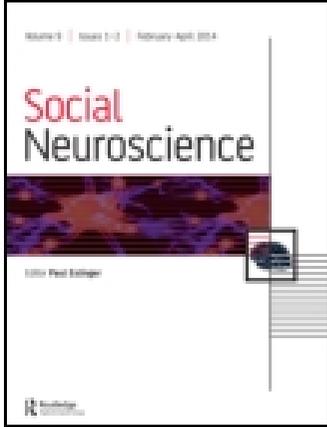


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The ongoing cognitive processing of exclusionary social events: Evidence from event-related potentials

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Exclusionary social events are known to cause alterations in neural activity and attention-related processes. However, the precise nature of these neural adjustments remains unknown as previous research has been limited to examining social interactions and exclusionary events as unitary phenomena. To address this limitation, we assessed neural activity during both inclusionary and exclusionary social interactions by examining event-related brain potentials at multiple points within each social event. Our results show an initial enhancement of anterior cingulate cortex -related activation, indexed by the anterior N2, in response to specific exclusionary events followed by an enhanced attentional orienting response, indexed by the P3a, to later segments of each exclusionary event. Decreases in this P3a activation from social inclusion to social exclusion were associated with self-reported increases in anxiety, negative affect, and feelings of depression from inclusion to exclusion. Together, these findings provide novel insights into the dynamic and ongoing neural processes associated with attentional allocation toward social exclusion and the nature of the relationships between neural and behavioral reactions to exclusionary social interactions.

Keywords: Social exclusion; Event-related brain potentials; Anterior cingulate cortex; Exclusion-related attention; N2; P3a; P3b.

Social exclusion leads to alterations in neural activity as well as the nature of behavioral choices (Baumeister, DeWall, Ciarocco, & Twenge, 2005; Eisenberger, Gable, & Lieberman, 2007; Eisenberger, Lieberman, & Williams, 2003; Themanson, Khatcherian, Ball, & Rosen, 2013; Twenge, Baumeister, Tice, & Stucke, 2001; Williams, 2009) and gives rise to a diffuse pattern of severe impairments across social, emotional, and cognitive domains (Baumeister et al., 2005; Baumeister, Twenge, & Nuss, 2002; Eisenberger et al., 2003; Masten et al., 2009; Themanson, Ball, Khatcherian, & Rosen, 2014; Williams, 2001, 2007,

2009). These consequences, including decreases in self-esteem and the fulfillment of needs (Williams, 2001), develop quickly during the reflexive stage of the exclusion process and lead individuals to reflect upon their exclusion in an attempt to regulate these impairments (Williams, 2009). During the reflective stage, individuals engage in behaviors to regain their social standing or establish control over their others with aggressive social behaviors (MacDonald & Leary, 2005; Twenge et al., 2001). If exclusion persists, individuals may suffer from long-term depression, anxiety, loneliness, and helplessness (MacDonald &

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Leary, 2005; Williams, 2007, 2009; Williams, Forgas, Von Hippel, & Zadro, 2005). Importantly, during the reflective efforts to regain social standing and gain attention from others, attention is directed toward exclusion and away from other tasks or processes, resulting in a decreased ability to properly engage self-regulatory processes during cognitive task execution (Baumeister et al., 2005; Themanson et al., 2014).

Researchers suggest that the decrease in self-regulation to other tasks is due to the motivational importance of social exclusion compared to other self-regulatory processes, which results in enhanced self-regulatory processing toward exclusionary events or interactions and an associated decrease in the motivation and attentional control needed for other tasks (Baumeister et al., 2002; Themanson et al., 2014). This self-regulatory attentional allocation toward exclusion may also deplete the capacity for properly engaging other self-regulatory processes and lead to the underregulation of these other processes due to the limited nature of self-regulation (Baumeister & Heatherton, 1996). This underregulation of self-regulation can be associated with the dysfunctional consequences in other self-regulatory processes seen in social exclusion research.

