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# Event-related delta and theta responses may reflect the valence discrimination in the emotional oddball task

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## Abstract

How emotion and cognition interact is still a matter of debate. Investigation of this interaction in terms of the brain oscillatory dynamics appears to be an essential approach. To investigate this topic, we designed two separate three-stimulus oddball tasks, including emotional stimuli with different valences. Twenty healthy young subjects were included in the study. They completed two tasks, namely: the positive emotional oddball task and the negative emotional oddball task. Each task included the target, non-target, and distractor stimuli. Positive and negative pictures were the target stimuli in the positive and negative emotional oddball task. We asked participants to determine the number of target stimuli in each task. During sessions, EEGs were recorded with 32 electrodes. We found that (negative) target stimuli elicit higher delta (1–3.5 Hz) and theta (4–7 Hz) power responses but not the phase-locking responses compared to (positive) distractor stimuli during the negative oddball task. On the other hand, the same effect was not seen during the positive emotional oddball task. Here, we showed that the valence dimension interacted with the target status. Finally, we summarized our results that the presence of negative distractors attenuated the target effect of the positive stimuli due to the negative bias.

**Keywords** Valence discrimination · Event-related oscillations · Delta band · Theta band · Negative bias

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## Introduction

Emotion and cognition are two main and inseparable brain processes. Even if we are not aware of it, emotion greatly influences all our perception and cognition processes. In other words, emotion is one of the fundamental intrinsic features of cognitive mechanisms such as attention, memory, and decision-making (Duncan and Barrett 2007). It has been known that cognitive processes are represented by brain oscillations since Berger's pioneering work. Similarly, affective processing has been systematically studied using electroencephalography (EEG) (see for reviews: Olofsson et al. 2008; Güntekin and Başar 2014). However, it is still not completely understood how cognitive and emotional mechanisms interact with each other. In this study, we aimed to investigate the oscillatory brain mechanism involved in the process of target detection based on valence. We proposed that our approach reveal possible evidence for the link between target status and valence dimension, which can be interpreted as a more general concept such as emotion-cognition interaction.

According to a generally accepted approach, emotional stimuli are mostly defined in two dimensions (Bradley et al. 2001). Valence is the dimension varying from positive to negative (pleasant to unpleasant), while the arousal level indicates its intensity (Bradley et al. 2001). EEG is one of the most fundamental methods of studying emotional processing and its underlying mechanisms. A comprehensive review on event-related potentials (ERPs) findings suggested that the valence effects are observed in the early time window (100–250 ms) while the later time window (200–1000 ms) is affected by the arousal dimension (Olofsson et al. 2008). Moreover, valence and arousal effects are not specific to the time windows; these dimensions elicit different ERP components. Studies indicated that emotional (high arousal) stimuli elicit higher P300 and late positive potential (LPP) responses than neutral stimuli (low arousal) (Cuthbert et al. 2000; Schupp et al. 2000, 2007; de Cesarei and Codispoti 2011; Solomon et al. 2012; Zhang et al. 2013). Besides the consistent findings on arousal effects, there are mixed results about the valence. Some studies showed that negative stimuli produce larger early ERP (e.g., N1, P1) components or LPP than positive ones (Bernat et al. 2001; Smith et al. 2003; Delplanque et al. 2004; Carretie et al. 2006). Other studies, however, reported the opposite results that the positive stimuli elicited greater ERP responses than the negative and neutral stimuli (Cuthbert et al. 2000; Keil et al. 2002). Also, some studies found no difference between negative and positive stimuli (Schupp et al. 2003; Franken et al. 2008; Solomon et al. 2012).

As mentioned in the previous paragraph, ERP studies have provided notable information to understand emotional processing. Nonetheless, a well-structured consensus, especially about the valence dimension, has not been reached yet. We should note that considering the emotional processing studies, another critical issue can be the variability in experimental protocols, and this may be the reason for mixed results in the literature.

Emotional picture processing has been investigated with many designs and tasks such as passive viewing design, block design, implicit task, categorization task, and oddball task (see for example Schupp et al. 2000; Delplanque et al. 2006; Briggs and Martin 2008; Balconi et al. 2009; Klados et al. 2009; Feng et al. 2012; Weinreich et al. 2016; Schubring and Schupp 2019). Each experimental design can reflect a different side of emotional processing. This high variability of experimental protocols employed in previous studies should be taken into consideration while interpreting and/or comparing the results. Here, we focused on the paradigm in which emotion and cognition interaction can be assessed since the current study's main aim was to investigate possible evidence for the interaction between target status (cognition) and valence dimension (emotion). An explanation for the effect of emotion on cognitive processes

can be provided by using suitable tasks. Such could be the oddball task associated with several cognitive processes, such as target recognition, focused attention, and decision-making (Başar-Eroğlu et al. 2001; Polich 2007). In the scope of the emotional oddball task, emotional stimuli were mostly presented as the target stimuli and non-target stimuli were non-complex and simple figures. For instance, an ERP study using this experimental design showed that the valence categorization of emotional target stimuli that are interspersed among the non-emotional frequent stimuli (e.g. square, circle) generates P3b responses (Delplanque et al. 2006). On the other hand, some emotional oddball tasks included pleasant and unpleasant pictures serving as target (rare) and non-target (frequent) stimuli in the same experimental block. It was found that emotional pictures in the different valence categories (pleasant or unpleasant images) used as target and non-target stimuli elicit higher LPP irrespective of valence effects (Weinberg et al. 2012).

To broaden our understanding about the electrophysiological substrates of emotional processing concerning the valence dimension and its relation to cognition (i.e., target status of emotional stimuli), the event-related brain oscillation method may use, in addition to related ERP literature. For example, it is suggested that the P300 component is mainly dominated by delta oscillation (Demiralp et al. 2001), and theta oscillation contributes to this component (Başar-Eroğlu et al. 1992). In this respect, considering ERP literature on the topic mentioned in the previous paragraph, investigating slow oscillatory dynamics, namely delta and theta, might help disentangle different components of the ERP response previously shown in studies with emotional stimuli. Taken all together, it seems essential to analyze the time–frequency properties of EEG signals via event-related brain oscillatory approach as a complement to ERP findings.

In the present study, two separate three-stimuli oddball tasks were recruited, unlike the conventional oddball studies. All stimuli (target, non-target, distractor) are complex visual images, and their valence ranges positive, negative, and neutral. It was thought that determining positive or negative stimuli as a target in the continuous complex visual processing stream activates cognitive mechanisms that are related to the discrimination and decision-making process. We focused on the delta (1–3.5 Hz) and theta (4–7 Hz) frequency bands since the accumulating body of evidence showed that lower frequencies are sensitive to both cognitive processing (Ergen et al. 2008a, b; Harper et al. 2017) and emotional processing (Aftanas et al. 2001a, b; Aftanas et al. 2004; Balconi et al. 2009; Klados et al. 2009; Knyazev et al. 2009; Sun et al. 2012; Zhang et al. 2013; Güntekin et al. 2017; Kurt et al. 2017). We performed both event-related phase-locking (inter-trial coherence-ITC) and power analysis in the time–frequency domain to achieve a more comprehensive framework of underlying oscillatory dynamics. These EEG analyses were conducted

over three regions, namely fronto-central, temporo-parietal, and parieto-occipital, since these regions are crucial in the emotion (i.e., Güntekin and Başar 2010, 2014; Csukly et al. 2016) and cognition (i.e., Jensen and Tesche 2002; Barbey et al. 2014; Alekseichuk et al. 2016; Reinhart and Nguyen 2019) according to previous literature. Specifically, our purpose was to compare delta and theta oscillatory responses to the stimuli considering the interaction between the target status of the stimuli (i.e., target, non-target, distractor) and valence of the stimuli (i.e., positive, negative, neutral) during emotional oddball tasks. We predicted that the valence dimension will interact with the target status. In the oddball paradigm, it is known that EEG responses increase from non-target to target stimuli (Başar-Eroğlu et al. 2001; Polich 2007). On the other hand, in the emotional oddball paradigm, emotion processing may interfere with the cognitive processes, which leads to differentiated oscillatory responses between the negative, positive and neutral pictures in addition to their cognitive demands (being a target, non-target or distractor stimuli) (Delplanque et al. 2006; Weinberg et al. 2012). Accordingly, based on the above-mentioned previous literature, we expected that the negative pictures may elicit higher oscillatory responses irrespective of their target status (as a target or distractor) compared with positive (target and distractor) and neutral (non-target) stimuli. In general terms, this study will be able to provide new insight into valence effect on cognition using EEG brain oscillation techniques.

