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The behavioral approach system and augmenting/reducing in auditory event-related potentials during emotional visual stimulation

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ABSTRACT

In the recent Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ, Corr and Cooper, 2016) the behavioral approach system (BAS) has been conceptualized as multidimensional in which facets of reward interest and reactivity, and goal-drive persistence, are separate from impulsivity. Aim of the present work was to highlight the predictive power of BAS and its facets in differentiating electrocortical responses by using an auditory augmenting/reducing event-related potential (ERP) paradigm during emotional visual stimulation. ERPs were recorded for 5 levels of intensity in 39 women. The RST-PQ was used to measure the total BAS (T-BAS) and its four facets of Goal-Drive Persistence (GDP), Reward Interest (RI), Reward Reactivity (RR), and Impulsivity (IMP). T-BAS and RI, and to a less extent GDP and RR, were significantly associated with higher N1/P2 amplitudes at central sites (C3, Cz, C4) across neutral, positive and negative slides. Similar, but less pronounced relations were found for GDP and RR, but this relation was lacking for Imp facet. In addition, N1/P2 slope at central sites was positively correlated with T-BAS, GDP, RI, RR, but not Imp. Indeed, T-BAS facets failed to maintain a significant correlation with N1/P2 slope, after controlling for T-BAS residual scores, indicating that T-BAS drives these significant correlations. LORETA analysis at 219 ms (P2 wave) from tone onset revealed a significant activation of the right inferior parietal lobule (IPL, BA40) and left anterior cingulate gyrus (BA32) in high T-BAS compared to low T-BAS participants. Results are discussed within a revised RST framework differentiating reward components from impulsivity.

1. Introduction

Augmenting/reducing (A/R) is assumed to reflect individual differences in the modulation of sensory input, and has usually been studied using amplitude measures of event-related potentials (ERP) elicited at different levels of stimulus intensity (e.g., Buchsbaum & Silverman, 1968). A pronounced increase in amplitudes of the auditory N1/P2 component, as a function of stimulus intensity, is thought to reflect sensory inhibition at high levels of stimulations (e.g., Zuckerman, 1994) produced by serotonergic neurotransmission (Hegerl & Juckel, 1993). This mechanism is essential for the filtering properties of a gating mechanism that regulates sensory input to the cerebral cortex (Buchsbaum, Goodwin, Murphy, & Borge, 1971; Buchsbaum & Silverman, 1968). Individuals are classified as augmenters or reducers depending on whether they show a strong increase or weak increase or decrease on ERP amplitudes with increasing of stimulus intensity. Beauducel, Debener, Brocke, and Kayser (2000) found that the N1/P2-slope calculated across 5–6 auditory intensity levels, spanning a wide intensity range, are required for a reliable assessment of auditory A/R. The amplitude-intensity function slope (AIF), defined as the slopes of the linear regression line for the individual P1/N1 and N1/P2 amplitudes across the 5–6 stimulus intensities (Brocke, Beauducel, John, Debener, & Heilemann, 2000; Brocke, Beauducel, Tasche, 1999; Hegerl, Gallinat, & Mrowinski, 1994; Hegerl, Prochno, Ulrich, & Müller-Oerlinghausen, 1989) has been used as index of individual modes of processing sensory input (e.g., Hegerl & Juckel, 1993).

A rich collection of findings have been reported by Buchsbaum, Haier, and Johnson (1983) and (Hensch, Herold, Diers, Armbruster, & Brocke, 2008) of psychiatric and psychological phenomena associated with augmenting-reducing. In addition, reserch has demonstrated that the N1/P2 AIF of the ERPs is one of the numerous endophenotypes that are gaining importance in psychiatry and genetic research (e.g., Brocke et al., 2006; Gottesman & Gould, 2003). The N1/P2 AIF is considered important for clinical practice as it has been good to predict responses to lithium and selective serotonin reuptake inhibitors treatments (Gallinat et al., 2000;

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Juckel et al., 2004; Mulert et al., 2007; Tien-Wen, Younger, Chen, & Tsai, 2005). The N1/P2 AIF has been proved to be associated with 5-HTTLPR, a genetic polymorphism of the serotonin transporter coding gene (Gallinat et al., 2003; Hensch et al., 2006; Strobel et al., 2003), and thus heritable (Sándor, Áfra, Proietti-Cecchini, Albert, & Schoenen, 1999).

In terms of personality traits, it was found that individuals scoring high on sensation seeking facets, and mainly on its disinhibition subscale, were augmenters and reducers tend to be sensation avoiding (Brocke et al., 2000; Brocke et al., 1999; Lukas, 1987; Stenberg, Rosén, & Risberg, 1988; von Knorring, 1980; Zuckerman, 1990; Zuckerman, 1994; Zuckerman, Murtaugh, & Siegel, 1974; Zuckerman, Simons, & Como, 1988). Moreover, Eysenck's extraversion trait was found positively associated with augmenting (Friedman & Meares, 1979; Soskis & Shagass, 1974; Stenberg et al., 1988). The validity of these findings was further supported by linking sensation avoiding and introversion with the defensive reducing pattern. The N1/P2 AIF was found correlated with a risk factor for bipolar disorder in healthy individuals (Hensch, Herold, & Brocke, 2007), and with sensation seeking trait, which is suggested to be characterized by low serotonergic neurotransmission and a potential risk factor for mental disorders (Brocke et al., 1999; Hegerl, Gallinat, & Mrowinski, 1995). In contrast, individuals with strong sensation-seeking tendencies are believed to be characterized by high dopaminergic, low noradrenergic, and low serotonergic activity (for a review see Zuckerman, 1994).

Augmenting has been also related to impulsivity (Barratt, Pritchard, Faulk, & Brandt, 1987; Carrillo-De-La-Pena & Barratt, 1993). Considering that impulsivity is an important trait of the reinforcement sensitivity theory (RST) of personality, it is surprising that no or little research has been done to evaluate the relation between RST traits and A/R of the ERPs. The most recent version of the RST (Corr & McNaughton, 2012; McNaughton & Corr, 2004, 2008; McNaughton & Gray, 2000) postulates three major neuropsychological systems controlling approach and avoidance behavior: (1) the Behavioral Approach System (BAS) controls active approach behavior in response to signals of reward and non-punishment and is activated by all forms of appetitive stimuli (including relief of nonpunishment); (2) the Fight-Flight-Freeze system (FFFS) as a primary system that controls active avoidance and is activated by all forms of aversive stimuli (including frustrating nonreward); (3) the Behavioral Inhibition System (BIS) controls passive avoidance in response to signals of punishment, nonreward, novelty, and by all forms of goal conflict, mainly for the co-activation of the FFFS and BAS. This is a revision of the original RST formulated by Gray (1982) that highlighted only two of these systems, the BIS and the BAS. In the original RST what is less apparent is the hidden complexity in and between these systems which renders any attempt to provide a psychometric description of them far from ordinary and prone to confusion (Corr, 2016). As a consequence of this state of affairs existing rRST questionnaires fail to provide a *comprehensive* descriptive model and all of the existing ones have significant theoretical and operational limitations with the result that there are still no comprehensive psychometric measures of the three revised systems. The most significant change to RST is the separation of FFFS/fear and BIS/anxiety processes (for a review see Rafael Torrubia, Caseras, Torrubia, & Caseras, 2008). Although the newer classes of RST measures have addressed the separation of FFFS and BIS, most of them still conceived the BAS, as a unitary dimension. However, there is compelling evidence that the BAS is multidimensional, both on the basis of empirical evidence (Carver & White, 1994; De Pascalis, Varriale, & D'Antuono, 2010) and theoretical grounds (Corr, 2008; Smillie, Cooper, Wilt, & Revelle, 2012). In order to move along the temporo-spatial gradient to the final primary biological reinforcer, Corr (2008) argued that it is necessary to engage in *sub-goal scaffolding*. These processes, at each stage of the temporo-spatial gradient, consists of a number of operations (i.e., identifying the biological reinforcer, planning behavior, and executing the plan) that involve other systems as working memory, executive control, etc.; this is in accordance with the type of required cognitive operations. The function of the BAS is to coordinate these functions as they relate to approach behaviors. BAS controlled approach may be expected to entail a series of subprocesses, some of which sometimes oppose each other: (1) *behavioural restraint* serving to plan and execute effective sub-goal scaffolding; and (2) *impulsive behaviour* serving when cognitive planning can be replaced, at short temporo-spatial distance, by fast 'getting', or a physical grabbing of the final biological reinforcer at near-zero temporo-spatial distance (Carver, 2005; Corr, 2008). This theoretical assumption does not imply that the emotional component of BAS behaviour would be attenuated at the early stages of approach behaviour, since the fulfilment of sub-goals is likely to entail periodic bursts of emotional excitement to maintain motivation across time/space ('temporal bridging', Corr, 2008) during which approach behaviour is not being immediately reinforced (goal drive persistence).

Consistent with both theoretical and empirical considerations, Corr and Cooper (2016) developed the Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ) that is recommended as the most appropriate measure of the rRST that allows the separation of the FFFS and BIS and the important distinction of reward sensitivity and impulsivity (Corr & Cooper, 2016). Mainly, the four sub-scales of the BAS (Reward Interest, RI; Goal-Drive Persistence, GDP; Reward Reactivity, RR; Impulsivity, Imp) makes this tool to test an open empirical question, i.e., if the four BAS facets exhibit an unique predictive power, or they are redundant. According to Corr and Cooper (2016) it is especially important to separate reward interest and reactivity from impulsivity. This is since the first facet concerns with individual disposition to identify the biological reinforcer, the second with individual differences in emotional response to reward, the third reflects the need for a rapid action sufficient to 'capture' the final biological reinforcer, at the later stages of BAS behavior, when continued planning and behavioral caution are not appropriate.