The alteration in self-regulatory control toward exclusion has been evidenced on the level of the entire social interaction (macro-level of the interaction) with neuroimaging research (Eisenberger et al., 2003, 2007). However, this research does not address the nature of this activation within the ongoing processing of social interactions. Accordingly, researchers have begun to examine event-related brain potentials (ERPs) during exclusionary social interactions to more precisely determine the nature of exclusion-related processing (Crowley et al., 2009; Crowley, Wu, Molfese, & Mayes, 2010; Themanson et al., 2013). This literature has revealed momentary changes in neural activation related to the individual events within an interaction (micro-level of the interaction), but results have been mixed in relation to attention-related ERP components, with findings related to different ERP components depending on the specific nature of the social task and some findings suggesting greater initial attentional allocation to inclusionary events rather than exclusionary events (Themanson et al., 2013). To address this issue, this study was designed to examine the ongoing neural processing of social exclusion by investigating multiple informational images within each exclusionary event. By utilizing multiple images for each event, the present study is able to investigate the dynamic nature of how individuals respond to moments of exclusion within the larger framework of different social interactions and determine how the brain redirects self-

regulatory control toward these exclusionary events. Further, by examining multiple informational frames within the current methodology, the present study utilizes a longer examination window that may help to clarify the literature related to attentional allocation toward exclusionary social events and interactions.

NEURAL ACTIVITY DURING SOCIAL EXCLUSION

Hemodynamic research

As indicated above, researchers have examined neural responses to social exclusion (Crowley et al., 2009, 2010; Eisenberger et al., 2003, 2007; Themanson et al., 2013). Research utilizing functional magnetic resonance imaging (fMRI) has shown greater dorsal anterior cingulate cortex (dACC) and right ventrolateral prefrontal cortex (rVLPFC) activation during exclusionary interactions compared to inclusionary interactions (Eisenberger et al., 2003, 2007). Participants' self-reported feelings of social distress following exclusion were positively correlated with dACC activation during exclusion suggesting the dACC functions as a neural alarm in response to the pain felt by being excluded (Eisenberger et al., 2003). Conversely, the rVLPFC activation was negatively correlated with both social distress and dACC activation during exclusion, indicating that the rVLPFC is activated to regulate and suppress exclusion-related dACC activation and one's negative feelings in response to being excluded (Eisenberger & Lieberman, 2004; Eisenberger et al., 2003). Although informative, these studies were only able to report on aggregated neural activity at the macro-level of the social interaction due to the poor temporal resolution of fMRI methodologies. This did not allow for an examination of dynamic neural responses to specific social events within the interactions, the micro-level of the interaction. Therefore, an analysis of the specific events within ongoing social interactions (i.e., ERPs) has been initiated in an attempt to learn more about the nature of neural activations present during social exclusion.

Event-related potentials

Recent research utilizing ERPs has helped clarify the pattern of neural activity associated with social exclusion, with findings showing multiple ERP differences between inclusionary and exclusionary events (Crowley et al., 2009, 2010; Themanson et al., 2013).

Importantly, this research utilized two different methodologies to examine exclusion-related ERPs. In one methodology, one image was shown to represent either an inclusionary or an exclusionary event, allowing for the examination of slow-wave ERPs (Crowley et al., 2009, 2010). In the other methodology (Themanson et al., 2013), a series of images adapted from the Cyberball paradigm (Williams, Cheung, & Choi, 2000) were presented sequentially to present a ball being thrown from participant to participant. These methodological differences did not allow for similar analyses in all cases. For example, Crowley et al. (2009, 2010) found consistently larger late positive potential (LPP) amplitudes for exclusionary events within an exclusionary interaction compared to LPP amplitudes within inclusionary interactions. The LPP is an ERP component that often extends as far as 1000–2000 ms following stimulus presentation. The LPP has been used as an indicator of several different cognitive processes, but is generally thought to be an index of attentional allocation to motivationally significant emotional stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000). Given the slower nature of the LPP, analyses of the LPP were not possible in the Themanson et al.'s (2013) methodology. Further, Themanson et al. (2013) examined both inclusionary and exclusionary events in the contexts of social inclusion as well as social exclusion, but this analysis was not possible in the Crowley et al. (2009, 2010) methodology. In spite of these differences, some ERP findings can be compared across the studies.

