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Social exclusion modulates event-related frontal theta and tracks ostracism distress in children

Stefon J.R. van Noordt [a], Lars O. White [b,c], Jia Wu [c,e], Linda C. Mayes [c,e], Michael J. Crowley [c,d,e,f,*]

[a] Cognitive and Affective Neuroscience Laboratory, Department of Psychology, Brock University, Saint Catharines, ON, Canada
[b] Department of Child and Adolescent Psychiatry, Psychotherapy and Psychosomatics, University of Leipzig, Leipzig, Germany
[c] Yale Child Study Center, Yale School of Medicine, New Haven, CT, United States
[d] Program for Anxiety Disorders, Yale School of Medicine, New Haven, CT, United States
[e] Developmental Electrophysiology Laboratory, Yale School of Medicine, New Haven, CT, United States
[f] Center for Translational Developmental Neuroscience (CTDN), Yale School of Medicine, New Haven, CT, United States

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ABSTRACT

Social exclusion is a potent elicitor of distress. Previous studies have shown that medial frontal theta oscillations are modulated by the experience of social exclusion. Using the Cyberball paradigm, we examined event-related dynamics of theta power in the EEG at medial frontal sites while children aged 8–12 years were exposed to conditions of fair play and social exclusion. Using an event-related design, we found that medial frontal theta oscillations (4–8 Hz) increase during both early (i.e., 200–400 ms) and late (i.e., 400–800 ms) processing of rejection events during social exclusion relative to perceptually identical "not my turn" events during inclusion. Importantly, we show that only for the later time window (400–800 ms) slow-wave theta power tracks self-reported ostracism distress. Specifically, greater theta power at medial frontal sites to "rejection" events predicted higher levels of ostracism distress. Alpha and beta oscillations for rejection events were unrelated to ostracism distress at either 200–400 ms or 400–800 ms time windows. Our findings extend previous studies by showing that medial frontal theta oscillations for rejection events are a neural signature of social exclusion, linked to experienced distress in middle childhood.

Introduction

Loss of social connections poses a threat to survival for many species (MacDonald and Leary, 2005). In humans, the potency of the experience is so strong that it triggers distress even when the excluders are fictitious (Crowley et al., 2009; Zadro et al., 2004) or from despised outgroups (Gonsalkorale and Williams, 2007). In real world situations, social exclusion negatively impacts physical and mental health (Cohen and Janicki-Deverts, 2009; Holt-Lunstad et al., 2010), reflected in lower levels of self-esteem (Deater-Deckard, 2001) and poorer academic self-confidence (Buhs, 2005), as well as higher levels of aggression, depression, and anxiety (Ladd, 2006). Within the neurosciences, the study of social pain has become a fruitful line of inquiry, creating situations in which the participant is left out of an interaction, evaluated poorly, or "voted off the island" (Eisenberger et al., 2003; Guyer et al., 2009; Kujawa et al., 2014).

One of the most widely used experimental paradigms for studying social exclusion, the Cyberball paradigm (Williams and Jarvis, 2006), reliably induces mild distress, offering a way to experimentally probe the neural correlates of being physically "left out" of an interaction. Ostensibly played over the Internet as a virtual ball toss-and-catch game, Cyberball requires a participant to make throws to, and receive throws from two or more cyber players. Unbeknownst to the participant, the players are in fact computer-generated. Seamlessly and without warning, an "exclusion" phase ensues—the cyber players exclude the participant, throwing only to one another. These seemingly simple bouts of ostracism negatively impact self-esteem and belonging (Ruggieri et al., 2013; Williams et al., 2000). For example, compared to those low in social anxiety, high socially anxious individuals are slower to recover from distress following ostracism (Oaten et al., 2008), and victims of bullying score lower on feelings of recognition by others after being socially excluded compared to non-victims (Ruggieri et al., 2013).

A number of studies have now used Cyberball to examine the neural correlates of social exclusion, and suggest that the medial frontal cortex plays a fundamental role in regulation of negative affect associated with exlclusion (Gunther-Moor et al., 2012; Rotge et al., 2015; Themanson et al., 2013). Functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) measures both show that various frontal responses are related to measures of distress, ostracism, mood, and attachment (Crowley et al., 2009, 2010; Eisenberger et al., 2003; Masten et al., 2009; McPartland et al., 2011; Sreekrishnan et al., 2014; White et al., 2012, 2013). fMRI studies have identified a number of frontal

* Corresponding author at: Yale Child Study Center, 230 South Frontage Rd., New Haven, CT 06473, United States. Fax: +1 203 785 7926.
E-mail address: michael.crowley@yale.edu (M.J. Crowley).

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regions engaged during social exclusion including the dorsal and ventral ACC, medial prefrontal cortex, ventro-lateral prefrontal cortex (Gunther-Moor et al., 2012), subgenual ACC (Masten et al., 2009, 2011), and right ventral prefrontal cortex (Eisenberger et al., 2003).

Several event-related potential (ERP) studies document activation patterns at frontal scalp sites that track experienced distressed during social exclusion. For example, rejection events have been shown to engage distinct slow-wave ERP activity at left/medial frontal sites, which is correlated with self-reported distress in adults (Crowley et al., 2009). Similarly, Crowley et al. (2010) found that in middle-childhood, children scoring higher in ostracism distress elicited larger (i.e., more negative) slow wave ERPs at medial frontal sites following rejection events in the Cyberball task. Similar results were reported by White et al. (2012) who found that larger negative slow-wave ERP activity in left/medial frontal sites to rejection events predicted decreased quality of attachment in children. More recently, the effects of kin exclusion were examined in children and their mothers. Slow-wave ERP activity at frontal sites was correlated with ostracism distress when linked to rejection events during exclusion by kin, but not strangers (Sreekrishnan et al., 2014).

