Running head: ANTICIPATION OF AFFECTIVE IMAGES AND ERD OF ALPHA ACTIVITY

Anticipation of Affective Images and Event-Related Desynchronization (ERD) of Alpha Activity: an MEG Study

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Abstract

We investigated the event-related power decrease (event-related desynchronization: ERD) of the alpha bands associated with the anticipation of affective images. Participants (n = 19) were presented with emotionally positive or negative images under different anticipatory conditions, and their brain responses were recorded using magnetoencephalography (MEG). In the Affective Cue conditions, the cue stimulus indicated the emotional valence (positive or negative) of the image. In the Null Cue condition, the cue stimulus did not include any information about the valence of the image, and in the No Cue condition, the affective image was presented without a preceding cue. The cues in the affective and null conditions were followed by emotional images. During the anticipation period for the affective image, the alpha ERD preceding an anticipated negative image was larger than that preceding an anticipated positive image; this effect had an occipital dominance. Furthermore, during the anticipation period, the lower-2-alpha ERD of the right frontal area showed the same result. These results demonstrate that anticipation of negative stimuli induced alpha ERD in both the visual and the right frontal cortex, indicating that top-down modulation may be provided by the right frontal cortex to the visual cortex.

Section: Cognitive and Behavioral Neuroscience

Keywords: anticipation, event-related desynchronization, alpha, affective image

Anticipation of Affective Images and Event-Related Desynchronization (ERD) of Alpha Activity: an MEG Study

1. Introduction

Emotional responses are thought to play a vital role in the ability to adapt to the environment and ultimately the ability to survive (Ekman, 1992). The mechanism for processing emotional information consists of evaluative, experiential, and expressive components (LeDoux, 1987). Evaluation of emotional events that are destined to happen in the future are a necessary part of adaptive behavior (Ueda et al., 2003).

One of the physiological indices used to investigate anticipation is event-related desynchronization or synchronization (ERD or ERS) of cortical rhythms. Since the discovery of a 10 Hz (alpha) rhythm in the human brain (Berger, 1929), much attention has been devoted to understanding the nature of this rhythmic activity. Recently, it has been proposed that there are several local cortical rhythms that can be functionally distinguished from each other (Bastiaansen et al., 1999). When an individual is relaxed with their eyes closed, alpha activity can be recorded from occipital and parietal areas using electorencephalography (EEG) or magnetoencephalography (MEG). It seems likely that at least some part of the occipital alpha oscillations that originates from primary visual cortex is closely linked to the activity of the visual system. The alpha rhythm in occipital areas is thought to indicate a lack of active information processing, and, in the reverse situation, the attenuation of this rhythm indicates the onset of active information processing (Bastiaansen et al., 1999). Based on these findings, it could be expected that anticipatory attention to a visual stimulus would be represented by the desynchronization of alpha activity in the occipital area, and that this desynchronization would be anticipatory in nature, occurring prior to the stimulus presentation.

Though a number of studies have been published demonstrating anticipatory ERD in the contralateral pre- and post-central areas prior to movement (Defebvre et al., 1996; Derambure et al., 1993; Pfurtscheller, 1992; Pfurtscheller and Aranibar, 1977; Pfurtscheller and Berghold, 1989; Pfurtscheller et al., 1996; Stancak and Pfurtscheller, 1995; Toro et al., 1994), relatively few studies have investigated ERD during the anticipation of a stimulus. In one experiment using a reading task, ERD started 1 s prior to the stimulus presentation and was located in occipital area (Pfurtscheller, 1992). Furthermore, long lasting ERD of the alpha band has been observed during the period preceding the presentation of the visual stimuli that were to be classified (Pfurtscheller and Klimesch, 1991). The authors interpreted this ERD as being related to the anticipation of the stimulus. Bastiaansen and colleagues have reported ERD during the anticipation of a feedback stimulus (Bastiaansen et al., 2002; Bastiaansen et al., 1999). In these studies, ERD was measured in relation to the anticipation of a knowledge of results (KR) stimulus that provided either visual or auditory feedback on performance following every trial. Preceding the visual KR stimulus, an ERD was present that had an occipital maximum.

