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ORIGINAL PAPER

Changes in Brain Activity During the Observation of TV Commercials by Using EEG, GSR and HR Measurements

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Abstract In this study we were interested to analyse the brain activity occurring during the "naturalistic" observation of commercial ads intermingled in a random order within a documentary. In order to measure both the brain activity and the emotional engage of the 15 healthy subjects investigated, we used simultaneous EEG, Galvanic Skin Response (GSR), Heart Rate (HR) recordings during the whole experiment. We would like to link significant variation of EEG, GSR, HR and Heart Rate Variability (HRV) measurements with the memory and pleasantness of the stimuli presented, as resulted successively from the subject's verbal interview. In order to do that, different indexes were employed to summarize the cerebral and autonomic measurements performed. Such indexes were used in the statistical analysis, performed with the use of Analysis of Variance (ANOVA) and z-score transformation of the estimated cortical activity by solving the associated EEG inverse problem. The results are summarized as follows: (1) in the population analyzed, the cortical activity in the theta band elicited during the observation of the TV commercials that were remembered is higher and localized in the left frontal brain areas when compared to the activity elicited during the vision of the TV commercials that were forgotten ($p < 0.048$). Same increase in the theta activity occurred during the observation of commercials that were judgment pleasant when compared with the other ($p < 0.042$). Differences in cortical activity were also observed for the gamma activity, bilaterally in frontal and prefrontal areas. (2) the HR and HRV activity elicited during the observation of the TV commercials that were remembered or judged pleasant is higher than the same activity during the observation of commercials that will be forgotten ($p < 0.001$ and $p < 0.048$, respectively for HR and HRV) or were judged unpleasant ($p < 0.042$ and $p < 0.04$, respectively for HR and HRV). No statistical differences between the level of the GSR values were observed across the experimental conditions. In conclusion, the TV commercials proposed to the population analyzed have increased the HR values and the cerebral activity mainly in the theta band in the left hemisphere when they will be memorized and judged pleasant. Further research with an extended set of subjects will be necessary to further validate the observations reported in this paper. However, these conclusions seems reasonable and well inserted in the already existing literature on this topic related to the HERA model.

Keywords High resolution EEG · TV commercials · Autonomic signals

This is one of several papers published together in Brain Topography on the "Special Topic: Cortical Network Analysis with EEG/MEG".

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Introduction

In these last years we assisted to an increased interest in the use of brain imaging techniques, based on hemodynamic or electromagnetic recordings, for the analysis of brain responses to the commercial advertisements or for the investigation of the purchasing attitudes of the subjects (Ioannides et al. 2000; Knutson et al. 2007; Astolfi et al. 2008a; Morris et al. 2009). The interest is justified by the possibility to correlate the particular observed brain activations with the characteristics of the proposed commercial stimuli, in order to derive conclusions about the adequacy of such ad stimuli to be interesting, or emotionally engaging, for the subjects. Standard marketing techniques so far employed involved the use of an interview and the compilation of a questionnaire for the subjects after the exposition to novel commercial ads before the massive launch of the ad itself (ad pre-test). However, it is now recognised that often the verbal advertising pre-testing is flawed by the respondents' cognitive processes activated during the interview, being the implicit memory and subject's feelings often inaccessible to the interviewer that uses traditional techniques (Zaltman 2003). In addition, it was also suggested that the interviewer on this typical pre-testing interviews has a great influence on what respondent recalls and on the subjective experiencing of it (McDonald 2003; Franzen and Margot 2001). Taking all these considerations in mind, researchers have attempted to investigate the signs of the brain activity correlated with an increase of attention, memory or emotional engagement during the observation of such commercial ads. Researchers within the consumer neuroscience community promote the view that findings and methods from neuroscience complement and illuminate existing knowledge in consumer research in order to better understand consumer behaviour (e.g., Ambler et al. 2000; Klucharev et al. 2008).

It is very well known that the hemodynamic measurements of the brain activity allow a level of localization of the activated brain structures on the order of cubic mm, being capable to detect activations also in deep brain structures such as amigdala, nucleus accumbens etc. However, the lack of time resolution, due to the delay of the cerebral blood flow's increment after the exposition to the stimuli, make the fMRI unsuitable to follow the brain dynamics on the base of its subseconds activity. The use of EEG allows to follow the brain activity on a ms base, but it has the problem that the recorded EEG signals are mainly due to the activity generated on the cortical structures of the brain. In fact, the electromagnetic activity elicited by deep structures advocated for the generation of emotional processing in humans is almost impossible to gather from usual superficial EEG electrodes (Nunez 1995; Urbano et al. 1998). It has underlined as a positive or negative emotional processing of the commercial ads it is an important factor for the formation of stable memory traces (Kato et al. 2009). Hence, it became relevant to infer the emotional engage of the subject by using indirect signs for it. In fact, indirect signs of emotional processing could be gathered by picking variations of the activity of the anatomical structures linked to the emotional processing activity in humans, such as the activity of sweat glands on the hands and/or the variation of the heart rate (Baumgartner et al. 2006).

In particular, by monitoring autonomic activity using devices able to record the variation of the skin conductivity (Galvanic Skin Responses, GSR) and the heart rate (HR) it is possible to assess the "internal" emotional state of the subject, measuring the level of the autonomic system. In fact, Galvanic Skin Response (GSR) activity is actually viewed as a sensitive and convenient measure of indexing changes in sympathetic arousal associated with emotion, cognition, and attention (Critchley 2002). Studies using functional imaging techniques (Critchley 2002; Nagai et al. 2004) have related the generation and level of electrodermal activity to specific brain areas. These specific regions are the ventromedial prefrontal cortex, orbitofrontal cortex, left primary motor cortex, and the anterior and posterior cingulate, which have been shown to be associated with emotional and motivational behaviours (Critchley 2002; Nagai et al. 2004). Such findings indicate the close association of peripheral and central measures of arousal, re-emphasise the close connections between electrodermal activity, arousal, attention, cognition and emotion. In addition, the link between the heart rate (HR) or the Heart Rate Variability (HRV) and the sympatho/vagal balance has been already suggested (Malik et al. 1996; Malliani 2005; Montano et al. 2009).

In this study we were interested to analyse the brain activity occurring during the "naturalistic" observation of commercial ads intermingled in a random order in a documentary. To measure both the brain activity and the emotional engage of the 15 healthy subjects investigated, we used simultaneous EEG, GSR and HR measurements during the whole experiment. We would like to link significant variation of EEG, GSR and HR measurements with the memory and pleasantness of the stimuli presented, as resulted successively from the subject's verbal interview. In order to do that, different indexes were employed to summarize the cerebral and autonomic measurements performed and to be used in the statistical analysis.

The aim was to recreate, as much as possible, a "naturalist" approach to the task, in which the observer is viewing the TV screen without particular goals in mind. In fact, the subjects were not instructed at all on the aim of the task, and they were not aware that an interview about the TV commercials observed intermingled to the documentary would be generated at the end of the task. The experimental questions of the present study are the following:

(1) In the particular task employed and for the analyzed population, are there particular EEG activities in the spectral domain that correlates with the memorization

performed or the pleasantness perceived by the subjects?

(2) Always in the same experimental conditions above, are there particular autonomic indexes, derived from GSR and HR recordings, that correlate with the memorization or the pleasantness of the commercials perceived by the subjects?

