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To cite this article: Caitlin M. Hudac (2018): Social priming modulates the neural response to ostracism: a new exploratory approach, Social Neuroscience, DOI: 10.1080/17470919.2018.1463926

To link to this article: https://doi.org/10.1080/17470919.2018.1463926

Accepted author version posted online: 10 Apr 2018.
Published online: 16 Apr 2018.

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Social priming modulates the neural response to ostracism: a new exploratory approach

Caitlin M. Hudac

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ABSTRACT

The present study sought to evaluate whether social priming modulates neural responses to ostracism, such that making arbitrary interpersonal decisions increases the experience of social exclusion more than making arbitrary physical decisions. This exploratory event-related potential (ERP) study utilized the Lunchroom task, in which adults (N = 28) first selected one of two options that included either interpersonal or physical descriptors. Participants then received ostracism outcome feedback within a lunchroom scenario in which they were either excluded (e.g. sitting alone) or included (e.g. surrounded by others). While the N2 component was sensitive to priming decision condition, only the P3 component discriminated between ostracism decisions. Further inspection of the neural sources indicated that the amygdala, anterior cingulate cortex, and superior temporal gyrus were more engaged for exclusion than inclusion conditions during both N2 and P3 temporal windows. Evaluation of temporal source dynamics suggest that the effects of ostracism are predominant between 250–500 ms and were larger following interpersonal than physical decisions. These results suggest that being ostracized evokes a larger neural response that is modulated following priming of the social brain.

ARTICLE HISTORY

Received 8 October 2017
Revised 7 February 2018
Published online 18 April 2018

KEYWORDS

Ostracism; social exclusion; social priming; event-related potentials; source estimation

Introduction

Ostracism (i.e. being ignored and/or excluded) is an intensely negative social experience with destructive consequences for aspects of fundamental social needs and general affective well-being (Baumeister & Leary, 1995; Williams, 2006, 2007). This is not an uncommon phenomenon and recent studies suggest that people are ostracized on a daily basis (Nezlek, Wesselmann, Wheeler, & Williams, 2015). Even brief exposure to ostracism elevates negative affect (Buckley, Winkel, & Leary, 2004; Chow, Tiedens, & Govan, 2008) and moderates self-reported levels of belonging, self-esteem, and meaningful existence (Zadro, Williams, & Richardson, 2004). At a biological level, social exclusion is associated with symptoms of stress, including heightened pupillary reactivity (Silk et al., 2012), modulation of heart rate (Gunther Moor, Crone, & van der Molen, 2010; Wagner, Gunther Moor, & van der Molen, 2010), and increased salivary cortisol (Blackhart, Eckel, & Tice, 2007).

Much of the work targeting neural mechanisms underlying ostracism and social exclusion have employed the Cyberball paradigm, a popular task comparing peer engagement versus peer exclusion (Williams, Cheung, & Choi, 2000; Williams & Jarvis, 2006). In this virtual game, participants ostensibly take turns tossing a ball between two or more players, and the proportion of throws is manipulated so that the participant experiences a period in time without receiving the ball from the other players (i.e. social exclusion) in contrast with other periods of fair play (i.e. social inclusion). Over the past decade, the Cyberball task has been shown to engage a broad range of social brain regions during periods of exclusion, including the anterior cingulate cortex (ACC), anterior insula, and ventral prefrontal cortex (Bolling et al., 2011; Masten, Eisenberger, Pfeifer, & Dapretto, 2010; Moor et al., 2012; see Eisenberger, 2012b for review). In the seminal functional imaging study, Nieuwenhuis, Yeung, van den Wildenberg, and Ridderinkhof (2003) found that greater activation within the ACC, a region implicated in the affective distress of physical pain (Eisenberger, 2012a; Sawamoto et al., 2000; van der Meulen, van IJ Zendoorn, & Crone, 2016), positively correlated with greater self-reported distress during exclusion periods. In contrast, greater activation within the ventrolateral prefrontal cortex, a region implicated

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in the inhibition and regulation of distress (Kalisch, Wiech, Herrmann, & Dolan, 2006; Riva, Romero Lauro, DeWall, & Bushman, 2012), negatively correlated with reduced distress. Subsequent work has confirmed correspondence between social distress and social brain activation, particularly within the ACC and insula (Eisenberger, 2012b). Taken together, these results suggest that this network of brain regions is sensitive to the experience of ostracism.

**Evidence from event-related potentials (ERP)**

Despite the reliability of this paradigm, there is contention on whether these activation patterns indeed reflect the active experience and processing of social pain (Eisenberger, 2003, 2012b), considering the poor temporal specificity of functional imaging. An event-related potentials (ERP) approach provides an opportunity to better understand the immediate response to social exclusion at the millisecond level, and ERP studies implicate several key components in the Cyberball task: First, an early N2 component occurring over frontal electrodes between 100–250 ms post-stimulus onset is sensitive to exclusion (Sreekrishnan et al., 2014; Themanson et al., 2013; Weschke & Niedeggen, 2013). Other work noted the N2 is not affected by the probability of receiving the ball toss (Gutz, Küpper, Renneberg, & Niedeggen, 2011; Niedeggen, Sarauli, Cacciola, & Weschke, 2014), but may instead be related to conflict monitoring (Themanson et al., 2013).

Second, a mid-latency P3 component elicited between 250–600 ms post-stimulus onset is increased during exclusion periods across posterior (Crowley, Wu, Molfese, & Mayes, 2010; Themanson et al., 2015) and central (Gutz et al., 2011) electrodes. P3 positivity is known to be responsive to target stimuli (Comerchero & Polich, 1999) and is thought to reflect higher-level cognitive processes, including attention reorienting (Donchin & Coles, 2010; Katayama & Polich, 1998; Linden, 2005) and reward significance (Keil et al., 2002; Yeung & Sanfey, 2004). Ostracism responses as reflected by the P3 component decrease in amplitude over the course of the experiment (Kawamoto, Nittono, & Ura, 2013) and are also reduced as a function of involvement (Niedeggen et al., 2014), suggestive of the sensitivity of the P3 to context and motivation.