As with the KR stimulus described above, the anticipation of an affective or motivational stimulus might also result in alpha ERD. In studies using negative somatic stimuli, ERD of alpha rhythms in anterior areas preceded predictable painful stimuli (Babiloni et al., 2003; Del Percio et al., 2006). Previous studies have reported that ERD/ERS was induced in response to an emotionally charged visual stimulus, and suggested that ERD and ERS are influenced by emotional valence (Aftanas et al., 1996; Aftanas et al., 2001a, 2001b) and the arousal resulting from emotional pictures (Aftanas et al., 2002). Aftanas et al. (2001b) measured ERD/ERS responses to emotionally neutral, positive, and negative pictures, and suggested that differences induced by emotional valence were associated with increased theta and alpha activity and anterior hemispheric asymmetries. Similarly, in our previous event-related fields study, the anticipated valence of emotional images affected visual evoked responses; the amplitude of the visual evoked field for anticipated negative images was inhibited (Onoda et al., 2006). Therefore, anticipation of valence might also affect alpha ERD for emotional images.

The purpose of the current study was to investigate the effect of anticipation of emotional images on alpha ERD. We examined whether ERD of alpha activity during anticipation was influenced by the valence of emotional images, and whether anticipation of valence affected alpha ERD during the presentation of an emotional image.

2. Results

Temporal Change of Alpha Activity

Activity in the three alpha sub-bands (lower-1-alpha, lower-2-alpha, and upper-alpha) in the occipital area had the largest ERD. The time course of this activity on an occipital channel is shown in Figure 1. The power of the alpha bands decreased after the stimulus presentation; ERDs for the images were observed in all conditions. ERD for S1 had a peak around 500 ms after the cue presentation, and returned to baseline before S2 in some conditions. In the Affective Cue Negative condition, the decrease in the ERD in lower-2-alpha did not return to baseline. The ERD for S2 had a longer duration compared with that for S1. We observed that the temporal pattern was divided to three periods, and these periods of power change were termed Post-S1, Pre-S2, and Post-S2. Their mean powers were parameterized by averaging in the range of 400-600 ms after S1, 1500-1900 ms after S1 (the 500-100 ms preceding onset of S2), and 500-1000 ms after S2, respectively.

== Fig. 1 around here ==

Alpha ERD during the Post-S1 Period

Figure 2A shows the topography of alpha power during post-S1. The spatial distribution of alpha ERD was similar for all three conditions and exhibited occipital dominance. Repeated measures two-way ANCOVAs (cue x frequency covariated with the absolute power of the baseline) were performed on the power of Post-S1 in each channel, and the *p*-values for the main effect of cue were rendered in the topography map (Figure 2B middle). The main effect of cue was significant in parietal regions ($F(2,36)=9.67$, $\varepsilon=0.94$, $p<.001$ at a statistically significant peak channel), and post hoc analyses revealed that the power of the Affective Cue Negative condition was smaller than other two conditions (*p's*<.01; Figure 2C.). A significant main effect of frequency was observed in broad regions, and the power of the lower-2 and upper alpha were smaller than the lower-1-alpha. None of the channels showed a significant interaction between cue and frequency.

== Fig. 2 around here ==

Alpha ERD During the Pre-S2 Period

Topographies of alpha power during Pre-S2 (the 500-100 ms preceding the onset of an affective image) are shown in Figure 3A. The power distribution of the Affective Cue Negative condition exhibited parietal and occipital dominance. In contrast, the power distributions of the Affective Cue Positive and Null Cue conditions demonstrated no clear dominant region. Figure 3B shows the *p*-values map of the repeated measures ANCOVAs for power during Pre-S2. The main effect of cue was significant in the occipital area ($F(2,36)=5.35$, $\varepsilon=0.96$, $p<.01$ at a statistically significant peak channel), and power during Pre-S2 decreased more for the Affective Cue Negative condition than for the Affective Cue Positive condition ($p<.01$; Figure 3C). The differences from the baseline period were significant in the Affective Cue Negative condition in lower-1 and lower-2 alpha sub-bands (*t-test*: *p's*<.01), while the comparisons with baseline for the other conditions were not significant. The interaction of cue and frequency was significant in the right frontal area ($F(4,72)=2.91$, $\varepsilon=0.84$, $p<.05$ at a statistically significant peak channel). Post hoc analysis revealed that the lower-2 alpha power was smaller for the Affective Cue Negative condition than for the Affective Cue Positive condition ($p=.057$).

