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Validation of an EEG Classification Procedure Aimed at Physiological Interpretation

M. Guillard, M. Philippe, F. Laurent, J. Martinerie, J.P. Lachaux ,G. Florence

***Abstract*—**One approach to assess neural networks underlying the cognitive processes is to study Electroencephalography (EEG). It is relevant to detect various mental states and characterize the physiological changes that help to discriminate two situations. That is why an EEG (amplitude, synchrony) classification procedure is described, validated. The two situations are "eyes closed" and "eyes opened" in order to study the "alpha blocking response" phenomenon in the occipital area.

The good classification rate between the two situations is 92.1 % (SD = 3.5%) The spatial distribution of a part of amplitude features that helps to discriminate the two situations are located in the occipital regions that permit to validate the localization method. Moreover amplitude features in frontal areas, "short distant" synchrony in frontal areas and "long distant" synchrony between frontal and occipital area also help to discriminate between the two situations. This procedure will be used for mental fatigue detection.

***Keywords*—**Classification, EEG Synchrony, alpha, resting situation.

I. Introduction

IN the medical and military context, monitoring of the mental state of the combatant is relevant. We present in this paper, the use of mathematical tools and one approach to give the spatial information on the scalp that permit to discriminate two mental states. It may be of interest to compare the neural assemblies involved in two different situations. Therefore, an adapted EEG signal processing chain was set up and validated in the present study.

Many EEG signal quantifications were studied in alpha frequency band like the alpha power density [1] and alpha attenuation coefficient [2] and [3] to study fatigue in resting situations. For these quantifications, there are diurnal variations and correlation with sleepiness scales. A quantification using non linear method [4] is also an alternative to detect the difference between eye open and eye closed situation. For this technique, there is no assumption about the frequency band of the EEG signal. The article of Palva [5] underlines the relevancy of α-frequency band oscillations for the study of attention and consciousness. In this paper, we focus on alpha frequency band (8 to 14 Hz) and with quantification method based on "amplitude" and "synchrony" [6] that represent respectively the signal power and the phase locking value between two signals.

To validate this chain, we studied the “Alpha blocking response” phenomenon that is a well known phenomenon because there is an increase of power in the alpha frequency band when the subject with eyes opened closed his eyes. The data set used in this work and the classification procedure are described in the next chapter.

F. M. Guillard is with the Aerospace Medical Institute of Health, Army Department, 91223, Brétigny sur Orge, France (phone: 0033 169237143; fax: 0033 169237002; e-mail: mguillard@ imassa.fr).

S. M. Philippe is with the Aerospace Medical Institute of Health, Army Department, 91223, Brétigny sur Orge, France.

T. J. Martinerie is Cognitive and Brain Imaging Laboratory, CNRS, UMR 7225 – CRICM, Paris, France.

F. F. Laurent is Cognitive and Brain Imaging Laboratory, CNRS, UMR 7225 – CRICM, Paris, France.

F. J.P. Lachaux is with INSERM U821 – Brain Dynamics and Cognition, Lyon, France.

S. G. Florence is with the Aerospace Medical Institute of Health, Army Department, 91223, Brétigny sur Orge, France.

II. Material and Method

A. Experiment

The EEG data of 10 healthy subjects aged between 21 to 35 years old were recorded during the morning at 9:00 am. During the protocol the subject was sat in a chair in front of a computer screen in a resting situation in which the participants had first the Eyes Opened (EO) for 2 minutes, and second the Eyes Closed (EC) for 2 minutes.

B. Data acquisition

Monopolar EEG was studied by means of 60 sintered Ag/AgCl ring electrodes mounted on a cap (BRAINCAP, Brain Products GmbH) and placed according to the international 10-20 system. Linked mastoids and AFz were used respectively as reference and ground. In addition, one electrode glued below the left eye (EOG) was used to detect eye blinks and vertical eye movements. Impedances were kept below 10 kΩ. The EEG were amplified, filtered (band pass: 0.1 Hz – 150 Hz), and digitized at 1 KHz using BRAINAMP amplifiers and BRAINVISION RECORDER software (Brain products GmbH).