## Materials and methods

### Subjects

Twenty healthy young subjects (ten females and ten males) participated in the study. All subjects' ages ranged from 18 to 24 ( $21.40 \pm 1.31$ ). Before starting the experiment, all subjects filled up the forms that included questions about their medical histories, visions, hearings, sleeping routines, sleep durations for the previous night, and drug/alcohol/smoking habits if they use. None of the subjects had any diagnosed neurological or psychiatric disease. All subjects had normal or corrected-to-normal visions. We obtained written informed consent from all participants. There was no compensation for participation as indicated in the written informed consent. The local ethics committee approved the study (no: 10840098-604.01.01-E.47610).

## Experimental design

### Stimuli

A total of 100 pictures (40 negative, 40 positive, and 20 neutral) used in this study were selected from the

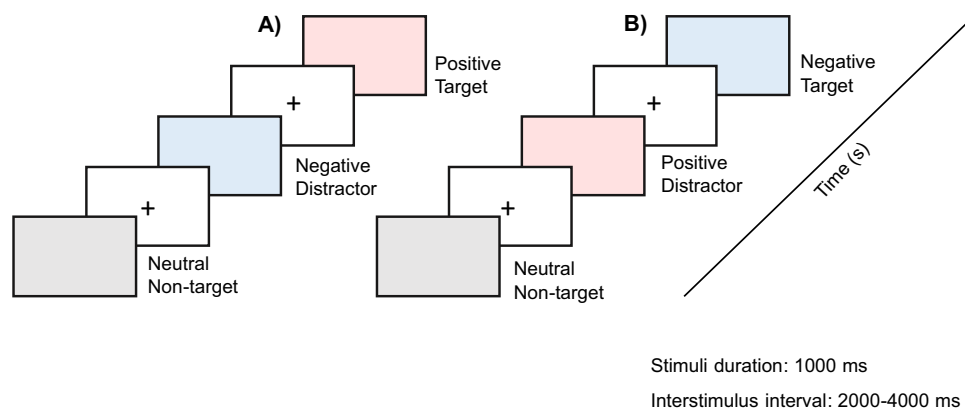
International Affective Picture System (IAPS) database based on normative ratings of valence and arousal (See Supplementary Materials Table S1, S2, S3, Figure S1). These selected pictures served as the target, distractor, and non-target stimuli in two separate emotional oddball tasks. Different sets of positive and negative pictures were used in each emotional oddball task, while both of the tasks included the same neutral pictures. The numbers and names of selected IAPS pictures were given in Supplementary Materials (Table S4).

### Design and procedure

The experimental procedure consisted of two emotional oddball tasks (negative emotional oddball task and positive emotional oddball task) prepared and presented using E-Prime software (Psychology Software Tools Inc., Pittsburgh, PA). The oddball tasks included three types of stimuli: target, non-target, and distractor stimuli. The target stimuli were the ones that the participants were asked to pay attention to. On the other hand, they were also instructed to ignore other types of stimuli (the distractor and non-target stimuli) during the tasks. All stimuli were presented on a 19-inch computer monitor with a refresh rate of 60 Hz. The distance between the computer screen and the subjects was approximately 90 cm. The duration of the stimuli was 1 s and the inter-stimulus intervals varied randomly between 2 and 4 s.

Each task contained 20 positive pictures with two repetitions, 20 negative pictures with two repetitions, and 20 neutral pictures with six repetitions, resulting in 200 trials. Trials within each task were presented in randomized order. Also, the order of the task blocks was counterbalanced across the participants. During the positive emotional oddball task, the participants were instructed to pay attention to the positive pictures, which were the target stimuli and ignore the negative and neutral pictures (the distractor and the non-target stimuli, respectively) (Fig. 1a). During the negative emotional oddball task, the participants were instructed to pay attention to the negative pictures which were the target stimuli and ignore the positive and neutral pictures (the distractor and the non-target stimuli, respectively) (Fig. 1b). The participants were instructed to count the target stimuli in their minds during task blocks. At the end of the experimental procedure, the numbers of the mental count of emotional target stimuli (both the positive and negative pictures) were noted (See Supplementary Materials Table S5). Also, participants evaluated all stimuli in terms of valence (1: negative, 9: positive) and arousal (1: low, 9: high) using the Self-Assessment Manikin (Bradley and Lang 1994) after the experimental procedure.

**Fig. 1** The experimental design of the study. **a** The representation of the positive emotional oddball task, **b** The representation of the negative emotional oddball task



## EEG recording

The EEG was acquired from 30 scalp locations using an elastic cap (Easy-cap) according to the International 10–20 System with the Ag/AgCl electrodes. The EEG sites were Fp1, Fp2, F7 F3, Fz, F4, F8, Ft7, Fc3, Fcz, Fc4, Ft8, Cz, C3, C4, T7, T8, Tp7, Cp3, Cpz, Cp4, Tp8, P3, Pz, P4, P7, P8, O1, Oz, and O2. Two linked earlobe electrodes (A1 + A2) were used as references. The ground electrode was placed behind the right earlobe. For electro-oculogram (EOG), two Ag/AgCl ring electrodes were placed above and below the left eye to record and detect eye blinks and movements. Impedances of all electrodes were kept below 15 k $\Omega$ . EEG signals were amplified by using a BrainAmp MR plus 32-channel DC system machine (Brain Product GmbH, Germany). EEG was recorded with a 500 Hz sampling rate, and the band limit was 0.01–250 Hz with 0.1  $\mu$ V resolutions. No online filters were used during EEG recording, including a notch filter (Note that EEG was recorded in the Faraday cage, and a 50 Hz notch filter was applied to data offline see next section.). During the experiments, all subjects were seated in a dimly lit and isolated room.

## EEG data analysis

### Preprocessing

EEG data were preprocessed using the Brain Vision Analyzer 2.2 (BVA) software (Brain Products, Germany). As a first step of preprocessing, data were digitally filtered by the 8th order Zero Phase Shift Butterworth Filters (The Infinite Impulse Response Filters) between 0.5 (low cutoff)–60 Hz (high cutoff), and 50 Hz notch filter was applied. Filtered continuous data were decomposed into distinct components using Independent Component Analysis (ICA) to detect and remove artifacts caused by eye movements. The restricted infomax algorithm was used in the calculation of ICA. All recorded EEG and EOG channels (32 channels) were chosen

for the ICA decomposition. The number of computed ICA components was equal with the number of chosen channels. Each component was carefully checked and regarding their topology, voltage ranges, and the improvement in the data that resulted from the extraction of these components, components for the horizontal and vertical eye movements were removed. After the removal of the detected components (these components were set to zero), the remaining components were composed with the inverse ICA analysis. The maximum component number removed for a subject was two. Afterward, continuous data were segmented according to the stimulus onset (2 s before and after for delta frequency, 1 s before and after stimulus for theta frequency). Manual artifact rejection was employed for the segmented data to clean residual artifacts. In this step, all data were manually checked, segment by segment. Accordingly, segments with artifacts (e.g., remaining eye movement-related artifacts, and muscle activity) were excluded. Also, the numbers of remaining epochs were balanced across the two tasks and three stimulus types (See Supplementary Materials Table S6).

