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Task-related dissociation of EEG β enhancement and suppression

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ABSTRACT

Previous investigations of EEG β processes can be divided into two categories: one in which β enhancement is obtained and one in which β suppression is obtained. The current study investigated the β band range (14–30 Hz) by subdividing the signal into 2 Hz sub-bands. We presented participants with photographs of faces expressing happy, angry, sad or neutral expressions under two primary tasks in which participants judged the emotion the individual was expressing, or how the way the other person feels makes the participant feel. Results revealed a pattern of both β suppression and enhancement that appeared to depend on whether the task required first-person emotional experience (self-task) or perspective-taking (other-task). Specifically, the self-task was associated with enhancement while the other-task was associated with suppression. While some previous research has reported β enhancement to emotion-inducing stimuli, other research has reported β suppression in tasks also associated with mu suppression. To our knowledge, the current data are the first to reveal both β enhancement and suppression within a single experiment and suggests a neurocognitive dissociation of enhancement and suppression within the β band range.

1. Introduction

The ability to discriminate one's intentions from another's is critical to perspective-taking (Batson et al., 1991). Of all the emotions one might feel, only a portion of them reflect one's own emotional state. Some emotions one feels are mirror reflections of a conspecific's emotions — one experiences them, not because they are her own but because she observed the conspecific expressing them. But one is not obligated to act on the emotional motives of others. It is possible to recognize when the emotions one experiences are simulations of another's emotions. Sometimes called self-other discrimination, this process includes discriminating feelings one experiences because it reflects one's own emotional state from those feelings one experiences because one observed another expressing them.

While humans perpetually, albeit mostly unknowingly, imitate one another (i.e., chameleon effect; Chartrand et al., 1999), without discriminating self from other one might not only mimic facial expressions and body postures, but also respond to the emotions of others as though they were one's own. The behavior of any individual would be, in the presence of others, a manifestation of the individual's emotions, convolved with those of her conspecific. Rather than resembling a chameleon, human social interactions might be more similar to the unitary movements of a shoal of sardines. Humans, however, achieve genuine perspective-taking because they are capable of experiencing the emotions of conspecifics, without the obligation to act on them.

In recent years, electroencephalography (EEG) has shed light on some of the brain processes underlying empathy and perspective-taking. Various labs have demonstrated relationships of self-report measures of empathy with EEG mu (8–13 Hz) and beta (β) (14–30 Hz) modulation. Both of these band ranges have been implicated in simulation — the process of experiencing another's thoughts/feelings/intentions by simulating the motor expression of those. For instance, multiple labs have shown that other-induced mu suppression is related to self-reported perspective-taking skills (Perry et al., 2010; Hoenen et al., 2013; Woodruff et al., 2011b; Woodruff and Klein, 2013) Surprisingly, these reports reveal an inverse relationship between mu suppression and self-report measures of empathy and perspective-taking. Also, higher mu suppression difference scores (other-induced mu suppression values subtracted from self-induced mu suppression) are associated with higher self-reported PT (Woodruff et al., 2011a, 2011b), consistent with claims that PT is not simply simulation of the other's emotions, but a simultaneous recognition that they are not one's own.

Consistent with claims mu rhythms reflect simulation processing, suppression of the mu rhythm has been suggested to relate to premotor cortex mirror neuron input to sensorimotor cortex, thereby representing a putative measure of mirror neuron function. Similarly, some have suggested modulation of β rhythms may also reflect mirror neuron input (Muthukumaraswamy and Johnson, 2004; Hari et al., 1998; Milston et al., 2013). Muthukumaraswamy and Johnson looked at event-related synchronization/desynchronization of β rhythms, noting initial desynchronization followed by a diminished rebound. Similarly, using magnetoencephalography, Hari et al. (1998) reported a diminished rebound effect in the 15–25 Hz range. Analogous to mu

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suppression data, findings such as these have been taken to reflect possible mirror processing in the β band range.

Alternatively, other labs have reported enhancement of β rhythms, primarily in response to emotional stimuli (Güntekin and Başar, 2007; Güntekin and Başar, 2010; Ray and Cole, 1985; Woodruff et al., 2011a). A review conducted by Güntekin and Başar (2014) concluded that β-enhancement (βE) obtains when one views emotional as compared to neutral valence imagery. Güntekin and Tülay (2014) found that when subjects viewed emotional pictures from the International Affective Picture System (IAPS), higher levels of event-related β oscillations were elicited by negative stimuli presented in blocked but not randomized trial presentation. Similarly, Woodruff et al. (2011a) found β-enhancement (βE) was greater for negative as compared to neutral IAPS imagery in β-2 (25–30 Hz) and that this enhancement associated with higher levels of self-reported personal distress, suggesting βE may be related to emotional information pertaining to the self as opposed to the processing of vicarious emotions.

Sakihara et al. (2012) investigated EEG correlates of facial perception using event related synchronization (ERS). Participants viewed randomly presented faces, which were composed of the participant's own face, a familiar face or a non-familiar face. They found greater right prefrontal areas β-ERS, 400–800 ms after the presentation of the stimulus when viewing one's own face compared to another's, suggesting βE reflects neural processing about the self, and less so about others.