== Fig. 3 around here ==

Alpha ERD During the Post-S2 Period

Topographies of alpha power during Post-S2 (500-1000 ms after onset of the affective image) are shown in Figure 4A. The power distribution for all six conditions exhibited a similar occipital dominance. Repeated measures three-way ANCOVAs were performed on the power of Post-S2 changes in each channel for the valence dimension of the emotional images (positive or negative), cue condition (Affective, Null, or No), and frequency, covaried with the absolute power of the baseline. Figure 4B shows the *p*-values map for these ANCOVAs. In the occipital area, significant two-way interactions were observed between cue and valence, and frequency and cue. The power of the occipital channel that showed the largest *F* value for the interaction between cue and valence is shown in Figure 4C ($F(2,36)=3.63$, $\varepsilon=0.87$, $p<.05$). Post hoc analysis revealed that a decrease in lower-2-alpha power during Post-S2 in the occipital area was larger for the No Cue Negative condition than for the Affective and Null Cue Negative conditions (*p's*<0.01). Furthermore, there was a significant interaction between frequency and cue in the occipital channel; the decrease in lower-2-alpha power was larger for the No Cue conditions than for the Affective and Null Cue conditions (*p's*<0.01).

== Fig. 4 around here ==

3. Discussion

We investigated the event-related power changes (ERD) of the alpha band in MEG related to the anticipation of an upcoming affective image. During the anticipation period (Pre-S2), the power change in the occipital area in the Affective Cue Negative condition was significantly larger than that seen in the other conditions, relative to the baseline period. This result provides evidence that the visual cortex is in a preparatory state prior to the presentation of a cued negative image. Bastiaansen and his colleagues reported that alpha ERD in visual cortex preceded the presentation of a feedback stimulus about the quality of time estimations performed by the participants (Bastiaansen et al., 2002; Bastiaansen et al., 1999). Thus, alpha ERD was recorded prior to feedback stimulus in the studies of Bastiaansen and colleagues and in the present study prior to stimuli evoking negative emotion. These situations share the commonality of stimuli with a negative valence. This suggests that the occurrence of alpha ERD depends on whether the anticipated stimulus has an affective value.

Klimesch et al. (1998) suggested that the lower alpha band (8-10 Hz) might be more sensitive to anticipatory processes than the upper alpha band, although the results described in Bastiaansen et al. (1999, 2002) do not support this conclusion. A possible reason for the discrepancy between the two studies may be that Bastiaansen et al. (1999,

2002) used fixed frequency bands while Klimesch et al (1998) used individual frequency band selection. Results of the current study supported Klimesch et al.'s findings (1998), as the lower-2-alpha of both frontal and occipital areas was affected by emotional anticipation.

Another key finding in the present study was that the right frontal area showed an ERD during the negative anticipation period in lower-2-alpha. Some areas of frontal cortex are known to be involved in visual attention, and a distributed frontal attentional network may be the source that generates top-down biasing signals that modulate activity in visual cortex (Pessoa et al. 2003). Indeed, activation of the right prefrontal cortex during negative anticipation have been reported in fMRI studies using similar paradigms (Nitschke et al., 2006; Ueda et al., 2003). Here, the alpha ERD seen in right frontal and occipital areas prior to the appearance of negative stimuli implies that right frontal cortex provides top-down regulation of the activity in visual cortex.