During the preprocessing, EEG data were not re-referenced, online referencing scheme remained for the further EEG analyses.

### Event-related EEG analysis

EEG oscillations have three features: frequency, power, and phase. Several methods were developed to analyze the oscillatory activity using these basic elements. One of the most widely used methods is the time–frequency analysis which allows EEG oscillation to be represented in both the time and frequency domain. In this study, the time–frequency analyses were computed on single epochs by means of Wavelet Transforms. Event-related phase-locking and event-related power analyses were conducted by convolving 3-cycle Complex Morlet Wavelet with 60 frequency steps for each specified frequency range. To verify that our findings did not critically rely on cycle parameters that we

used (3-cycle) in the Wavelet analysis, we redefined cycle as 6-cycle. The main findings presented here were repeated by analyses using the newly defined cycle, demonstrating the robustness of our findings to a different cycle. For the Wavelet Analysis results using 6-cycle, please see Supplementary Materials Table S7, S8, S9, and S10. All the event-related analyses were performed in BVA software.

Event-related phase-locking refers to synchronization between phase angles measured just after the stimulus onsets among the trials. The phase-locked oscillatory activity means the high consistency of the phase angles within the same time period. Phase-locking values vary between 0 and 1. Low phase synchronization values are near 0 and high phase synchronization values are near 1.

Yet oscillatory responses can also be non-phase-locked (induced). Event-related power is the total of phase-locked (evoked) and non-phase-locked (induced) activities. It refers to spectral power changes between before and after the stimulus onset. It is measured by subtracting the baseline from the post-stimulus activities. In this study, -500 to -300 ms interval was used as the baseline for the delta and theta frequencies. The decibel (dB) normalization was used to quantify the power changes.

EEG data were analyzed with 4 s (2 s before and after the stimuli) epochs in the delta frequency band (1–3.5 Hz) to avoid the edge effect caused by wavelet transform and 2 s (1 s before and after the stimuli) epochs in the theta frequency band (4–7 Hz). 3 locations with 12 electrodes (F3, F4, C3, and C4 electrodes for fronto-central location; T7, T8, TP7, and TP8 electrodes for temporo-parietal location; P7, P8, O1, and O2 electrodes parieto-occipital location) were chosen for analysis. For each region, four neighbor electrodes that correspond to related regions were pooled together bilaterally (i.e., F3, F4, C3, and C4 electrodes for fronto-central location) to increase the statistical power of the analysis. After conducting the event-related EEG analysis, numerical values were exported for further statistical analysis. Values were calculated in the different time windows for each frequency band (0–800 ms for delta frequency, 0–400 ms and 400–800 ms for theta frequency). Since the delta is a slow frequency, analyzes were performed over a larger time window (0–800 ms) to capture the delta response. On the other hand, this large time window was divided into 2 for theta frequency which is relatively faster. In this way, both early (0–400 ms) and late responses (400–800 ms), which are important for emotional processing (i.e., Ito et al. 1998; Huang et al. 2006; Weinberg et al. 2012; Schupp et al. 2014), were analyzed.

### Statistical analysis

Jamovi (The Jamovi project, 2021) was utilized for statistical analysis. The main aim was to evaluate the differences in

oscillatory dynamics in response to different tasks and stimuli. For this purpose, we performed four separate repeated-measures ANOVAs for the different frequency bands (delta band [1–3.5 Hz] and theta band [4–7 Hz]) and time–frequency analyses (the event-related phase-locking and the event-related power analysis). For the event-related phase-locking and event-related power analyses of the delta band, repeated measures ANOVAs with the within-group factors of task (positive emotional oddball, negative emotional oddball), stimuli (target, non-target, distractor), location (fronto-central [F3-F4-C3-C4], temporo-parietal [T7-T8-TP7-TP8], parieto-occipital [P7-P8-O1-O2]) were performed. For the event-related phase-locking and event-related power analyses of the theta band, repeated measures ANOVAs with the within-group factors of time window (first time window [0–400 ms], second time window [400–800]), task (positive emotional oddball, negative emotional oddball), stimuli (target, non-target, distractor), location (fronto-central [F3-F4-C3-C4], temporo-parietal [T7-T8-TP7-TP8], parieto-occipital [P7-P8-O1-O2]) were performed. Post-hoc analyses were also performed with Jamovi software. For multiple comparisons, *p*-values were adjusted with the Bonferroni correction. Greenhouse–Geisser corrected *p* values are reported. The significance threshold was set at  $p < 0.05$ .

The Non-Parametric Independent Kruskal–Wallis Test was performed to test the significant differences in the valence and arousal scores across the negative, positive, and neutral IAPS images. Dwass–Steel–Critchlow–Fligner (DSCF) analysis was used as a post hoc test following the Kruskal–Wallis analysis for pairwise comparisons. Two-sided, adjusted *p* values of  $p < 0.05$  were considered significant.

## Results

### Behavioral results

The differences in the averaged valence and arousal scores of IAPS images (positive target, negative target, negative distractor, positive distractor, and neutral non-target images) were found statistically significant ( $\chi^2(4) = 84.7$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.856$ ;  $\chi^2(4) = 49.9$ ,  $p < 0.001$ ,  $\epsilon^2 = 0.504$ ).

Positive images' (target and distractor) valence scores were statistically higher than negative images' (target and distractor) valence scores (negative distractor vs. positive distractor:  $W = 7.459$ ,  $p < 0.001$ ; negative distractor vs. positive target:  $W = 7.655$ ,  $p < 0.001$ ; negative target vs. positive distractor:  $W = 7.654$ ,  $p < 0.001$ ; negative target vs. positive target:  $W = 7.656$ ,  $p < 0.001$ ). Neutral images' valence scores were statistically different from negative and positive images (negative distractor vs. neutral nontarget:  $W = 7.459$ ,  $p < 0.001$ ; negative target vs. neutral nontarget:

$W = 7.666, p < 0.001$ ; neutral nontarget vs. positive distractor:  $W = 7.511, p < 0.001$ ; neutral nontarget vs. positive target:  $W = 7.513, p < 0.001$ ). As expected, negative target ( $M = 2.25, SD = 0.63$ ) and negative distractor ( $M = 2.43, SD = 0.85$ ) pictures' valence scores were not statistically different ( $W = -0.785, p = 0.981$ ). The valence scores of the positive target ( $M = 7.03, SD = 0.65$ ) and positive distractor ( $M = 7.09, SD = 0.67$ ) pictures were also not statistically different ( $W = -0.479, p = 0.997$ ). The box plot of the averaged valence scores obtained from the participants can be seen in Fig. 2a. The arousal scores of the negative and positive images were significantly higher than those of neutral images ( $M = 1.16, SD = 0.21$ ) (negative target vs. neutral nontarget:  $W = -7.658, p < 0.001$ ; negative distractor vs. neutral nontarget:  $W = -7.582, p < 0.001$ ; neutral nontarget vs. positive target:  $W = 6.033, p < 0.001$ ; neutral nontarget vs. positive distractor:  $W = 5.589, p < 0.001$ ). Also, negative images' arousal scores were statistically higher than the positive images' arousal scores (negative target vs. positive target:  $W = -4.113, p = 0.030$ ; negative target vs. positive distractor:  $W = -4.592, p = 0.010$ ; negative distractor vs. positive distractor:  $W = -3.961, p = 0.041$ ), except that negative distractor images' valence scores were not different from positive target images' scores ( $W = -3.751, p = 0.061$ ). The arousal scores of the negative target ( $M = 4.41, SD = 1.38$ ) and negative distractor ( $M = 4.17, SD = 1.35$ ) pictures were not statistically different ( $W = 0.785, p = 0.981$ ). Similarly, positive target ( $M = 2.90, SD = 1.47$ ) and positive distractor ( $M = 2.75, SD = 1.48$ ) images' arousal scores were not statistically different ( $W = 0.708, p = 0.987$ ). The box plot of the averaged arousal scores obtained from the participants can be seen in Fig. 2b.