Methods

Experimental Design

Fifteen healthy volunteers (mean age 27.5 ± 7.5 years; 7 women) have been recruited for this study. The procedure of the experimental task consisted in observing a thirty minutes long documentary in which we inserted three advertising breaks: the first one after eight minutes from the beginning, the second one in the middle and the last one at the end of the movie. Each interruption was formed by the same number of commercial videoclips of about 30-s. During the whole documentary, a total of six TV commercials were presented. The clips were related to standard international brands of commercial products, like cars, food, etc. and public service announcements (PSA) such as campaigns against violence. Randomization of the occurrence of the commercial videos within the documentary was made to remove the factor "sequence" as possible confounding effect in the following analysis.

During the observation of the documentary and TV commercials, subjects were not aware that an interview would be held within a couple of hour from the end of the movie. They were simply told to pay attention to what they would have watched and no mention of the importance of the commercial clips was made. In the interview, subjects were asked to recall commercial clips they remembered. In addition, a question on the pleasantness of the advertisement has been performed. According to the information acquired, the neurophysiologic activity recorded has been divided into four different datasets. The first pool was related to the activity collected during the viewing of the commercial clips that the subjects had correctly remembered, and this dataset was named RMB. The second pool was related to the activity collected during the observation of the TV commercials that had been forgotten by the subjects, and this set was named FRG. The third pool is instead formed by the activity associated to subjects who affirmed to like the advertisement in exam. This group has been named LIKE. Analogously, the fourth and last group comprises all the cerebral and autonomic activity of subjects who answered in a negative way to the question on likeability. We referred to this dataset as DISLIKE.

Finally, the neurophysiologic activity during the observation of the documentary was also analyzed and a final pool of data related to this state was generated with the name REST. This REST period was taken as the period in which the subject looked at the documentary. We took into account a two minutes long sequence of the documentary, immediately before the appearance of the first spot interruption, employed in order to minimize the variations of the spectral responses owing to fatigue or loss of concentration.

Cerebral Recordings

The cerebral activity was recorded by means of a portable 64-channel system (BE+ and Galileo software, EBneuro, Italy). Informed consent was obtained from each subject after explanation of the study, which was approved by the local institutional ethics committee. All subjects were comfortably seated on a reclining chair, in an electrically-shielded, dimly-lit room. Electrodes positions were acquired in a 3D space with a Polhemius device for the successive positioning on the head model employed for the analysis. Recordings were initially extra-cerebrally referred and then converted to an average reference off-line. We collected the EEG activity at a sampling rate = 256 Hz while the impedances kept below 5 kΩ. Each EEG trace was then converted into the Brain Vision format (BrainAmp, Brainproducts GmbH, Germany) in order to perform signal preprocessing 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. These EEG traces were then segmented to obtain the cerebral activity during the observation of the TV commercials and that associated to the REST period. Since we recorded such activity from fifteen subjects, for each proposed advertisement we collected fifteen trials which have been grouped and averaged to obtain the results illustrated in the following sections. This dataset has been used to evaluate the cortical activity and calculate the power spectral density (PSD) for each segment.

Besides, we separately analysed two more traces derived from the previous one. Each EEG trace has been band pass filtered two more times in order to isolate the only spectral components in the theta band and those located between the beta and gamma band, that we call in the following the extended beta band (high pass = 13 Hz; low pass = 45 Hz; beta) from the whole EEG spectrum. All segments were exported in binary format and then converted for further data processing performed with in-house MATLAB software.

These filtered theta and extended beta filtered traces have been employed to calculate the Global Field Power (GFP; Lehmann and Skrandies 1980) for each segment, then converted in Z scores in order to extract cerebral indexes following described. Since for the phenomena we would like to investigate a clear role of the frontal areas have been depicted (Summerfield and Mangels 2005; Werkle-Bergner et al. 2006) we used the frontal electrodes to compute the GFP indexes used in the following of this study. The filtered EEG signals were subjected to the computation of the Global Field Power by taking into account the signals that comes from the following frontal and prefrontal electrodes of the 10-10 International System: F3, F4, AF3, AF4, F7, AF7, F8, AF8, Fz, AFz.

Autonomic Recordings

The autonomic activity, both the Galvanic Skin Response (GSR) and the Heart Rate (HR), has been recorded with the PSYCHOLAB VD13S system (SATEM, Italy) with a sampling rate of 10 Hz. Skin conductance was recorded by the constant voltage method (0.5 V). Ag–AgCl electrodes (8 mm diameter of active area) were attached to the palmar side of the middle phalanges of the second and third fingers of the participant's non dominant hand by means of a velcro fastener. The company also provided disposable Ag–AgCl electrodes to acquire the HR signal. Before applying the sensors to the subjects' skin, their surface has been cleaned following procedures and suggestions published in the international literature (Fowles et al. 1981; Venables 1991). GSR and HR signals have been continuously acquired for the entire duration of the movie and then filtered and segmented with in-house MATLAB software. For to the GSR signal, we employed a band pass filter with a low cut-off frequency of 0.2 Hz, in order to split the phasic component of the electrodermal activity from the tonic one, and a high cut-off frequency of 1 Hz to filter out noise and suppress artefacts caused by Ebbecke waves (Boucsein 1992). Instead, the HR signal has been band pass filtered (high pass = 0.02 Hz; low pass = 0.6 Hz) in order to analyse the only frequency components due to variations of the sympathetic and parasympathetic nervous system regardless the ones associated to thermoregulatory cycles (Berntson et al. 1997; Mendez et al. 2006).

As explained in the previous section, besides the autonomic activity of the subjects during the observations of the videoclips, we employed a part of the documentary to estimate the mean and standard deviation of the electrodermal activity and the cardiac signal in order to compute the z score variables. These variables have been computed for each TV spot and subject, and then used to form the experimental datasets previously described (RMB, FRG, LIKE, DISLIKE) in order to perform a statistical analysis across time and conditions. Moreover, from the HR signal, the power spectrum density (PSD) has been calculated according to the Welch method (Welch 1967). In this way, we obtained a signal in the frequency domain for the commercials analysed and for all subjects recorded. In order to compare the activity recorded during the advertisements with the one of the documentary, the PSD has been also evaluated for the REST period. In particular, the whole interval has been spanned with a series of time window of equal size of 30-s, each overlapped with the previous one of the 90%. In order to have a larger number of samples on which evaluating the values of mean and standard deviation of the PSD signal associated to REST period, the PSD has been computed for each time window. Spectral components were identified and then assigned, on the basis of their frequency, to one of two bands: Low Frequency (LF), [0.04, 0.15] Hz; High Frequency (HF), [0.15, 0.6] Hz (Malik et al. 1996). These components were obtained in absolute values of power (ms^2) and then converted in a-dimensional values of Z score as previously described. The Very Low Frequency (VLF) band, located in the lowest part of the spectrum, has been excluded from the present analysis since it is physiologically connected with long-term regulation mechanisms (Berntson et al. 1997; Mendez et al. 2006), not of interest for our purpose. Several studies indicates that the LF band corresponds to baroflex control of the heart rate and reflects mixed sympathetic and parasympathetic modulation of Heart Rate Variability (HRV); instead, HF band corresponds to vagally mediated modulation of HRV associated with respiration (Berntson et al. 1997; Malik et al. 1996; Mendez et al. 2006; Kreibig et al. 2007). For this reason, some researchers (Malik et al. 1996) propose the ratio LF/HF as index of the balance between the sympathetic and vagal activity. This was the measure we adopted to inspect and verify a likely correlation between the activity of the sympathetic nervous system with the subjects' answers regarding the memorization and the pleasantness of the TV commercials presented.