In our experiment, effects of valence in the parietal area were observed during Post-S1, and alpha ERD of S1 was larger for the Affective Negative Cue condition than for the Affective Cue Positive and Null Cue condition. Research on the processing of external positive and negative emotional stimuli (*e.g.*, film clips or affective gambling procedures) have typically reported observed differences in alpha activity in frontal and anterior temporal regions (Aftanas et al., 1996; Aftanas et al., 1998). In contrast, findings from studies examining hemispheric alpha asymmetries during self-generated positive and negative emotional states have found differences in alpha activity in the parietal region (Collet and Duclaux, 1987; Crawford et al., 1996; Smith et al., 1990). Crawford et al. (1996) suggested that emotional involvement in visually presented emotionally-laden material or affective gambling procedures requires subjects to evaluate external stimuli over time, and this calls upon prefrontal lobe abilities such as planning, organization, and context updating. Recalling past memories, however, is more likely to activate posterior regions associated with memory and imagery processes. Differences in ERD during Post-S1 in the present study appeared to depend on increased recall of negative memories induced by the negative cue.

In the current study, alpha ERD in the occipital area following affective images was smaller when the image was anticipated, and the tendency was prominent in the negative images. To date, there appear to be no other studies that have examined the effect of cuing on alpha ERD. Because ERD can be interpreted as an electrophysiological correlate of activated cortical areas involved in processing of sensory or cognitive information, the result of our experiment suggested that providing a cue prior to a stimulus image reduces the activation of visual cortex for the image. Of note, the effect of cuing appears to be larger for the anticipation and perception of negative as compared to positive stimuli.

The present results are globally in line with the notion that studying patterns of ERD in the alpha frequency range provides us with a window on the processes operating in thalamocortical circuits (Lopes da Silva, 1991; Steriade et al., 1990). It should be noted that ERD/ERS in other frequency bands most probably reflects different neurophysiological mechanisms; for example, it has been proposed that ERD/ERS in the theta frequency range is a reflection of cortico-hippocampal interactions (Miller, 1991). Aftanas and colleagues indicated that differences induced by pictures varying in emotional valence are associated mainly with theta activity (Aftanas et al., 2001a, 2001b). Therefore, future work should explore the anticipation of negative emotion on changes in the theta band.

It is important to note that the analysis in the current experiment relied on the distribution of band-limited power, which was topographically mapped onto the surface of the sensors. This poses a limitation due to the absence of source estimation for the alpha ERD. However, distributions topographically mapped onto the surface of the sensors are matched to distributions mapped onto the cortical surface in a positional relationship. This is because of a unique feature of the activity of gradiometers whereby they detect the largest signal just above the area where the current is generated (Ahonen et al., 1993). Furthermore, similarity between the location of blood oxygenation level-dependent (BOLD) responses and frequency-specific decreases in cortical power obtained with MEG have been reported, and ERD can give rise to a BOLD response (Hillebrand et al., 2005). In an fMRI study with higher spatial resolution than the methods applied here, our group reported that occipital and right frontal cortical areas are involved in negative anticipation (Ueda et al., 2003),. Taken together with the present findings, activations of the occipital and right frontal areas during the anticipation of negative stimuli appear to be a robust result.

In summary, the anticipation of negative images was associated with alpha ERD preceding the actual presentation of the stimulus, and the processing of the affective images was modulated by this anticipatory response. The critical finding in the present study was that the anticipation of negative visual stimuli induced preparatory alpha ERD in visual cortex. Given that our previous research using the same task was unable to detect a difference in stimulus valence using contingent magnetic variation (CMV) during an anticipation period (Onoda et al., 2006), it appears that alpha ERD is a more sensitive measure than CMV in assessing anticipatory effects of the affective content of images. Therefore, the ERD/ERS approach might be more useful than slow fields, such as CMV, in studying these anticipatory processes.

4. Experimental Procedure

Participants

Nineteen healthy adult volunteers (11 women and 8 men; mean age 24.2 years, *SD* 5.1 years) participated in the study. All participants had normal or corrected-to-normal visual acuity. The study was conducted according to a protocol approved by the Ethics Committee of the Hiroshima University School of Medicine. All participants provided written informed consent before their participation.