## EEG results

### Event-Related phase-locking analysis

#### Delta phase-locking analysis

The repeated-measures ANOVA results showed that there were main effects of the stimuli ( $F(1.37, 26.05) = 5.014, MSe = 0.013, p = 0.024, \eta^2_p = 0.209$ ) and the location ( $F(1.49, 28.39) = 55.270, MSe = 0.015, p < 0.001, \eta^2_p = 0.744$ ). However, these effects were dependent on the stimuli, task, and location factors since there were significant stimuli\*location and task\*stimuli\*location interactions.

The ANOVA results also showed that task\*stimuli\*location interaction was significant ( $F(3.07, 58.39) = 8.505, MSe = 0.001, p < 0.001, \eta^2_p = 0.309$ ) since stimuli\*location interaction ( $F(3.03, 57.61) = 9.420, MSe = 0.002, p < 0.001, \eta^2_p = 0.331$ ) was largely dependent on the task. Follow-up analysis using Bonferroni

correction revealed that in the temporoparietal region, the target stimuli ( $M = 0.364, SE = 0.019$ ) elicited higher responses than the non-target stimuli ( $M = 0.294, SE = 0.013$ ) during the negative emotional oddball task ( $p = 0.024$ ) (see Fig. 4a), but not during the positive emotional oddball task (see Fig. 4b). Also, in the fronto-central region, the target stimuli ( $M = 0.375, SE = 0.210$ ) elicited higher delta phase-locking responses than the distractor ( $M = 0.302, SE = 0.146$ ) and non-target stimuli ( $M = 0.306, SE = 0.011$ ) during the negative emotional oddball task ( $p = 0.010$  and  $p = 0.028$ , respectively), but not during the positive emotional oddball task ( $p = 1.000$ ). Yet, there was no such significant result in the parieto-occipital region.

Task\*stimuli interaction did not show any significance ( $F(1.96, 37.26) = 2.592, MSe = 0.0107, p = 0.089, \eta^2_p = 0.120$ ). The violin plot of the task\*stimuli interaction for the delta phase-locking values was given in Fig. 3a.

These results showed that the interaction between target status and negative valence caused higher delta phase-locking responses in temporo-parietal and fronto-central regions but not in the parieto-occipital region. On the other hand, same results were not seen for positive target.

### Theta phase-locking analysis

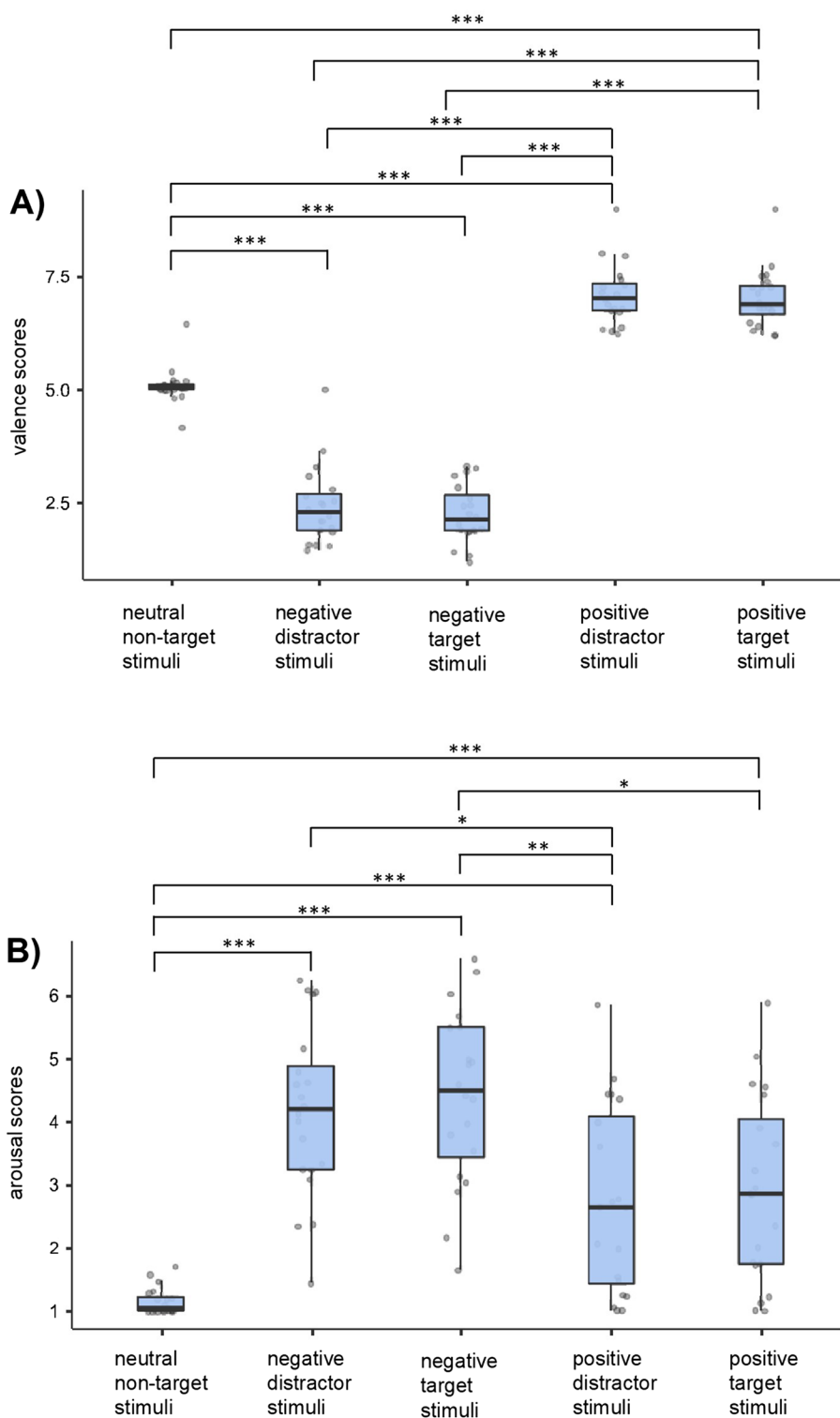
The repeated-measures ANOVA results revealed that there were main effects of the time ( $F(1.00) = 114.116, p < 0.001, MSe = 0.026, \eta^2_p = 0.857$ ) and the location ( $F(1.68, 31.94) = 12.894, MSe = 0.006, p < 0.001, \eta^2_p = 0.404$ ). However, the main effect of the location was dependent on the time since there was a time\*location interaction.

Follow-up pairwise comparisons showed that the time\*location interaction was significant ( $F(1.42, 27.00) = 8.267, MSe = 0.007, p = 0.004, \eta^2_p = 0.303$ ). Fronto-central ( $M = 0.348, SE = 0.017$ ) and parieto-occipital regions ( $M = 0.342, SE = 0.009$ ) elicited higher theta-phase-locking responses than the temporo-parietal region ( $M = 0.292, SE = 0.011$ ) during the first time window ( $p < 0.001$  for both comparisons). However, theta phase-locking responses were not statistically different between the brain region during the second time window ( $p = 1.000$ ).