In line with this view, Lang (1995) conceived the emotional system as consisting of the appetitive motivational and aversive system. The former facilitates approaching behaviors, such as mating, food taking or exploration, whereas the latter facilitates defensive behavior, such as avoidance, escape or defence. Lang and co-workers (Lang, Bradley, & Cuthbert, 1997) regard arousal and valence as the fundamental dimensions of the emotions, that is, arousal determines the intensity and valence the direction of activation. A "gating" function exerted by dopamine in regulating access of context representations into active memory in prefrontal cortex (a fuction which is impaired in schizophrenia) has been proposed by Braver and Cohen (2000). More recently, Berridge (2007, 2012) has examined three competing dopamine hypotheses which are debated in the current literature, i.e., (*i*) dopamine mostly mediates the hedonic impact of reward ('liking'), or (*j*) mediates learned predictions of future reward ('learning'), or (*k*) motivates the pursuit of rewards by attributing incentive salience to reward-related stimuli ('wanting'). Dopamine was neither necessary nor sufficient to mediate changes in hedonic 'liking' for sensory pleasures or learning, while dopamine activation was necessary for normal 'wanting' and to enhance cue-triggered incentive salience. The incentive reward system is equivalent to the BAS and produces motivation to approach reward, but the hedonic system is the pleasure system responsible for the enjoyment experienced following the gaining of reward (see Corr, DeYoung, & McNaughton, 2013; Corr & McNaughton, 2012).

Personality research on A/R has been centered almost exclusively on individual differences in extraversion-related constructs as such as sensation-seeking and impulsivity, while the relation between cortical A/R and approach components of behavior, as defined in the RST, to date, has been neglected. It is important to establish these relations because RST has largely superseded Eysenck's arousal theory of personality, and incorporated Zuckerman's sensations seeking factor under BAS Impuslsivity. The RST-PQ allows the separation of RI, GDP, RR, and Imp sub-factors of the BAS making feasible to test an open empirical question, i.e., whether the four sub-scales show unique predictive power, or are they redundant. According to Corr (2016) it is especially important to separate reward interest and reactivity (which themselves are different) from impulsivity, which serves a different function in the causal cascade from appetitive exploration to final capture of the desired object. We think that the A/R of the ERPs together with the emotional modulation of these responses is a good tool to test this separation conceptualized in the rRST theory (Corr, 2008; Corr & McNaughton, 2012; Corr et al., 2013). Validation of this theory may be especially informative of the relationship between dimensional nature of the BAS and clinical disorders (Alloy et al., 2012; Carver, 2004).

Thus, the aim of the present study was to test specific revised RST-derived predictions (Corr, 2008; Corr et al., 2013) regarding the interaction between BAS trait and positive and negative emotion, and how this interaction influences the A/R of the ERPs. We used a visual cue indicating, 2 s in advance, whether participants would see an emotional positive, negative or neutral picture. The visual cue was used since we assumed that the anticipation of emotional valence of the incoming picture should reduce the influence of novelty or orienting-response on auditory ERPs. First, considering that RST-PQ BAS subscales are correlated with Extraversion measure of the Eysenck Personality Questionnaire-Revised (Corr & Cooper, 2016), we expected that highly approach-oriented (i.e., high GDP, RI, and RR) individuals should be augmenters of N1 and P2 waves of the ERPs in response to increased levels of auditory stimulus intensity. Second, we expected an enhanced augmenting tendency in higher BAS individuals when positive pictures were presented because positive stimuli might open the gating mechanism. Findings corroborating this view have been recently reported on startle response (Aluja, Blanch, Blanco, & Balada, 2015). We did not expect significant ERP differences between high and low RST-PQ Impulsivity individuals given that, as theory and research have shown, impulsivity stands apart from the other BAS factors (Corr, 2016; Dawe, Gullo, & Loxton, 2004; Smillie, Jackson, & Dalgleish, 2006; Smillie, Pickering, & Jackson, 2006; Quilty & Oakman, 2004).

Further aim of this study was to test, in terms of augmenting/reducing of auditory ERPs, if the four BAS facets exhibit a unique predictive power, or they are redundant, especially for the important distinction between reward interest and reactivity versus impulsivity.

Low Resolution Electrical Tomography (LORETA) is a valid tool to identify multiple dipole locations for the N1 and P2 component of the ERPs (Mulert et al., 2005; Mulert, Juckel, Augustin, & Hegerl, 2002; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002). Thus, a secondary aim of the present study was to parallel ERP wave analysis, which should identify ERP waves sensitive to individual differences in BAS facets, with LORETA source localizations. In this way we can integrate auditory ERP waves with their cortical sources sensitive to individual differences in BAS components.

2. Methods

2.1. Participants

Forty right-handed healthy women students voluntarily participated in the study (19–33 years; mean age = 24.8, SD = 3.0). Since gender differences have been observed in augmenting/reducing of the ERPs (Bruneau, Barthelemy, Jouve, & Lelord, 1986) the sample was restricted to women to avoid possible gender differences as a confounding factor. We excluded participants reporting any lifetime history of hearing problems, treatments of significant psychiatric or neurologic disease, head trauma or loss of consciousness, substance dependence or strong use of amphetamine, cocaine, caffeine or nicotine. Participants who were in a menstrual period were invited for the EEG recordings between the 5th and 11th day after the onset of menses. This was done to avoid a possible effect of the menstrual cycle on auditory ERPs (Walpurger, Pietrowsky, Kirschbaum, & Wolf, 2004). Each participant was informed about the nature of the study upon arrival in the laboratory. Hand preference was measured with the Italian version of the Edinburgh Handedness Inventory (Salmaso & Longoni, 1985). Participants were asked to refrain from smoking or drinking coffee for at least three hours before the EEG recording. They gave informed consent prior to their inclusion in the study.

The research was conducted according to the ethical standards of the American Psychological Association (APA). Approval of this study was obtained from the Ethics Committee of the Department of Psychology, La Sapienza University of Rome, Italy (2014). Participants were seen individually in the laboratory and, upon arrival, were informed about the nature of the study. All of them gave their written informed consent for participation in the study.

The relation of BIS and FFFS with AIF of N1/P2 complex during emotional visual stimulation have been submitted elsewhere (De Pascalis, Fracasso, & Corr, 2016).

2.2. Questionnaires

We used in the present study a recently developed questionnaire measuring personality traits derived from the revised Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ; Corr & Cooper, 2016).

The version of the RST-PQ used in this study consisted 71 statements, measuring three major systems: *Fight/Flight/Fear System* (FFFS); *Behavioral Inhibition System* (BIS); and four *Behavioral Approach System* (T-BAS) factors which are considered in this study: Reward Interest (RI; e.g., "I am always finding new and interesting things to do"); Goal-Drive Persistence (GDP; e.g., "I put in a big effort to accomplish important goals in my life"); Reward Reactivity (RR; e.g., "I get very excited when I get what I want"); and Impulsivity (Imp; e.g., "I find myself doing things on the spur of the moment"). In the present research Cronbach's α values for Reward Interest, Goal-Drive Persistence, Reward Reactivity and Impulsivity were respectively 0.73, 0.88, 0.77, and 0.72. A total BAS (T-BAS) measure can be obtained as the sum of the four BAS facet measures ($\alpha = 0.88$).

State anxiety was also measured using the State Anxiety Inventory (STAI-Y1; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1988); participants rated 20-items on a scale from 1 = not at all, to 4 = very much so, indicating how they felt at that moment. The STAI-Y1 has been shown to have adequate internal consistency (see e.g., Metzger, 1976).

2.3. Emotional pictures

Emotional visual stimuli were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). In a pilot study, an independent sample of 30 women (22–36 age range, M = 24.6, SD = 2.6 yrs) students rated each image on valence and arousal to verify the initial selection. The ratings for positive, negative and neutral valence were obtained using a 9-point Likert Scale, ranging from 1 to 9 that varies from negative to positive with a neutral point (five). A similar scale was used to rate arousal levels, ranging from 1 (calm) to 9 (arousing). We selected from the IAPS all the positive pictures that had a score equal or higher than 7 in valence and 7 in arousal. We followed the same procedure for the negative images. We took the neutral images in a small interval around the 5-value for the valence (4.5–5.5). Since neutral images are typically rated lower in arousal relative to positive or negative images, this was quite difficult to select, from IAPS, a set of neutral images with a high arousal level such as that of emotional images. To remedy this problem, we selected from the IAPS 28 neutral pictures with the highest score on arousal, but we had to add 18 neutral, potentially highly arousing (but rated as emotionally neutral, i.e. emotional valence rating ranged from 4.5 to 5.5) surreal pictures, downloaded from the World Wide Web, as suggested in a previous study by Mourao-Miranda et al. (2003). Surreal pictures included scenes (8), objects (3), faces (2), human bodies with undistinguishable faces (2), and animals (3). The final picture set consisted of 45 positive/high-arousal images, 45 negative/high-arousal images, and 46 neutral images (see the Appendix A for the numbers of IAPS images used for each affective category). These selected images were then administered to the present experimental sample (N = 39). Emotional valence and arousal of the experimental sample for positive images were M = 6.9, SD = 0.4, and M = 6.1, SD = 0.8, respectively. For negative images valence and arousal were M = 2.4, SD = 0.5, and M = 6.2, SD = 0.8, respectively. However, the mean of arousal for the neutral images was inevitably not as high as we expected (valence: M = 5.3, SD = 0.4, arousal: M = 4.2; SD = 0.7). These ratings correspond to the ratings for women reported in the validation study by Bradley and Lang (2007).

