an individual Lower 2 Alpha frequency band, IAF Hz to IAF+2 Hz as an individual Upper Alpha frequency band and IAF+2 Hz to IAF+5 Hz as an individual SMR frequency band.

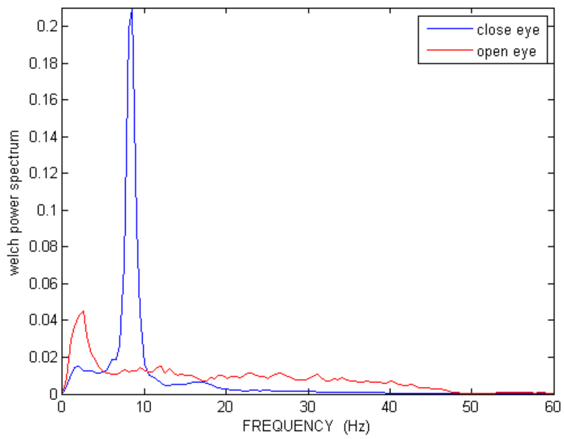

Figure 1. Power spectrum in oz channel for a case in closed and open eye

III. SELECTED APPROACH TO EXPERIMENTATION

A. Experimental setup and data acquization

Three healthy subjects (all females, 24-30 years old) participated in this study. The subjects did not suffer from any neurological or muscular disorders.

The EEG signal was recorded from two electrodes attached to the scalp of the subject, one on the Oz position and the other on Fz position, according to the international 10–20 system. A ground electrode was placed on left earlobe and the reference electrode was placed on right earlobe. For EEG recording, the FlexComp (Thought Technology Ltd.) differential amplifier was used. Sampling frequency was 256 Hz and A to D precision was 14 bit. Acquired signal was filtered with a butterworth band pass filter ranging from 0.4 to 45 Hz. Furthermore, a 50-Hz notch filter was enabled.

Also some parts of recorded signal which have higher amplitude than threshold limit because of eye blinking or motion artifacts, were omitted in next analysis from EEG signal.

B. Experimental paradigm

Each subject was seated on a comfortable armchair. To minimize the movement artifacts, the subject was asked not to move his body during the experiments. In the EEG recording session, a 2-minute EEG baseline with open eyes and a 2-minute EEG baseline with closed eyes were recorded from each subject.

Then we recorded a 2-minute EEG baseline with closed eyes in order to evaluate brain signal which is related to memory.

After this recording a 2-minute EEG baseline with open eyes and a 2- minute EEG baseline with closed eyes were recorded from each subject again.

The working memory task was performed as follows: first an A4 format paper with 12 simple black and white pictures was shown to the subject during 10s. Then the subject was asked to close the eyes during 2 min while trying to remember as many of the pictures as possible. After this minute the subject was asked to open the eyes and to name all the pictures he or she could remember. The total number of pictures remembered correctly was the working memory score [20].

In this paper, working memory exam is recorded 3 times for each case and in each repetition the set of pictures is different.

IV. RESULTS

We apply statistical exam to evaluate meaningful differences. Because data weren't normal distribution, wilcoxon exam had been used. Power of different subbands in FZ and OZ channel for all cases are shown in figure 2 and 3.The results of statistical exam are showed in table I and II.

Also a Davies-bouldin (DB) criterion has been used to evaluate feature extraction space [22]. This criterion is defined based on scattering matrix of clusters and shows its separability level. We should measure distance between each cluster to calculate the criteria. Then, the worst separability status should be selected. Finally, DB criteria would be average of the worst separability status in all clusters. Calculation trend is follows as:

$$DB = \frac{1}{C}\sum_{i=1}^{C}\max(R_{ij}), i \neq j \qquad (6)$$

In above equation, C represents the number of clusters and R_{ij} shows similarity between two different clusters:

$$R_{ij} = \frac{S_i + S_j}{D_{ij}} \qquad (7)$$

$$S_i = [\frac{1}{J_i}\sum_{j=1}^{J}\| X_j - Z_i \|^p]^{\frac{1}{p}}, X_j \in \text{cluster } i \qquad (8)$$

Here, S_i,S_j are scattering of the I th and j th matrix respectively. D_{ij} shows distance between averages of clusters.

Results show that the DB criterion of lower2 alpha band is lower than others.

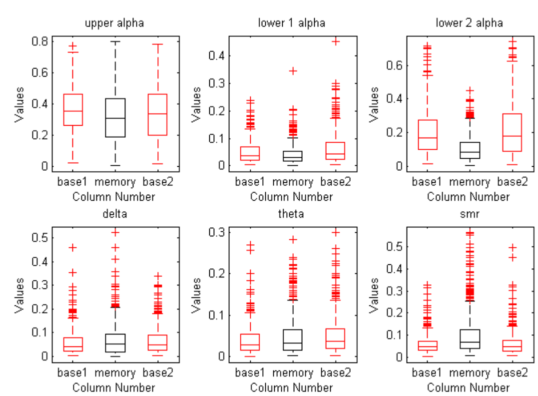

Figure 2. Comparison of different subbands for all cases in all exams (channal OZ), left:before exam, right:after exam and middle:memory

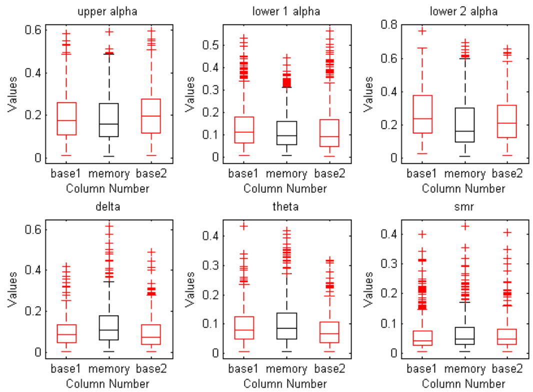

Figure 3. Comparison of different subbands for all cases in all exams (channal FZ), left:before exam, right:after exam and middle:memory

TABLE I. THE RESULTS OF STATISTICAL EXAM IN OZ CHANNAL.

EEG band	P-value	Difference of relative power between baseline 1 & memory
Lower1 alpha	5.6713E-09	5.8262
Lower2 alpha	3.5514E-70	17.7094
SMR	9.3942E-27	-10.7074

TABLE II. THE RESULTS OF STATISTICAL EXAM IN FZ CHANNAL.

EEG band	P-value	Difference of relative power between baseline 1 & memory
Lower1 alpha	1.2489e-05	4.3689
Lower2 alpha	1.1171e-23	10.0307
SMR	0.0032	-2.9469

V. CONCLUSION

We developed a system that evaluates the memory ofhumans based on the power spectral of their EEG signals. The aim of this study is to identify the effect of memory on EEG signal, which could be used in memory systems.

Our results show that:

- Because of employing memory in oz channel, power reduction in lower1 alpha, lower2 alpha and upper alpha band was observed.
- Power of SMR band increased when memory was used in oz channel.
- In case 2 and 3, we observed that power of theta and delta band increased during memory usage but this power decreased for first person.
- In FZ channel, power of lower1 alpha, lower2 alpha have been decreased during memory usage but power in SMR and delta subbands increased.

So the EEG during the retention period of the working memory task was characterized by a decreased power (synchronization) in the lower alpha band and an increased power in the SMR band.

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