Estimation of Cortical Activity

In this work, cortical activity from EEG scalp recordings was estimated by employing the high-resolution EEG technologies (Ding et al. 2005; He et al. 1999; Nunez 1995; Babiloni et al. 2001; De Vico Fallani et al. 2007) with the use of a realistic head model known as average head model from Mc Gill University. The scalp, skull and dura mater compartments were build by using 1200 triangles for each structures, and the Boundary Element Model was then employed to solve the forward electromagnetic model. For each subject it was generated the electrodes disposition on the scalp surface, through a non linear minimization procedure (Astolfi et al. 2008b). The cortical model consists of about 5,000 dipoles uniformly disposed on the cortical surface and the estimation of the current density strength for each dipole was obtained by solving the electromagnetic linear inverse problem according to techniques described in previous papers (Astolfi et al. 2007a, b; Babiloni et al. 2005) and illustrated in the following.

The solution of the following linear system at a particular instant in time t

$$\mathbf{Ax} = \mathbf{b} + \mathbf{n} \tag{1}$$

provides an estimation of the dipole source configuration **x** at time t that generates the measured EEG potential distribution **b** in the same instant. The system also includes the measurement noise **n**, assumed to be normally distributed (Nunez 1995; Grave de Peralta Menendez and Gonzalez Andino 1999). **A** is the lead field matrix, where each j-th column describes the potential distribution generated on the scalp electrodes by the j-th unitary dipole. The current density solution vector $\boldsymbol{\xi}$ of Eq. 1 was obtained as (Grave de Peralta Menendez and Gonzalez Andino 1999):

$$\xi = \arg\min_{x}\left(\|\mathbf{A}x - b\|_{\mathbf{M}}^2 + \lambda^2\|x\|_{\mathbf{N}}^2\right) \tag{2}$$

where **M**, **N** are the matrices associated with the metrics of the data and of the source space, respectively, λ is the regularization parameter and $\|x\|_M$ represents the M norm of the vector **x**. The solution of Eq. 2 is given by the inverse operator **G**:

$$\xi(t) = \mathbf{Gb}(t), \quad \mathbf{G} = \mathbf{N}^{-1}\mathbf{A}'\left(\mathbf{AN}^{-1}\mathbf{A}' + \lambda\mathbf{M}^{-1}\right)^{-1} \tag{3}$$

An optimal regularization of this linear system was obtained by the L-curve approach (He et al. 2006).

As a metric in the data space we used the identity matrix (i.e. M = I), while as a norm in the source space we used the following metric:

$$\left(\mathbf{N}^{-1}\right)_{ii} = \|\mathbf{A}_{i}\|^{-2} \tag{4}$$

where $(\mathbf{N}^{-1})_{ii}$ is the i-th element of the inverse of the diagonal matrix **N** and all the other matrix elements N_{ij} are set to 0. The L_2 norm of the i-th column of the lead field matrix **A** is denoted by $\|\mathbf{A}_{.i}\|$.

Statistical Spectral Analysis

In order to calculate the PSD for each segment and then transform the cortical activity into z-score variables, we employed the following mathematical procedure.

Let:

$$\mathbf{b}(t), \quad t \in [\tau \cdots \tau + \Delta\tau] \tag{5}$$

be the vector of scalp measurements in a given time window, with $\Delta\tau$ being the sampling time and $\hat{\mathbf{x}}(t)$ the corresponding vector of cortical estimates at time t given by Eq. 2, $\mathbf{b}(f,\tau)$ the Fourier transform of $\mathbf{b}(t)$. We define the matrix of Cross-Power Spectral Densities (**CSD**) as the matrix whose element (i, j) is the cross-spectrum of i-th and j-th channel of the signal. By using the exponent 'sens' to indicate the sensors' measurements and the exponent 'src' to indicate the cortical sources we have:

$$\mathbf{CSD}^{(\mathrm{sens})}(f,\tau) = \mathbf{b}(f,\tau)\mathbf{b}^{\mathrm{H}}(f,\tau), \tag{6}$$

where the $\mathbf{b}^{\mathrm{H}}(f,\tau)$ is the conjugate transposed (Hermitian) of $\mathbf{b}(f,\tau)$. Analogously:

$$\mathbf{CSD}^{(\mathrm{src})}(f,\tau) = \hat{\mathbf{x}}(f,\tau)\hat{\mathbf{x}}^{\mathrm{H}}(f,\tau) \tag{7}$$

By using Eq. 3 we could use the pseudoinverse G to obtain:

$$\mathbf{CSD}^{(\mathrm{src})}(f,\tau) = \mathbf{G}\cdot\mathbf{CSD}^{(\mathrm{sens})}(f,\tau)\cdot\mathbf{G}' \tag{8}$$

If $\mathbf{b}(t)$ and $\hat{\mathbf{x}}(t)$ are not deterministic signals, but rather we have several trials (realizations) of a stochastic process, Eq. 8 holds if we substitute **CSD**s with their expected values or with their estimates (i.e. $\left\langle \mathbf{CSD}^{(\mathrm{src})}(f,\tau)\right\rangle$).

In case we were interested in calculating the (Auto-)Power Spectral Densities (PSDs) of estimated cortical sources, we only need to compute the diagonal of $\mathbf{CSD}^{(\mathrm{src})}(f,\tau)$:

$$PSD_j^{(src)}(f,\tau) = \mathbf{G}_j\cdot\mathbf{CSD}^{(\mathrm{sens})}(f,\tau)\cdot\mathbf{G}'_j \tag{9}$$

where the variable j indicates the number of sources.

The spectral resolution of this method is inversely proportional to $\Delta\tau$.

The level of noise in the EEG linear inverse solutions can be addressed by estimation of the 'projection' $\mathbf{n}^{(src)}(t)$ of the EEG noise $\mathbf{n}^{(sens)}(t)$ onto the cortical surface by means of the computed pseudoinverse operator **G** (as described in Eq. 3); the variance of the noise on the estimated source strength $\hat{x}_j(t)$ is given by

$$\sigma_j^{2(src)} = C_{jj}^{(src)} = \left\langle n_j^{(src)},\quad n_j^{(src)}\right\rangle = \mathbf{G}_j\cdot\mathbf{C}^{(sens)}\cdot\mathbf{G}'_j \tag{10}$$

where $\mathbf{G}_j$ is the j-th row of the pseudoinverse matrix, $\mathbf{C}^{(sens)}$ is the EEG noise covariance matrix ($C_{ij}^{(sens)} = \left\langle n_i^{(sens)},\ n_j^{(sens)}\right\rangle$), and $\langle\cdot,\cdot\rangle$ is the expectation operator. A common choice for the estimation of the sensor noise covariance matrix is to select an interval of data (baseline) where no task-related activity is supposed to occur and thus all signals are believed to be noise:

$$\mathbf{n}^{(sens)} \equiv \mathbf{b}(t), \quad t \in baseline \tag{11}$$

According to the DSPM approach (Dale et al. 2000), the following normally-distributed cortical z-score estimator can be obtained for each j-th cortical location and for each time point considered:

$$z_j(t) = \frac{\hat{x}_j(t)}{\sigma_j^{(src)}} = \frac{\mathbf{G}_j\cdot\mathbf{b}(t)}{\sqrt{\mathbf{G}_j\cdot\mathbf{C}^{(sens)}\cdot\mathbf{G}'_j}} \tag{12}$$

This allows us to assess quantitatively the ratio between the estimated cortical activity $\hat{\mathbf{x}}$ at a particular instant in time and the amount of noise at cortical level, quantified through the standard deviation of its estimate. Values of z exceeding a given threshold represent levels of estimated cortical activity that are unlikely owing to chance alone but are related to the task performed by the experimental subject. For instance, the threshold for the z-score level at 5% is $z_{5\%} = 1.96$.