2.4. Acoustic stimuli and trial format

During the presentation of each picture, a sequence of 5 tones was binaurally delivered through headphones (Telephonics) by using STIM^2 (NeuroScan Inc., Herndon, USA). Each tone sequence consisted of a pseudo-randomized presentation of 5 tones (1000 Hz) at 5 different stimulus intensities (59, 70, 79, 88, and 96 dB-SPL). The auditory stimulus duration was of 30 ms (10 ms rise and 10 ms fall time), and interstimulus interval (ISI) varied pseudo-randomly between 1600 and 2100 ms.

Before starting the electrophysiological recording, all participants were screened for intact auditory abilities. All participants passed this screening. They were comfortably seated in an armchair placed in a sound attenuated room near the recording equipment. The presentation of images and tones was done after an initial 5 min recording of resting EEG. Tones were delivered according to the A/R paradigm (Buchsbaum & Silverman, 1968).

Fig. 1 depicts a schematic view of the time course of a trial. All stimuli were viewed at a visual angle of 7.5° × 7.5° and were presented on a monitor with a frame rate of 75 Hz (luminance of about 200 cd/m^2). Each trial began with the presentation of a fixation cue for 1500 ms, in the centre of a computer screen, of one of the following three fixation cue stimuli: a white dot circle (2 cm diameter), or an equilateral triangle (3 cm side), or a square (2 cm side). The cue indicated respectively that a positive, or negative, or neutral image would be displayed. A blank black-screen then appeared for 500 ms and an emotional image was next presented on the screen for a time period ranging, in pseudorandom order, from 8000 to 10500 ms to guarantee the presentation of 5 different intensity tones. The averaged picture presentation time was kept constant across valenced picture at about 9800 ms. Each picture presentation was followed by an intertrial interval (ITI) varying between 6 and 8 s (blank screen). The first tone probe occurred between 500 and 1000 ms after the onset of each image presentation. The duration of each trial was variable between 16 and 20.5 s.

The images were presented in pseudo-random order in 5 blocks (1-min rest between blocks). For each block 30 pictures were presented and the duration of each block was of about 10 min. An equal number of images from each category occurred in each block.

2.5. EEG recordings and data reduction

The EEG, and electro-ocular (EOG) activities were acquired continuously by using a 40-channel NuAmps DC amplifier system (Neuroscan Acquire 4.3) with tin electrodes located over 30 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T3, C3, Cz, T4, C4, T5, CP3, CPz, CP4, T6, P3, Pz, P4, TP7, TP8, O1, Oz, O2). Linked earlobes [(A1 + A2)/2] were used as a reference electrode. Amplifiers were set at a gain of 200, sampling rate of 1000 Hz, and with signals band-limited from 0.1 to 30 Hz (slope 48 dB/octave) with a 50 Hz notch filter. Electrode impedance was kept below 5 kΩ. The ground electrode was positioned 10 mm anteriorly to Fz lead. The horizontal and vertical EOG was monitored via a pair of tin electrodes placed 1 cm lateral to the outer cantus of each eye and the vertical EOG was monitored via bipolar montage using two electrodes placed above and below the centre of the left eye. The EEG was offline processed using Brain Vision Analyzer 2.1 system (Brain Product). The EEG was reconstructed into discrete, single-trial 1000-ms epochs. ERPs were time-locked to auditory tone onset, with a 150-ms pre-stimulus baseline. Trials that contained an eye blink or eye movement artifacts (EOG > 75 μV) were rejected and discarded from analysis. Ocular artifacts were corrected using the procedure of Gratton and colleagues (Gratton, Coles, & Donchin, 1983). To ensure an acceptable signal-to-noise ratio in the averaged ERP waveforms, only subject data including no less than 50 artifact-free epochs per condition were included. Based on this criterion, from the initial 40, only 39 participants were included in the analysis.

The EEG was averaged for each stimulus intensity and affective condition, and then baseline corrected. There were no differences between affective conditions in the number of rejected trials. Finally, the N1 and P2 waves of the auditory ERPs were extracted. Peak amplitudes were determined for the P1 as the most positive peak (M = 1.9, SD = 0.8 μV) within the period of 30–80 ms (M = 65.8, SD = 5.2 ms), for the N1 as the most negative peak (M = –8.2, SD = 3.1 μV) within 80–140 ms (M = 126.9, SD = 9.9 ms), and for P2 as the most positive peak (M = 8.9, SD = 3.1 μV) within 140–250 ms (M = 211.4, SD = 11.5 ms). Additional peak-to-peak values were calculated for P1/N1 (M = 10.3, SD = 3.1 μV) and N1/P2 (M = 18.0, SD = 5.9 μV) complexes.

2.6. Cortical sources analysis of the N1 and P2 waves

ERP responses were further analyzed using the last version of LORETA software provided by the KEY Institute for Brain-Mind Research (University Hospital of Psychiatry, Zurich, Switzerland; http://www.uzh.ch/keyinst/NewLORETA/LORETA01.htm, version 25-04-2015). LORETA analysis has been successfully used to locate the spatial source of significant ERP components (Decety, Yang, & Cheng, 2010; Nir et al., 2008; Schneider, Vogt, Frysch, Guardiera, & Struder, 2009; Yang, Perfetti, & Liu, 2010) and of conventional EEG recordings (Fuchs, Kastner, Wagner, Hawes, & Ebersole, 2002; Jurcak, Tsuzuki, & Dan, 2007; Roberto Domingo Pascual-Marqui, 2002; Pascual-Marqui et al., 2002). LORETA provides an algorithm to solve the inverse problem of EEG by assuming that neighboring grid points are more likely to be synchronized than grid points that are far from each other and to find the best solution that is consistent with the scalp distribution (Roberto D Pascual-Marqui, Michel, & Lehmann, 1994). Recent LORETA software version performs source localization in 6239 cortical gray matter voxels sized 5 mm^3 rather than 7 mm^3 offered by the

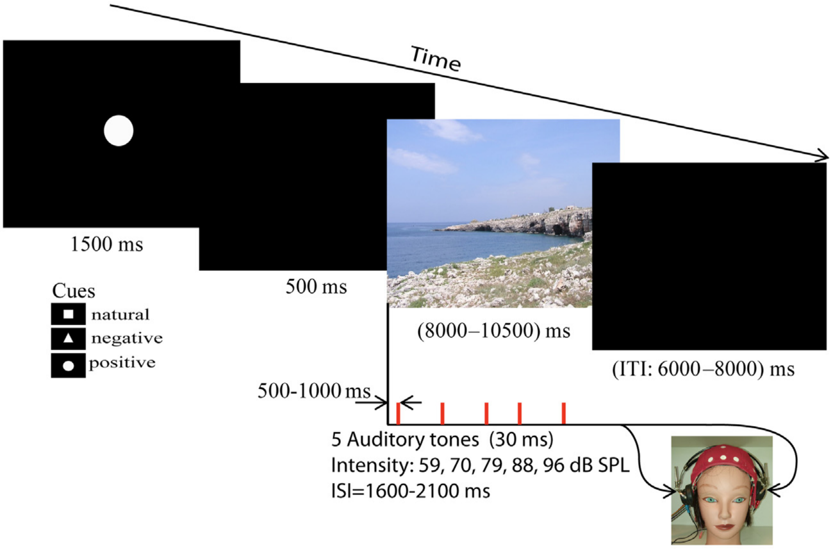

Fig. 1. Schematic diagram illustrating visual emotional display, timing, and auditory stimulation using the augmenting/reducing paradigm.

previous LORETA version, and localization inference is based on standardized values of the current density estimates (Wagner, Fuchs, & Kastner, 2004). The solution space of LORETA is restricted to cortical and some hippocampal and amygdala gray matter defined via a reference brain from the Brain Imaging Center at the Montreal Neurological Institute (MNI; (Collins, Neelin, Peters, & Evans, 1994; Mazziotta et al., 2001)). The LORETA implementation incorporates a 3-D shell spherical head model registered to a recognized anatomical brain atlas (Talairach & Tournoux, 1988). Individual 3-D electrodes are positioned by the Talairach coordinate system according to the spatial association between anatomical brain landmarks and scalp positions (Towle et al., 1993). sLORETA enables the computation of statistical maps from ERP components data that indicate the locations of the underlying source processes with low error (Pascual-Marqui, 2002) and does not require a priori hypotheses regarding field distribution of active sources. In the present experiment the coordinates of the 30 electrode positions were applied to a probabilistic anatomical template of the Talairach Atlas (McConnell Brain Imaging Centre, Montréal Neurological Institute, McGill University). These Talairach coordinates were used to compute the LORETA transformation matrix and then to transform ERPs of each subject into sLORETA forms. This resulted in the corresponding 3D cortical distribution of the electrical neuronal generators for each subject. For source reconstruction, subtractions of ERP traces between high and low personality traits were assessed, for the N1 and P2 waves, respectively within time intervals of 100–140 ms and 200–225 ms. Statistical significance was assessed using a non-parametric randomization test (Nichols & Holmes, 2002). To correct for multiple comparisons, a nonparametric single-threshold test was assessed defining a critical threshold (t-critical). Voxels with statistic values exceeding this threshold have their null hypothesis rejected. The omnibus hypothesis (that all the voxel hypotheses are true) is rejected if a voxel value exceeds the critical threshold for $p < 0.05$ defined by 5000 randomizations. Voxel-by-voxel t-values in Talairach space are displayed as statistical parametric maps (SPMs). Because *t*-tests assume Gaussian distributions of pixel activation, a log transform of the value of each LORETA pixel was carried out to produce more Gaussian-like distributions for each ERP component under examination. The second assumption of SPM, smoothness across neighboring pixels, is satisfied directly by the LORETA output. The *t*-test threshold was set to $p < 0.05$ and cluster size was set to ≥ 3 pixels, as is common in neuroimaging studies. sLORETA maps of high vs low personality levels were compared using a *t*-test for independent samples with the aforementioned nonparametric permutation test. It is important to note that this localization is not a complete listing of all significantly different cortical areas, but a listing of the local maxima of these differences. Although simulations have shown that LORETA localization performed better than some other localization methods, LORETA, as with all ERP localization algorithms, has accuracy limitations (Pascual-Marqui, 1999). Consequently, the significant brain regional differences reported in the present study between high and low levels of personality traits were examined only when N1/P2 differences between those traits were seen statistically significant.