However, others have proposed that these ERP responses are independent of the social context of the Cyberball paradigm (Somerville, Heatherton, & Kelley, 2006; Weschke & Niedeggen, 2015a) and instead may be indicative of reorienting attention following an affective response (Cacioppo et al., 2013). For instance, one event-related potential (ERP) study by Weschke and Niedeggen (2016) revealed that the P3 component is similarly responsive to reduced target probability for visual oddball (i.e. seeing oddball target) and Cyberball (i.e. receiving the ball in the exclusion block) tasks. Similarly, Cyberball tasks within a nonsocial context (e.g. ball tosses with a computer instead of players who were physically present) show no P3 differentiation between exclusion and inclusion. Other work suggests that the N2 amplitude was increased during exclusion periods with physical players present (Weschke & Niedeggen, 2013). As has been previously noted (Themanson et al., 2015), the active nature of the exclusion period restricts the ability to draw conclusions in comparison to the inclusion period, which is inherently passive (i.e. watching others throw the ball). One possible explanation is that both exclusion and inclusion periods activate an attention monitoring system that elicit N2 and P3 components to a greater or equivalent degree as an ostracism response system. Recent behavioral findings also indicate that while the Cyberball inclusion condition may be effective as a control condition, it may be less specific to the unique effects of being social included (Simard & Dandeneau, 2017). To better delineate between ostracism response and attention monitoring systems, the current study (a) implemented a new paradigm to address the inequity of participant involvement across conditions, and (b) utilized source estimation to better understand the neural substrates associated with the N2 and P3 that are involved in ostracism.

**Current study objectives**

This study sought to evaluate whether neural correlates are differentially engaged in response to social exclusion and social inclusion when the amount of active involvement preceding the ostracism event is controlled across conditions. To this end, the Lunchroom paradigm was developed, previously used to explore stereotyped cues (Kiat, Straley, & Cheadle, 2017). This paradigm is set in a social context (a lunchroom table) in which ostracism feedback was presented as a discrete event following a decision, rather than as part of an ongoing interaction as in the Cyberball paradigm. In this way, the paradigm was designed to include equivalent levels of subject engagement for each condition, such that subjects made an active decision and passively awaited the ostracism outcome (inclusion or exclusion). We hypothesized that social exclusion outcomes would generate larger neural ostracism responses, as captured by the N2 and P3 components.
The structure of our paradigm provided an opportunity to address an additional question: Considering the complex and often dynamic nature of ostracism outcomes (Chester & Riva, 2016), is it possible to be more or less affected by being ostracized? Thus, our second objective was to evaluate how the experience of ostracism is influenced by everyday situations, such as making decisions that may have dynamic consequences with friends and others. Specifically, this study tested whether engagement of the social brain prior to being ostracized would modulate the response to social exclusion. In our paradigm, participants made an arbitrary decision between options differing in either possessive descriptors (e.g., “parent’s tie”) or physical descriptors (e.g., “purple tie”) before receiving ostracism feedback. This manipulation was designed to prime participants by making them decide between people who own the object (interpersonal condition with possessive descriptor) or between kinds of objects (physical condition with physical descriptor). Recent neuroimaging work employing similar social priming techniques (Higgins & Eitam, 2014) suggests a network of brain regions responsible for different kinds of implicit priming (Wang & Hamilton, 2015), including the ACC during priming of social engagement. Thus, it was hypothesized that priming engagement of the social brain would increase the salience of ostracism, and subsequently, the response to social exclusion would be larger in the interpersonal relative to the physical condition.

Lastly, this study sought to bridge the gap between ERP and functional imaging studies by utilizing source estimation to better understand the temporal dynamics of the neural sources underlying the N2 and P3 components. Specifically, neural sources engaged during each respective time window were evaluated to better understand the generators of each component. Secondarily, source estimates were extracted across the full ERP time window to understand the dynamic process by which these sources are engaged over time. Aligned with prior imaging results, a set of brain regions engaged during ostracism were targeted, including the ACC, cingulate gyrus, medial frontal gyrus, and insula (Eisenberger, 2012b). In addition, other key social brain regions were predicted to be heightened during the interpersonal priming decision preceding the ostracism outcome, including the amygdala, superior temporal gyrus (STG), and fusiform gyrus (Adolphs, 2008; Allison, Puce, & McCarthy, 2000; Van Overwalle, 2009). In addition, we evaluated the superior parietal lobule (SPL) due to its association with social attention (Nummenmaa & Calder, 2009), particularly in reference to biological motion (Stevens, Fonlupt, Shiffrar, & Decety, 2000) and thinking about the intentions of others (Molenberghs, Cunnington, & Mattingley, 2012; Pelphrey, Morris, & McCarthy, 2004). It was predicted that ostracism brain regions implicated in processing social pain would be more active during exclusion relative to inclusion events and that this contrast would be heightened following interpersonal decisions.

Materials and methods

Participants

Adults (N = 29, 16 female) between 18 and 32 years old enrolled and completed this study. Sixteen of these participants were undergraduate students and received course credit for their participation. Subsequent to ERP data preprocessing, one female participant was excluded due to excessive blinks. Thus, this study reflects data collected from 28 adults (15 female, M = 22.71, SD = 5.01 years). All participants had normal or corrected-to-normal vision and were screened for neurological and psychiatric disorders. The local ethical review board approved this project and all participants gave written informed consent.