Combined, these studies examined the exclusion-related ACC activation through measurement of the anterior control-related N2 component (see Folstein and Van Petten (2008) for a review detailing how the N2 may subsume the functionality of the feedback negativity, or “fERN,” described by Crowley et al. (2010). As such, our reference to the anterior N2 incorporates the fERN detailed in other social exclusion research). The anterior N2 is maximal over fronto-central recording sites and is believed to be a psychophysiological index of cognitive control (Folstein & Van Petten, 2008) originating from the ACC (van Veen & Carter, 2002; Yeung, Botvinick, & Cohen, 2004), which has been related to the inhibition of action (Braver, Barch, Gray, Molfese, & Snyder, 2001), response conflict (Clayson & Larson, 2012), and neural activity derived from being excluded from an ongoing social interaction (Themanson et al., 2013). These studies consistently showed that the anterior N2 was activated by the specific act of being excluded from a social exchange, even if the individual was largely included throughout the interaction (Crowley et al., 2010; Themanson et al., 2013). This finding

supports the existing temporal theories of social exclusion as this N2 activation reflects the detection and reflexive phases of the exclusion process (Williams, 2009). The nature of the N2 results is consistent with ACC activation reflecting a general and sensitive process that is broadly activated by any undesired or unintended event throughout engagement with a task or interaction rather than the overall outcome of the interaction (Themanson et al., 2013). Further, the N2 findings are supportive of multiple theories regarding the functionality of the dACC, including conflict monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver, Gray, & Burgess, 2007; Yeung et al., 2004), neural alarm theory (Eisenberger & Lieberman, 2004), the predicted response outcome (PRO) model (Brown, 2013), and dACC theories based upon hierarchical reinforcement learning (Botvinick, Niv, & Barto, 2009), which state that the dACC supports the selection of control options based upon the expected value of control (Shenhav, Botvinick, & Cohen, 2013) or upon superordinate extended action plans (Holroyd & Yeung, 2012).

Contrary to the consistent N2 findings, ERP research on social exclusion has revealed mixed results in the examination of attention-related components, like the P3. The P3 is a large positive-going peak occurring approximately 300 to 800 ms following stimulus onset and reflects attentional processes as indexed by two subcomponents, the “P3a” and “P3b.” Though related, these two subcomponents represent distinct neural processes. The P3a has a fronto-central maximum and a shorter peak latency than the P3b. The P3a is hypothesized to be associated with the selection of stimulus information through attentional orienting (Knight, 1984; Kok, 2001; Rushby, Barry, & Doherty, 2005), reflecting the disengagement of a previous attentional focus to reengage attentional processes elsewhere (Squires, Squires, & Hillyard, 1975). Therefore, P3a amplitude can be theorized to index attentional orienting with increased amplitude indicating greater top-down control of focal attention (Polich, 2007). Conversely, the P3b has a parietal maximum and longer peak latency than the P3a. The P3b is thought to reflect neuronal activation associated with the revision of the mental representations of stimuli within a task environment (Donchin, 1981), including basic cognitive functions like memory updating and event categorization (Polich & Kok, 1995). The amplitude of the P3b is determined by attentional allocation during the updating of working memory (Donchin & Coles, 1988). Therefore, the P3b is sensitive to the amount of task-relevant attention allocated to a stimulus (Kok, 2001; Polich, 1986, 2007; Polich & Heine, 1996).

In these ERP examinations of social exclusion, larger P3b amplitudes were present to exclusionary events within the context of overall exclusionary interactions compared to inclusionary interactions (Crowley et al., 2010; Themanson et al., 2013), which corresponds with attentional reallocation toward social exclusion. However, the amplitude of the P3b has been shown to be larger for inclusionary events compared to exclusionary events regardless of the nature of the social interaction (Themanson et al., 2013). This finding is not consistent with the notion of attentional reallocation toward social exclusion and, when combined with the other P3b findings, leaves the specific nature of dynamic attentional processes during social interactions undefined.