In this particular application, we considered as baseline the estimated cortical activity during the viewing of the documentary. Here, we extend the DSPM approach to the analysis of the power spectra variations during the experimental task. The computation of the z-score level in the spectral case is performed according to the following:

$$\Sigma_j^{2(src)}(f) = Var\left\{PSD_j^{(src)}(f,\tau)\right\}_{\tau \in baseline}$$
$$M_j^{(src)}(f) = Mean\left\{PSD_j^{(src)}(f,\tau)\right\}_{\tau \in baseline}$$
$$Z_j(f,\tau) = \frac{PSD_j^{(src)}(f,\tau) - M_j^{(src)}(f)}{\Sigma_j^{(src)}(f)} = \frac{\mathbf{G}_j \cdot \mathbf{CSD}^{(\mathrm{sens})}(f,\tau) \cdot \mathbf{G}'_j - M_j^{(src)}(f)}{\sqrt{\Sigma_j^{2(src)}(f)}} \quad (13)$$

where $Var\{PSD_j^{(src)}(f,\tau)\}_{\tau \in baseline}$ indicates the variance of the estimate of the spectral density of the EEG measurements during the baseline period at the considered frequency f, and $Z_j(f, \tau)$ is the z-score for the j-th current dipole at frequency f, while the inverse operator **G** is the same used for the temporal case. The $Z_j(f, \tau)$ is a Z score variable for construction.

Following these calculations it has been possible to obtain and analyse spectral Z variables for the canonical frequency bands of interests: Theta (4–7 Hz), Alpha (8–12), Beta (13–24), Gamma (25–40). It must be noted that such Z-score transformation of the cortical data is different from the z-score transformation adopted on the GSR, HR and GFP values described in the previous paragraph, since these last z-score referred to autonomic and EEG signals from the scalp surface, while the z score transformation described by Eqs. 12 and 13 are related to the estimated cortical signals.

In order to proper deal with the issue of the execution of multiple univariate statistical tests, like those designed in Eq.13, we used the so called "Bonferroni correction" for the evaluation of the significant z-scores (Zar 1984). Hence, the z scores value presented in the cortical maps of Figs. 1 and 2 are referred to the Bonferroni corrected z-values.

Indexes Employed

In order to investigate the cerebral activity elicited during the observation of videoclips and analyse its variation according to the exposition of the brand advertised, we employed a series of indexes defined on the basis of the two GFP signals calculated in the theta and extended beta frequency bands. For each single TV commercial and subject, from these two cerebral signals we extracted

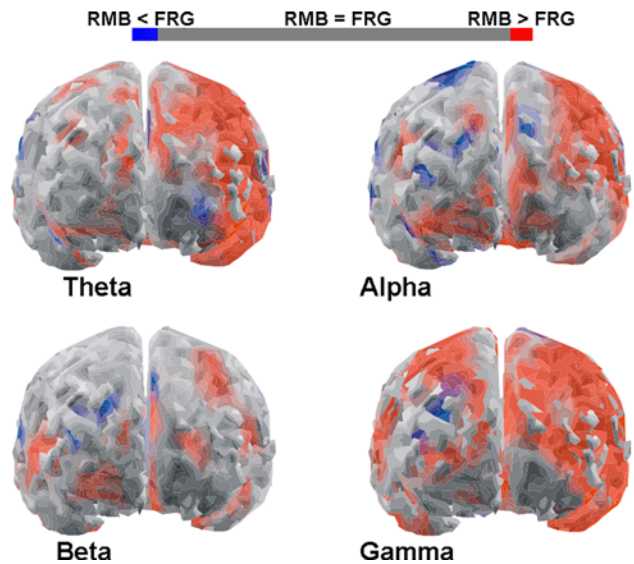

Fig. 1 Figure presents four cortical z-score maps, in the four frequency bands employed. Colour bar represents cortical areas in which increased statistically significant activity occurs in the RMB group when compared to the FRG group in red, while blue is used otherwise ($p < 0.05$ Bonferroni corrected). Grey colour is used to map cortical areas where there are no significant differences between the cortical activity in the RMB and FRG groups

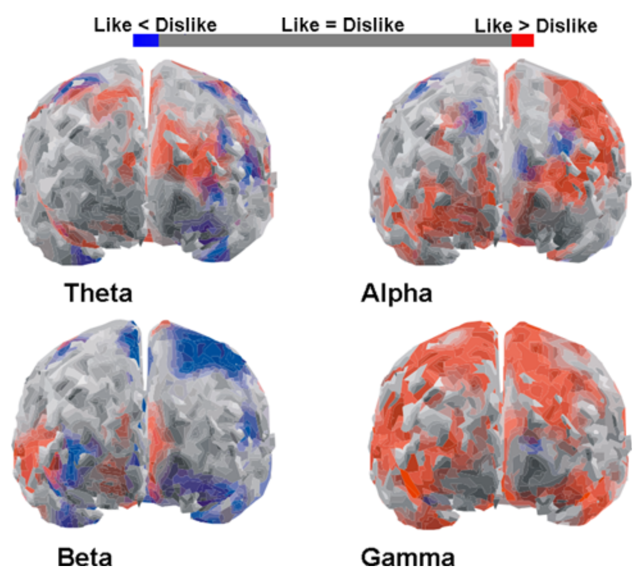

Fig. 2 Four cortical maps for the groups LIKE and DISLIKE. Same conventions than in the previous figure except the use of red colour to code the cortical areas in which the brain activity of the LIKE group is significantly higher than the activity of the DISLIKE group. The blue colour is used to map brain areas in which the activity of the DISLIKE group is significantly higher than the activity of the LIKE group

information regarding the total number of peaks occurred along the clip length.

In fact, we define a peak in the two z-scored GFP waveforms in theta and extended beta band a part of the GFP waveform in which the values exceeds the threshold of $z = 2$, associated with a $p < 0.05$ (uncorrected for multiple comparisons). We then defined the following Percentage index on the z-score GFP, by defining for each commercial presented to the subject

$$\text{Percentage index for the ith commercial} = \frac{(N_{PEAKS}\text{ of the GFP during the time period of the ith commercial of interest})}{(N_{PEAKS}\text{ of the GFP during the length of all the ith commercial})} \quad i = 1, \ldots, 6 \tag{14}$$

The period of interest was either the period in which the brand was exposed overtly in the commercial (BRAND period) or the period of time in which it was not exposed (NO BRAND period)

Contrast Between Experimental Conditions on the Cortical Spectral Maps

We initially calculated statistical spectral maps for each subject, each TV commercial, in the four frequency bands. Since we transformed the PSD data into Z variables, it has been possible to group the single subjects activities according to the answers which they gave during the interview. In this way the cerebral activity recorded during the observation of the advertisements has been considered as belonging to the groups RMB and FRG or LIKE and DISLIKE. The cortical maps depicting the statistical contrasts between RMB and FRG conditions as well as the LIKE and DISLIKE conditions were then generated for each frequency band considered.

All the statistically-activated areas of each subject were mapped on a common cortical representation through such transformation. For display purposes, we represented the results obtained from the average brain model created with the BRAINSTORM software freely downloadable from internet (www.brainstorm-web.net). In particular, the average brain model was used to display the cortical areas that are statistically significantly activated during the different experimental conditions in all the subjects analyzed.