2.7. Statistical analyses

We performed zero-order correlations to evaluate the relation of the P1/N1, N1/P2 amplitude and slope measures with T-BAS and its four components (RI, GDP, RR, Imp). The bias-corrected bootstrap method was used to assess the significance of these correlations, which is effective in controlling for type 1 errors associated with multiple comparisons (Efron & Efron, 1982). This bootstrap analysis was performed in two steps. In the first step, 5000 new samples were generated by random re-sampling with replacements from the available data under the condition that each of the 5000 samples had the same size as the original sample. Critical values for the upper and lower 95% bias-corrected confidence limits for all the zero-order correlation coefficients were then estimated. All coefficients with an associated confidence interval that did not include zero were considered statistically significant ($p < 0.05$, two tailed).

To test for differences in self-report emotional valence an analysis of variance (ANOVA) was performed with Valence (positive, negative, neutral) as within-subject factors. A similar ANOVA was used for Arousal levels. Additional analyses of covariance were computed to determine the influence of individual differences, separately, with T-BAS, RI, GDP, RR, Imp, as covariate factors.

In line with original reports (e.g., Beauducel et al., 2000; Brocke et al., 2000; Stenberg et al., 1988) the amplitudes of the P1, N1, P2, and peak-to-peak values for P1/N1 and N1/P2 complexes were calculated. In addition, the individual slopes of the linear regression line (least-squares technique) for the P1/N1 and N1/P2 amplitudes were calculated across the five stimulus intensities. All parameters were calculated for C3, Cz, and C4 scalp locations (Zuckerman, 1990).

To examine valence effects on the P1/N1, and N1/P2 amplitude measures, separate repeated measures ANCOVAs were conducted, using a 3 Valence (positive, negative, neutral) × 3 Electrode site (C3, Cz, C4) × 5 Stimulus intensity (59, 70, 79, 88, and 96 dB-SPL) as within-subject factors with included, in four separate analyses, T-BAS, GDP, RI, and RR as a continuous covariate variable. For the P1/N1 and N1/P2 slopes, separate ANCOVAs similar to those used for the amplitude scores were conducted, with the exception that Stimulus intensity factor not present.

An alpha level of 0.05 was used for all analyses. Bonferroni corrected follow-up comparisons were conducted to assess effects of picture type and electrode location. Degrees of freedom were adjusted using Huynh-Feldt adjustments when the assumption of sphericity was violated.

For significant main and interaction effects involving personality traits of interest we applied separate median splits on personality scores for graphical illustrations or to understand the direction of the effects. Subjects were considered as belonging to either group ‘high’ or ‘low’ when their scores on the personality measures were above or below the median. Personality scores falling on the median were excluded. The number of individuals falling on the median were: 3 for T-BAS (N = 19 high T-BAS, N = 17 Low T-BAS); 7 for GDP (20 high GDP, 12 Low GDP); 5 for RI (18 high RI, 16 low RI); 2 for RR (18 high RR, 19 low RR), and 9 for Imp (14 high Imp, 14 Low Imp).

3. Results

The results will be presented in separate sections. First we will present the results on the influence of T-BAS and its sub-traits on emotional and arousal levels. Secondly, we will report findings on the influence of individual differences in T-BAS, and its sub-traits of GDP, RI, RR, and Imp on A/R of the ERPs and their emotional modulation. Last, we will present LORETA differences between BAS personality traits when ERP effects were found statistically significant.

3.1. Affective and arousal ratings

As expected, paired *t*-test showed that negative images were rated as more unpleasant than positive ones (t = −48.81, p < 0.0001). In addition, negative and positive images were respectively rated as more unpleasant (t = −28.39, p < 0.0001) and pleasant (t = 16.15, < 0.0001) than neutral (Negative Images: M = 2.4, SD = 0.5; Positive Images: 6.9, SD = 0.4; Neutral Images: M = 5.3, SD = 0.4).

Paired *t*-tests performed on the arousal ratings revealed no significant differences between negative and positive arousal ratings (Negative arousal: M = 6.20, SD = 0.77 vs. Positive arousal M = 6.12, *SD* = 0.76, t = 0.48, p = 0.64), while negative and positive arousal ratings were both higher than neutral arousal ratings (M = 4.21, SD = 0.69, t = 10.70, and t = 12.98, p < 0.0001, respectively).

The correlation matrix of T-BAS and its sub-traits with valence and arousal measures showed a significant association of positive valence with GDP scores (r = 0.34, p < 0.05) and RI scores (r = 0.33, p < 0.05), while all the remaining correlations were all not significant (p > 0.05).

3.2. Personality measures

Descriptive statistics for personality and initial state anxiety scores are reported in Table 1.

Pearson correlation coefficients among personality and state anxiety measure are reported in Table 2. Correlation data confirm the pattern of associations reported by Corr and Cooper (2016) in their development and validation of the RST-PQ. As reported in previous research (e.g., Carver & White, 1994; Corr, 2015) the BIS measure proved to be independent from BAS measures (Table 2), while it was significantly associated with the FFFS measure (Corr & McNaughton, 2012).

Table 1
Mean (M), standard deviation (SD) and range of variability for RST-PQ personality traits (*) and state anxiey.

N = 39	BIS	FFFS	T-BAS	GDP	RI	RR	Imp	STAI-Y1
M	54.8	26.2	91.3	22.1	20.0	30.3	18.9	37.7
SD	11.8	5.3	9.6	3.2	3.7	3.3	3.6	7.9
Range	33–81	15–38	72–110	13–27	12–26	22–36	11–26	25–57

(*) BIS: Behavioral Inhibition System, FFFS: Fight-Flight-Freezing System; T-BAS: Total score for the Behavioral Approach System; GDP: Goal-Drive Persistence; RI: Reward Interest; RR: Reward Reactivity; Imp: Impulsivity.

Table 2
Pearson correlation coefficients for personality (RST-PQ) and initial state anxiety (N = 39).

	1	2	3	4	5	6	7	8
1 BIS	1	0.63†	0.12	0.25	0.00	−0.01	0.10	0.47•
2 FFFS		1	0.09	0.34*	0.01	−0.05	−0.03	0.16
3 T-BAS			1	0.75†	0.73†	0.69†	0.62†	−0.15
4 GDP				1	0.67†	0.28	0.18	−0.25
5 RI					1	0.26	0.10	−0.26
6 RR						1	0.42•	−0.02
7 Imp							1	0.11
8 STAI-Y1								1

(*) BIS: Behavioral Inhibition System, FFFS: Fight-Flight-Freezing System; T-BAS: Total score for Behavioral Approach System; GDP: Goal-Drive Persistence; RI: Reward Interest. RR: Reward Reactivity; Imp: Impulsivity.

† p < 0.0001.
• p < 0.01.
* p < 0.05.

3.3. Correlations of T-BAS and its sub-traits with P1/N1 and N1/P2 amplitudes

The zero-order correlations between T-BAS and its facets with measures of P1/N1 amplitudes, obtained during each emotion condition for the 5 stimulus intensities, were all not significant. In contrast, some correlations between personality and N1/P2 amplitudes reached the level of significance. Mainly T-BAS and RI, and to a less extent GDP and RR facets showed to be significantly and positively associated with N1/P2 amplitudes during the presentation of negative, positive, and neutral images mainly at the highest auditory intensities of stimulation (88 and 96 dB). But, Impulsivity traits failed to show any significant relationship with N1/P2 amplitude. Correlations of interest are reported in Table 3.

3.4. Correlations of T-BAS trait and its facets with P1/N1 and N1/P2 slopes

The correlations of P1/N1 and N1/P2 slopes (across neutral, positive, negative pictures, and an overall averaged measure) with the T-BAS traits, along with their 95% associated bootstrapped confidence intervals are reported in Table 4. The P1/N1 slope was not found significantly associated with any of the T-BAS measures. But, the N1/P2 slope was the only measure that yielded robust and positive associations with T-BAS and GDP, RI, and RR sub-traits, although there was any significant association with IMP facet. These findings are consistent with our expectations (see Table 4).