Design and procedure

In this paradigm (see Figure 1 for paradigm design), participants selected avatars to represent themselves and were then introduced to two other characters representing their best friends. Participants were told that they would be given a choice between two options and that this decision was the basis for whether or not their best friends would sit with them at the lunchroom table. For each trial, participants were presented with two options that had the same noun. Decision themes for the noun included objects, activities, food, and clothing. The interpersonal condition varied in possessive descriptor between the two options (e.g. grand-mother’s casserole versus parent’s casserole). There were 10 possible possessive descriptors: “boss”, “classmate”, “coworker”, “friend”, “grandparent”, “parent”, “partner”, “roommate”, “sibling”, and “teacher”. The physical condition varied in physical descriptor between the two options (e.g. tofu casserole versus chicken casserole). The same noun was included for both decision types, such that each noun was included once as the basis for both physical and interpersonal decision trials. A full list of arbitrary decisions is available in SI Table 1. All participants saw the same trials, such that decision pairs were fixed and led to a predetermined outcome feedback. For instance, regardless of whether a participant...
chose “curly hair” or “straight hair”, this decision led to an exclusion outcome. However, the order of trial presentation was random. Participants were given up to 3000 ms to make their decision.

After indicating their decision, participants received ostracism outcome feedback via a lunchroom scenario where they were either excluded (avatar sitting alone) or included (avatar surrounded by best friends). The ostracism outcome feedback was visually presented for 1000 ms. To increase the salience of the outcome, after the initial 1000 ms, an auditory token (300 ms) was presented subsequently to increase the salience of the outcome.

Table 1. Ostracism results for ERP components. Positive differences indicate a larger effect (i.e. greater amplitude or faster latency) for exclusion relative to inclusion outcomes. Significant differences ($p < .05$) are noted in bold.

<table>
<thead>
<tr>
<th>Component</th>
<th>Measure</th>
<th>Region</th>
<th>Interpersonal ostracism effect</th>
<th>Physical ostracism effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Difference</td>
<td>t(193)</td>
</tr>
<tr>
<td>N2</td>
<td>Amplitude (µV)</td>
<td>Left frontal</td>
<td>0.62</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medial frontal</td>
<td>0.85</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right frontal</td>
<td>0.51</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Latency (ms)</td>
<td>Medial frontal</td>
<td>–0.64</td>
<td>–0.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left frontal</td>
<td>–4.37</td>
<td>–0.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medial frontal</td>
<td>17.39</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right frontal</td>
<td>21.84</td>
<td>1.84</td>
</tr>
<tr>
<td></td>
<td>Medial central</td>
<td>19.58</td>
<td>2.34</td>
<td>0.022</td>
</tr>
<tr>
<td>P3</td>
<td>Amplitude (µV)</td>
<td>Left frontal</td>
<td>1.78</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medial frontal</td>
<td>4.38</td>
<td>2.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right frontal</td>
<td>3.15</td>
<td>1.87</td>
</tr>
<tr>
<td></td>
<td>Latency (ms)</td>
<td>Medial frontal</td>
<td>–0.55</td>
<td>–0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left frontal</td>
<td>–9.68</td>
<td>–0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medial frontal</td>
<td>6.07</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right frontal</td>
<td>16.24</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medial central</td>
<td>8.47</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Figure 1. Schematic of paradigm design. Following an initial fixation, trials began with a decision phase in which participants selected one of two options that required the participant to make an arbitrary physical or interpersonal decision. The participant-selected avatar (i.e. to represent themselves; shown here with a green shirt) was either included or excluded at the lunch table. ERPs were time-locked to the onset of the outcome phase. An auditory token (300 ms) was presented subsequently to increase the salience of the outcome.
screen for another 1000 ms. A social and biological sound of a male voice exclaiming “Yeah!” was presented during inclusion trials, and a nonsocial and nonbiological sound of three descending tones (e.g., “sad trombone”) was presented during exclusion trials. Although a formal measurement of subjective experience was not collected, research assistants recorded qualitative data in response to two follow up questions for 24 of the 28 participants (transcripts available in SI Table 2). Notably, 50% reported negative feelings (e.g., being upset or sad) when their friends did not sit with them and an additional 33.3% reported being confused or uncertain about why they were excluded, which suggests that the manipulation was successful.

Of the 160 total trials, participants saw 40 trials for each of the four conditions based upon decision and ostracism outcome: Interpersonal Exclusion, Interpersonal Inclusion, Physical Exclusion, and Physical Inclusion. Stimuli were presented using E-Prime 2.0 software (Psychological Software Tools, Inc., Pittsburgh, PA) on a separate computer that integrated with ongoing electroencephalography (EEG) data collection to mark events. Subjects were seated 60–80 cm away from a Tobii TX300 (Tobii Technology, Falls Church, VA), which served as the monitor for stimuli presentation and an eye tracker. Eye tracking data was not analyzed for this study. The monitor was positioned at eye level and adjusted to capture eye position and display the stimuli at a visual angle of 18.1° horizontal and 20.8° vertical.

**EEG recording and processing**

EEG was acquired using a 256-channel AgAgCl high-density electrode array to record visual ERPs using Net Station® 4.4.2 software (Electric Geodesic, Inc., EGI, Eugene, OR). Electrode impedances recorded before and after the task were below 60 kΩ to maximize signal-to-noise ratio, producing high-quality signals for subsequent analyses. The ongoing EEG signals were digitized at 4 milliseconds intervals for each of the 256 electrode sites. High-pass filters were set to 0.1 Hz and low-pass filters to 30 Hz with a gain of 10 kΩ. Epochs were time-locked to the onset of the ostracism outcome, thus were segmented from continuous EEG with a 100 ms baseline period prior to ERP onset to 700 ms following onset (i.e. prior to auditory tokens). Segmentation accounted for event offset, recorded monthly to verify the timing of event markers, and anti-alias filtering offset. Voltage shifts greater than 150 µV during the epoch (e.g. eye blinks) were classified as artifacts and ocular artifact correction was implemented. For epochs and electrode channels on which artifacts were detected, the ERP signal was deleted and replaced with an average signal interpolated from immediately adjacent electrode locations following standard procedures. Manual data quality checks for all epochs and channels were conducted to ensure that other artifacts (e.g. electrical noise) were not subsequently included. Remaining epochs were then referenced again to the average of all electrodes, baseline corrected, and averaged across conditions.