Statistical Analysis

Statistical analysis of the values of the z-score for GSR, HR, LF/HF, GFP, Percentage Index variables were performed by using the Analysis of Variance (ANOVA) with different main factors. The log transformation was used to stabilize the variance of each variable by using the formula (Zar 1984):

$$X' = \log(1 + |X|) * \text{sign}(X) \tag{15}$$

where X is the original variable, X' is the log-transformed variable, sign(X) returns the sign of the variable X.

The main factors of the different ANOVAs performed on transformed GSR, HR, LF/HF and GFP variables are: BAND with the levels (THETA, BETA), BRAND with the levels (BRAND, NO BRAND), REPORT with the levels (RMB, FRG) for the group of subjects that remembered the particular spot (RMB) or viceversa (FRG), and again REPORT with the levels (LIKE, DISLIKE) to categorize the report of the subjects about the pleasantness (LIKE) or unpleasantness (DISLIKE) of the spot. The Greenhouse & Geisser correction was used where necessary for the violation of the sphericity hypothesis (Zar 1984). Post hoc analysis with the Duncan's test at the 5% statistical significance level was also performed.

Results

Statistical Images of the Cortical Activity During the Observation of the TV Commercials

The EEG signals gathered during the observation of the commercial spots were subjected to the estimation of the cortical power spectral density by using the techniques described in the "Methods" section. In each subject, the cortical power spectral density were evaluated in the different frequency bands adopted in this study and contrasted with the values of the power spectral density of the EEG during the observation of the documentary through the estimation of the z-score.

These cortical distributions of the z-scores obtained during the observation of the commercials were then organized in two different populations: the first one was composed by the cortical z-scores relative to the observation of commercial videos that were remembered during the interview (RMB group), while the second was composed by the cortical distribution of the z-scores relative to the observation of commercial videos that were forgotten

(FRG group). A contrast will be made between these cortical z-score distributions of these two population, and the resulting cortical distributions in the four frequency bands highlight the cortical areas in which the estimated power spectra statistically differs between the populations.

Figure 1 presents four cortical maps, in which the brain is viewed from a frontal perspective. The maps are relative to the contrast between the two population in the theta (upper left), alpha (upper right), beta (lower left) and gamma (lower right) frequency bands. The colour scale on the cortex coded the statistical significance: where there are cortical areas in which the power spectrum does not differ between the two populations, a grey colour was employed. The red colour was employed when the cortical areas present a statistically significance power spectral activity greater in the population that remembered the commercial videos (RMB) with respect to the other, while the blue colour coded the opposite situation (i.e. the power spectral activity in the group that forget the commercial videos is greater with respect to the brain activity in the group that remembers the ads).

Figure 1 presents an increase of cortical activity in the theta band that it is prominent on the left pre and frontal hemisphere for the RMB group. The statistical significant activity in the alpha frequency band for the RMB group is still increased in the left hemisphere although there are few zones in the frontocentral and right prefrontal hemisphere where the cortical activity was prominent for the FRG group. In the beta band there are spots of significant increase of cortical activity for the RMB group when compared to the FRG group on the left pre and frontal hemispheres, while increase of cortical activity in the FRG group is scarcely present on the right hemisphere. Finally, in the gamma band is observed a significant increase of cortical activity in a large zone of the pre and frontal hemispheres in the RMB group when compared with the FRG one.

Figure 2 presents the contrast between the LIKE and DISLIKE groups in the four frequency bands considered in this analysis. Same convention of Fig. 1 is used. The significant increase of the frontal activity in the theta band is clearly visible (in red) in the LIKE group when compared to the DISLIKE one, in the upper left part of the Fig. 2. Scattered increased of cortical activity on the left hemisphere is also present in the DISLIKE group (in blue). In the alpha frequency band (upper right of the Fig. 2) significant increase of cortical activity is present on the left hemisphere and on the orbitofrontal right hemisphere in the LIKE group when compared to the DISLIKE one. The cortical activity in the beta band is greater in the DISLIKE group in the prefrontal left areas when compared to the LIKE group (lower left of Fig. 2), while the gamma frequency band (lower right of the Fig. 2) presents a statistical increase of the activity of the pre and orbito-frontal cortical areas rather bilaterally for the LIKE group when compared to the DISLIKE one.

Statistical Analysis of the Average Level of the GFP and the Autonomic Variables (GSR and HR) During the Commercial Videos

Figure 3 shows the typical responses of the z-score variable obtained by the Global Field Power (GFP) computed on the subset of frontal electrodes in the theta (left panel) and the extended beta (right panel) frequency bands for a representative subject during the observation of a particular commercial within the documentary. It is worth of note that the GFP in the theta and in the beta band presents different series of peaks, occurring at different frames of the proposed commercial video. These frames are reported at the top of the images and the arrows point to the particular GFP relative to the frame illustrated. The coloured areas in pink depicts the time interval in which the particular brand is overtly presented in the spot. In the case of Fig. 3 such brand corresponds to a particular and well known brand of biscuits in Italy. The time scale is in seconds.

While the GFP is a measure relative to the cerebral activity during the observation of the commercial video in different frequency bands, the Fig. 4 presents the z-score waveforms of Galvanic Skin Response (GSR) and Heart Rate (HR) for the same representative subject. It is worth of note that the conventions employed in this figure are similar to those presented in the Fig. 3 being the axes scales the same (i.e. z-score and time in seconds). However, Fig. 4 also presents the mean values of the GSR and the HR in time interval of 5 s, as a red line overlaying the z-score waveforms.

Although the Figs. 3 and 4 are relative to a single subjects, it can be appreciated the different time-scale of the cerebral and autonomic signals, during the observation of the commercial videos. Z scores for the autonomic signals did not reached in this particular subject a statistical significance for all concerns the GSR, while the threshold for the statistic significance was reached in some time instants for the HR values.

The z-scores for the GFP and for the autonomic variables GSR, HR as well as LF/HF for the heart rate variability were then computed for all the subjects and the commercial videos presented, and subjected to the successive statistical analysis of variance (ANOVA).

The Analysis of the GFP Values

The analysis of the variation of the average values of the GFP during the observation of the commercial videoclips will be performed by using three different factors for the ANOVA. The first main factor was the BAND one, with the levels theta and extended beta frequency (including beta and gamma conventional bands). The second factor is the BRAND one, with two levels (NO BRAND and BRAND) and the third