3.5. Correlations of T-BAS and its facets with N1/P2 slopes: testing the unique role of BAS

Since T-BAS, GDP, RI, and RR were found significantly associated with N1/P2 slope at C3 during neutral, negative and positive pic-

Table 3
Th e highest correlations, along with their 95% associated bootstrapped confidence intervals (CI), of the N1/P2 amplitude at C3, C3 and C4 leads with T-BAS and its GDP, RI, RR, and Imp subtraits.

N1/P2 Amplitude	C3-96 dB NEG	C4-96 dB NEG	C3-88 dB POS	Cz-88 dB POS	C4-79 dB POS	C4-88 dB POS	C4-88 dB NEU	C4-96 dB NEU
T-BAS	0.38^{*}	0.38^{*}	0.36^{*}	0.33^{*}	0.35^{*}	0.36^{*}	0.33^{*}	0.36^{*}
95%CI	(0.18, 0.59)	(0.15, 0.57)	(0.14, 0.52)	(0.11, 0.53)	(0.16, 0.54)	(0.13, 0.56)	(0.08, 0.45)	(0.16, 0.58)
GDP	0.33^{*}	0.31	0.30	0.29	0.21	0.29	0.28	0.29
95%CI	(0.08, 0.45)	(0.13, 0.54)	(0.13, 0.49)	(0.11, 0.46)	(−0.00, 0.44)	(0.09, 0.39)	(0.10, 0.33)	(0.10, 0.45)
RI	$0.44^{\bullet}$	$0.45^{\bullet}$	0.39^{*}	0.35^{*}	0.35^{*}	0.37^{*}	0.37^{*}	0.38^{*}
95%CI	(0.28, 0.60)	(0.32, 0.60)	(0.25, 0.55)	(0.12, 0.52)	(0.13, 0.51)	(0.24, 0.55)	(0.24, 0.54)	(0.22, 0.57)
RR	0.32^{*}	0.35^{*}	0.29	0.27	0.25	0.28	0.31	0.36^{*}
95%CI	(0.15, 0.52)	(0.11, 0.54)	(0.13, 0.43)	(0.09, 0.51)	(0.06, 0.41)	(0.09, 0.45	(0.12, 0.48)	(0.18, 0.54)
Imp	−0.006	−0.042	0.067	0.04	0.24	0.12	−0.01	0.006
95%CI	(−0.27, 0.29)	(−0.25, 0.23)	(−0.03, 0.31)	(−0.26, 0.34)	(−0.01, 0.45)	(−0.21, 0.41)	(−0.25, 0.34)	(0.22, 0.28)

* $p < 0.05$.
$^{\bullet}$ $p < 0.01$.

Table 4
Zero-order correlations, along with their 95% associated bootstrapped confidence intervals (CI), of the P1/N1 and N1/P2 and N1/P2 slopes across Neutral (NEU), Negative (NEG), Positive (POS), and Overall Averaging (Avg) with T-BAS, GDP, RI, RR, and Imp measures of the RST-PQ.

	T-BAS		GDP		RI		RR		Imp	
P1/N1 slope	r	95%CI	r	95%CI	r	95%CI	r	95%CI	r	95%CI
C3_NEU	0.18	(−0.02, 0.41)	0.19	(−0.02, 0.37)	0.15	(0.02, 0.26)	0.14	(0.01, 0.28)	0.05	(−0.01, 0.20)
Cz_NEU	0.10	(−0.08, 0.34)	0.09	(−0.01, 0.30)	0.09	(−0.01, 0.12)	0.03	(−0.02, 0.22)	0.09	(0.01, 0.26)
C4_NEU	0.09	(−0.07, 0.31)	0.10	(−0.05, 0.21)	0.11	(−0.08, 0.26)	0.09	(0.01, 0.26)	−0.04	(−0.01, 0.22)
C3_NEG	0.32	(0.11, 0.53)	0.27	(0.10, 0.33)	0.30	(0.13, 0.47)	0.25	(0.14, 0.45)	0.13	(0.01, 0.32)
Cz_NEG	0.19	(−0.01, 0.45)	0.12	(−0.06, 0.36)	0.19	(0.02, 0.43)	0.10	(0.02, 0.42)	0.19	(0.01, 0.39)
C4_NEG	0.21	(−0.00, 0.44)	0.20	(−0.01, 0.42)	0.23	(0.07, 0.44)	0.18	(0.03, 0.42)	0.00	(−0.01, 0.11)
C3_POS	0.22	(−0.02, 0.47)	0.24	(0.05, 0.48)	0.25	(0.12, 0.47)	0.25	(0.13, 0.48)	−0.16	(−0.31, 0.08)
Cz_POS	0.16	(−0.04, 0.45)	0.13	(−0.02, 0.41)	0.19	(0.05, 0.22)	0.15	(0.04, 0.23)	−0.03	(−0.21, 0.17)
C4_POS	0.10	(−0.08, 0.39)	0.11	(−0.07, 0.38)	0.06	(−0.05, 0.25)	0.15	(0.01, 0.29)	−0.08	(−0.22, 0.18)
NEU Avg	0.12	(−0.06, 0.36)	0.13	(−0.06, 0.36)	0.12	(−0.06, 0.35)	0.08	(−0.03, 0.31)	0.04	(0.01, 0.13)
NEG Avg	0.25	(0.05, 0.48)	0.20	(−0.01, 0.46)	0.25	(0.11, 0.47)	0.17	(0.02, 040)	0.13	(0.01, 0.33)
POS Avg	0.18	(−0.04, 0.45)	0.18	(−0.02, 0.41)	0.19	(0.01, 0.42)	0.21	(0.01, 0.44)	−0.10	(−0.21, 0.07)
Averall Avg	0.20	(−0.01, 0.46)	0.15	(−0.01, 0.40)	0.14	(0.01, 0.31)	0.12	(0.01, 0.27)	0.00	(−0.00, 0.13)
N1/P2 slope										
C3_NEU	$0.52^{\dagger}$	(0.31, 0.68)	$0.42^{\bullet}$	(0.09, 0.47)	$0.44^{\bullet}$	(0.09, 0.50)	$0.48^{\bullet}$	(0.16, 0.51)	0.16	(−0.12, 0.45)
Cz_NEU	0.38^{*}	(0.21, 0.55)	0.29	(0.09, 0.39)	0.30	(0.11, 0.43)	0.33^{*}	(0.08, 0.45)	0.20	(0.06, 0.38)
C4_NEU	$0.48^{\bullet}$	(0.29, 0.64)	0.38^{*}	(013, 0.56)	$0.45^{\bullet}$	(0.24, 0.62)	$0.48^{\bullet}$	(0.27, 0.63)	0.08	(−0.27, 0.11)
C3_NEG	$0.50^{\bullet}$	(0.29, 0.65)	$0.41^{\bullet}$	(0.16, 0.60)	$0.52^{\dagger}$	(0.33, 0.68)	$0.44^{\bullet}$	(0.19, 0.62)	0.06	(−0.28, 0.31)
Cz_NEG	0.29	(0.11, 0.46)	0.19	(0.01, 0.39)	0.26	(0.08, 0.48)	0.30	(0.15, 0.46)	0.06	(−0.29, 0.32)
C4_NEG	$0.44^{\bullet}$	(0.26, 0.62)	0.36^{*}	(0.13, 0.57)	$0.47^{\bullet}$	(0.29, 0.64)	$0.47^{\bullet}$	(0.30, 0.62)	−0.07	(−0.28, 0.14)
C3_POS	0.33^{*}	(0.12, 0.54)	0.28	(0.03, 0.51)	0.35^{*}	(0.15, 0.57)	0.33^{*}	(0.11, 0.53)	−0.02	(−0.32, 0.23)
Cz_POS	0.25	(0.08, 0.46)	0.20	(0.03, 0.43)	0.26	(0.09, 0.51)	0.26	(0.09, 0.46)	−0.02	(−0.31, 0.22)
C4_POS	0.29	(0.11, 0.46)	0.23	(0.05, 0.44)	0.32^{*}	(0.15, 0.52)	0.34^{*}	(0.18, 0.50)	−0.12	(−0.35, 0.10)
NEU Avg	$0.47^{\bullet}$	(0.28, 0.63)	0.37^{*}	(0.13, 0.55)	0.39^{*}	(0.18, 0.59)	$0.43^{\bullet}$	(0.23, 0.60)	0.16	(−0.12, 0.41)
NEG Avg	$0.44^{\bullet}$	(0.25, 0.60)	0.34^{*}	(0.11, 0.54)	$0.44^{\bullet}$	(0.25, 0.64)	$0.43^{\bullet}$	(0.24, 0.58)	0.02	(−0.28, 0.28)
POS Avg	0.29	(0.12, 0.48)	0.24	(0.05, 0.47)	0.31	(0.13, 0.54)	0.31	(0.13, 0.49)	−0.05	(−0.33, 0.19)
Averall Avg	$0.42^{\bullet}$	(0.24, 0.60)	0.34^{*}	(0.12, 0.55)	0.38^{*}	(0.18, 0.59)	$0.41^{\bullet}$	(0.21, 0.58)	0.09	(−0.19, 0.35)

† $p < 0.001$.
$^{\bullet}$ $p < 0.01$.
* $p < 0.05$ two-tailed.

tures (see Table 4), to evaluate the specific contribution of GDP, RI, and RR facet that is not captured by T-BAS we calculated the correlation of individual residual scores on GDP, RI, and RR with N1/P2 slope. Residual scores were obtained by regressing each of GDP, RI, RR on the T-BAS scores. None of the residual association of these personality measures and N1/P2 slopes reached the significance level (Table 5). Thus, considering that the significant correlations of GDP, RI, and RR with N1/P2 slope (Table 4) had vanished after that each of these constructs were deprived of their common T-BAS component, it seems more likely that T-BAS drives these significant correlations. To test this hypothesis we reran correlation for T-BAS and N1/P2 slope measures by removing GDP, RI, and RR components, one at time from T-BAS. This was done by computing the factor score on T-BAS by subtracting the individuals' scores on GDP, RI, or RR. As Table 6 clearly shows, removing one component at a time from T-BAS did not compromise the significance of the previously observed significant relationships between T-BAS and N1/P2 slopes reported in Table 4. Instead, the observed high degree of overlap between the confidence interval for T-BAS and its reduced versions suggests that the change in the size of the correlation coefficients was not statistically significant in any case.

