Article

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Modulation of cognitive processing by emotional valence studied through event-related potentials in humans

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Abstract

This experiment investigated whether the emotional content of a stimulus could modulate its cognitive processing. Particularly, we focused on the influence of the valence dimension on the cognitive processing triggered by a non emotional oddball task. To this end, event-related potentials (ERPs) were recorded from 25 sites during a visual oddball paradigm. Three sets of pictures (unpleasant, neutral and pleasant) with low arousal values served as rare target items. Subjects were simply asked to realize a standard/target categorization task, irrespective of the picture valence. A temporal principal component analysis allowed us to identify several evoked components (i.e. P1, P2, N2, P3a and P3b). Emotional effects observed on P1, P2 and P3b showed that the valence content of the stimulus modulates the cognitive processes at several points in the information processing stream.

Keywords: Emotion; P3a; P3b; P1; P2; Valence; Principal Component Analysis; Event-related potential

The investigation of the emotion–cognition relationship is facilitated by the use of electrophysiological markers such as the event-related potentials (ERPs), which are task dependent with a high temporal resolution [2]. Several studies aimed at examining the time course and the topography of ERPs in response to affective or neutral pictures [5]. Such an approach focused on components that could be related to the main dimensions of emotional processing, i.e. valence (from unpleasant to pleasant) and arousal (from relaxed to aroused). One consistent finding among these studies is that emotionally intense situations elicit larger P300 and other late positivities than neutral ones. This has been interpreted as an arousal effect that reflects the engagement of the motivational system for a more complete processing of the stimulus [5].

When interactions between emotion and cognition are concerned, various experimental strategies can be employed. For instance, some authors investigated whether cognitive processing could differ as a function of the context induced by an external emotional stimulation [6] or of the emotional reactivity of the participants [7]. Other studies explored the likelihood that cognitive processing were triggered by emotional features, such as valence or arousal [1]. Recently [4], it was demonstrated that, even if the task did not require an explicit affective evaluation, the early stages of processing could be influenced by affective characteristics of the stimulus. In short, these findings indicate the existence of a relatively fast implicit emotional processing of the stimulation.

In the same vein, the present study examined emotion-cognition relationships by focusing on the influence of the implicit processing of the emotional *valence* of target stimuli on the cognitive processing induced by a non emotional oddball task. This influence was examined all along the stream of information processing, i.e. early visual and attentional processing, deviance detection and reorienting processing indexed by the P3a, and context updating indexed by the P3b.

As P3a, P3b and other components may be evoked very close together in time, the classical baseline to peak measures seemed inadequate to distinguish their superimposed activities. Thus, in order to disentangle the different components elicited in response to rare target stimuli, we used a temporal principal component analysis (PCA). Furthermore, in order to avoid influences of

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emotional arousal, target stimuli possessed low and homogeneous arousal values across valence levels. Indeed, presenting stimuli with high arousal values could make them more relevant for the task and, therefore, induce higher P3b values [3]. Moreover, as specified by Polich and Kok [11], arousal influences may mask distinct valence influences by affecting the ERPs non specifically. Thus, the main objective of the current study was to characterize the modulation of cognitive processing by the valence dimension of stimuli used as targets in a non emotional oddball task.

Twelve right-handed healthy undergraduate female students (20.6 ± 1.96 years) were included in the study. The oddball task comprised a total of 250 stimuli, divided into two conditions presented with unequal probabilities (70 vs. 30%). A red and white checkerboard served as frequent standard picture ($n = 175$). Three groups of 25 pictures (unpleasant, U; neutral, N; pleasant, P) served as rare target items. They were taken from the International Affective Picture System (IAPS)[1] [9] and were selected in such a way that they differed significantly in the valence dimension (means: U = 2.91, N = 4.79, P = 7.53; $F(2,72) = 561$, $P < 0.001$) but not in the arousal dimension (means: U = 5.09, N = 5.12, P = 5.12; $F(2,72) = 0.07$, not significant). All stimuli were randomly presented for a duration of 1000 ms, occupying about 15° of horizontal visual angle. The interval between stimuli varied randomly between 800 and 900 ms.

