An electroencephalographic Peak Density Function to detect memorization during the observation of TV commercials

G. Vecchiato, G. Di Flumeri, A.G. Maglione, P. Cherubino, W. Kong, A. Trettel, F. Babiloni

***Abstract*— Nowadays, there is a growing interest in measuring the impact of advertisements through the estimation of cerebral reactions. Several techniques and methods are used and discussed in the consumer neuroscience. In such a context, the present paper provides a novel method to estimate the level of memorization occurred in subjects during the observation of TV commercials. In particular, the present work introduce the Peak Density Function (PDF) as an electroencephalographic (EEG) time-varying variable which is correlated with the cerebral events of memorization of TV commercials. The analysis has been performed on the EEG activity recorded on twenty healthy subjects during the exposition to several advertisements. After the EEG recordings, an interview has been performed to obtain the information about the memorized scenes for all the video clips watched by the subjects. Such information has been put in correlation with the occurrence of transient peaks of EEG synchronization in the theta band, by computing the PDF. The present results show that the increase of PDF is positively correlated, scene by scene, ($R=0.46$, $p<0.01$) with the spontaneous recall of subjects. This technology could be of help for marketers to overcome the drawbacks of the standard marketing tools (e.g., interviews, focus groups) when analyzing the impact of advertisements.**

I. Introduction

In these last years we are assisting to an increasing interest in the use of brain imaging techniques for the analysis of brain responses to commercial stimuli [1]. The interest is justified by the possibility to investigate brain activations to derive conclusions about the adequacy of commercial stimuli. Standard marketing techniques involve the use of in depth interviews or focus groups during which customers are exposed to the product before its massive launch (ad pre-test) or afterwards (ad post-test). However, it is now recognized that the verbal advertising pre-test is biased by the respondents' cognitive processes activating during the interview and by the influence that the interviewer may have on their recalls [2]. Thus, neuroscientists investigate the signs of the brain activity correlated with variations of cognitive and emotional engagement during several economic experimental tasks.

In fact, there are high hopes that neuroimaging technology could solve some of the problems that marketers face such as streamline marketing processes and save money by providing more efficient trade-off between costs and benefits. In addition, neuroimaging is thought to reveal information about consumer preferences that is unobtainable through conventional methods[3].

In this scenario, the aim of the present study is to present a novel electroencephalographic (EEG) tool which is able to detect events of memorization related to the observation of TV commercials. Several neuroscientific studies describe the role of cerebral frontal areas in memorization tasks. Particularly, left frontal lobe is considered as part of the network devoted to the encoding of new information [4]. This model is supported by experimental findings that highlighted how the synchronization of the frontal EEG activity in the theta band is correlated with the memorization of complex items [5] as well as commercial advertisements [6]. To measure the synchronization of the EEG activity, the Global Field Power (GFP, [7]) is used. It is a time-varying metric reflecting the potential distribution of neural activity: a low GFP reflects a flat potential distribution, i.e. de-synchronization of neural activity with few peaks whereas a high GFP stands for a potential distribution with many peaks, i.e. synchronization. Hence, the frequency of GFP peaks could be used as a possible time-varying parameter to be correlated with the occurrence of events of memorization, such as the number of frame segments of an advertisements that will be spontaneous recalled. For this reason, we introduce the Peak Density Function (PDF, [8]) as a novel tool to describe the memorization activity during the observation of TV commercials.

In the present work we will show that the increase of the PDF is positively correlated with the number of scenes of the proposed TV commercials that are spontaneously remembered by subjects.

II. Material and Methods

A. Experimental design

Twenty Italian healthy subjects (24.05 ± 1.3 years) have been recruited for this study. The procedure of the experimental task consisted in observing an eight minutes long documentary in which we inserted an advertising break formed by six 30 seconds long commercial video clips. Randomization of the occurrence of the commercial videos was made to remove the factor sequence as possible confounding effect. All videos were new for the enrolled

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subjects and they concern hi-tech, clothing and sport products.