Table 5
Residual correlation of GDP, RI, RR with N1/P2 slope at C3 for neutral, negative, and positive pictures..

N1/P2 slope	Residual GDP		Residual RI		Residual RR	
	r	95%CI	r	95%CI	r	95%CI
C3 NEU	0.31	(0.14, 0.50)	0.28	(0.13, 0.46)	0.21	(−0.01, 0.41)
C3 NEG	0.29	(0.12, 0.48)	0.08	(−0.08, 0.27)	0.22	(−0.01, 0.42)
C3 POS	0.19	(−0.01, 0.42)	0.05	(−0.11, 0.27)	0.08	(−0.15, 0.31)

Table 6
Correlation of T-BAS and its reduced forms with N1/P2 slope at C3 for neutral, negative, and positive pictures.

N1/P2 slope	T-BAS		T-BAS_NoGDP		T-BAS_NoRI		T-BAS_NoRR		T-BAS_NoIMP	
	r	95%CI	r	95%CI	r	95%CI	r	95%CI	r	95%CI
C3 NEU	0.52[†]	(0.31, 0.68)	0.52[†]	(0.32, 0.69)	0.51[†]	(0.31, 0.68)	0.47[•]	(0.26, 0.66)	0.49[•]	(0.25, 0.65)
C3 NEG	0.50[•]	(0.29, 0.65)	0.49[•]	(0.30, 0.65)	0.45[•]	(0.23, 0.62)	0.46[•]	(0.26, 0.64)	0.50[•]	(0.28, 0.65)
C3 POS	0.33[*]	(0.12, 0.54)	0.33[*]	(0.13, 0.54)	0.30	(0.08, 0.51)	0.29	(0.08, 0.50)	0.35	(0.13, 0.55)

Note. T-BAS: Total score for the Behavioral Approach System;
T-BAS_NoGDP: T-BAS scores by removing Goal-Drive Persistence;
T-BAS_NoRI: T-BAS scores by removing Reward Interest;
T-BAS_NoRR: T-BAS scores by removing Reward Reactivity;
T-BAS_NoIMP: T-BAS scores by removing Impulsivity.

[†] $p < .001$.

[•] $p < 0.01$.

[*] $p < 0.05$.

3.6. Individual differences in T-BAS trait and its facets on N1/P2 complex

In this section we performed separate ANCOVAs, for T-BAS and each of its facets (GDP, RI, and RR, IMP) entered as the covariate, to examine how individual differences in these trait measures interact with the emotion modulation and A/R of the N1/P2 complex. The analysis was focused on N1/P2 amplitude and N1/P2 slope and included only the C3, Cz and C4 leads, as these sites were demonstrated as the most sensitive to A/R of the ERPs (see e.g., (Brocke et al., 2000; Zuckerman, 1990)). Since we have shown that T-BAS drives these significant correlations between GDP, RI and RR with N1/P2 slope, we expected that ANCOVAs should disclose the same significant effects for T-BAS and its facets with the exception of IMP.

The ANCOVA performed on the N1/P2 peak amplitude revealed a significant second order interaction of T-BAS with stimulus intensity, $F(4148) = 4.48$, $p = 0.03$, $\eta^2_p = 0.06$. Follow-up contrasts indicated that, the auditory intensity of 88 and 96 dB elicited significantly larger N1/P2 amplitudes in high T-BAS compared to low T-BAS participants ($p < 0.05$). This effect can be clearly derived from the overlapping ERP waveforms displayed across stimulus intensity (Fig. 2a). Further, the second order interaction of Valence with T-BAS was significant, $F(2,74) = 3.35$, $p = 0.041$, $\eta^2_p = 0.05$. The decomposition of this interaction revealed that the N1/P2 amplitude during positive pictures was higher in high T-BAS compared to low T-BAS participants (Fig. 2b).

The analysis on the N1/P2 slope scores yielded a robust main effect for T-BAS, $F(1,37) = 8.04$, $p = 0.007$, $\eta^2_p = 0.19$, indicating higher slopes in high T-BAS compared to low T-BAS participants (bottom right quadrant of Fig. 2).

Separate ANCOVAs on N1/P2 amplitude, using GDP, RI, and RR as a covariate, yielded similar findings to that obtained for T-BAS factor. That is, for each of these factors, we obtained a significant second order interaction of the factor with stimulus intensity (GDP: $F(4148) = 3.08$, $p = 0.02$, $\eta^2_p = 0.013$; RI: $F(4148) = 5.15$, $p < 0.001$, $\eta^2_p = 0.006$; RR: $F(1148) = 3.76$, $p = 0.006$, $\eta^2_p = 0.007$). As obtained for T-BAS, follow-up contrasts indicated that, the auditory intensity of 88 and 96 dB elicited significantly larger N1/P2 amplitudes in high GDP, RI, and RR participants as compared with low level ones ($p < 0.05$).

Separate ANCOVAs performed on N1/P2 slope scores with GDP, RI, and RR as a covariate yielded a main effect that was similar to that obtained for T-BAS factor (GDP: $F(1,37) = 4.64$, $p = 0.038$, $\eta^2_p = 0.11$, RI: $F(1,37) = 7.25$, $p = 0.0106$, $\eta^2_p = 0.16$; RR: $F(1,37) = 7.74$, $p = 0.008$, $\eta^2_p = 0.17$). As obtained for T-BAS trait, these significant effects indicated that higher levels of these subtraits were all associated to higher N1/P2 slopes. It is important to note that we failed to find any significant main or interaction effect involving the IMP facet ($F < 1$).

3.7. T- BAS and its facets using LORETA source localization

Since higher T-BAS as well as GDP, RI, and RR facets are associated with higher N1/P2 amplitude and slope measures, to the temporal analyses we have also provided LORETA analyses on N1 and P2 time windows (100–140 ms and 200–225 ms) to locate cortical sources of significant differences on current density between high vs low levels of T-BAS measure.

In terms of individual differences in T-BAS, we found that high T-BAS, compared to low T-BAS participants, had a significantly higher activity at 211 ms (i.e., a maximal positive t value in the time window of P2 wave) in the right inferior parietal lobule (IPL, BA40) and left anterior cingulate cortex (ACC, BA32). In addition, high GDP, as compared low GDP participants, at time frame of 203 ms had higher activity in the same cortical structures found for T-BAS (i.e., BA40, supramarginal gyrus; ACC, BA32). Moreover, high RI at 203 ms had higher activity at superior frontal gyrus and posterior cingulate cortex (PCC) in the left hemisphere (BA10 and BA30), while high RR had more activity in the anterior cingulate (BA24 and BA32). These regional differences are displayed in Fig. 3 and Table 7.

4. Discussion

The findings of this study corroborate the view that auditory A/R, as traditionally defined, is related to the temperamental traits of T-BAS and its subtraits of GDP, RI, and RR, as measured by the RST-PQ. In line with RST theory we found a positive relation of T-BAS, GDP, RI, and RR scores with N1/P2 slope, but we failed to find a significant relation for the Imp facet (see Table 4). However, the present study shows that impulsivity is not related to augmenting, a finding that does not support original A/R reports of larger N100 amplitudes at Cz in higher impulsive individuals (Barratt et al., 1987; Carrillo-De-La-Pena & Barratt, 1993). Behavioral studies have consistently shown the multidimensional nature of impulsivity, and there have been numerous attempts to clarify the multifactorial dimensions of impulsivity (Caseras, Avila, & Torrubia, 2003; Miller, Joseph, & Tudway, 2004; Quilty & Oakman, 2004; Reynolds, Ortengren, Richards, & de Wit, 2006; Reynolds, Penfold, & Patak, 2008; Whiteside & Lynam, 2003). A valid criticism of this literature is that different results are obtained depending on which impulsivity tests are used. Thus, we think that our ERP-impulsivity lacking relationship can be due to the fact that the dimension named as "impulsivity" in previous research does not correspond to the impulsivity dimension investigated here. Indeed, it is important to note that impulsivity from RST-PQ is a measure of rash impulsivity, typically described by items referring to the tendency to act rashly and without consideration of consequences, or as a behaviour that occurs without reflection or careful deliberation (e.g., "I often do risky things without thinking of the consequences"). In sum, our lacking impulsivity/ERP find-

Table 7
MNI coordinates and Brodmann areas (BA) of significant differences in current density of P2 ERP waves between high T-BAS (N = 19) vs Low T-BAS (N = 17), high GDP (N = 20) vs Low GDP (N = 12), high RI (N = 18) vs low RI (N = 16), and high RR (N = 18) vs low RR (N = 19). ERPs were elicited by auditory tones delivered using the augmenting/reducing paradigm.