**ERP extraction and analysis**

ERP extraction focused on two electrode regions (frontal and central) across left, medial, and right hemispheres (Figure 2; see Supplemental Material for list of sensors). Visual inspection of the grand-averaged waveform indicated a negative deflection between 80–280 ms that was most prominent across left frontal, medial frontal, and medial central clusters that

<table>
<thead>
<tr>
<th>Component</th>
<th>Region</th>
<th>Interpersonal ostracism effect</th>
<th>Physical ostracism effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Diff (nAmp) t(193)  p</td>
<td>Diff (nAmp) t(193)  p</td>
</tr>
<tr>
<td>N2</td>
<td>Amygdala</td>
<td>0.086  2.01  0.046</td>
<td>0.084  1.96  0.052</td>
</tr>
<tr>
<td></td>
<td>Anterior cingulate cortex</td>
<td>0.037  2.50  0.013</td>
<td>0.027  1.82  0.070</td>
</tr>
<tr>
<td></td>
<td>Cingulate gyrus</td>
<td>−0.001 −0.03  0.977</td>
<td>−0.029 −1.62  0.106</td>
</tr>
<tr>
<td></td>
<td>Fusiform gyrus</td>
<td>−0.023 −0.86  0.391</td>
<td>0.039  1.46  0.145</td>
</tr>
<tr>
<td></td>
<td>Insula</td>
<td>0.017  1.69  0.092</td>
<td>0.009  0.91  0.367</td>
</tr>
<tr>
<td></td>
<td>Medial frontal gyrus</td>
<td>0.013  0.89  0.374</td>
<td>0.002  0.11  0.910</td>
</tr>
<tr>
<td></td>
<td>Superior parietal lobule</td>
<td>−0.071 −0.79  0.433</td>
<td>−0.068 −0.76  0.451</td>
</tr>
<tr>
<td></td>
<td>Superior temporal gyrus</td>
<td>0.033  2.4  0.017</td>
<td>0.001  0.08  0.934</td>
</tr>
<tr>
<td>P3</td>
<td>Amygdala</td>
<td>0.173  2.52  0.012</td>
<td>0.073  1.06  0.289</td>
</tr>
<tr>
<td></td>
<td>Anterior cingulate cortex</td>
<td>0.139  4.16  &lt;.0001</td>
<td>0.073  2.16  0.032</td>
</tr>
<tr>
<td></td>
<td>Cingulate gyrus</td>
<td>0.026  0.98  0.326</td>
<td>−0.026 −0.99  0.323</td>
</tr>
<tr>
<td></td>
<td>Fusiform gyrus</td>
<td>−0.031 −0.79  0.433</td>
<td>0.074  1.86  0.064</td>
</tr>
<tr>
<td></td>
<td>Insula</td>
<td>0.042  2.02  0.045</td>
<td>0.012  0.57  0.570</td>
</tr>
<tr>
<td></td>
<td>Medial frontal gyrus</td>
<td>0.092  3.43  0.001</td>
<td>0.035  1.31  0.193</td>
</tr>
<tr>
<td></td>
<td>Superior parietal lobule</td>
<td>−0.056 −0.41  0.681</td>
<td>−0.100 −0.74  0.459</td>
</tr>
<tr>
<td></td>
<td>Superior temporal gyrus</td>
<td>0.102  3.32  0.001</td>
<td>0.021  0.7  0.487</td>
</tr>
</tbody>
</table>
resembled the N2, which is relatively early compared to the representation of the N2 by prior studies starting approximately 120–130 ms (Niedeggen et al., 2014; Weschke & Niedeggen, 2013). However, although several social exclusion studies define the N2 as a later latency negative deflection, a negative deflection beginning between 80–100 ms is evident in the ERP waveforms (Sreekrishnan et al., 2014; Themanson et al., 2013; Weschke & Niedeggen, 2013). The P3 was detected as the most positive value in the 200–550 ms time window that was consistent with the beginning of the positive deflection (see Figure 2) and prior work using the lunchroom framework (Kiat et al., 2017), though this time window is early in reference to prior work (Comerchero & Polich, 1999). Although Kiat et al. (2017) focused on lateral central electrodes, the scalp topographies from the current study were not as robust across lateral central and posterior clusters (see Figure 3) and were subsequently removed from analyses. Although we noted a shift from posterior to anterior medial electrodes across the time window, we opted to focus on the frontal P3 due to its prominence in the latter part of the time window.

Peak amplitude and latency were extracted for each participant and condition for the N2 (negative peaks) and the P300 (positive peaks) across the declared time windows within the three frontal clusters and medial central electrode clusters (electrodes available in Supplemental Material). Multilevel models were generated in SAS 9.3 using PROC MIXED separately for each component (N2, P3) and cluster (left frontal, medial frontal, right frontal, medial central) with a random intercept to capture individual difference variance between subjects. The model parameters included a full factorial design between arbitrary priming decision (2: interpersonal, physical) and ostracism outcome (2: exclusion, inclusion). Least square difference correction for multiple corrections was applied for post-hoc pairwise comparisons.