CURRENT STUDY

Given the LPP findings associated with exclusionary events (Crowley et al., 2009, 2010), which extended 900 ms after stimulus presentation and reflect attentional allocation to motivationally relevant emotional stimuli (Cuthbert et al., 2000; Schupp et al., 2000), we suggest that exclusion-related neural changes may continue to exist beyond the first informational image within our Cyberball methodology (Themanson et al., 2013). This would help explain the different attention-related findings from the two exclusion-ERP methodologies. Thus, simply examining the short-time window from the informational image to the next throw image in the series (Themanson et al., 2013) may not be sufficient to capture evidence for enhanced attentional allocation toward exclusion. Accordingly, a longer examination of the events within a social interaction, taking into account multiple informational images in our Cyberball methodology, may elucidate the nature of the attentional allocation toward social exclusion and clarify the dynamic process that leads to perceptions of exclusion as well as the negative consequences of being the target of exclusion.

Based on this idea of ongoing neural changes in response to social exclusion and previous fMRI and ERP findings examining the exclusion-related neural activity, we hypothesized that we would replicate previous findings for this methodology for the first informational image, with (1) greater N2 and smaller P3b activation to exclusionary throws (ETs) in the first informational image and (2) greater P3b activation to ETs in the exclusion block compared to the inclusion block. For the second informational image in our methodology, we hypothesized that (3) enhanced activation of attentional processes, indexed by the P3a or P3b, would be present in response to ETs across

interaction types, reflecting the ongoing allocation of attention toward the undesired exclusionary experience and (4) the modulation of this ongoing attentional allocation toward exclusion in the second informational frame, indexed by modulations in the P3 component from inclusionary to exclusionary interactions, would be associated with changes in the self-reported negative consequences of exclusion, suggesting the allocation of limited self-regulatory processes toward exclusion events may underregulate the self-regulatory attentional control of one's responses to exclusion.

METHODS

Participants

Sixty-six undergraduate students between the ages of 18 and 22 were recruited to participate in this study. Participants in the study were awarded research credit toward a class requirement, but no other compensation was provided. Participants ($n = 8$) who did not fully complete the study (i.e., did not complete both task sessions, missing questionnaire data) were discarded from the analyses as were participants ($n = 3$) with excessive noise and artifacts obtained during ERP data collection, resulting in a sample size of 55 participants (29 females, 26 males). The study was approved by the Institutional Review Board of Illinois Wesleyan University.

Self-report assessments

After obtaining informed consent, participants completed a series of questionnaires. These self-reports included a simple demographics questionnaire, the Edinburgh Handedness Inventory (Oldfield, 1971), the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988), the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), the Beck Depression Inventory-II (BDI-II) (Beck, Steer, & Brown, 1996), and a brief need-threat scale (NTS) that has been used in previous social exclusion research (Williams et al., 2000; Zadro, Williams, & Richardson, 2004). The PANAS, STAI, BDI-II, and NTS were administered both before the Cyberball task began and after each of the two Cyberball task blocks during the experiment. The NTS administered before the task instructed the participants to represent their feelings "right now" and used the present tense "feel" while the NTS used after each Cyberball block asked

participants to report how they “felt” during the game and included the manipulation check questions used by Zadro et al. (2004).

Cyberball manipulation

Following the completion of the first set of questionnaires, participants were told that they would be playing an online game with two other individuals, each located at different nearby universities. Unknown to the participants, the two other players were actually computer-generated players controlled by the Cyberball (Williams et al., 2000) computer program. Each participant completed the same two blocks of the Cyberball paradigm (inclusion, exclusion). In each block, the Cyberball game was set for 156 throws, with the computerized players waiting between 2 and 3 seconds after receiving the ball to make a throw to enhance the sense that the player was actually making a choice about which other player should receive the ball. In the first block (inclusion), the participant had a 50% chance of receiving the ball on each throw throughout the block. In the second block (exclusion), the participant had the same 50% chance of receiving the ball until receiving a total of 20 throws (approximately 80–90 throws into the block) from the other participants. Following this initial inclusionary phase, the participant was no longer included in any of the remaining throws in the block. During the Cyberball blocks, participants’ neuroelectric activity was recorded for data analysis in accordance with the guidelines of the Society for Psychophysiological Research (Picton et al., 2000).