Task\*stimuli interaction did not show any significance ( $F(1.48, 28.09) = 0.241, MSe = 0.002, p = 0.720, \eta^2_p = 0.013$ ). The violin plot of the task\*stimuli interaction for the theta phase-locking values was given in Fig. 3a.

These results showed that in terms of theta phase-locking values in the emotional oddball paradigms, the location-related differences were significant in the first time window, but not in the second time window (Fig. 4).

**Fig. 2** The box plots of the averaged **a** valence and **b** arousal scores for IAPS pictures as neutral non-target, negative distractor, negative target, positive distractor, and positive target stimuli. Asterisks indicate statistical significance (\* $p \leq .05$ ; \*\* $p \leq .01$ ; \*\*\* $p \leq .001$ ). Dots represent the observed scores



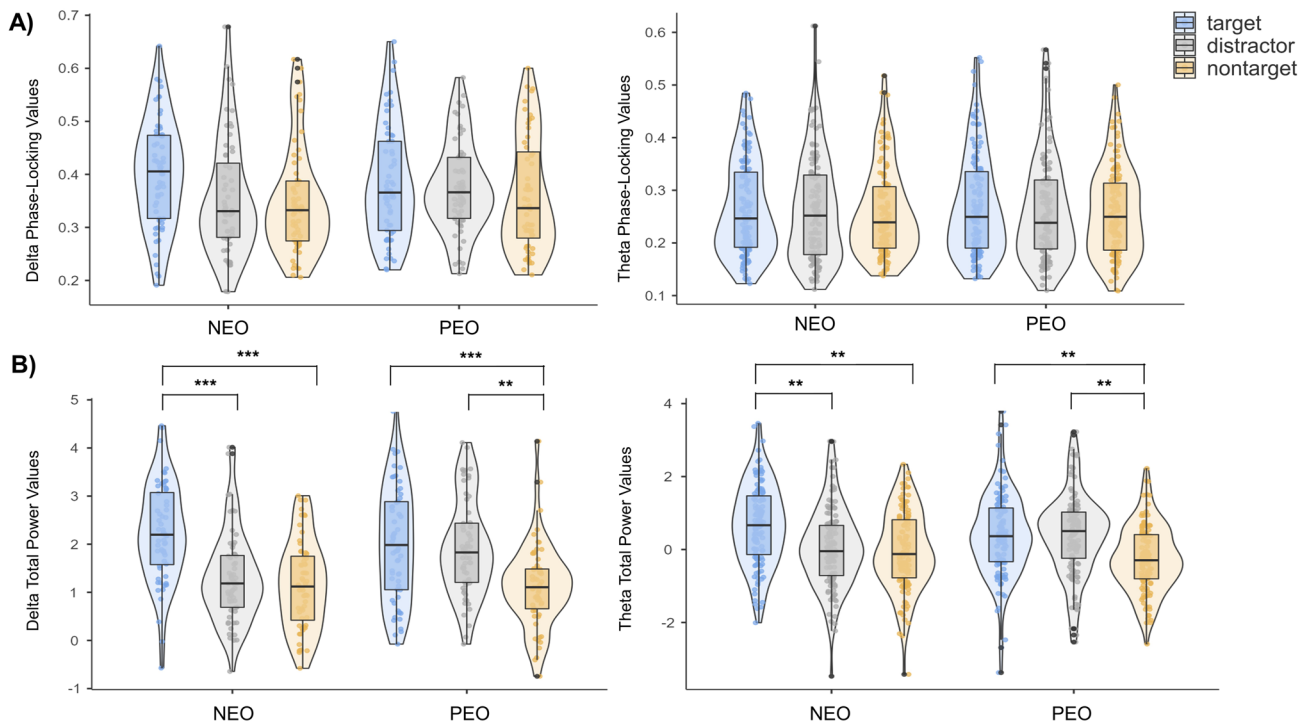
**Event-related power analysis**

**Delta event-related power analysis**

A repeated measures ANOVA revealed that there were significant main effects of the stimuli ( $F(1.75,$

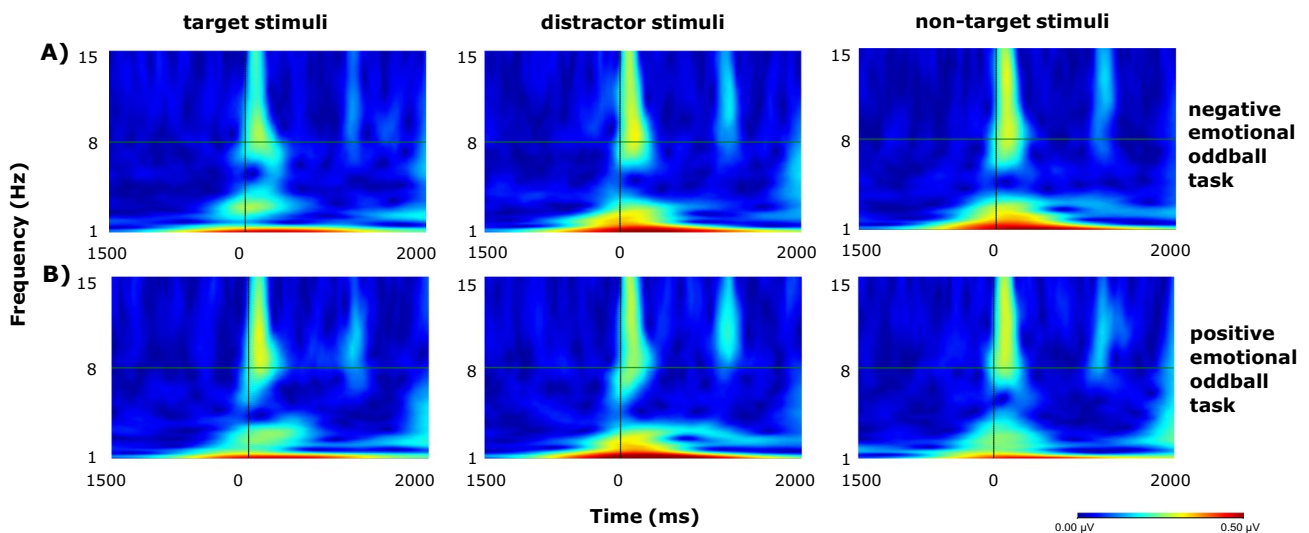
$33.32) = 21.034, MSe = 1.610, p < 0.001, \eta^2_p = 0.518$ ) and the location ( $F(1.75, 33.31) = 25.496, MSe = 0.838, p < 0.001, \eta^2_p = 0.573$ ). These effects were dependent on the task since there were significant task\*stimuli and task\*stimuli\*location interactions.