Source estimation and analysis

Source waveforms were generated for candidate brain regions using a finite difference model through the GeoSource® software program (v2.0; Electrical Geodesics, Inc., Eugene, OR). The program implements a forward modeling approach to accurately compute the electrode locations in relation to brain tissue. Finite difference model estimates were constrained by the Montreal Neurological Institute (MNI) average adult magnetic resonance imaging database. Tissue volumes were parceled using 7-mm voxels, each serving as a dipole source location with three orthogonal orientations (in x, y, and z orientations). The finite difference model applied estimations across a total of 2447 source dipole triplets. Conductivity values used in the finite difference model included 0.25 S/m for brain, 1.8 S/m for cerebral spinal fluid, 0.018 S/m for skull, and 0.44 S/m for scalp (Ferree, Eriksen, & Tucker, 2000). Weighting was placed equally
across locations with regularization carried out via Tikhonov ($1 \times 10^{-2}$) using standardized low-resolution brain electromagnetic tomography as a constraint. Eight \textit{a priori} candidate brain source regions were extracted for both the N2 and P3: Amygdala, anterior cingulate cortex (ACC), cingulate gyrus, fusiform gyrus, insular cortex, medial frontal gyrus, superior parietal lobule (SPL), and superior temporal gyrus (STG).

First, identical to ERP multilevel design, multilevel models were generated in SAS 9.4 using PROC MIXED separately for each source region and time window to test effects of priming decision, ostracism outcome, and the subsequent interaction with a random subject intercept. Mean source estimates were created via GeoSource for each individual during both ERP temporal windows (N2, 80–280 ms; P3, 200–550 ms).

Second, to characterizing the temporal dynamics associated with source engagement of ostracism responses, source engagement was estimated via GeoSource using a moving window approach with 100 ms bins offset by 50 ms (i.e. 0–100 ms, 50–150 ms, and so on). Multilevel models were identical to N2 and P3 time window analyses with the addition of a main effect and interactions of time bin to test for ongoing dynamic changes.

**Results**

**Behavioral results**

There were no reaction time differences during the decision phase, $t(54) = .71$, $p = .71$, between interpersonal ($M = 1288.0$ ms, $SD = 622.3$) and physical decisions ($M = 1227.1$ ms, $SD = 599.3$).

**ERP results**

Ostracism outcome differences (i.e. value for exclusion relative to inclusion outcomes) are reported for each component, measure, and region in \textbf{Table 1} and illustrated in \textbf{Figure 4}.

**N2 amplitude**

Multilevel models revealed a marginal main effect of ostracism outcome, such that the N2 amplitude was estimated to be larger (i.e. more negative) for exclusion compared to inclusion outcomes by 1.10 µV across medial central electrodes, $F(1, 81) = 3.08, p = 0.083$. Across medial frontal electrodes, the N2 was estimated to be larger following physical compared to interpersonal decisions by 0.51 µV, $F(1, 81) = 4.71, p = 0.033$. This was evident

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{scalp_topography.png}
\caption{Scalp topography for N2 and P3 components. Scalp topography for each of N2 and P3 components illustrate the relative voltage distribution averaged across 100 ms temporal windows.}
\end{figure}
only when the participant had been excluded [decision difference = 1.49 µV; \( t(81) = 2.29, p = 0.25 \)], but not when the participant was included [decision difference = 0.51 µV; \( t(81) = 0.78, p = 0.44 \)]. There were no priming decision or ostracism outcome condition differences across left or right frontal clusters.

### N2 latency

Across medial frontal electrodes, N2 latency was significantly faster following interpersonal (\( M = 162.2 \) ms, \( SE = 6.50 \)) than physical priming decisions (\( M = 188.4 \) ms, \( SE = 6.76 \)), \( F(1, 81) = 12.60, p = 0.0006 \). Pairwise comparisons indicated this pattern was evident for inclusion, [N2 difference = 34.2 ms; \( t(81) = 3.28, p = 0.002 \)] more so than exclusion outcomes [marginal N2 difference = 18.2 ms; \( t(81) = 1.74, p = 0.085 \)]. Multilevel models across medial central electrodes indicated a marginal effect of ostracism outcome, \( F(1, 81) = 1.7, p = 0.093 \), indicating a faster N2 latency for exclusion (\( M = 167.3 \) ms, \( SE = 9.42 \)) than inclusion outcomes (\( M = 147.7 \) ms, \( SE = 10.0 \)) specifically following interpersonal, \( t(81) = 2.34, p = .022 \), but not physical priming decisions, \( t(81) = .07, p = .94 \).

### P3 amplitude

Multilevel models revealed a marginal main effect of ostracism outcome indicating a larger P3 amplitude (i.e. more positive) for exclusion compared to inclusion outcomes across medial and right frontal, \( F(1, 81) = 4.44, p = 0.038 \), and \( F(1, 81) = 6.38, p = 0.014 \), respectively. Pairwise comparisons indicated that these effects were larger following interpersonal (\( p's < .064 \)) compared to physical priming decisions (\( p's < .093 \). A marginal effect across medial central electrodes, \( F(1, 81) = 2.78, p = 0.10 \), indicated the opposite pattern, such that the P3 was larger for inclusion relative to exclusion outcomes.

### P3 latency

A main effect of ostracism outcome was evident across right frontal electrodes, \( F(1, 81) = 64.88, p = 0.03 \), such that P3 latency was slower for exclusion (\( M = 366.8 \) ms, \( SE = 12.02 \)) compared to inclusion outcomes (\( M = 341.1 \) ms, \( SE = 11.5 \)). This effect was evident following physical, \( t(81) = 2.14, p = 0.036 \), but not interpersonal priming decisions, \( t(81) = 0.07, p = .94 \).

### Neural source results: temporal windows

Ostracism outcome differences (i.e. values for exclusion relative to inclusion outcomes) are reported for each time window and region Table 2.
**P3 source engagement**
Similar to the N2 time window, P3 multilevel models indicated more source engagement during exclusions compared to inclusion outcomes within the amygdala and ACC, $F(1, 193) = 6.44, p = 0.012$, and $F(1, 193) = 19.98, p = 0.001$, respectively. Two additional regions were also sensitive to ostracism outcome in this same pattern, including MFG and STG, $F(1, 193) = 11.22, p = 0.001$, and $F(1, 193) = 8.06, p = 0.005$, respectively. Pairwise comparisons (see Table 2) indicated that these main effects were driven by interpersonal ($p$’s < .045) and not physical priming decisions ($p$’s > .19) with one exception: the ACC exhibited a significant ostracism discrimination following physical decisions, although it was reduced compared to interpersonal decisions.