Stimuli

Geometric patterns (white triangles on a black background) were used as cue stimuli (S1). The orientation of the triangles differed for each condition. For the S2 stimuli, 160 images (80 positive images and 80 negative images)[1] were chosen from the International Affective Picture System (IAPS), based on their normative valence ratings (Lang et al., 1999). Negative images included pictures such as animals that are typically frightening, fear face, and mutilated human bodies. Positive images included pictures such as adorable animals, happy face, and sports. Nude pictures were not used. Ratings of the IAPS are measured on a nine-item scale (where 9 = high pleasure, high arousal; and 1 = low pleasure, low arousal). The mean valence levels for the positive and negative images used in this experiment were 7.3 (*SD* = 0.4) and 2.8 (*SD* = 0.7),

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[1] IAPS numbers used in this study were: Positive: 1340, 1500, 1540, 2150, 2260, 2311, 2340, 2389, 4640, 5260, 5470, 5910, 7230, 8120, 8500, etc. Negative: 1052, 1220, 2900, 3051, 3120, 3261, 6241, 6410, 6561, 6570, 6836, 7361, 9410, 9415, 9440, etc.

respectively; and the difference in mean valence was significant ($t(79) = -46.9$, $p < .001$). The mean arousal levels for the positive and negative images were 5.1 (SD = 1.1) and 5.4 (SD = 0.9) respectively; there was no significant difference ($t(79) = 1.3$, *ns*). Brightness was also controlled between the two categories.

Procedure

The emotional anticipation paradigm in the present experiment was identical to that used in a previous experiment (Onoda et al., 2006). The cue stimuli and emotional images were presented on a screen located 2.0 m in front of the participants. Participants were instructed to anticipate the image stimuli when the cue stimulus was presented and to keep their eyes open and to concentrate on the center of the screen. Participants were also asked not to move their eyes or body before, during or immediately after the presentation of a stimulus. The durations of the cue stimuli and the emotional images were 200 ms and 1000 ms, respectively. The interstimulus interval (from the offset of the cue stimulus to the onset of an emotional image) was 1800 ms, and the inter-trial interval varied randomly between 3000 and 5000 ms.

There were six conditions in this experiment: “Affective Cue Positive”; “Affective Cue Negative”; “Null Cue Positive”; “Null Cue Negative”; “No Cue Positive”; and “No Cue Negative”. In the Affective Cue and Null Cue conditions, the cue stimulus was presented when a trial started. For instance, the narrow apex of the white triangles used as the cue stimuli pointed leftward for the Affective Cue Positive condition and rightward for the Affective Cue Negative condition. The relation between the directions of the white triangle and the two affective conditions was counterbalanced across participants. The directions of the white triangles in the Null Cue conditions were always upward. Exactly 1800 ms after the offset of the cue stimulus, the emotional (Positive or Negative) image was presented for 1000 ms. In the No Cue conditions, the emotional image was suddenly presented with no prior stimuli.

Each image was used three times, once in each condition (Affective Cue, Null Cue, and No Cue conditions). There were 80 trials in each condition. Brief rest periods were provided every 10 minutes.

MEG Recording

MEGs were recorded at a sampling rate of 250 Hz (band pass filter: 0.1-80 Hz) using a 306-channel whole head neuromagnetometer (VectorView, Neuromag: Helsinki, Finland). Participants sat in a comfortable position in a magnetically shielded room and viewed images projected onto a screen from outside the room via a video projector. Head position was determined by activating four small coils positioned bilaterally at the brows and postauricular points.

