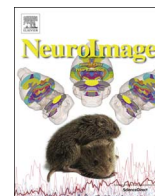




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Why don't you like me? Midfrontal theta power in response to unexpected peer rejection feedback

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ABSTRACT

Social connectedness theory posits that the brain processes social rejection as a threat to survival. Recent electrophysiological evidence suggests that midfrontal theta (4–8 Hz) oscillations in the EEG provide a window on the processing of social rejection. Here we examined midfrontal theta dynamics (power and inter-trial phase synchrony) during the processing of social evaluative feedback. We employed the Social Judgment paradigm in which 56 undergraduate women (mean age=19.67 years) were asked to communicate their expectancies about being liked vs. disliked by unknown peers. Expectancies were followed by feedback indicating social acceptance vs. rejection. Results revealed a significant increase in EEG theta power to unexpected social rejection feedback. This EEG theta response could be source-localized to brain regions typically reported during activation of the saliency network (i.e., dorsal anterior cingulate cortex, insula, inferior frontal gyrus, frontal pole, and the supplementary motor area). Theta phase dynamics mimicked the behavior of the time-domain averaged feedback-related negativity (FRN) by showing stronger phase synchrony for feedback that was unexpected vs. expected. Theta phase, however, differed from the FRN by also displaying stronger phase synchrony in response to rejection vs. acceptance feedback. Together, this study highlights distinct roles for midfrontal theta power and phase synchrony in response to social evaluative feedback. Our findings contribute to the literature by showing that midfrontal theta oscillatory power is sensitive to social rejection but only when peer rejection is unexpected, and this theta response is governed by a widely distributed neural network implicated in saliency detection and conflict monitoring.

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1. Introduction

From an evolutionary perspective, people are strongly motivated to gain social acceptance as social disconnection may diminish fundamental resources for survival (Baumeister and Leary, 1995). It has been hypothesized that people have evolved a highly sensitive threat-detection system that could protect them from social disconnection (Eisenberger and Lieberman, 2004), and dysfunction of this system has been linked to a wide range of psychological disorders (e.g., from diminished self-esteem to social anxiety and depression) (Masten et al., 2011; Masten et al., 2009;

Nishiyama et al., 2015; Somerville et al., 2010). Neuroimaging studies have indeed shown that the brain is equipped with an efficient alarm system that quickly detects signs of social disconnection (Eisenberger, 2012). Two core structures of this neural alarm system are the anterior cingulate cortex (ACC) and the anterior insula (AI), and recently it has been shown that increases in AI generated theta (4–8 Hz) oscillatory power can be observed during social exclusion events (Cristofori et al., 2013). Notably, oscillatory activity in the theta band is also involved in the processing of negative feedback (e.g., Van de Vijver et al., 2011), but typically these studies investigate performance monitoring in which the increase in theta power after negative performance feedback is interpreted to reflect a prediction error of the participant. The question thus remains whether theta oscillatory reactivity can be taken to reflect as a neural signature of social isolation, especially since the neural substrates that generate

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rhythmic activity in the theta band are associated with a variety of cognitive affective processes, including both negative affect and cognitive control (Shackman et al., 2011).

The majority of studies investigating the neural correlates of the emotional distress resulting from social disconnection have used a paradigm coined 'Cyberball' (Eisenberger et al., 2003), a virtual ball-tossing game in which participants are first included and then excluded. Using Cyberball, fMRI studies have found increased activation in both dorsal and ventral parts of the ACC, with the ventral ACC being most sensitive to the experience of social exclusion (Eisenberger and Lieberman, 2004). Additionally, event-related brain potential (ERP) studies typically show that exclusion in Cyberball is manifested by a late positive potential (LPP) (Crowley et al., 2010; Gutz et al., 2011; Sreerishnan et al., 2014). Recent EEG studies have shown that this LPP during social exclusion is governed by theta oscillatory activity (Cristofori et al., 2013; Van Noordt et al., 2015), and this activity in theta band power was interpreted as a neural signature of 'social pain' (Cristofori et al., 2013). Although these Cyberball studies have contributed considerably to our understanding of the neural mechanisms of social pain processing, a notable limitation to the Cyberball paradigm is that the exclusion blocks elicit not only emotional distress due to social exclusion, but also cognitive conflict due to – for example – participants' expectancy violation about receiving the ball (cf., Somerville et al., 2006; Van der Veen et al., 2014; Woo et al., 2014).

A paradigm that has been successfully used in dissociating cognitive conflict from the psychophysiological processes induced by a social threat is the Social Judgment paradigm (SJP), introduced by Somerville et al. (2006). In this paradigm, participants are led to believe that they have been evaluated based on first impressions by a panel of peers. During the experiment participants are asked to predict whether these peers liked or disliked the participant. Thereafter participants receive the actual peer feedback communicating social rejection or acceptance that is either congruent or incongruent with their prior predictions. The advantage of the SJP is that it allows for a detailed assessment of social acceptance vs. rejection processing vis-à-vis participants' expectancies about the social evaluative outcome.