The only region that was sensitive to priming decision was the SPL, $F(1, 193) = 4.02, p = 0.046$, such that more source engagement was estimated following physical ($M = .51 \text{ nA, } SE = .12$) relative to interpersonal decisions ($M = .31 \text{ nA, } SE = .04$).

*Neural source results: dynamics of source engagement*

Here, three regions that were associated with ostracism outcome for both temporal windows were targeted: ACC, amygdala, and STG (other regions illustrated in SI Figure 1). Periods of the waveform that indicate significant ostracism discrimination are illustrated in Figure 5.

**ACC dynamics**
Multilevel models revealed a significant effect of slope, $F(1, 2613) = 70.76, p < .0001$, such that ACC activation is estimated to increase from 150–400 ms post-feedback onset. A significant interaction between ostracism outcome and time bin, $F(1, 2613) = 2.96, p = 0.007$, indicated that ACC engagement increases more rapidly for exclusion compared to inclusion outcomes. There was a significant interaction between ostracism outcome and priming decision, $F(1, 2613) = 4.69, p = .031$, such that there was greater ACC activation for exclusion compared to inclusion following interpersonal decisions between 250–600 ms ($p$’s < .0026). In contrast, following physical decisions, ostracism discrimination was evident between 350–600 ms ($p$’s < .043).

A main effect of priming decision, $F(1, 2613) = 11.96, p = .0006$, indicated that ACC activation was predicted to be greater (on average) following physical compared to interpersonal decisions.

**Amygdala dynamics**
Multilevel models revealed a significant effect of slope, $F(1, 2613) = 39.72, p < .0001$, such that amygdala activation is estimated to increase from 200–550 ms post-feedback onset. There was a marginal interaction between ostracism outcome and priming decision, $F(1, 2613) = 3.15, p = .076$, such that ostracism discrimination was evident following interpersonal decisions between 250–500 ms ($p$’s < .032), but there were no periods of significant ostracism discrimination following physical decisions ($p$’s > .11).

![Figure 5. Dynamic modulation of neural sources. Estimated neural source engagement is plotted over time for the anterior cingulate cortex (ACC), amygdala, and superior temporal gyrus (STG). Box insets indicate the temporal period with significant ostracism outcome discrimination between exclusion (red) and inclusion (blue) outcomes, specifically for interpersonal decisions (solid lines). The dashed black horizontal line indicates the temporal period in the ACC (350–600 ms) of ostracism outcome discrimination for the physical priming decision condition.](image-url)
A main effect of priming decision, $F(1, 2613) = 4.22$, $p = .04$, indicated that amygdala activation was predicted to be greater (on average) following physical compared to interpersonal decisions.

**STG dynamics**

Multilevel models revealed a significant effect of slope, $F(1, 2613) = 50.11$, $p < .0001$, such that STG activation was estimated to increase from 150–400 ms post-feedback onset. There was a significant interaction between ostracism outcome and priming decision, $F(1, 2613) = 14.76$, $p = .0001$, such that ostracism discrimination was evident following interpersonal decisions between 250–600 ms ($p's < .028$), but there were no periods of significant ostracism discrimination following physical decisions ($p's > .24$).

**Discussion**

The goal of the current study was to evaluate neural responses to ostracism in a paradigm that controlled for level of participant engagement prior to the inclusion/exclusion outcomes. In the current experiment, rather than varying the target probability of being included in a social game as in the Cyberball paradigm, participants had equal likelihood of being excluded every trial throughout the experiment. As part of the Lunchroom task, participants made an arbitrary decision and, subsequently, were socially excluded or included, ostensibly based upon that decision. In this way, potential involvement of an attention monitoring system (Cacioppo et al., 2013) was equalized across conditions to better specify responses to ostracism and social exclusion. In addition, the paradigm was intentionally designed with the hypothesis that arbitrary interpersonal decisions would prime the social brain network, resulting in an increased ostracism response, more so than physical decisions.

Fronto-central ERPs time-locked to the ostracism outcome elicited an early N2 negative deflection (80–280 ms) and a mid-latency P3 positive deflection (200–550 ms). Aligned with our hypotheses and prior work (Crowley et al., 2010; Gutz et al., 2011; Themanson et al., 2015; Weschke & Niedeggen, 2013), the P3 was sensitive to ostracism, as indicated by larger amplitude to exclusion compared to inclusion outcomes. In contrast, the N2 amplitudes and latencies were more sensitive to the priming decision than ostracism outcome. Source estimation indicated the amygdala, ACC, and STG regions were engaged and discriminated between ostracism outcomes during the temporal windows for both the N2 and P3, consistent with prior imaging work (Eisenberger, 2012b), particularly following interpersonal decisions. Evaluation of the temporal dynamics of this source engagement indicated that ostracism discrimination effects were evident particularly between 250–500 ms post-outcome onset, although activation from all three regions increased preceding this period. These findings delineate potential functional roles of each component and highlight the process by which these neural substrates are engaged in ostracism responses.