ERP	X (MNI)	Y (MNI)	Z (MNI)	t (max)	BA	Lobe	Structure	No. of Voxels $p < 0.01$
Hi vs Lo T-BAS	−10	20	40	6.80	BA32	Frontal	Cingulate Gyrus	10
P2 (211 ms)	45	−35	35	6.60	BA40	Parietal	Inferior Parietal Lobule	11
Hi vs Lo GDP	40	−45	35	6.54	BA40	Parietal	Supramarginal Gyrus	10
P2 (203 ms)	−5	40	5	5.85	BA32	Limbic	Anterior Cingulate	35
Hi vs Lo RI	−10	55	0	6.05	BA10	Frontal	Superior Frontal Gyrus	25
P2 (203 ms)	−5	−55	10	5.73	BA30	Limbic	Posterior Cingulate	22
Hi vs Lo RR	0	25	25	6.80	BA24	Limbic	Anterior Cingulate	17
P2 (211 ms)	−5	20	30	6.25	BA32	Limbic	Cingulate Gyrus	17

Note: A positive value of t indicates a higher current density, for the P2 wave, in Hi than Lo T-BAS, GDP, RI, and RR participants. A negative X(MNI) coordinate indicates the left and a positive value the right hemisphere.

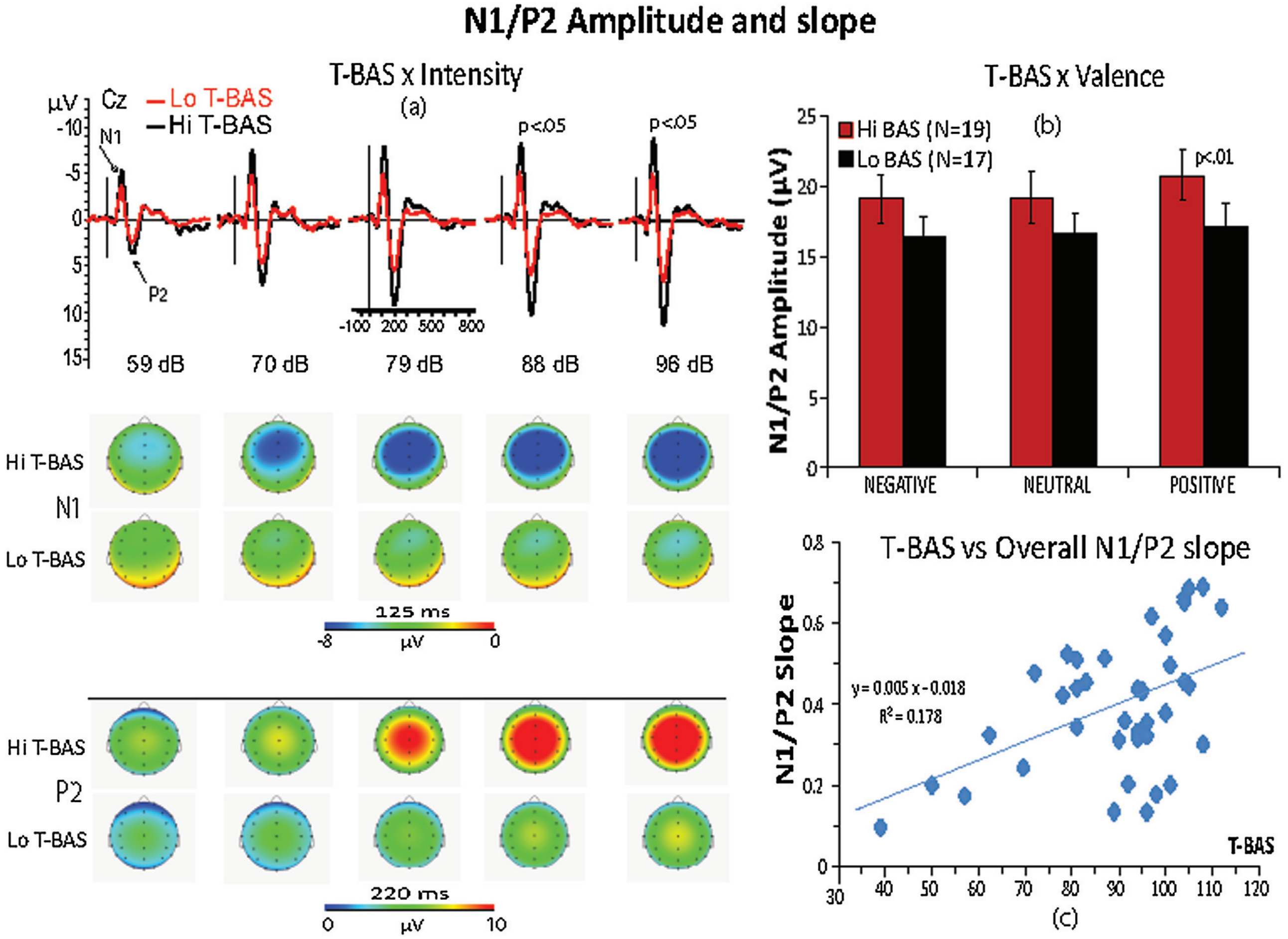

Fig. 2. Grand average midline ERP responses and scalp maps of N1 and P2 amplitudes for 5 tone intensities (59, 70, 79, 88, 96 dB SPL) in high and low T-BAS participants (left panel). Histogram in the upper-right panel is displaying the influence of T-BAS and Valence of the picture on overall N1/P2 amplitude. Scatterplot in the bottom-right panel illustrates the relationship between BAS and overall N1/P2 slope.

ings indicate that this trait measure is related to but distinct from reward-reactivity and other T-BAS factors (Smillie, Jackson et al., 2006). Although our results support the importance of the search for multiple BAS processes suggested by Carver and White (1994) work, they also challenge all recent psychometric attempts to measure rRST with a single one-dimensional BAS factor (Jackson, 2009; Reuter, Cooper, Smillie, Markett, & Montag, 2015; Smederevac, Mitrović, Čolović, & Nikolašević, 2014).

Our findings clearly indicate that high T-BAS individuals are ERP augmenters and corroborate the theoretical view (Corr, 2016) that the BAS is multidimensional, and especially, there is an important distinction between impulsivity and the other three. Using ANCOVA we observed significant associations between P1/N1 and N1/P2 amplitudes and T-BAS: high T-BAS participants were augmenters of N1/P2 amplitude as compared with low T-BAS ones, in response to increased levels of auditory intensity (see Fig. 2a). This observation substantiates the positive association, reported in pioneer studies, between augmenting and action-oriented temperamental traits as sensation seeking (Burkhard Brocke et al., 1999; Hegerl et al., 1995; Zuckerman et al., 1974).

Although we failed to find a modulation effect of emotional valence on auditory probes, the effect of the interaction between emotional valence and individual differences in T-BAS functioning was significant. Independently from auditory intensity, high T-BAS