Data Analysis

The sensor array was comprised of 102 sets of sensor units, each of which comprised two orthogonal planar gradiometers and one magnetometer. The data recorded with the 102 pairs of gradiometers was used for further analysis, rather than that obtained with the entire sensor unit, because the planar gradiometers have a unique feature whereby they detect the largest signal just above the area where the current is generated. The classical method used for ERD/ERS computation involves the following steps: (1) calculating individual alpha frequency (IAF) (Klimesch et al., 1996); (2) applying bandpass filters (lower-1-alpha IAF x 0.6 to IAF x 0.8, lower-2-alpha IAF x 0.8 to IAF x 1.0, upper-alpha IAF x 1.0 to IAF x 1.2) to the single MEG epochs (Doppelmayr et al., 1998); (3) removing the component of visual evoked fields from single MEG epochs that are time-locked to an event (Kalcher and Pfurtscheller, 1995); (4) calculating the amplitudes of the filtered MEG epochs using a Hilbert transform in order to obtain an estimate of the power in that particular frequency band; (5) calculating the root mean square value of the power in order to obtain the representation value of each orthogonal gradiometer set; (6) integrating the power over 100 ms intervals in order to obtain a more reliable estimate of the power; (7) averaging the power in each time interval over epochs; (8) expressing the power in each time interval as a ratio of the power in a baseline. This baseline period was comprised of the interval from 800 to 100 ms pre-S1. This procedure was repeated for each channel, condition, and subject. The resulting measure was the average power increase (ERS) or decrease (ERD) in a particular frequency band, in a particular time interval relative to the level of the power in the baseline.

Statistical Analysis

For the pre-S2 analysis, the data from the two Null Cue conditions was merged into a single Null Cue condition, with the result that the mean power was compared among the three cue conditions: Affective Cue Positive, Affective Cue Negative, and Null Cue. Data were analyzed with a 3 x 3 repeated measures two-way ANCOVA (cue x frequency) with the absolute power of the baseline as the covariate. The ratios of the six conditions were compared in the post-S2 analysis, and were analyzed with a 2 x 3 x 3 repeated measures three-way ANCOVA for the valence of the emotional images, the three cue conditions, and frequency. Again, the covariate was the absolute power of the baseline. Prior to performing the ANCOVA, the power ratios were corrected using the value of Pre-S2. Greenhouse-Geisser adjustments were applied to the degrees of freedom for variables with more than two levels in the repeated measures ANOVAs.

Multiple comparisons were made using Bonferoni’s multiple test procedure. The significance level was set at $p = 0.05$.

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Figure

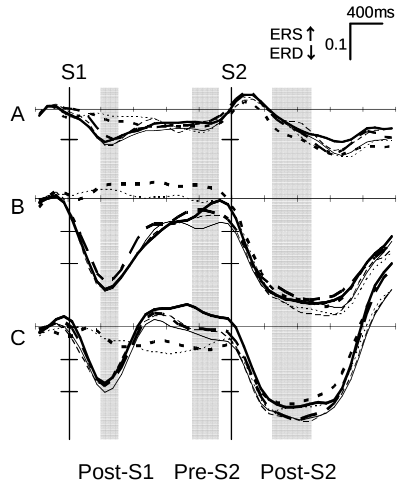

Figure 1. The time course activities of the alpha lower-1-alpha (α1), lower-2-alpha (α2), and upper-alpha (α3) on an occipital channel demonstrated the most remarkable ERD. The horizontal axis shows time from S1 through to post-S2, and the vertical axis shows the power of the alpha band activity. Gray areas indicate time periods used for comparison in the ANOVAs. Thick line: positive conditions; thin line: negative conditions; solid line: Affective Cue conditions; broken line: Null Cue conditions; dotted line: No Cue conditions.