**N2 modulation by social priming**

Unlike prior work that has found an increased N2 response to social exclusion (Sreekrishnan et al., 2014; Themanson et al., 2013; Weschke & Niedeggen, 2013), our results revealed a sensitivity to social priming but not ostracism. Specifically, our data indicated faster N2 latencies and greater N2 amplitude (i.e. more negative) for interpersonal compared to physical decisions across medial frontal electrodes. Of note, the N2 amplitude finding was restricted to the exclusion outcome, indicating that while N2 latency was sensitive to social priming regardless of outcome, N2 amplitude only discriminated between priming in exclusion events. This suggests that the overall priming effect on the N2 may influence the speed of processing more so than the magnitude, which may be selectively sensitive to ostracism. Generally speaking, the N2 is thought to reflect top-down attentional control and conflict monitoring (Falkenstein, Hoormann, & Hohnsbein, 1999; Nieuwenhuis et al., 2003). An explanation may be that, as intended by our experimental design, the act of deciding between two social categories successfully engaged the social brain prior to the outcome, subsequently increasing the speed of the system for monitoring the subsequent social (ostracism) feedback, but only modulating the capacity of this system in exclusion events.

Alternatively, considering that the N2 amplitude only discriminated between priming decisions in the exclusion condition, the N2 may reflect the engagement of a reward-specific system more so than the social brain. One other study found a similar N2 amplitude differentiation of social context (i.e. computer-based versus live Cyberball players) that was unique to the exclusion condition (Weschke & Niedeggen, 2013). In that study, the N2 amplitude was greater for participants interacting with live players relative to computer-based players during exclusion periods. The authors suggest the N2 reflects the modulation of the reward system, such that receiving the ball equates to a social reward that is potentially more valuable from a live player than from a computer-based player. Extending this to the current study, it may be the case that participants are more
hurt by exclusion following interpersonal decision. This is aligned with the perspective that neural responses to ostracisms are reflective of social pain more so than conflict monitoring (Eisenberger, 2012b).

**P3 sensitivity to ostracism**

As described above, this work supports prior reports of the P3 amplitude capturing the appraisal of ostracism. It is proposed that in the context of the Cyberball paradigm the P3 is related specifically to the activation of an early alarm system (Gutz et al., 2011; Kawamoto et al., 2013) that relates to a pre-attentive neural system triggered by ostracism (Williams, 2006). In contrast, other results challenge the role of the Cyberball P3 within a neural alarm system for social pain, considering equivalent responses between exclusion conditions and frequency violation (Niedeggen et al., 2014; Weschke & Niedeggen, 2016) and the lack of modulation based upon whether the players are present or not (Weschke & Niedeggen, 2013). Considering that the Lunchroom paradigm was designed to control for frequency of anticipation (outcomes were equiprobable) and consisted solely of simulated avatar ‘friends,’ our results support the notion that the frontal P3 amplitude reflects recruitment of the alarm system. Additionally, the ostracism effect was larger when the priming decision was interpersonal, suggesting that social brain priming was effective and resulted in increased sensitivity to ostracism.

Our paradigm was built in part to better isolate processing related to social inclusion by equalizing participant involvement across exclusion and inclusion conditions. Whereas the frontal P3 exhibited a larger response for exclusion, the medial central P3 response indicated a potential marker for inclusion, as evident by increased amplitude. Previously, Niedeggen et al. (2014) suggested that the central and parietal P3 response to inclusion relates to the participants’ expectation of social inclusion. In that study and subsequent work (Niedeggen, Kerschreiter, Hirte, & Weschke, 2017; Weschke & Niedeggen, 2015b), the P3 amplitude to inclusion events was reduced as involvement in the Cyberball ball-tossing game increased and corresponded to participants’ self-reported proportion of time spent possessing the ball. This notion that the P3 amplitude reflects a violation of expectancy (aligned with visual probability P3 paradigms, (Polich & Bondurant, 1997; Stadler, Klimesch, Pouthas, & Ragot, 2006)) is inconsistent with our findings. Instead, our results suggest that when participant involvement is controlled, the P3 may be topologically sensitive as both an ostracism and inclusion marker. Although beyond the scope of this paper, future work would benefit from a deeper examination of the ERP topology in relation to inclusion events.

**Engagement of neural sources**

Our final objective was to bridge the gap between ERP and fMRI findings by using source estimation to specify the sources generating the N2 and P3 components. Of the eight targeted key social brain regions, source estimation indicated that five regions were at least marginally more engaged in exclusion outcomes: ACC, amygdala, insula, MFG, and STG. Importantly, these ostracism effects were present following interpersonal but not physical priming. In other words, there were no neural source differences from being excluded or included around the lunchroom table unless preceded by making an arbitrary decision between people. The one exception to this effect was the ACC, which discriminated between ostracism outcomes for both priming conditions, emphasizing a potential dominant role for the ACC in ostracism processing, regardless of context.

A critical innovation of this study was the implementation of source dynamics to empirically evaluate the respective timing of neural sources immediately upon receiving ostracism outcome feedback. Close inspection of the three regions implicated in both N2 and P3 time windows (ACC, amygdala, and STG) indicated source engagement increased approximately 150 ms post-outcome onset and began discriminating between ostracism conditions at 250 ms, as evident in the boxed portions of the source activation dynamics in Figure 5. For the ACC, these effects were driven in part by a more rapid slope for exclusion than inclusion outcomes, such that ACC increased in activity at a faster rate. The fact that all three regions are engaged and discriminating between conditions during the same temporal period is reinforced by evidence of functional connectivity across these regions during social perception (Bickart, Hollenbeck, Barrett, & Dickerson, 2012; Demenescu et al., 2013; Wu et al., 2016). For instance, in one study of empathetic response, the amygdala was more strongly connected to regions implicated in social pain (including the ACC) when viewing self-caused relative to other-caused pain (Akitsuki & Decety, 2009). Taken together, these results support a tightly connected network of brain regions responsible for encoding ostracism.