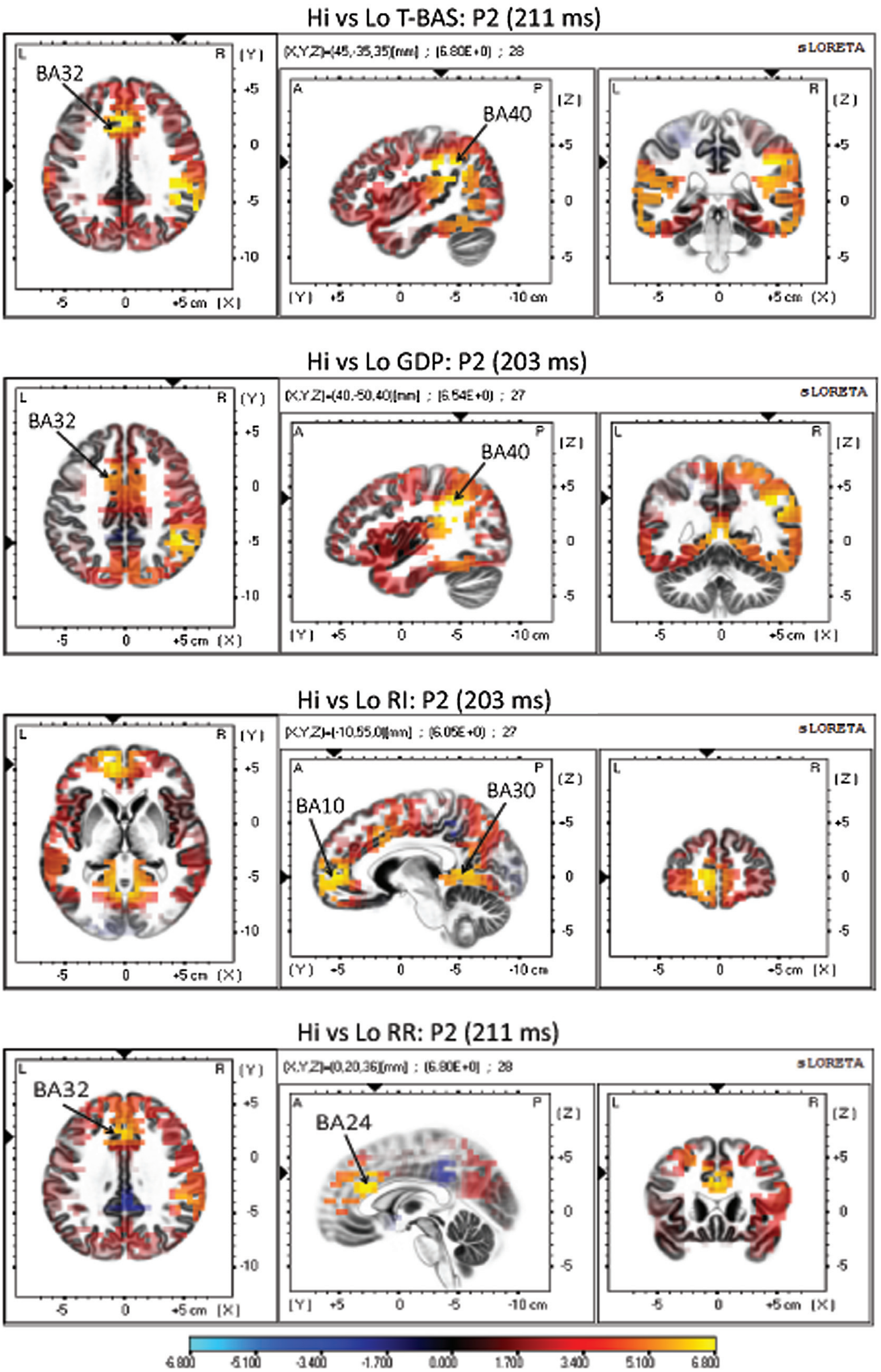

Fig. 3. Maps of sLORETA differences comparing low vs. high T-BAS groups (P2 wave). A higher current density difference (yellow color) occurred in high T-BAS in the anterior cingulate gyrus (BA32) at a time-frame of 219 ms (corrected threshold, p < 0.01). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

participants as compared to low T-BAS ones, had a larger N1/P2 complex during the view of positive valenced images (Fig. 2b). This effect can be explained by the higher sensitivity of high BAS individuals to appetitive pictures (Sommer, Van Der Molen, & De Pascalis, 2016). We think that the visual cue, anticipating of 2 s the emotional value of the subsequent picture, could have facilitated the intake of positive pictures in higher T-BAS participants. Low T-BAS participants, on the other side, were less interested to positive pictures and thus reduced in advance the activation induced by these pictures (Fig. 2b). The present ERP results suggest that individual differences in behavioral approach can affect attention processes as early as 100 ms after stimulus onset, and are indicative of the close link between the behavioral approach and early attention systems.

Indeed, this result parallels a number of previous findings obtained with various experimental paradigms showing, e.g., higher startle reflex response in pleasant pictures in higher reward sensitivity participants (Aluja et al., 2015), larger ERP amplitudes as early as 100 ms elicited by appetitive pictures in higher behavioral approach sensitivity individuals (Gable & Harmon-Jones, 2012).

On the whole the present findings, in line with the revised RST theoretical view (Corr, 2008, 2016), demonstrate the multidimentional nature of T-BAS by showing that, although GDP, RI and RR have common underlying electrocortical mechanisms, these are separated from Imp, which serves a different function in the causal chain of events from anticipatory pleasure to the final "excitement pleasure attack" for the capture of the desired object. This was possible thanks to the development of the RST-PQ T-BAS scale (Corr & Cooper, 2016) that allows the differentiation between reward sensitivity and rash impulsivity (Dawe et al., 2004; Quilty & Oakman, 2004; Smillie, Jackson et al., 2006; Smillie, Pickering et al., 2006) and to test of the multidimensional nature of the BAS, as also suggested by Carver and White (1994).

Finally, using sLORETA source localization method we found a significant activation of the left ACC (BA32) and the right parietal IPL (BA40) in both high T-BAS compared to low T-BAS and high GDP compared to low GDP participants. The higher activation of the ACC in higher approach-related traits is reported in a plethora of neuroimaging studies that, using various methodologies and experimental paradigms, have converged on the anterior cingulate cortex (ACC) as a neurophysiological correlate of extraversion-related traits. For example, Eisenberger, Lieberman, and Satpute (2005), using fMRI recordings during an oddball task, found neuroticism associated with increased dACC reactivity, typically associated with discrepancy detection, whereas extraversion associated with rACC and lateral prefrontal cortex (LPFC) activations. Canli, Amin, Haas, Omura, and Constable (2004), using fMRI and the emotional Stroop attention task, demonstrate that changes in rostral ACC activation are associated with the personality trait of extraversion. Moreover, the rostral ACC has been involved in assessing the salience of emotional and motivational information and in the regulation of emotional responses (Bush, Luu, & Posner, 2000).

Studies using positron emission tomography have evidenced that positive emotionality (or extraversion), a trait believed to protect against substance use disorders, was positively associated with enhanced baseline-resting metabolism in various frontal regions that included ACC (Volkow et al., 2011). Further, using LORETA algorithm, the association between agentic-extraversion and EEG-theta activity within rostral subdivisions of the ACC has been reported (Chavanon, Wacker, & Stemmler, 2011). Yet, using current density of alpha activity we also found a unique association between higher BAS scores and left-sided activation in the middle frontal gyrus (BA11, see De Pascalis, Cozzuto, Caprara, & Alessandri, 2013).

The IPL plays an important role in different aspects of attention (Behrmann, Geng, & Shomstein, 2004; Clower, West, Lynch, & Strick, 2001; Shapiro, Hillstrom, & Husain, 2002), i.e., maintaining attention on current task goals and responding to salient and new events in the environment (Singh-Curry & Husain, 2009). This structure has been found to be activated in response to emotional words during the emotional Stroop task (Compton et al., 2003) and to increases in functional connectivity between the AC and IPL linked to greater extraversion across individuals in response to positive stimuli (Haas, Omura, Amin, Constable, & Canli, 2006).

Importantly, findings from the present study also extend previous findings to show that the ACC and IPL activation is associated with both higher T-BAS and its GDP facet. But we also found that RI and RR facets are in part dissociated from T-BAS since higher RR scores are associated with the activation of both the rostral ACC (BA24) and dorsal ACC (BA32), while higher scores on RI facet showed higher activity in the superior frontal gyrus (BA10) and in the PCC in the limbic lobe. In terms of cortical source localization of the ERPs, the present findings indicate that RST-PQ is a good tool to separate appetitive exploration (i.e., RI, GDP) and RR (though themselves are different they share the activation of ACC) from rapid responding of Impulsivity (for which we failed to find any ERP correlate and this facet appear to be independent from the other T-BAS facets). One reason for the lacking association between impulsivity and processes represented by N1 and P2 could be due to the fact that we measured rash impulsivity (a dimension describing behaviours that occurs without reflection) and the A/R paradigm during of valenced pictures that did not require any action response as "the excitement attack to capture the desired object" (Corr, 2008), but rather simply to process the delivered stimuli.

Although LORETA provides good localization accuracy, a major limitation of the present study is in the fact that only 30 electrodes were used for source analysis. This reduces the spatial resolution, and with impaired spatial resolution, there is a smaller chance that LORETA will be able to separate two closely spaced sources (Congedo & Joffe, 2009; Greenblatt, Ossadtchi, & Pflieger, 2005). Thus, a greater number of recording electrodes is recommended in future studies to enhance spatial resolution. Another limitation of the present study lies in the fact that our findings are restricted to women participants and, thus, cannot be generalized to men. Thus, further studies are necessary to replicate the present findings by considering gender and state emotionality measures as potential variables influencing the association between RST traits, and ERP responses. In conclusion, the present study served to test theoretical constructs of RST in terms of emotional modulation of auditory A/R and source localization of the ERP components, and indicated that these T-BAS, and reward components can be differentiated from impulsivity. Mainly, sLORETA source localization findings indicated that higher T-BAS and GDP participants share the activation of both frontal and parietal regions (left ACC and right IPL/Supramarginal Gyrus), while higher RI and RR have different cortical activation regions reflecting separate but interacting brain systems that together allow the individual to move towards the final biological reinforcer, as is necessary for the sustenance of life (Carver & White, 1994; Corr, 2008).

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Appendix A.

Numbers of IAPS images used for each affective category:

Pleasant/high Arousal Stimuli

1920, 2057, 2070, 2080, 2165, 2311, 2352, 4002, 4004, 4210, 4220, 4232, 4300, 4310, 4470, 4520, 4550, 4572, 4599, 4608, 4611, 4651, 4652, 4658, 4660, 4669, 4670, 4672, 4680, 4681, 4800, 5629, 8030, 8080, 8090, 8160, 8185, 8190, 8300, 8420, 8490, 8500, 8501, 8502, 8503.

Unpleasant/high Arousal Stimuli:

1300, 1321, 2710, 3015, 3030, 3051, 3060, 3140, 3160, 3170, 3181, 3250, 3350, 3530, 6260, 6300, 6312, 6313, 6350, 6370, 6510, 6530, 6540, 6550, 6560, 6571, 6821, 6830, 7380, 9005, 9006, 9180, 9181, 9252, 9300, 9320, 9340, 9405, 9410, 9433, 9800, 9810, 9910, 9911, 9920

Neutral/high Arousal Stimuli:

1616, 2214, 2381, 2485, 2840, 2880, 5220, 5410, 5470, 5535, 5720, 5740, 5750, 5789, 5920, 7205, 7207, 7230, 7270, 7350, 7352, 7495, 7496, 7502, 7510, 7640, 7820, 7830. Eighteen high-arousal neutral stimuli were selected from the web. They are available on request at: vilfredo.depascalis@uniroma1.it

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