**Fig. 3** The violin plots of the task\*stimuli interaction. **a** The event-related phase-locking in delta (1–3.5 Hz) and theta (4–7 Hz) frequency bands. Lots were prepared using the phase-locking values obtained from 12 electrodes (F3, F4, C3, C4, T7, T8, TP7, TP8, P7, P8, O1, and O2). **b** The event-related power analysis in delta

and theta frequency bands. Plots were prepared using the power values obtained from 12 electrodes (F3, F4, C3, C4, T7, T8, TP7, TP8, P7, P8, O1, and O2). PEO: positive emotional oddball, NEO: negative emotional oddball. Asterisks indicate statistical significance (\*\* $p \leq .01$ ; \*\*\* $p \leq .001$ ). Dots represent the observed scores



**Fig. 4** The grand average figures of event-related phase-locking analysis (1–15 Hz) in time–frequency domain for each task (negative and positive emotional oddball tasks) and stimuli type (target, distractor,

and non-target stimuli) over the parieto-occipital region (P7–P8–O1–O2). **a** the negative emotional oddball task **b** the positive emotional oddball task

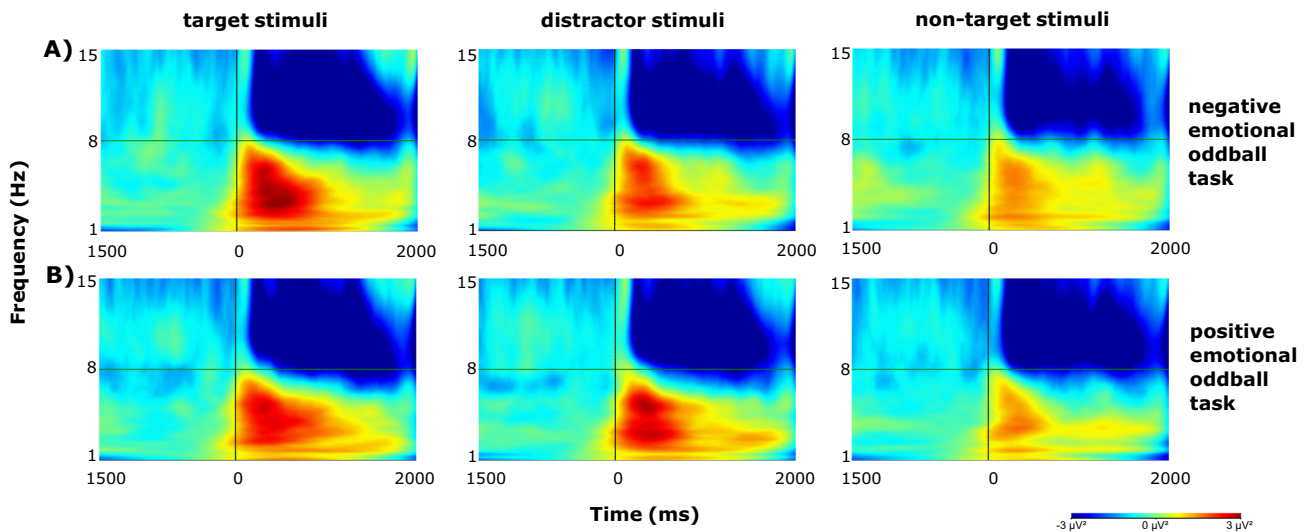
The ANOVA results indicated that there was an interaction between task and stimuli ( $F(1.81, 34.46) = 11.955$ ,  $MSe = 1.185$ ,  $p < 0.001$ ,  $\eta^2_p = 0.386$ ). Follow-up pairwise

comparisons revealed that the delta power in response to target stimuli (negative IAPS pictures) ( $M = 2.223$ ,  $SE = 0.169$ ) was higher than that of the distractor stimuli (positive IAPS

pictures) ( $M=0.926, SE=0.127$ ) and the non-target stimuli (neutral IAPS pictures) ( $M=1.154, SE=0.146$ ) during the negative emotional oddball task ( $p < 0.001$  for both comparisons) while there was no differentiation between the distractor (positive IAPS pictures) and the non-target stimuli (neutral IAPS pictures) during the same task ( $p = 1.000$ ) (see Fig. 5a). On the other hand, during the positive emotional oddball task, both the target (positive IAPS pictures) ( $M=1.998, SE=0.231$ ) and the distractor stimuli (negative IAPS pictures) ( $M=1.922, SE=0.167$ ) elicited higher delta power responses than the non-target stimuli (neutral IAPS

pictures) ( $M=1.133, SE=0.164$ ) ( $p < 0.001$  and  $p = 0.003$ , respectively), whereas there was no statistical difference between the target (positive IAPS pictures) and the distractor stimuli (negative IAPS pictures) ( $p = 1.000$ ) (see Fig. 5b and Fig. 6). The violin of the task\*stimuli interaction for the delta total power values was given in Fig. 3b.

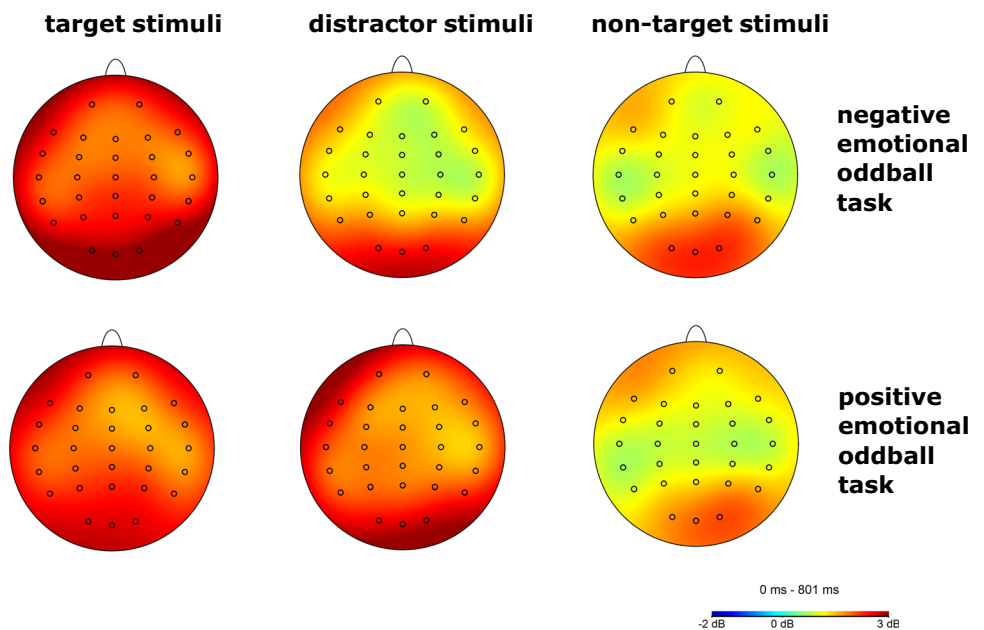
The ANOVA results also showed that there was an interaction between task, stimuli and location ( $F(2.83, 53.69) = 3.241, MSe = 0.437, p = 0.031, \eta^2_p = 0.146$ ). Follow-up pairwise comparisons showed that negative distractor stimuli ( $M = 2.406, SE = 0.264$ ) in the positive emotional



**Fig. 5** The grand average figures of event-related power analysis (1–15 Hz) in time–frequency domain for each task (negative and positive emotional oddball tasks) and stimuli type (target, distractor, and

non-target stimuli) over the parieto-occipital region (P7-P8-O1-O2). **a** The negative emotional oddball task, **b** the positive emotional oddball task

**Fig. 6** Scalp topographies of event-related power analysis (delta frequency) for each task (negative and positive emotional oddball tasks) and stimuli type (target, distractor, and non-target stimuli)



oddball task has a higher delta power response than positive distractor stimuli ( $M=0.961$ ,  $SE=0.152$ ) in the negative emotional oddball task over the parieto-occipital region ( $p=0.006$ ), whereas there was no statistical difference between negative and positive distractor stimuli over the temporo-parietal (negative distractor:  $M=1.724$ ,  $SE=0.178$ ; positive distractor:  $M=0.961$ ,  $SE=0.152$ ) and fronto-central regions (negative distractor:  $M=1.638$ ,  $SE=0.192$ ; positive distractor:  $M=0.856$ ,  $SE=0.134$ ) ( $p=0.696$ ,  $p=0.212$ , respectively).