In previous ERP studies, we examined the feedback-related negativity (FRN) elicited by social evaluative peer feedback in the SJP. The FRN is a frontocentral negative deflection in the ERP peaking approximately 250 ms after the onset of the feedback stimulus, and a vast literature suggests that the FRN is generated by the ACC (Bellebaum et al., 2010; Segalowitz et al., 2010; Warren et al., 2015). In terms of its functional significance, the FRN is typically interpreted to reflect prediction error (Alexander and Brown, 2011). That is, the FRN is larger in amplitude for feedback that is incongruent with individuals' prior expectancies about the feedback outcome. Although it has been frequently observed that the FRN is larger for feedback that is worse than expected (Gehring and Willoughby, 2002), our two previous ERP studies revealed that the FRN was larger for unexpected vs. expected feedback in the SJP (Dekkers et al., 2015; Van der Molen et al., 2014). It should be acknowledged, however, that these ERP analyses did not capture all relevant information that is contained in the EEG. Due to single-trial averaging, the FRN represents the time-domain average of neural activity that is time-locked (phase-locked) to the onset of the feedback stimulus, and thus lacks information about neural activity that is not phase-locked with the event (Makeig et al., 2004). Myriad of studies demonstrated that non-phase locked oscillatory power yields cognitively relevant data, and specifically modulations in theta-band power have shown to be sensitive to feedback manipulations in various cognitive and affective studies (e.g., Cavanagh et al., 2012; Christie and Tata, 2009; Cohen et al., 2009; Crowley et al., 2014; De Pascalis et al., 2012).

Here we will employ the SJP to investigate rhythmic changes in

both theta-band oscillatory power (i.e., the magnitude of neural activation) and inter-trial phase synchrony (i.e., the consistency in timing of oscillatory activity) during social evaluative feedback processing. Our hypotheses were directed at the theta-band, since Cyberball studies have reported on increased theta power during social exclusion (Cristofori et al., 2013; Van Noordt et al., 2015), and prior ERP studies have linked the FRN to modulations in theta power and phase synchrony (Cavanagh et al., 2010; Van de Vijver et al., 2011). We tested two competing hypotheses that should reveal whether theta power is specifically implicated in processing social rejection, or whether expectancy violation is contributing to the involvement of theta power in processing social rejection. If indeed theta power is a neural correlate of processing social rejection (Cristofori et al., 2013; Van Noordt et al., 2015), then theta power should be significantly increased in social rejection conditions, irrespective of participants' prior expectancies. However, if theta power is modulated by expectancy violation, a significant increase in theta power would be expected in conditions in which social evaluative feedback violates participants' prior predictions. Further, we exploratively examined source activity of feedback-related theta power and, based on prior studies (Cohen, 2014; Cristofori et al., 2013), expected to find the ACC and AI as main source generators of this EEG signal. With respect to theta phase synchrony, we hypothesized to find stronger inter-trial phase synchrony in conditions in which social evaluative feedback violated participants' expectancies. This hypothesis is in line with our previous FRN findings (Dekkers et al., 2015; Van der Molen et al., 2014) and is guided by the fact that the FRN reflects neural activity that is phase-locked to the feedback stimulus. To warrant similarity in results between the FRN and theta inter-trial phase synchrony in social evaluative feedback processing, we also measured the FRN component in the ERP.

2. Method

2.1. Participants

Seventy-one right-handed female undergraduate students participated in this study.¹ Fifteen participants were excluded from analysis due to recording problems ($n=5$), bad EEG data ($n=9$) or disbelief in the cover story of the SJP ($n=1$), yielding a total sample of 56 participants for the analyses (age range=18–24 years, $M=19.67$, $SD=1.47$). Participants were recruited from or within the proximity of Leiden University and received course credit or fixed payment for participation. Participants had normal or corrected-to-normal vision, were right-handed, and free from use of psychoactive medication. All participants signed informed consent prior to the experiment. The study's protocol was reviewed and approved by the medical ethical review committee of the Leiden University Medical Center.

2.2. Social Judgment paradigm

We employed a modified version of the SJP (Gunther Moor et al., 2010; Somerville et al., 2006; Van der Molen et al., 2014). Participants were led to believe that they were enrolled in a study on first impressions. Prior to testing, participants were required to send a personal portrait photograph to the investigators. A panel of peers from other universities would then evaluate this photograph. This peer panel would be asked to judge – based on their

¹ A sub-sample ($n=31$) of the current participants took part in a previous study examining EEG brain potential responses to feedback in the SJP (Van der Molen et al., 2014).

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