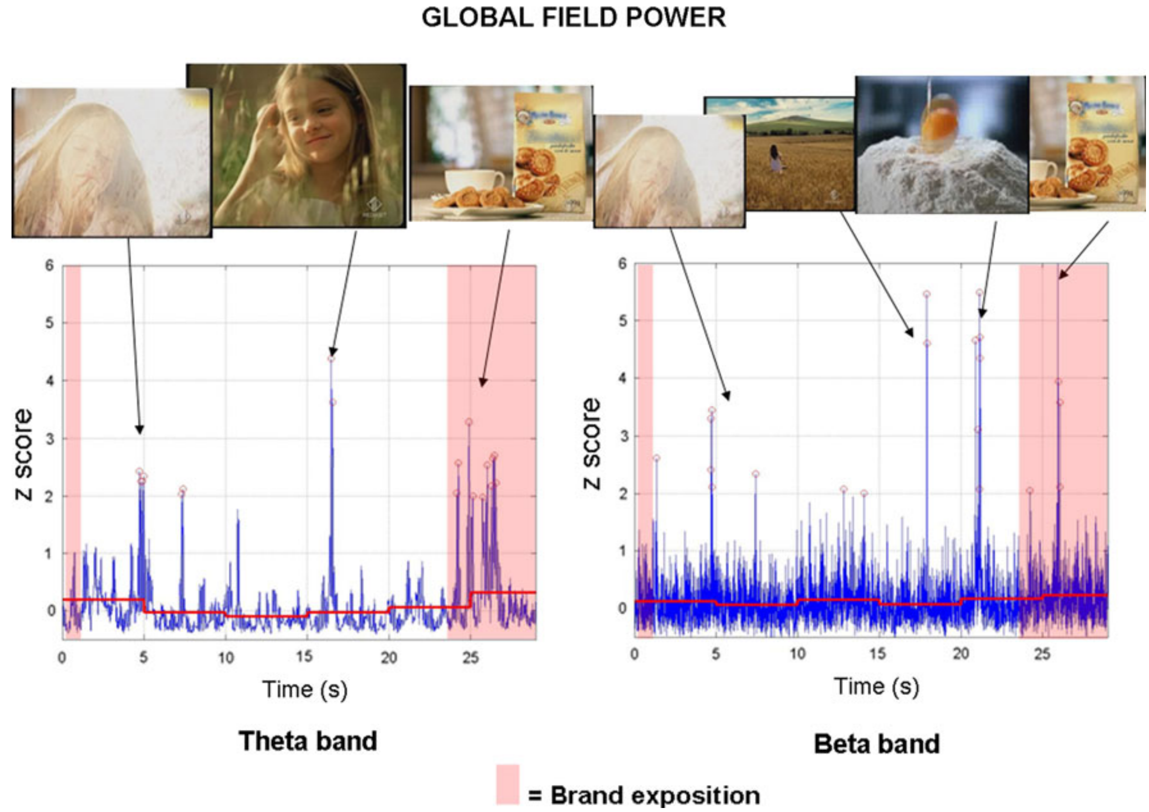

Fig. 3 Figure shows a typical responses of the z-score obtained by the Global Field Power (GFP) computed on the subset of frontal electrodes in the theta (*left panel*) and beta (*right panel*) frequency bands for a representative subject during the observation of a particular commercial within the documentary. The GFP in the theta and in the beta band presents different series of peaks, occurring at different frames of the proposed commercial video. These frames are reported at the top of the images and the arrows point to the particular GFP relative to the frame illustrated. The coloured areas in pink depicts the time interval in which the particular brand is overly presented in the spot. In the case of this figure such brand corresponds to a particular and well know brand of biscuits in Italy. The time scale is in seconds

factor is named REPORT, with the two couple of levels related to the memorization of the spot (RMB, FRG) or its pleasantness (LIKE, DISLIKE).

Hence, the ANOVA performed on the GFP index uses all these three main factors BAND, BRAND and REPORT. The ANOVA statistical outcome, in the case in which REPORT has the level RMB and FRG, is that no significant interactions occurred between all the employed factors. In particular, the BAND × BRAND × REPORT interaction is not significant at $p < 0.73$, while also the other combination of factors are not significant, with BAND × REPORT with $p < 0.78$ and BAND × BRAND with a $p < 0.47$.

When the levels of the REPORT factor will became LIKE and DISLIKE then the ANOVA performed on the BAND and BRAND factors return a significant statistical interaction between all of them (BAND × BRAND × REPORT with a $p < 0.038$). In addition, also the interaction between BAND × REPORT was statistically significant with a $p < 0.048$, while the BRAND × REPORT interaction is not significant, having a $p < 0.9$. The Fig. 5 shows the BAND × REPORT interaction, with the representation of the average values of GFP in the two analyzed frequency bands (theta and extended beta bands). The average values are presented together their 2 standard deviation bars. The label GFP Theta and GFP Beta refers to the values of the GFP for the theta and beta band, respectively.

It is possible to appreciate the increase of the theta values for the GFP for the LIKE condition when compared to the DISLIKE one, while in the beta band this situation is reversed. Such data are congruent with the data for the cortical activity presented for the LIKE and DISLIKE groups in Fig. 2 (lower left map).

Detailed post hoc analysis with the Duncan procedure returned an increased statistically significant value of the GFP in the theta band in the LIKE condition ($p < 0.05$) when compared to the DISLIKE group ($p < 0.05$). It can be observed also a decrease of the beta and higher frequency band for LIKE group as compared to the DISLIKE one, but with no statistical significance ($p < 0.4$).

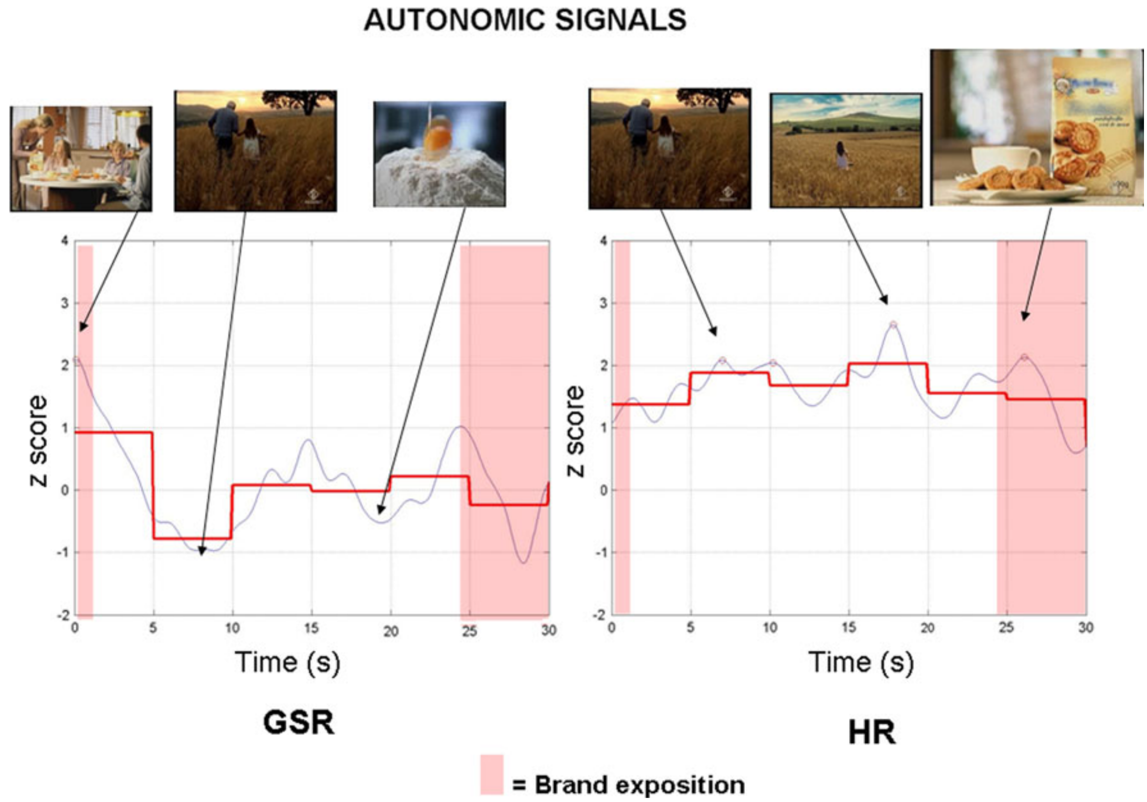

Fig. 4 Figure presents the z-score values for a typical subject during the observation of the same commercial video of Fig. 3. Same conventions of the previous figure. The mean values of the GSR and the HR are presented as the average on a time interval of 5 s, depicted in the panels with a red line overlaying the z-score waveforms