C. Data quantification

First, with BRAINVISION ANALYSER software (Brain Product GmbH), the data were segmented in 2 seconds intervals with a 50 percent overlap. A method for off line removal of ocular artifact from Gratton [7] and a manual rejection of segments with artifacts due to muscular activity were applied. At this step, the number of selected segments must be more than 30. Second, with MATLAB software (The MahWorks), a common average reference including all EEG signals was used, each signal was reduced and centered for each segment and then a band pass filter between 8 and 14 Hz was applied. A Hilbert filter permitted to extract instantaneous amplitude and phase. For one segment, mean value of logarithm of amplitude (60 values) and phase locking value (1660 values) or synchrony were extracted [8].

D. Data reduction

For each subject, a “single trial” (considering each segment) approach was realized as followed. We considered two independent groups and we computed a non parametric statistical test of permutation with $p < 0.05$ [9] to take into account the high dimensional EEG data. In our application, the number of data was 1730. A list of statistically significant amplitude and synchrony is extracted.

For all subjects, we build a list of common statistically significant amplitude and synchrony with the same difference between the two groups. Other lists for 9 subjects out of 10 and another one for 8 subjects out of 10 and so on.

E. Classification procedure

In the classification procedure, the number of selected input variables or feature must be at least 100 for classification performance and the input variables are extracted from the list common to the maximum of subjects.

A bootstrap procedure was implemented with 90% of the dataset used as a learning set and 10% as a testing set. Furthermore, a random distribution between the two situations is used in order to validate the classification algorithm. The number of iteration is 30 for the two bootstrap procedures. The classification algorithm is a linear discriminante analysis with Mahalanobis distance.

The classification procedure is applied for each subject and for all subjects (one algorithm for all the subjects). The results associated to the classification procedure are presented in chapter III.C.

III. RESULTS

A. Data quantification

The mean number of selected segments is 56.8 (SD = 3.6) for EC situation and 54.1 (SD = 7.6) for EO situation.

B. Data reduction

159 features or variables were selected after data reduction for 8 subjects out of 10 (Fig. 1). The number of selected features for the case 9 out of 10 and 10 out of 10 were less the 100 so they were not selected.

The spatial distribution of the selected features is presented in table 1 in four groups that correspond to the type of quantification that are "Amplitude" or "synchrony" and the variation between the two studied situations that are "increase" or "decrease".

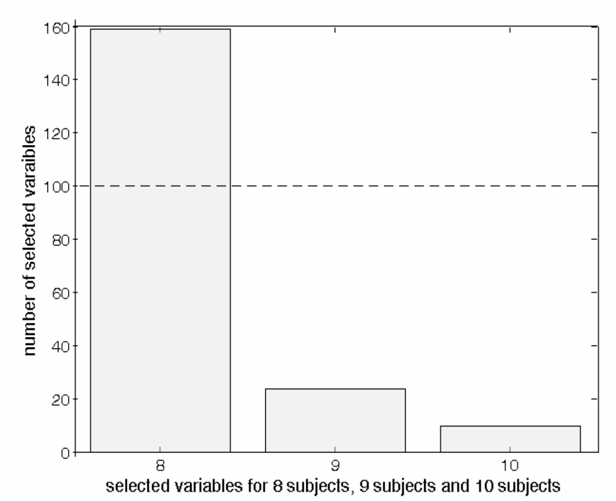
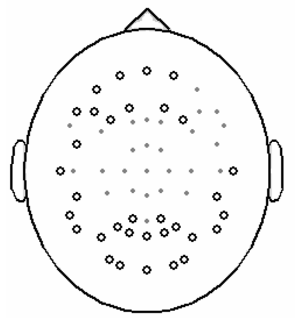
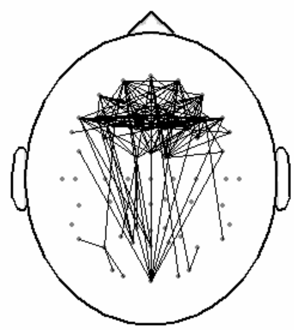