Electroencephalographic (EEG) activity was recorded at 25 electrode sites of the extended 10–20 system, using tin electrodes referenced to linked earlobes with a forehead ground (impedance < 5 kΩ). Four additional electrodes were placed at the outer canthi of each eye and above and below the right eye for a bipolar recording for electro-ocular activity. The EEG was recorded at a sampling rate of 300 Hz. The high–low bandpass was set between 0.016 and 70 Hz (50 Hz notch filter). Eye-movement artifacts were corrected from the EEG by a dynamic regression analysis in the frequency domain [16] and remaining trials with artifacts exceeding ±120 μV were excluded from the analysis in all channels. EEG epochs (−100 to 750 ms time-locked to the stimulus onset) were low-filtered below 30 Hz (3 dB octave/slope), baseline corrected (−100 to 0 ms) and averaged offline.

Participants gave informed consent and sat in a reclining lounge chair located in a sound attenuated, electrically shielded, and dimly lighted room. Electrodes were attached and participants were informed that a checkerboard would be repeatedly presented (the frequent item) and that they would have to react as quickly as possible, by pressing the spacebar of the keyboard, when they would see a picture different from the checkerboard (the rare target item). They were also told to avoid blinking and to maintain gaze on the white centered cross, which occurred on the computer screen between the picture presentations.

The grand average ERP waveforms to standard pictures, unpleasant, neutral and pleasant targets at 15 locations are represented in Fig. 1A. The 1200 (25 electrodes × 4 conditions × 12 subjects) ERP averages (225 points from 0 to 750 ms) were submitted to a temporal PCA using a covariance matrix. All factors obtained (eigenvalue > 1) were Varimax rotated and the number of those kept for further analyses was established when at least 90% of cumulative variance in the data was explained. Eight temporal factors (TF) were extracted (Fig. 1B). TF2 and TF4 were excluded as they were the result of the autocorrelated nature of the data [15]. Topographical distributions of the factor scores as a function of the condition are shown in Fig. 1C. Regarding their latency window, their distribution and their apparent sensitivity to the experimental conditions, TF1 can be associated with the parietally peaking positive P3b component and TF5 with the fronto-centrally peaking positive P3a component. TF3 may correspond to the centrally peaking negative N2 and TF6 to the occipitally peaking positive P2. TF7 may represent an early part of the occipital P1 component and TF8 a late portion of the P1.

In order to avoid interpreting results in terms of variations around the grand mean averaged ERP (i.e. the ERP obtained by averaging all subjects, all conditions and all sites waveforms), the mean amplitude was calculated for each factor in the temporal window in which at least 70% of the variance in the data set was explained by the factor (0.7 criterion). The averaged windows were: early part of the P1 from 110 to 133 ms, late part of the P1 from 150 to 165 ms, P2 from 180 to 213 ms, N2 from 233 to 323 ms, P3a from 343 to 390 ms and P3b from 406 to 603 ms. These averaged amplitudes were submitted to Greenhouse–Geisser corrected analyses of variance (ANOVAs) with emotional conditions (three levels) and electrodes (25 levels) as within-subject variables. When suitable, comparisons between the paired three levels of valence were performed with a Conditions (2) × Electrodes (25) ANOVA. For each analysis, we assessed scalp distribution differences among conditions using McCarthy and Wood's normalization procedure [10]; post hoc comparisons were made with the Tukey HSD test.