Event-related markers were created on a computer collecting ERP data from the participants while they were engaged in the Cyberball paradigm. The event markers were inserted at the first image in each ball

toss where information was provided on which player was going to be the recipient of the ball toss (i.e., throw to human participant at the bottom of the screen and throw to computerized player across the screen). The inclusion of these event markers allowed for the quantification of moment-to-moment ERP activity in response to inclusionary (throw to human participant) or exclusionary (throw to computerized player) events. Both of these event types were present in the larger context of the generally inclusive or exclusive social interactions. The current study will examine both the first informational image (with the event marker) and the second informational image immediately following in the sequence (see Figure 1). Each throw image was presented on the screen for 450 ms and was immediately replaced on the display by the next image in the sequence (Themanson et al., 2013), which created the movement of the thrown “ball” during the Cyberball interaction.

Neuroelectric assessment

The electroencephalogram (EEG) was recorded from 64 sintered Ag–AgCl electrodes embedded in an elastic cap arranged in a 10–10 system montage (Chatrian, Lettich, & Nelson, 1985) with an average-ear reference and forehead ground (AFz). Vertical and horizontal bipolar electrooculographic activity was recorded to monitor eye movements. A Neuroscan Synamps2 bioamplifier (Neuro Inc., El Paso, TX, USA) was used to continuously digitize (500 Hz sampling rate) and low-pass filter (30 Hz; 24 dB/octave) the raw EEG signal. Offline processing of the stimulus-locked ERP included eye blink correction using a spatial filter (Compumedics Neuroscan, 2003), creation of stimulus-locked epochs (–800 to 2500 ms relative to the event marker), baseline removal

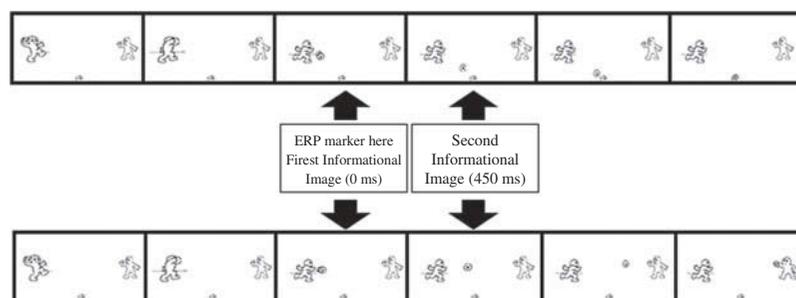


Figure 1. Timing of ERP markers during throws in ongoing Cyberball game. Markers were inserted at the first informational image providing information about the recipient of each throw. For the current study, primary analyses were conducted on the second informational image in the series, with analyses on the first information image examined as a replication of previous research. The figure presents an inclusionary throw to the participant (hand at bottom of screen) in the top series of images and an exclusionary throw away from the participant in the bottom series of images.

(800 ms pre-stimulus interval), and artifact rejection (epochs with signal that exceeded $\pm 75\mu\text{V}$ were rejected). For analyses on the first informational image, the N2 component was quantified as the average amplitude in the discrete latency window running from 200 to 320 ms after the event marker at FCz, whereas the P3b was quantified as the average amplitude in the discrete latency window running from 320 to 450 ms following the event marker at Pz, replicating the previous research (Themanson et al., 2013). For analyses on the second informational image, the P3 was quantified as the average amplitude in the discrete latency window running from 670 to 900 ms following the event marker in the first informational image. This time window represents the same time frame (320–450 ms) utilized for the analysis of the P3 in the first informational image as the individual throw images were spaced 450 ms apart. EEG activity was recorded using Neuroscan Scan software (v4.3.1; Compumedics Neuroscan, Charlotte, NC, USA). Stimulus presentation, timing, and the recording of participants' responses for the Cyberball paradigm were controlled by Neuroscan Stim (v2.0; Compumedics Neuroscan) software.