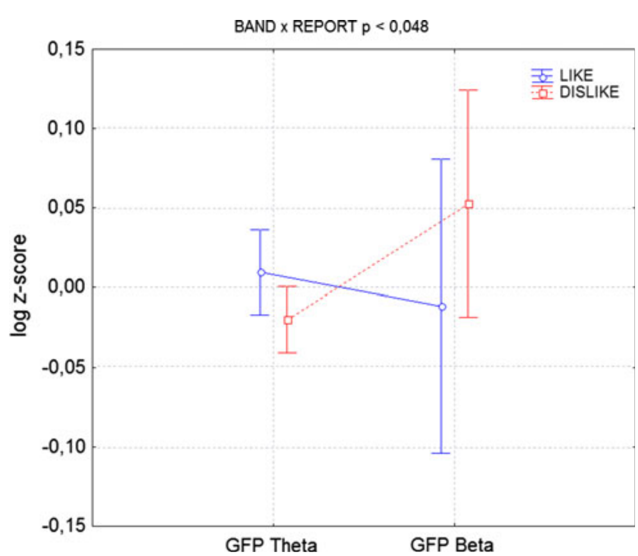

Fig. 5 Figure shows the BAND × REPORT interaction, with the representation of the average values of GFP in the two analyzed frequency bands (theta and beta). The average values are presented together their 2 standard deviation bars. The label GFP Theta and GFP Beta refers to the values of the GFP for the theta and beta band, respectively

Analysis of the Average Values of the Autonomic Variables (GSR, HR)

The analysis of the average values of the autonomic variables gathered in the experimental group was performed by using another factor AUTONOMIC, with two levels (GSR and HR, including the transformed z score of the GSR and HR recordings, respectively), and the already employed factors BRAND and REPORT with the same levels already described in the case of GFP.

REMEMBER/FORGET The ANOVA performed in the case in which the levels of the factor REPORT are RMB and FRG returned a statistically significant interactions between the AUTONOMIC and REPORT factors ($p < 0.023$), while the three way interaction between all the employed factors is not significant ($p < 0.5$), as well as the interactions of AUTONOMIC × BRAND ($p < 0.44$) and BRAND × REPORT ($p < 0.63$).

Duncan post hoc tests suggest that the values of the HR index are significantly increased during the observation of commercials in the RMB group when compared to the values of HR during the observation of commercials that will be forgotten (FRG group, $p < 0.010$). On the contrary, the values of the GSR do not change significantly between the RMB and the FRG groups ($p < 0.5$).

LIKE/DISLIKE In the case in which the REPORT factor presents the levels LIKE/DISLIKE, the ANOVA returns a statistically significant interaction between all the factors employed, with a AUTONOMIC × BRAND × REPORT significance of $p < 0.05$. The interactions between the main factors AUTONOMIC × REPORT is also statistically significant, with a $p < 0.047$ while there are no interaction between the factors BRAND × REPORT ($p < 0.48$). The post hoc analysis performed with the Duncan procedure returns that the values of the HR are statistically significantly higher in the LIKE group versus DISLIKE group in the BRAND condition ($p < 0.048$) while there is a trend that is not statistically significant in the NO BRAND condition ($p < 0.08$). There are no significance differences between the values of the GSR variable between the LIKE and DISLIKE groups, for both BRAND ($p < 0.54$) and NO BRAND conditions ($p < 0.43$). The Fig. 6 shows the AUTONOMIC × REPORT interaction, with the representation of the average values of GSR and HR for the two conditions (LIKE, DISLIKE) together with the representation of their 2 standard deviations by bars around the average values during the BRAND condition.

Analysis on the Heart Rate Variability Ratio LF/HF

A one-way ANOVA has been performed for the analysis of the index LF/HF derived from the heart rate variability, by

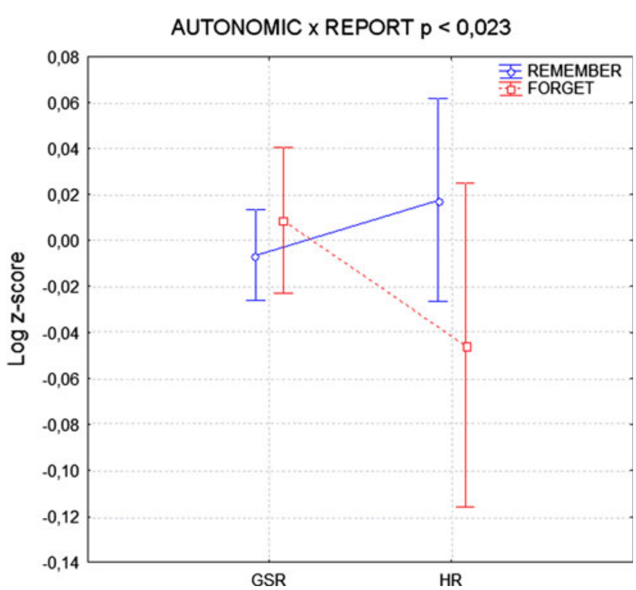

Fig. 6 Figure shows the AUTONOMIC × REPORT interaction, with the representation of the average values of GSR and HR for the two conditions (LIKE, DISLIKE) together with the representation of their 2 standard deviations by bars around the average values during the BRAND condition

using the factor REPORT with all the four levels included (i.e. RMB, FRG, LIKE, DISLIKE).

The results of the ANOVA reported a statistically significant increase of the LF/HF ratio for the LIKE group when compared to the DISLIKE group, with a statistical significance of $p < 0.04$. In addition, the ratio LF/HF is also lower in the RMB group when compared to the FRG one ($p < 0.042$).

Statistical Analysis of the Peaks of the GFP with the Percentage Index

In this section we analyse the outcome of the statistical analysis for the Percentage Index described above, that takes into account the number of peaks of the GFP during different time period of the commercials proposed to the subjects. Also in this case different ANOVAs were used with the factors BAND, BRAND and REPORT already described above.

REMEMBER/FORGET

The ANOVA reports a statistically significant interaction between the three factors BAND, BRAND and REPORT (with levels RMB/FRG) with a $p < 0.026$. Another significant interaction exists between the factors BRAND and REPORT ($p < 0.018$), as well as for BAND and BRAND ($p < 0.001$). Duncan post hoc tests reveals that the values of the Percentage index are higher for the theta band in the RMB group when compared to the FRG one, with a statistical significance of $p < 0.0048$) during the BRAND level, and with a statistical significance of $p < 0.0043$ in the case of NO BRAND level. No significant variation of the Percentage index is reported in the higher frequency bands and in the different BRAND levels.

LIKE/DISLIKE

In the case in which the REPORT levels are LIKE and DISLIKE, the performed ANOVA returned a statistically significant interaction of the main factors BAND and BRAND and REPORT with a $p < 0.05$. Also the interactions between the couple of the main factors are statistically significant, i.e. BAND × BRAND ($p < 0.001$), BAND × REPORT ($p < 0.003$), BRAND × REPORT ($p < 0.001$). The post hoc tests performed with the Duncan procedure show that also in this case the value of the Percentage index in the theta band is able to discriminate between the REPORT levels LIKE and DISLIKE during both the BRAND and NO BRAND time period of the spot ($p < 0.0035$ and $p < 0.045$, respectively). In addition, there is no statistical differences between the values of the Percentage index in the upper frequency band in order to discriminate the LIKE-DISLIKE conditions in the BRAND and NO BRAND periods ($p < 0.92$ and $p < 0.69$, respectively).