The SPL was the only brain region to be selectively sensitive to priming decision, as indicated by greater source engagement following physical relative to
interpersonal decisions within the P3 time window. As part of the attention system, the SPL has been implicated in the top-down modulation of attention (Corbetta & Shulman, 2002), particularly in the context of memory retrieval (Ciaramelli, Grady, & Moscovitch, 2008; Koenigs, Barbay, Postle, & Grafman, 2009; Wagner, Shannon, Kahn, & Buckner, 2005). Thus, although the SPL was initially targeted due to its role in social attention (Nummenmaa & Calder, 2009), these results suggest the SPL is more dedicated to attentional than social processes. One interpretation of this finding is that subjects may require increased attentional resources to parse meaning for outcomes following physical decisions, whereas interpersonal priming may hold longer in short-term memory, requiring less memory recall and/or attention reorienting.

**Limitations**

One of the limitations of the current study is that there was no self-report of stress or other individual differences related to changes in mood in order to confirm the affective experience of being excluded. For instance, several studies have found that rejection events during the Cyberball task elicit slow-wave activity across left and medial frontal electrodes that is related to self-reported distress (Crowley et al., 2009, 2010; Sreekrishnan et al., 2014) and decreased quality of parental attachment in youth (White et al., 2012). Although the current study did not evaluate slow-wave activity, it is possible that extended processing continues beyond our ERP time window and may relate to the affective experience of being socially excluded. Future work would benefit from objective measurements to better account for physiological reactions (i.e. breathing or heart rate changes) or facial affect (i.e. expression of positive versus negative emotions).

This study is described as exploratory in part due to the fact that the topography and timing of the ERP components are not entirely consistent with prior work. For instance, the N2 component is usually thought to start closer to 120–130 ms, which is much later than the beginning negative deflection that starts ~ 80 ms observed in this study. Similarly, the time window chosen for the P3 (200–550 ms) is earlier than the common time windows for the P3, including the subcomponents of the P3 known as the P3a (250–450 ms) and P3b (350–600 ms) (Comerchero & Polich, 1999). While it is possible that the Lunchroom task elicits a much faster response due to the nature of the visual feedback, early N2 deflections are evident in the grand-averaged waveforms in other studies (Sreekrishnan et al., 2014; Themanson et al., 2013; Weschke & Niedeggen, 2013), highlighting a need to better understand this early processing. The P3 in the current study was also unusual in frontal distribution relative to prior work that identified a posterior P3 (Crowley et al., 2010; Themanson et al., 2015) and central P3 (Gutz et al., 2011). Here, we focused on the frontal P3 as the most prominent component as evident in Figure 3. Yet, a prior study using the lunchroom framework (Kit et al., 2017) indicated a stronger lateral central P3 in exclusion trials following a neutral more so than socially-meaningful (i.e. stereotyped) decision. In light of the ostracism effect reversal across central electrodes (i.e. greater response to inclusion over exclusion) in the current study, it will be important to continue to evaluate posterior and central P3 contributions.

In addition, it is important to acknowledge the exploratory nature of these analyses and subsequently caution over-interpretation. Considering the novelty of the paradigm, we did not consider *a priori* hypotheses regarding the ERP topography and neural source generation. Rather, as an exploratory study, we elected to test amplitude, latency, and source models across regions without omnibus test correction. Considering that the *posthoc* comparisons were significant with corrections, these results may be considered a first step in understanding ostracism when active involvement is controlled across conditions. Second, the nature of the ERP waveform response to this novel paradigm should be replicated to confirm the early temporal window of the N2, the frontal topography of the P3, and the dependent relationships between adjacent components. Lastly, although the paradigm did control participant involvement during the activity, it is possible that the variability of physical stimulus characteristics (e.g., luminance, intensity) or auditory feedback anticipation for the main contrast (i.e. exclusion versus inclusions) affected the neural response to ostracism. Taken together, future research should extend this work by systematically modifying the task to empirically assess task properties. In addition, continued work would benefit by implementation of more sophisticated analytical (e.g. generalized mixed models) (Lo & Andrews, 2015) and potentially waveform de-composition methods (e.g. temporal-spatial PCA or continuous ICA) (Delorme, Miyakoshi, Jung, & Makeig, 2015).

**Conclusion**

This study offers new insight into the dynamic and modulatory nature of neural responses in the context of ostracism and social exclusion. By more clearly dissociating active task participation from the expression of ostracism, our results support prior work (Themanson et al., 2013; Weschke & Niedeggen, 2013), suggesting separable roles of the N2 and P3 in modulation of social information and
sensitivity to ostracism outcomes, respectively. Further, social brain regions previously activated during functional imaging, particularly within the amygdala, ACC, and STG (Eisenberger, 2003, 2012b; Masten et al., 2009, 2010; Moor et al., 2012; Williams et al., 2000), are also differentially engaged in response to ostracism outcomes. Critically, closer inspection of the temporal dynamics of these brain regions suggest a period of increased activation between 250–600 ms post-outcome onset, offering new evidence of the process by which these brain regions are engaged. These findings emphasize how daily (seemingly) benign choices intensify the effects of ostracism. Considering the known impact of ostracism on behavior (Oaten, Williams, & Jones, 2008; Svetieva et al., 2016; Warburton, Williams, & Cairns, 2006), there may be potential adverse consequences following arbitrary social decisions and how we subsequently interact with the environment. A deeper understanding of neural dynamics of ostracism may lead to the discovery of possible protective mechanisms in the brain that can be bolstered by interventions (e.g. social supports and positive relationships; Eisenberger, Taylor, Gable, Hilmert, & Lieberman, 2007). Continued exploration of these processes may provide essential clues to successfully strengthen healthy social relationships and interactions at pivotal developmental periods.

Acknowledgments

Thank you to the individuals for their participation in this study. The author is grateful for assistance with data collection and input on earlier drafts from Dr. Allison L. Skinner, as well as being grateful for feedback and suggestions from the anonymous reviewers and Dr. Anne B. Arnett. This research did not receive any specific grant from funding agencies in the public, commercial, and not-for-profit sectors. The author would like to thank Dr. Dennis L. Molfese for supporting her graduate work.

Disclosure statement

No potential conflict of interest was reported by the author.

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