Statistical analyses

For the first informational image, separate omnibus 2 (block: inclusion, exclusion) \times 2 (throw: inclusionary throws [ITs] to the participant, ETs ignoring the participant) repeated-measures analyses of variance (ANOVAs) were conducted separately to compare the average amplitude of the N2 component at FCz and the P3b component at Pz across the different trial blocks and types of throw within the Cyberball paradigm, replicating previous analyses on ERPs in this Cyberball methodology (Themanson et al., 2013). For the second informational image, an omnibus 2 (block: inclusion, exclusion) \times 2 (throw: ITs to the participant, ETs ignoring the participant) \times 4 (site: Fz, FCz, Cz, Pz) repeated-measures ANOVA was conducted to examine the average amplitude of the P3 across different trial blocks, throw types, and electrode sites within Cyberball. Self-report measures were examined in three-level (time: baseline, after the inclusion block, and after the exclusion block) repeated-measures ANOVAs to verify the expected pattern of behavioral findings associated with social inclusion and exclusion. Follow-up analyses utilized repeated-measures ANOVAs and two-tailed paired-samples *t* tests with Bonferroni correction as appropriate. An experiment-wise alpha level of $p \leq .05$ was set for all analyses prior to Bonferroni correction.

RESULTS

Self-report assessments

Omnibus analyses revealed the expected block effects for all scales and subscales on the NTS, PANAS, STAI-State, and BDI-II, F 's(2,53) ≥ 6.4 , p 's $\leq .003$, partial $\eta^2 = .19$ (see Figure 2). Examining pairwise comparisons between different Cyberball blocks and baseline measures for the PANAS, NTS, STAI-State, and BDI-II revealed that measures taken following the exclusion block were significantly different from all other measurements on all scales and subscales, t 's(21) ≥ 3.6 , p 's $\leq .002$, with the exception of the baseline measurements on the negative affect (NA) scale of the PANAS, $t(54) = .3$, $p = .79$, and the BDI, $t(54) = 2.2$, $p = .03$. In these instances, it appears that being included in a social interaction reduces the participants' levels of NA and depressive symptomology from baseline levels, providing evidence for the beneficial effects of social exclusion. Further, the process of being excluded from a social interaction increases these negative states back up to a level similar to those reported at baseline. For the manipulation check measures (e.g., extent ignored/excluded) in which there was no baseline measurement, two-level repeated-measures ANOVAs showed significantly greater reporting of being ignored/excluded following exclusion compared to the following inclusion, F 's(1,54) ≥ 217.7 , p 's $\leq .001$, partial $\eta^2 \geq .80$. In sum, these findings suggest that social exclusion resulted in a significant decrease in all needs fulfillment, positive mood, positive affect, and the percentage of time the participants felt included as well as significant increases in feelings of being ignored/excluded, NA, depressive symptoms, and state anxiety compared to measures taken following social inclusion.

Neural measures

First informational image

Omnibus ANOVAs examining the first informational image within the Cyberball throws replicated previous research analyzing the different throws within each Cyberball interaction (Themanson et al., 2013). Specifically, analyses revealed that both the N2 and the P3b showed a main effect for Throw (F 's(1,54) ≥ 149.7 , p 's $< .001$), with larger N2 amplitude and smaller P3b amplitude for ETs (N2 $M = .2 \mu\text{V}$, $SD = 1.1$; P3 $M = -.2 \mu\text{V}$, $SD = 1.5$) compared to ITs (N2 $M = 2.5 \mu\text{V}$, $SD = 1.8$; P3 $M = 5.0 \mu\text{V}$, $SD = 3.2$). These findings indicate that