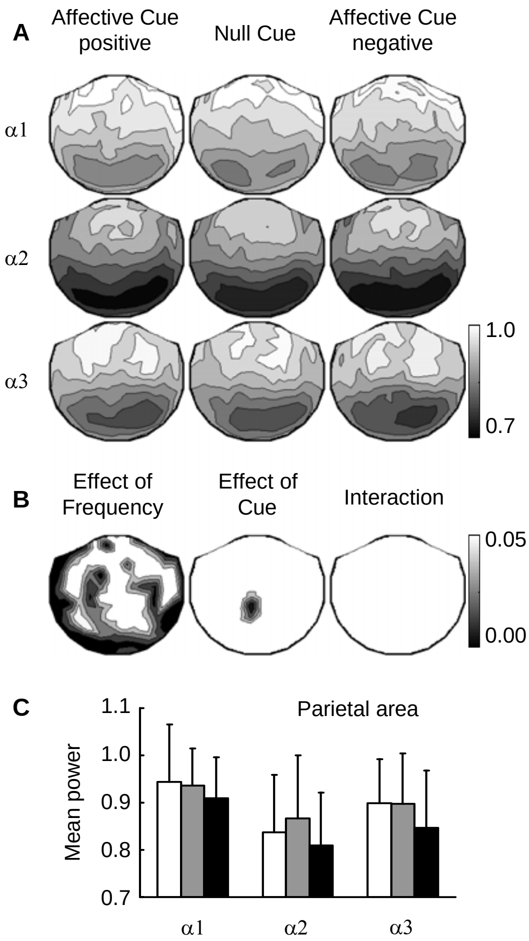

Figure 2. (A) ERD topographies of the lower-1-alpha (α1), lower-2-alpha (α2), and upper-alpha (α3) in the three conditions (Affective Cue Positive, Null Cue, and Affective Cue Negative) during Post-S1. Black denotes a power decrease (ERD). (B) The *p*-value map for the repeated two-way ANCOVAs involving Cue (Affective, Null, and No) and Frequency (α1, α2, and α3) during Post-S1. Significance is depicted as black, and non-significance as white. (C) Mean power during Post-S1 in the parietal channel which had the statistically largest effect of anticipation in the repeated two-way ANOVAs for each channel. The ordinate axis shows the power ratio from baseline. White, gray, and black columns show the Affective Cue Positive, Null Cue, Affective Cue Negative conditions, respectively.

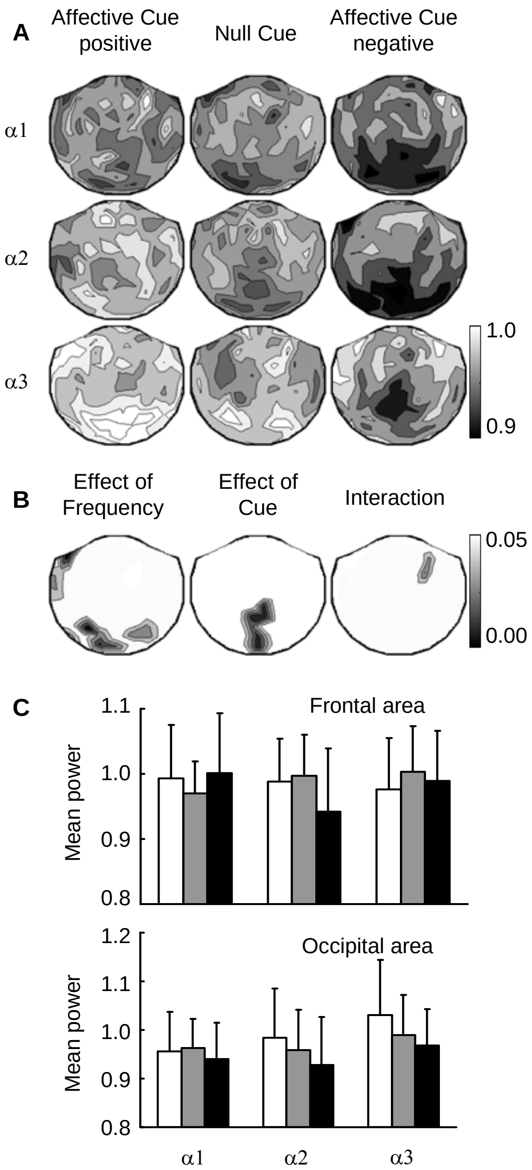

Figure 3. (A) ERD topographies during Pre-S2 for the lower-1-alpha (α1), lower-2-alpha (α2), and upper-alpha (α3) in the three conditions (Affective Cue Positive, Null Cue, and Affective Cue Negative). Black denotes a power decrease (ERD). (B) The *p*-value map for the repeated two-way ANCOVAs involving Cue (Affective, Null, and No) and Frequency (α1, α2, and α3) during Pre-S2. Significance is depicted as black, and non-significance as white. (C) Mean power during Pre-S2 in the frontal channel which had the statistically largest interaction, and the occipital channel which had the statistically largest

effect of anticipation in the repeated two-way ANOVAs for each channel. The ordinate axis shows the power ratio from baseline. White, gray, and black columns show the Affective Cue Positive, Null Cue, Affective Cue Negative conditions, respectively.