Before the EEG recordings, all subjects were simply told to pay attention to what they would have watched with no about the importance of the commercial clips. They were not aware that an interview will be held afterwards. During the interview, subjects were asked to spontaneous recall the observed spots and to tell the specific parts of the plot they remembered. Afterwards, the experimenter showed on a series of papers three frame sequences of each advertisement inserted in the movie along with pages with three pictures related to an equal number of advertisements that were not inserted in the commercial break used as distractors and for no further comparison. This is done to ensure that the following ratings will be given on material actually watched. Finally, the experimenter asked subjects to give a score ranging between 1 (lowly pleasant) and 10 (highly pleasant) according to the feeling they perceived during the observation of each remembered ad. EEG signals have been recorded during the whole observation of the movie. Moreover, a 2 minutes open-eyes rest period (OE) have been recorded before the task. The neurophysiologic activity related to the observation of the commercial break (SPOT) and the one related to the documentary (DOC) were segmented and analyzed. The DOC dataset was used for a baseline correction and it comprises the lasts 2 minute of documentary before the beginning of the commercial break.

B. Behavioral data analysis

Every TV commercial was segmented in scenes. According to the subjects' spontaneous recalls during the interview, for each advertisement we formed a binary matrix of dimensions *s* x *n* (*s* = subjects number, *n* = scenes number) in which 1 indicates a scene the subject remembered, 0 vice versa. Hence, we obtain 6 matrices of dimensions 20 x *n* (*n* depends on the TV commercial) that will be correlated with the EEG features.

The data related to the pleasantness score will be not showed here because out of the scope of the present work.

C. EEG recordings

Informed consent was obtained from each subject after explanation of the study, which was approved by the local institutional ethics committee. We collected the EEG data by a portable 64-channel system (BE+ and Galileo software, EBneuro, Italy), at a sampling rate of 256 Hz, impedances kept below 5 kΩ. Sixteen electrodes (FPz, Fz, Cz, Pz, Oz, AF3, AF4, F3, F4, T7, C3, C4, T8, P3, P4) were located on a cap according to the 10–20 international system. Right ear was used as reference, left ear as ground.

Each EEG trace was then converted into the Brain Vision format (BrainAmp, Brainproducts GmbH, Germany) in order to perform signal pre-processing such as artefacts detection, filtering and segmentation. Raw EEG traces were first band pass filtered (high pass = 2 Hz; low pass = 47 Hz), and the Independent Component Analysis (ICA) was then applied to detect and remove components due to eye movements, blinks, and muscular artefacts.

Subsequently, the pre-processed EEG signals have been transformed by means of the Common Average Reference (CAR) and the Individual Alpha Frequency (IAF) has been calculated on the OE segment for each subject in order to define the band of interest according to the method suggested in the current scientific literature [9]. Such band is in the following reported as "IAF ± x", where IAF is the Individual Alpha Frequency, in Hertz, and x is an integer displacement in the frequency domain which is used to define the band. In particular we have analyzed the brain activity in the theta band defined as [IAF-6, IAF-4].

D. EEG signal processing

The acquired EEG has been filtered in the theta band segmented to build the SPOT and DOC datasets, which have been used to calculate the Global Field Power (GFP, [7]) across the frontal and prefrontal left electrodes (AF3 and F3) as a measure of average EEG power in the theta band. For each subject, the SPOT GFP signals were converted in Z-scores (Z_{GFP}) using the DOC dataset as baseline. Then we computed the envelope of such signal and detected the number of peaks satisfying the condition $Z_{GFP} > 2$.

E. Peak Density Function

We have defined the Peak Density Function (PDF), a smooth and continuous function of the time, as the convolution between the peak function of each subject and a Gaussian kernel function according to the method published in literature [8]. The values of the kernel function at the time of peak occurrences (t_P) are read, summed and divided by the area of the kernel (Eq. (1)):

$$PDF\,(t) = \frac{\sum_{t_0}^{t_1} g(t_P)}{\int_{t_0}^{t_1} g(t^*)dt^*};\ t_0 = t_P - \frac{t_W}{2}, t_1 = t_P + \frac{t_W}{2} \quad (1)$$

where g is the Gaussian kernel function ($\sigma = f_c/2$) centered at t and represented in the finite time window t_W ($t_W = 4\ f_C$), t_P is the time of peak event. Convolution here simply means the replacement of each peak with unity area kernel function ($\int_{t_0}^{t_1} g(t^*)dt^* = 1$) centered at the actual peak.

Then we have calculated the Z-score of the PDF (Z_{PDF}), for each subject and TV commercial, and assumed as memorized only those scenes in which the function Z_{PDF} showed a peak greater than 0 or a scene average value greater than 0, i.e. to take the scenes during which the PDF is greater than its spot average (Fig. 1).