The β-rhythm results reviewed here seem to represent a contradiction insofar as movement observation studies with little or no emotional content are associated with β-suppression (Muthukumaraswamy and Johnson, 2004; Hari et al., 1998) while experimental stimuli that involve emotional content but not movement observation are associated with βE (Güntekin and Başar, 2007; Güntekin and Başar, 2010; Ray and Cole, 1985; Woodruff et al., 2011a). One possible explanation of the suppression/enhancement differences is that distinct neural processes are contributing to the β signal, one set of neurons desynchronizing and a different set synchronizing. Under this explanation, whether suppression or enhancement is obtained depends on which of these two processes is dominating the β frequency during a given task. If a task makes particular demands on understanding the emotions or intentions of another, mirror processing-related suppression predominates the β frequency while a task making demands on first-person emotional experience may lead to a predominance of the neural processes associated with βE.

The current study builds upon previous research by utilizing photographs of emotional faces under two experimental conditions — one in which a participant assesses how the person in the photograph feels and one in which the participant assesses how the way the photographed person feels makes her feel. Manipulating perspective-taking in this way, we tested two hypotheses: 1) β suppression and Enhancement would obtain in a single experiment and, 2) suppression would be associated with vicarious emotional experience (other task) while enhancement would be associated with first-person emotional experience (self task). In order to more fully characterize the β band range (14–30 Hz), we subdivided the data into 2 Hz sub-bands. Based on previous data showing greater emotion-related enhancement in the 25–30 Hz sub-band (Woodruff et al., 2011a, 2011b), we hypothesized greater enhancement effects in upper compared to lower sub-bands.

2. Methods

2.1. Participants

30 right handed college students (13 male, 17 female) participated in this study and received course credit to do so. Data from three participants were not included in analysis due to technical issues during recording. Participants ranged in age from 18 to 30 ($\overline{x} = 19.76$, $s = 2.62$). All participants were right handed and had no self-reported history of neurological or psychiatric disorders. All activity was carried out under the approval of the Northern Arizona University Institutional Review Board. Participants were given course credit.

2.2. Experimental paradigm

Participants viewed a series photographs of happy, sad, angry and neutral faces derived from (Ekman and Friesen, 1976), displayed on a Dell Inspiron laptop computer screen using the stimulus presentation software DirecrtRT (2008.1.0.13 Empirisoft, New York City, New York, United States). Eight of the individuals in the photographs were female and 5 male with each photograph containing only one actor. Participants were presented with six total blocks of approximately 80 s each. The same images were presented in each block and were pseudo-randomly ordered with the constraint that no more than 3 faces with the same emotion occurred in succession. While images were identical across all blocks, the tasks performed differed. In two blocks, participants were required to estimate the age of the actors in the photos (age control). In a different two blocks, participants indicated which of the four emotions was being displayed in each photo (other condition). The remaining two blocks required participants to indicate how the emotion of the actor makes the participant feel (self-condition). All blocks were 80 s in duration and order of presentation was randomly specified. In order to minimize overt motor movements that may reduce our ability to detect socially relevant aspects of brain signals, participants were instructed to make their judgments but did not communicate those judgments. Participants sat approximately 96 cm in front of the 14.1 inch computer screen. Images appeared in the center of the screen and subtended 5.3° horizontally and 8.3° vertically.

2.3. Electroencephalography procedures

Electroencephalographic (EEG) data were recorded (Mistar 202, St. Petersburg, Russia) simultaneously from 32 channels (Easy cap, Electro-Cap International Inc., Eaton, Ohio, USA, 2009) with all electrode impedances less than 5 kΩ. Electrodes were placed according to the International 10–20 electroencephalography system. Data were low-pass-filtered offline at 30 Hz and high pass filtered at 0.1 Hz (WinEEG 2.80.19 St. Petersburg, Russia). Principal components analysis was used to remove all eye blink artifacts, and all epochs with signal deviation of more than 100 μV were excluded. There were no significant differences between conditions in amount of data excluded (all p's > .40).

2.4. Data processing and analysis

β was defined as oscillatory activity within the 14–30 Hz band range. In addition, β was further broken down to eight 2-Hz bands fur further analysis with the first four defined as β1 and the latter four defined as β2. β enhancement/suppression effects for self were assessed by taking the log transformed ratio of *self* to *age* and for other by the log transformed ratio of other to age. The ratios were submitted to a (2 × 2 × 3) omnibus repeated measures ANOVA with the factors of band-range (β1, β2), task (self, other) and electrode (C3, Cz, C4). We also assessed correlations between β ratios and both the Interpersonal Reactivity Index (IRI; Davis, 1983) and the Empathy Quotient (EQ, Baron-Cohen and Wheelright, 2004).

3. Results

Log transformed β ratios were submitted separately for each of the four electrode clusters (Fp's, F's, Fc's and C's) to a 2 × 3 × 8 Repeated Measures (RM) ANOVA with task (self, other), electrode (left, middle or right) and band range (eight, 2 Hz-bands from 14 to 30 Hz) serving as within-subjects factors. All reported p-values were Greenhouse–Geisser corrected for possible violations of sphericity. Only ANOVA's for Frontal (F) and Central (C) electrodes produced statistically