Analyses performed on the amplitudes of the P3a, N2 and early part of the P1 did not reveal any significant main effect of condition nor any Conditions × Electrodes interaction. In contrast, amplitudes of the P3b, P2 and late portion of the P1 revealed a significant Conditions × Electrodes interaction before and after the normalization procedure. The late

[1] The IAPS identification numbers are as follows. Standard picture: 7182. Unpleasant pictures: 1270, 1280, 2100, 2120, 2700, 2750, 2753, 3160, 3190, 4621, 6241, 6610, 6800, 6940, 7361, 9005, 9008, 9041, 9102, 9180, 9390, 9402, 9411, 9417, 9520. Neutral pictures: 1112, 1390, 1560, 2220, 2351, 2681, 3210, 4232, 4300, 4651, 5970, 6314, 6900, 6910, 6930, 7501, 7560, 7620, 8021, 8060, 8117, 8250, 8260, 9404, 9415. Pleasant pictures: 1463, 1710, 1811, 1999, 2040, 2050, 2080, 2150, 2160, 2165, 2352, 2550, 2630, 4603, 4610, 4641, 7230, 7260, 7282, 7430, 7570, 8162, 8503, 8531, 8540.

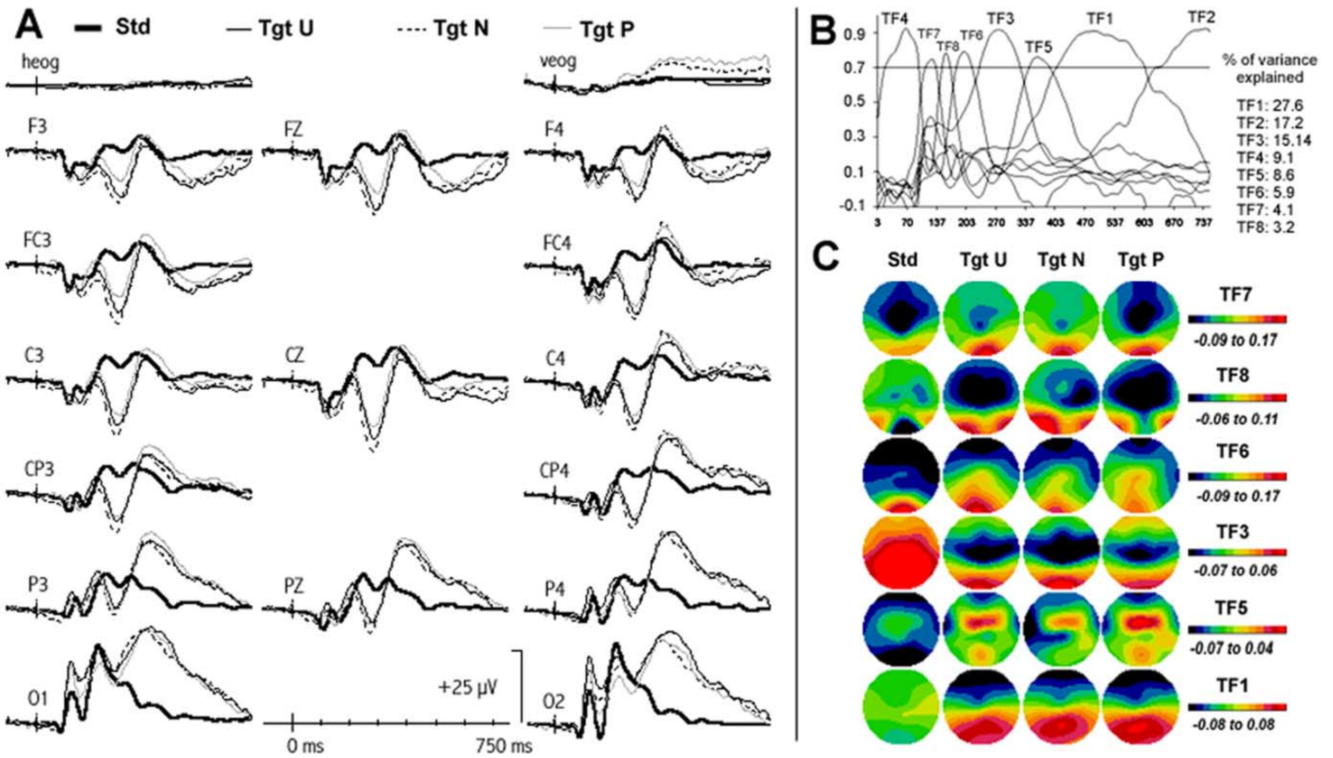

Fig. 1. (A) Averaged ERPs for the standard and the three target categories at 15 electrode sites. Std, standard; Tgt, target; U, unpleasant; N, neutral; P, pleasant. (B) Loadings as a function of time for the rotated factors. Variance explained by each factor is also indicated. (C) Topographical distribution of the factor scores as a function of the experimental conditions obtained with Statmap 3D.