In this way it was possible to arrange the cerebral data as we did for the behavioral responses. Specifically, we formed a binary matrix of size *s* x *n*, for each TV commercial, in which 1 indicates a hypothesized memorized scene, 0 vice versa. The present matrix will be correlated with the behavioural responses. In the following analysis, we have decided to not consider the first scene of all TV commercials because assumed to be a transient.

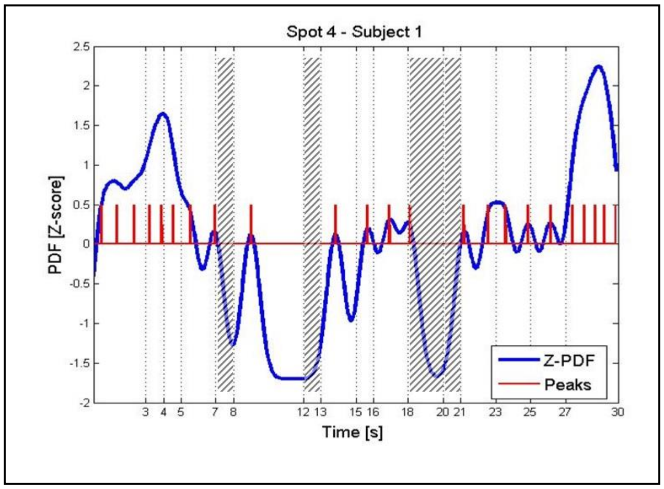

Figure 1. Example of use of PDF to classify the hypothesized memorized scenes for the subject 1 for the Spot 4. The GFP peaks are showed in red, whereas the blue waveform if the constructed Z_{PDF}. The vertical dotted lines indicate the spot scenes division. The scenes that we hypothesize the subject does not memorize, by using the introduced condition on PDF, are crossed out.

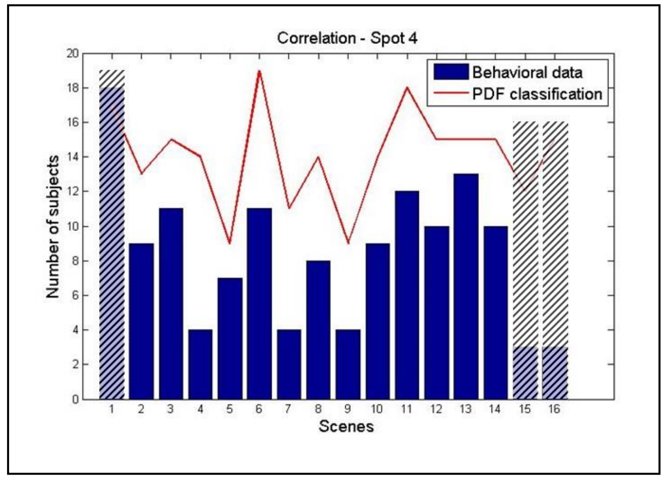

Figure 2. The blue bars indicate, for each scene of the spot, the number of subjects that declared to remember that scene; the red line indicate, for each scene, the number of subjects that, using the PDF, we have hypothesized they had memorized that scene. The scenes not considered in the correlation analysis are crossed out.

F. *Statistical analysis*

For each spot we had two matrices: one related to the declared remembered scenes (behavioral data), and the other referring to the hypothesized memorized scenes (cerebral data). Therefore, we have constructed, for each TV commercial, two vectors of dimension *n-1* (*n* = number of scenes), in which the n^{th} element contain the number of subjects that have remembered the scene, or that we hypothesized they had memorized, respectively. We have calculated the correlation between these two vectors for each TV commercial. In order to increase the robustness of the statistical analysis, we also have concatenated the data belonging to all the spots and calculated the overall correlation.

III. Results

A. *Behavioral results*

By analyzing the behavioral data we have noted that, for each spot, the last scenes, the ones in which the brand appeared, were remembered only by one or two subjects. For this reason we have decided to not consider the related data.

B. *Correlation results*

In Figure 2 we show, for one representative spot, the vector of behavioral data, i.e. the number of subjects that declared to remember that specific scene, and the one formed by using the PDF, i.e. the number of subjects that we have hypothesized remembering that specific scene.

In Table 1 the results of correlation between behavioral and cerebral data, for each spot, are reported.