These results showed that delta power responses reflected the interaction between the target status and valence dimension. In the oddball paradigm, while the target stimulus is expected to elicit higher responses than the distractor and non-target stimulus, the valence dimension of the stimuli has been found to interfere this cognitive process. Also, the task\*stimuli\*location interaction results showed that the parieto-occipital region was more sensitive to distractor stimuli with different valence values, while the temporo-parietal and fronto-central regions were not.

### Theta event-related power analysis

A repeated measures ANOVA showed that there were main effects of the stimuli ( $F(1.98, 37.66)=16.332$ ,  $MSe=1.574$ ,  $p<0.001$ ,  $\eta^2_p=0.462$ ), time ( $F(1, 19)=19.428$ ,  $MSe=2.089$ ,  $p<0.001$ ,  $\eta^2_p=0.506$ ), and location ( $F(1.31, 24.93)=6.467$ ,  $MSe=4.279$ ,  $p=0.012$ ,  $\eta^2_p=0.255$ ). These effects were dependent on the task, location, and time since there were significant stimuli\*task, time\*location ( $F(1.27, 24.04)=9.742$ ,  $MSe=0.815$ ,  $p=0.003$ ,  $\eta^2_p=0.339$ ), stimuli\*location, and time\*stimuli\*location interactions.

The ANOVA results indicated that there was an interaction between task and stimuli ( $F(1.91, 36.26)=3.881$ ,  $MSe=2.037$ ,  $p=0.031$ ,  $\eta^2_p=0.170$ ). Follow-up analysis using Bonferroni correction revealed that the target stimuli ( $M=0.647$ ,  $SE=0.183$ ) elicited higher theta power responses than the distractor stimuli ( $M=0.037$ ,  $SE=0.187$ ) during the negative emotional oddball task ( $p=0.010$ ) but not during the positive emotional oddball task ( $p=1.000$ ) (see Fig. 5a). Conversely, the distractor stimuli ( $M=0.039$ ,  $SE=0.189$ ) elicited higher theta power responses than the non-target stimuli ( $M=-0.260$ ,  $SE=0.130$ ) during the positive emotional oddball task ( $p=0.005$ ) but not during the negative oddball task ( $p=1.000$ ) (see Fig. 5b). Also, target stimuli (positive emotional oddball task:  $M=0.373$ ,  $SE=0.189$ ; negative emotional oddball task:  $M=0.647$ ,  $SE=0.183$ ) generated higher theta power responses than the non-target stimuli (positive emotional oddball task:  $M=-0.260$ ,  $SE=0.130$ ; negative emotional oddball task:  $M=-0.020$ ,  $SE=0.169$ ) during both tasks ( $p=0.002$  for the negative emotional oddball task,  $p=0.007$  for the positive emotional oddball task). The violin plot of the task\*stimuli

interaction for the theta total power values was given in Fig. 3b.

The ANOVA results also showed that there was a significant time\*stimuli\*location interaction ( $F(3.05, 57.97)=2.809$ ,  $MSe=0.119$ ,  $p=0.047$ ,  $\eta^2_p=0.129$ ) since stimuli\*location interaction ( $F(2.79, 53.03)=4.084$ ,  $MSe=0.628$ ,  $p=0.013$ ,  $\eta^2_p=0.117$ ) was largely dependent on the time factor. Follow-up comparisons revealed that in the first time window, theta power responses in response to the target stimuli over the parieto-occipital region ( $M=1.288$ ,  $SE=0.156$ ) was higher than over the temporo-parietal region ( $M=0.252$ ,  $SE=0.129$ ) ( $p<0.001$ ) while there was no differentiation of theta power in response to the target stimuli between two locations in the second time window ( $p=1.000$ ) (See Fig. 7).

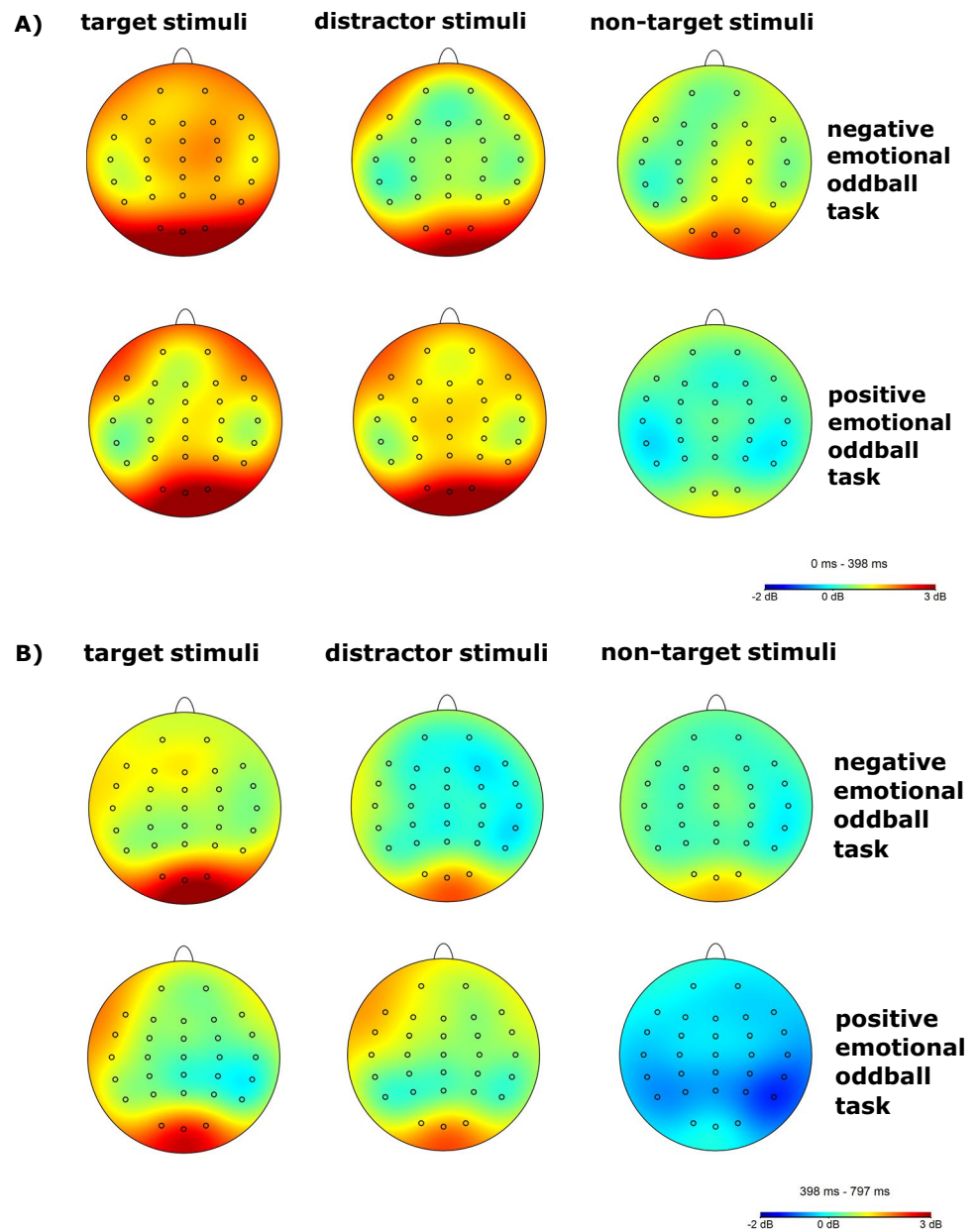
Similar with the results of the delta event-related power analysis, main finding of the theta event-related power analysis is that there was an interaction between the target status and valence dimension. Also, another important finding is that while there was a difference between regions (temporo-parietal nad parieto-occipital regions) in the first time window for target stimuli, no such difference was observed in the second time window.