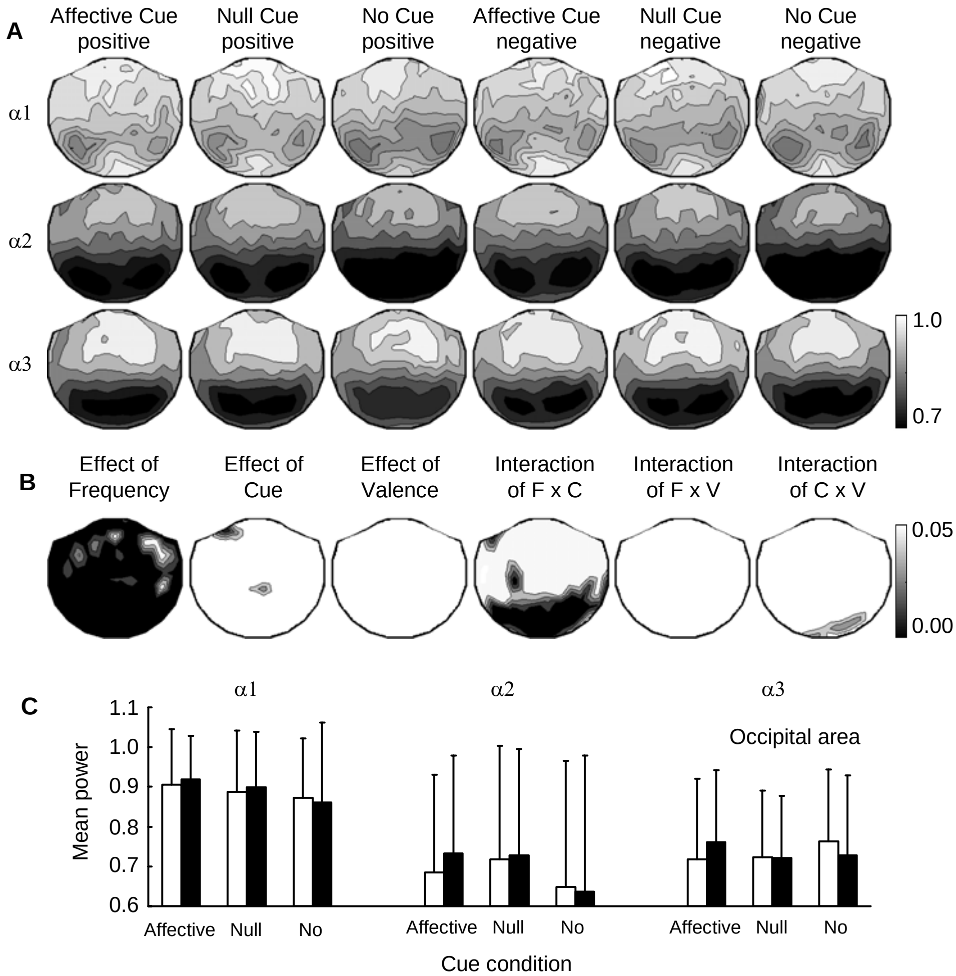

Figure 4. (A) ERD topographies of the lower-1-alpha (α1), lower-2-alpha (α2), and upper-alpha (α3) in the all six conditions during the Post-S2 period. For the ERD topographies, black denotes a power decrease (ERD). (B) The *p*-value maps of repeated three-way ANCOVA involving Valence of the affective image (Positive, Negative), Cue (Affective, Null, No) and Frequency (α1, α2, α3) during post-S2. For the *p*-value maps, significance is depicted as black, and non-significance as white. (C) ERD (*M*+*SD*) of the three frequency bands in the all six conditions during Post-S2. The occipital channel which showed the largest interaction of the Anticipation and Valence are shown. The ordinate axis shows

the mean power ratio from baseline. White and black column show Positive and Negative conditions, respectively.