Although the ERP approach has utility as a fixed-latency, average amplitude measure, it discards important information about task-relevant EEG oscillatory dynamics that could provide new insights into neural processing of social exclusion. Due to signal averaging, ERPs only reflect phase locked activity and typically do not distinguish among the EEG frequency spectra most strongly engaged for a particular event type (theta, 4–7 Hz; alpha, 8–15 Hz; beta, 16–30 Hz, etc.). Thus a useful complement to the ERP approach is the event-related spectral perturbation (ERSP), which reflects the event-locked spectral properties of induced power changes in the EEG signal (Makeig et al., 2004). Specifically, ERSP is a temporally sensitive measure of relative change in mean EEG power from baseline associated with stimulus presentation or response execution. Unlike ERPs, ERSPs capture changes in spontaneous EEG activity occurring across frequency spectra. They are sensitive to signal fluctuations that are temporally stable, but not coherent in phase angle (Makeig et al., 2004). A recent study by Cristofori et al. (2013) strongly supports the utility of examining EEG oscillations in response to social exclusion. They collected intracerebral EEG recordings while epileptic patients played Cyberball. Patients showed increased power in the theta band during overall exclusion versus inclusion experience, leading Cristofori et al. (2013) to propose theta as a "neural signature" of social exclusion.

While the theta-social exclusion connection is compelling, a large body of literature also links theta-band oscillatory dynamics to attentional processes and cognitive control (Basar et al., 2001; Cavanagh et al., 2010; Klimesch, 1999; Sauseng et al., 2006). Theta signatures in the EEG have been observed during error/conflict monitoring (Trujillo and Allen, 2007) and feedback processing (Cavanagh et al., 2010), behavioral inhibition and attentional control (Cavanagh et al., 2012), task switching (Sauseng et al., 2006), engagement of working memory (Sauseng et al., 2010), the regulation of affective responses (Knyazev, 2007; Luu et al., 2000b) and cognitive re-appraisal of emotions (Ertl et al., 2013). Many of these processes may be engaged during social exclusion, suggesting the nature by which theta oscillations can be considered a neural signature of social exclusion needs further elucidation.

Current study

The goal of the current study is to understand how we might consider theta as a neural signature of social exclusion in Cyberball with a sample of typically developing children. This paper is a follow-up of a previous report on this sample (Crowley et al., 2010) in which we examined social exclusion and event-related potentials. Previous work implicated medial frontal ERP activity as a neural correlate social exclusion. Thus, we focus on this region for our event-related spectral analyses (see Supplemental Materials for posterior, lateral left and lateral right regional data). Building upon the established link between theta and an overall exclusion experience (Cristofori et al., 2013), we focus on the theta dynamics for the rejection events that comprise social exclusion. First we ask, do any aspects of a rejection event time course particularly engage theta dynamics versus alpha or beta EEG dynamics? Second, we contrast rejection events where participants do not receive the ball during exclusion with "not my turn" events where participants do not receive the ball during the course of an inclusion block (fair play). In this way, the perceptual characteristics of individual events compared ("rejection" vs. "not my turn") are identical. Finally, we examine the association between theta during rejection events and the psychological experience of social exclusion referred to as ostracism distress.

Methods

Participants

Thirty-three children (17 male) 8–12 years of age participated in this study. Children's ethnic backgrounds were as follows: 91% Caucasian, 9% African-American. Children played Cyberball while an EEG was acquired. Families were recruited via mass mailings with addresses provided by a credit and information agency. The parent of each child provided written parental informed consent while their child gave their written assent. The Yale University School of Medicine Human Investigation Committee approved this research. Children were compensated forty dollars for their participation

Procedure

Cyberball social exclusion task

Cyberball is a computerized ball-toss game in which a participant ostensibly plays with two other players on over the internet. Players pass a white ball amongst themselves including the participant. The ball color changes with the ball position reflecting throws to the participant and the other players. Prior to each throw event, the ball disappears, then the glove is outlined in yellow as a cue signaling a throw will occur. The ball reappears on path to the subject or on a path to one of the other players (see Fig. 1 for timing and more details). Abruptly, the other players exclude the participant, throwing only to one another. This exclusionary experience is distressing to participants, as per their self-reports of distress on a Need Threat Scale (described below).

Each participant sat in a dimly lit (60-W bulb), sound attenuated room, 60 cm from a 17 in. LCD monitor. Prior to beginning the experiment, the child's gender and ethnicity were identified. Settings within the game ensured that the other players on the screen were of a similar age, ethnic appearance and gender (drawing on a bank of opponent pictures taken at the Child Study Center for use in research). At the outset of the game, the child saw an actual Google™ webpage, followed by a "Cyberball" web page, followed by a screen with a green status bar. Several other modifications were introduced to make the Cyberball game more engaging to children. The child chose from one of six different ball gloves to be his or her personal glove throughout the game. A female voice narrated instructions on the computer screen. From throw to throw, the ball traveled randomly along different paths (straight line, arc or sine wave); lifelike sound effects occurred as the ball traveled (swoosh) and landed in a glove. After the experiment, the child and parent were debriefed and informed that the other players were not real.

When the game began, the child's glove was at the bottom center of the screen; the gloves of the other two players, chosen by the computer, were to the left and right of the screen center. Pictures of the other "players" appeared above their names and respective gloves. Participants used their left and right index fingers on a response pad to throw left or right to the other players. Each child was told that a picture was taken of them with a camera (focused on them) and that the other players would see this over the internet.Next, the child then overheard one experimenter telling a second experimenter s/he would