## Discussion

In this study, we examined delta and theta EEG responses during the valence discrimination process. Our main aim was to determine the oscillatory pattern that occurs when distinguishing between complex emotional visual stimuli in terms of their valence (positive, negative, and neutral). In this way, we investigated the possible interaction between the target status and valence dimension in terms of brain dynamics. The main findings of the present study were as follows: (1) The target stimuli elicited higher delta power, delta phase-locking, and theta power responses than the non-target stimuli. (2) Delta and theta power responses, but not the phase-locking responses, differed between positive and negative emotional oddball tasks. (3) Distractor stimuli with the negative valence attenuated the effect of the target with the positive valence due to the negative bias.

Previous studies found that positive and negative pictures (high arousal) elicit higher delta power (Balconi et al. 2009; Klados et al. 2009; Knyazev et al. 2009; Zhang et al. 2013; Kurt et al. 2017) and theta power responses (Aftanas et al. 2001a, b; Aftanas et al. 2004; Sun et al. 2012) than neutral (low arousal) pictures. Consistent with the literature, we found positive and negative (target) images that elicited higher delta and theta power responses than neutral (non-target) images. It should be noted that the target status of the emotional images contributed to these findings. Various authors reported that EEG responses of

**Fig. 7** Scalp topographies of event-related power analysis (theta frequency) for each task (negative and positive emotional oddball tasks) and stimuli type (target, distractor, and non-target stimuli). **a** Topographies for first time window (0–398 ms). **b** Topographies for second time window (398–797 ms)



target (infrequent) stimuli differ from that of non-target (frequent) stimuli during the oddball paradigm, which indicates several cognitive functions such as attention, signal detection, and working memory (Başar-Eroğlu et al. 1992). Moreover, impairment of oddball response has been associated with many diseases such as Alzheimer's disease (Güntekin et al. 2008), Parkinson's disease (Güntekin et al. 2020a, b), bipolar disorder (Atagün et al. 2013), and schizophrenia (Ergen et al. 2008a, b). In this study, we included healthy young participants, and therefore, we expected increased EEG power during the presentation of the target stimuli, which indicates a healthy functioning brain. Our results met our expectations in line with the literature.

In this study, unlike the classical oddball studies, we used modified oddball paradigms and added the same number of distractor stimuli to the tasks as the target ones. In this way, we created discrimination tasks in which positive, negative, and neutral IAPS images were used. Our results showed that valence had a significant effect during the target detection, and it was represented by the lower frequency bands. Delta and theta power responses during participants' allocate their attention to negative target stimuli were higher than during the presentation of the positive distractor stimuli. On the other hand, even if positive stimuli were the target and negative stimuli were the distractors, delta and theta power activity in response to positive and negative visual stimuli were similar as opposed to generally expected oddball task

results. In other words, the emotional content of the target and distractor stimuli influenced the brain responses which are typically elicited by the target stimuli. The reason for this asymmetry might be the negativity bias, which means that negative stimuli elicit faster and more prominent responses than positive and neutral stimuli because of their high evolutionary significance (Carretie et al. 2001; Smith et al. 2003). It has been demonstrated that negative content elicited higher LPP responses (Ito et al. 1998; Huang et al. 2006; Schupp et al. 2014) and higher delta and theta power responses (Klados et al. 2009; Güntekin et al. 2017) than the positive or neutral stimuli although some researchers suggested that both positive and negative stimuli elicited strong EEG responses if they had high arousal level (Franken et al. 2008). At this point, task variability should be considered while interpreting the results. The critical question is, in which experimental designs do negative bias occur? Our result showed that negative bias can be seen during the valence discrimination task, even if some similar studies contrasted with our results (Weinberg et al. 2012). Although Weinberg et al. (2012) did not report any statistically significant LPP differences, they showed that participants identified negative targets more quickly than positive and neutral targets, which also indicates negative bias. As in Weinberg's study, a negative bias represented by behavioral results was also shown in our study. In addition, in our study, the EEG reflections of these behavioral results were also demonstrated. Possibly, our time–frequency analysis approach revealed the negative bias results, which can be only seen in behavioral results in Weinberg's study. Our results (increased theta power responses to negative stimuli compared to positive stimuli irrespective of their assigned cognitive stimuli category) also nicely fit with the fear conditioning literature that shows the conditioning stimuli with negative valence elicit increased theta responses (Chien et al. 2017).

Another possible explanation of our results might be how participants perceived IAPS pictures. Although participants discriminated emotional pictures in terms of valence (positive, negative, and neutral), pictures' arousal values may have influenced the emotional discrimination process. According to Rozenkrants and Polich (2008), arousal plays an essential role in the emotional oddball task. In this study, perceived arousal values of negative images were higher than positive images. This is consistent with the result that the negative target stimuli had higher delta and theta power responses than the positive distractor.

Another important point of the current study was obtained from the phase-locking analysis. Although there was a significant result that target stimuli had higher delta phase-locking values than non-target stimuli over the temporo-parietal and fronto-central regions, this result was only specific to negative emotional oddball task. Also, during the same task, target stimuli elicited higher delta phase-locking responses

than the distractor over the only fronto-central region. In other words, while valence discrimination was found to be sensitive to delta and theta power responses more globally as previously mentioned, the same effect was only observed over the specific brain region in the delta phase-locking response. As we know, power and phase-locking responses may increase or decrease together, or they may produce independent results (Güntekin et al. 2020a, b). To take a closer look at the oscillatory activities, a high phase-locking value means that oscillations have similar phase angles within a certain time period (Herrmann et al. 2005). The total power response consists of evoked and induced activities. Evoked power responses are phase-locked activities. On the other hand, induced power responses are not phase-locked and they are not strongly synchronized with the stimulus onset (Kolev and Yordanova 1997; Herrmann et al. 2014). To the best of our knowledge, there are no study in the literature focusing on phase-locking and power (induced, evoked, and total power) response differences during valence discrimination. In future studies, investigating evoked and induced power responses separately may provide a better understanding of emotional discrimination.

There were some limitations of this study that should be considered for future studies. In this study, we only used two experimental tasks in which positive and negative images were target stimuli. Future studies may also use a task in which neutral images are the target stimuli, and emotional images are non-target stimuli. In this way, the interaction between the target status and valence can be better understood. Although Weinberg et al. (2012) prepared their experimental design as fully crossed emotional content and experimental status, each task contained only two types of valence conditions and indeed, it may not exactly reflect the discrimination process based on three main valence dimensions (positive, negative, and neutral). Another limitation was that our participants perceived negative pictures as more arousing than positive pictures in line with the normative arousal ratings of the selected pictures. It is quite difficult to select positive and negative pictures that have equivalent arousal ratings since the positive pictures are often less arousing than the negatives. In future studies, positive pictures which lead to higher arousal ratings (such as erotic pictures of IAPS) can be selected to achieve the robust effect.

## Conclusion

The present study revealed the brain oscillatory dynamics underlying valence discrimination. It was shown that negative stimuli produced attentional bias compared to positive stimuli. Moreover, we found that target status and negative valence interacted with each other because of this attentional bias (i.e. negative bias), and delta and theta power responses

play a significant role in this processing. Delta phase-locking responses, on the other hand, had a role in the specific brain region during the processing of negative target stimuli.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s10339-023-01158-w>.

**Author Contribution** BG, TA initiated and planned the study and designed the protocol. BB, BG, TA wrote, reviewed, and edited the paper. TA, HA, YD, CG, ŞK recorded, and BB analyzed the data. BG supervised and controlled the study. All authors contributed to the manuscript revision, read and approved the submitted version.

**Availability of data and material** The data of this study are available on request from the corresponding author.

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