Fig. 1 Number of selected variables common to 8, 9 and 10 subjects out of 10

TABLE I
SPATIAL DISTRIBUTION OF SELECTED FEATURES FOR CLASSIFICATION ALGORITHM

Quantificatio n Features	Decrease between "EC" and "EO" situation	Increase between "EC" and "EO" situation
Amplitude features		No amplitude selected
Synchrony features		No synchrony selected

On the figure above, each point represents an electrode. On the second line, circles are selected amplitude variables, and on the third line, black lines are selected synchronies.

There is no increase observed between the situations EC and EO.

C. Classification procedure

Classification procedure results for each subject with 159 selected input features are presented below (Fig. 2). The standard deviation for each classification result is represented.

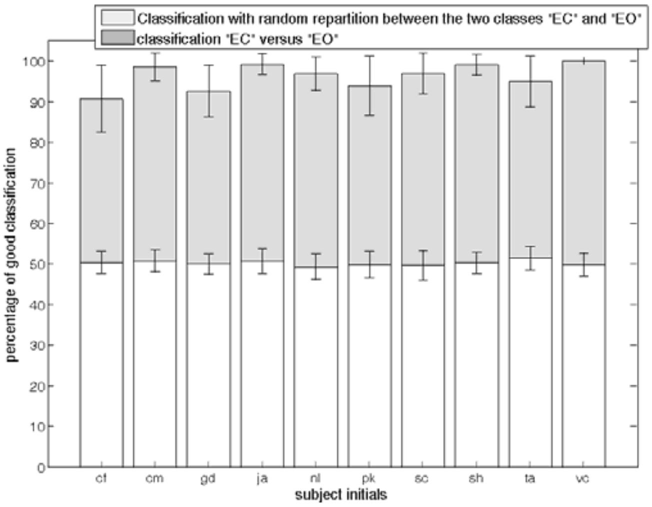


Fig. 2 Classification performance between "EC" and "EO" situations for each subject

For all subjects, the mean correct classification rate is 92.1% (SD 3.5%). With the random distributions between the two groups, the mean correct classification rate is 51.0 % and the standard deviation is 1.7%.

IV. Discussion

A. Amplitude

The decrease of amplitude features in the occipital area underline the "alpha blocking response" phenomenon. More over, we notice that there is a decrease in other areas that are parietal, temporal, frontal and parieto-frontal. There is only decrease of amplitude feature. This phenomenon is described by Laufs [10] that conclude that the pattern of brain activation observed during spontaneous reduction in the alpha band depends on the general level of brain activity as indexed over the broader spectral range in the EEG. In this paper, the theta (4 – 7 Hz) and the beta (13-30Hz)) frequency bands are studied in detail.

B. Synchrony

There are two main types of synchrony decreases between the two EC and EO situations. First, "short distant" synchronies in fronto and fronto-parietal areas. Second, "long distant" synchronies between the occipital area and the fontal, fronto-parietal areas. Theses results are in contradiction with the article of Herbert [11] that observed an increased of "long distance" synchronies between EC situation and transcendental meditation.

V. Conclusion

We can conclude that the EEG classification procedure is validated on real dataset. Nevertheless, some additional validation on other datasets needs to be done in order to confirm the results for the synchronies and the impact of time of the day parameter on the selected features for classification. Moreover, theta and beta frequency band could be studied.

This processing chain can be used for more operational application with for instance the detection of the mental fatigue. Dataset with subjects of the French air force during Alpha Jet simulator session of 3 hours are under process.

In order to improve the classification results, another classification technique called support vector machine have to be evaluated [12] because it will permit to evaluate the "weight" of each input variable in order to discriminate two situations.

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