We assume the correlation R is significant at $p < 0.05$, so in our case the correlation found in the 3rd and 4th spot result significant.

TABLE I. Results of correlation

Spot	Pearson's correlation		
	N scenes	***R***	***p***
Spot 1	16	0.445	0.085
Spot 2	10	0.598	0.068
Spot 3	10	0.689	0.027
Spot 4	13	0.731	0.004
Spot 5	10	-0.127	0.785
Spot 6	12	0.120	0.759

Table 1. Pearson's correlation results for each TV commercial (first column). The second column indicates the number of considered scenes of the spot after discarding the first and the last ones. R and p-values (third and fourth column) are the Pearson's correlation results between the number of spontaneous recalled scenes and the number of hypothesized remembered scenes determined by the Z_{PDF}.

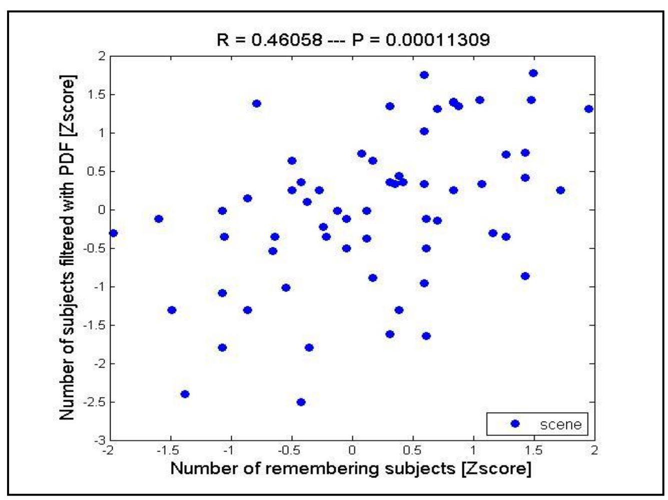

Figure 3. Scatterplot of the Z-score of number of subjects that we have hypothesized to remember the scene as a function of the Z-score of number of subjects that claimed to remember the same specific scene. Each dot is associated to the values of a single scene. The overall correlation result is R=0.46, p<0.01.

Then, before merging the data related to all commercials, we performed the z-score of behavioral and cerebral data and calculated the overall correlation. The result is $R = 0.46$, $p<0.01$, as illustrated in Figure 3.

IV. Discussion

A. Behavioral data

The analysis of behavioral data highlighted two criticalities related to the selected stimuli. First, there are two TV commercials which can be considered as an unique flow of images rather than sequence of difference scenes. The related scenes do not present a proper change of context but mainly a change of actors on the same background. For this reason we hypothesize that subjects had difficulties to describe which scene they remembered. This could be an explanation of the bad correlation results for these two spots. Second, it was difficult to understand if subjects correctly remembered to have watched the brand at the end of the advertisement. They declared to remember the clip but without any specific mention to the logo of the company. For this reason we preferred to not take into account the data related to the observation of the last part of the clip. However, we noticed that this last part of the commercial (at most two seconds) does not influence the goodness of the results. These observations suggest that better correlation results could be achieved by selecting as stimuli TV commercials with clear separation of scenes. Since the behavioral data relate with spontaneous words of subjects, we believe that such answers reflect the cognitive engage of subjects. Different strategies of memorization could be deeper investigated to determine more proper procedure for collecting behavioral data.

A. Cerebral data

The present work proposed a Peak Density Function that has been proved to be an efficient method to determine significant increase of memorization activity during the observation of TV commercials. This function has been defined from the average theta power of the EEG signals related to the left frontal lobe. These region has been considered several time as location of memorization activity in different tasks [10]. In the present analysis, PDF time intervals above the average or significant increase of activity (peak) have been positively correlated with the spontaneous recall of subjects, scene by scene.

Although for space limitation we don't provide comparative results, the present tool goes beyond the state-of-the-art technology because the correlation between the cerebral signal and the memorization events have been proved to be significant scene by scene, instead of across the whole video clip as previously reported [6]. This novel method could be used to calculate the probability of memorization for each scene of the interested commercial and used to better understand social behavior [11], memory and sensory tasks [12-13]. Further investigations are needed to test the Peak Density Function performance with a larger number of TV commercials and experimental subjects. Moreover, the role of the attractiveness could also play a role in such a phenomenon.

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