Discussion

Methodological Issues

In this work we extensively used the z-score transformation for the original cerebral and autonomic variables gathered from the participants to the study. This was done since the use of the z-score allowed to set the activity of the autonomic and cerebral indexes gathered during the commercial to the average level of the activity of such parameters during the observation of the documentary.

The use of the Global Field Power (GFP) has a very long tradition in summarizing the brain activity in particular scalp areas or over the entire scalp surface (Lehmann and Skrandies 1980). Here, we used the GFP as an indicator of the frontal brain activity in two particular frequency bands; theta and an extended beta band. The choice for these frequency bands was done due to the analysis of the previous literature on the memory studies performed by using the EEG (reviewed in Summerfield and Mangels 2005). In particular, a recent study of Werkle-Bergner and colleagues (Werkle-Bergner et al. 2006) reports as the increase of EEG activity in the theta and gamma bands for the encoding of complex material (visual as well as cognitive one) were particular relevant on the frontal and prefrontal hemispheres. Hence, beside to the use of the z-score cortical power spectral maps, we used also the statistical analysis of these GFP indicators to derive sensitive indexes of the subject's appreciation and memorization of the commercial videos. Hence, the use of frontal leads for the estimation of the GFP indexes derives from the results reported in literature of the importance of these cortical areas for the encoding of the proposed audiovisual material (Werkle-Bergner et al. 2006).

As indicated above, the LF/HF index has been used instead of the direct use of the LF and HF variables since in literature it has been suggested that such ratio is an indicator of the shift of the sympatho/vagal balance of the heart activity (Malik et al. 1996). In fact, it was important for the aim of this study to get an indication of the hypothesized shift of such balance during the exposition to commercial videos that will be memorized or judged pleasant when compared to the others.

Results from the Autonomic Indexes

The measurements of the heart rate and the heart rate variability (through the ratio LF/HF) reports a statistically significant difference when the experimental group are viewing commercial videos that resulted memorized (RMB vs. FRG) as well as pleasant (LIKE vs. DISLIKE) for the population analysed. In particular, data suggested that heart rate variability index LF/HF is sensitive to the LIKE and RMB conditions being a greater value when compared to the DISLIKE and FRG conditions, respectively. This could be congruent with the general activation of the sympathetic system occurring during the observation of pleasantness images and videos. In addition, during the observation of the commercials for the LIKE condition, also the z-scored HR variables appear to be statistically different when compared to the DISLIKE group.

The results, offered by the analysis of the experimental data here provided, stated that the z-score levels of the GSR variable during the LIKE/DISLIKE or RMB/FRG maintained statistically similar values. If we adopt the hypothesis that GSR measures not the level of pleasantness of a situation but rather the level of arousal of the subject in a particular situation, as suggested in the specialized literature by several Authors (Nagai et al. 2004; Critchley 2002), we could conclude that the level of arousal between the population did not change across the entire set of the commercial videos presented, irrespective of the RMB, FRG, LIKE or DISLIKE conditions.

Taken together, the indications provided by the autonomic measurements in the analyzed population suggest that HR, LF/HF are variables able to track the occurrence of memorization and pleasantness of the commercial videos. In addition, the proposed commercials did not elicit particular changes in the arousal of the investigated population. This is important since it was previously known that participants react to the viewing of highly aversive films with heart rate deceleration and a marked electrodermal increase (Baldaro et al. 2001; Palomba et al. 2000; Steptoe and Wardle 1988; Oliveri et al. 2003). In this particular case, due to the particular nature of the videoclips presented (commercial advertising) such orienting and aversive reaction was not generated.

Cerebral Indexes

The analysis of the statistical cortical maps in the different conditions (RMB vs. FRG and LIKE vs. DISLIKE) suggested that the left frontal hemisphere was highly active during the RMB condition, especially in the theta and gamma band, while the activity of the brain is greater in the LIKE condition than in the DISLIKE except that in beta band, being the activity in the LIKE condition for the gamma band rather symmetrical. These results are in agreement with different observations on the RMB condition performed in literature (Summerfield and Mangels

2005; Werkle-Bergner et al. 2006 Astolfi et al. 2008a). In addition, the results here obtained for the LIKE condition are also congruent with other observations performed with EEG in a group of 20 subjects during the observation of pictures from the International Affective Picture System (IAPS, Aftnas et al. 2004). Such observations indicated an increase of the EEG activity in the theta band for the anterior areas of the left hemisphere. It is worth to note that there were methodological differences between the Aftanas and colleagues study and the present one, mainly related to the use of different material as stimuli, and different processing algorithms. Nevertheless, the convergence of these results, obtained in the "naturalistic" conditions of the observation of commercial videos within the documentary with those of more controlled memory and affective tasks, deserve attention.

The use of the GFP index in the employed frequency bands has been analysed with the ANOVA by taking its average values along the time period of the commercials affected by the BRAND exposition against the remaining time period (NO BRAND). The statistical analysis has returned a significant variation only for the LIKE/DISLIKE conditions, irrespective by the BRAND or NO BRAND period, with an increase of the GFP in the theta band for the LIKE condition. In addition, it was reported a decrease of the beta values for the LIKE group against the DISLIKE one. No significant variations of the GFP average values for the REMEMBER/FORGET levels. Also these particular results could be interpreted and linked to the previous reported studies, in which the increase of the power spectra in the theta band was already obtained (Aftnas et al. 2004; Astolfi et al. 2008a).

Beside to the use of GFP with average values, the use of a particular Percentage index reporting the percentage of GFP peaks exceeding the statistical threshold in the BRAND and NO BRAND periods has been investigated. The results suggested that such Percentage index is sensitive to detect the differences between RMB and FRG in both the time period analyzed, as well as for the LIKE and DISLIKE conditions.

Taken together, the results indicated the cortical activity in the theta band on the left frontal areas was increased during the memorization of commercials, and it is also increased during the observation of commercials that were liked by the subjects. These results are in agreement with the role that has been advocated for the left pre and frontal regions during the transfer of sensory percepts from the short term memory toward the long-term memory storage by the HERA model (Tulving et al. 1994). In fact, in such model the left hemisphere plays a key role during the encoding phase of information from the short term memory to the long term memory, whereas the right hemisphere plays a role in the retrieval of such information.

Conclusion

The results of the present study suggested the following answers to the questions elicited in the "Introduction" section:

(1) In the population analyzed, the cortical activity in the theta band elicited during the observation of the TV commercials that were remembered (RMB) is higher and localized in the left frontal brain areas when compared to the activity elicited during the vision of the TV commercials that were forgotten (FRG). Same increase in the theta activity occurred during the observation of commercials that were judged pleasant (LIKE) when compared with the others (DISLIKE). Other differences could be noted in the gamma band between the analyzed conditions, bilaterally in frontal and prefrontal areas.

(2) The HR and HRV activity elicited during the observation of the TV commercials that were remembered or judged pleasant is higher than the same activity during the observation of commercials that will be forgotten or were judged unpleasant. No statistical differences between the level of the GSR values were observed across the experimental conditions.

In conclusion, the TV commercials proposed to the population analyzed have increased the HR values and their cerebral activity mainly in the theta band in the left hemisphere, when they will be memorized and judged pleasant. Further research with an extended set of subjects will be necessary to further validate the observations reported in this paper. However, these conclusions seems reasonable and well inserted in the already existing literature on this topic related to the HERA model.

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