portion of the P1 was more positive for unpleasant stimuli than for pleasant ones ($F(24, 264) = 5.28$; $P < 0.01$) at parieto-occipital sites (P3, P4, Pz, O1 and O2). The P2 related to the unpleasant stimuli was more positive than to the pleasant stimuli ($F(24, 264) = 8.96$; $P < 0.001$) at parieto-occipital sites (P4, Pz, O1 and O2). This component was also larger to pleasant than to neutral stimuli ($F(24, 264) = 5.55$; $P < 0.05$), on a wider area (C4, CP3, CP4, P3, P4, Pz, T7, T8, TP7 TP8, P7and P8). Finally, unpleasant pictures evoked smaller P3b than pleasant ones ($F(24, 264) = 6$; $P < 0.001$), particularly at fronto-central sites (Fp1, Fp2, F3, Fz and Cz).

The objective of the present study was to show that several steps of cognitive processing could be influenced by an implicit valence evaluation.

First, we demonstrated that the early visual processing indexed by the late part of the P1 component was modulated by the emotional content of the stimulation, mainly at occipital sites. Smith et al. [13] noticed that, in an emotional categorization task, the amplitude of the P1 is larger for the unpleasant arousing stimulation than for the pleasant arousing ones. This result is interpreted as a negativity bias in attention allocation in the extrastriate visual cortex, with higher resources devoted to unpleasant stimuli. The present study shows that this negativity bias could also occur when arousal dimension is low and when the subjects are engaged in an implicit evaluation task.

Second, we found that another attention related component (P2) could be modulated by the valence of the stimulation in an implicit affective evaluation task. In a non-emotional categorization task, Carretié et al. [4] showed that the P2 amplitude was higher, at frontal and central sites, in response to arousing unpleasant stimuli than in response to arousing pleasant ones. Our findings extend the results of these authors by showing that the negativity bias on early attentional processing can be triggered by the valence content of the stimulation when the emotional arousal is reduced.

Third, in the present investigation, the rare stimuli of the oddball task elicited both a P3a and a P3b, which is now a classical finding when principal component analyses are used to analyse the data [14]. The processing of rare target stimuli is thought to include a detection of the deviance from the context (indexed by the P3a) and a latter updating process as a function of the stimulus relevance to the task (indexed by the P3b). The processing engaged in this task was not based on the emotional content of each stimulus but on the rare/frequent distinction. Consequently, each rare picture possessed the same status with regard to context updating and the same relevance to the task. Then, amplitude of the P3b should not have been different between the three levels of valence [8]. However, even if the maximum of P3b amplitude was observed on parietal sites and did not significantly differ between the three valence levels, the amplitude distributions differed at frontal and central sites as a function of the valence. Previous studies have already shown P3b amplitude variations as a function of variables that were not related to the task structure or categorization of the stimuli, i.e. food intake, high body temperature or ultradian cycles [11]. Yet, this P3b amplitude modulation was found at all recording sites and it was thus interpreted as an increased allocation of processing resources. On the contrary, in the present study, we found a difference in the scalp topography of the P3b amplitude between pleasant and unpleasant conditions. Topographical effects on P3b can be observed when two types of stimuli lead to a difference in the relative contribution of different intracranial sources [12]. Thus, our data suggest that the P3b neuronal network involved in the context updating takes into account the valence content of the stimulation, even if the arousal dimension is kept low.

Our results are in line with those of Smith et al. [13] suggesting that the valence of the ongoing stimulus is taken into account at several points in the information processing stream. Thus, the affective content can implicitly interact with many cognitive processes along this stream.

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