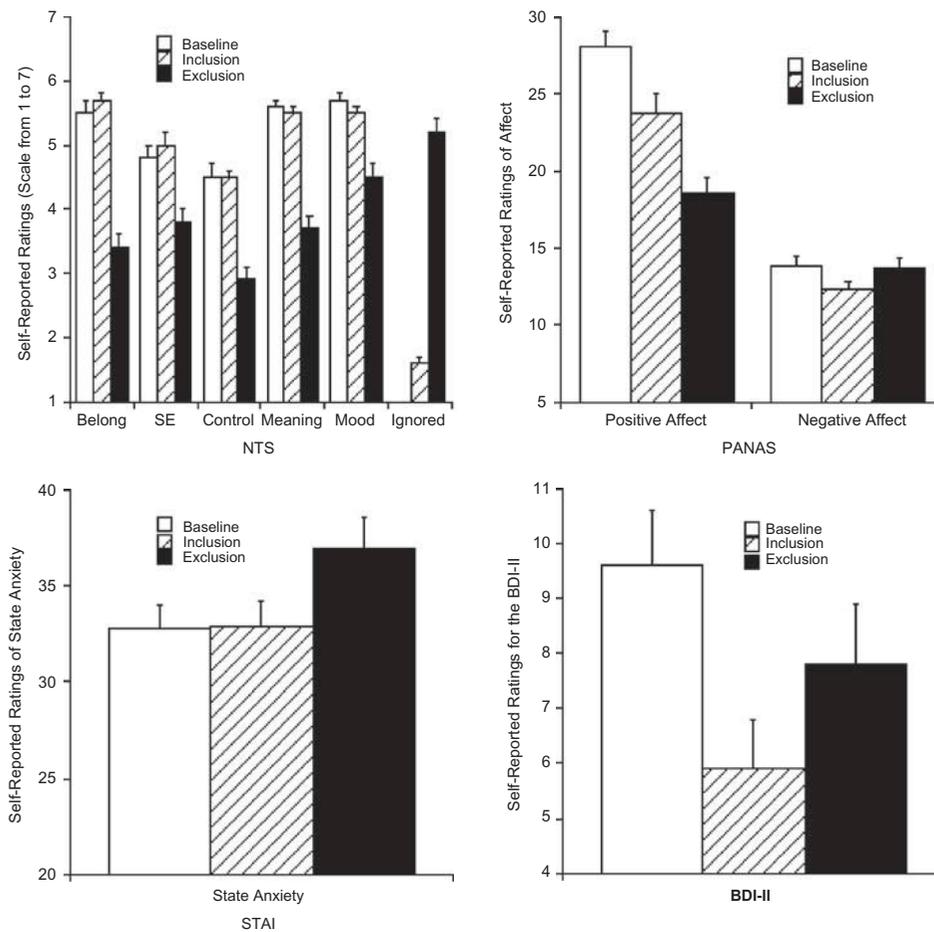


Figure 2. Participants' self-reported feelings relating to each scale of the need-threat scale (NTS; *top left*), Positive and Negative Affect Schedule (PANAS; *top right*), State-Trait Anxiety Inventory (STAI; *bottom left*), and the Beck Depression Inventory-II (BDI-II; *bottom right*) at baseline and following each block of the Cyberball paradigm (inclusion, exclusion). Error bars represent standard errors in all graphs. Note for the NTS: Belong = Need for Belonging; SE = Need for Self-esteem; Control = Need for Control; Meaning = Need for Meaningful Existence; Mood = Extent Feeling a Positive Mood; Ignored = Extent Feeling Ignored and Excluded.

the neural alarm activation and the related adaptations in attentional allocation were active during each social interaction (inclusion, exclusion) and were sensitive to the specific momentary exclusionary events during each of the social interactions. Figure 3 provides ERP waveforms by Cyberball block and throw type, highlighting the observed differences in N2 and P3b amplitudes to the first informational image. No other significant effects were present in these analyses for the first informational image.

Previous research using this Cyberball methodology has shown differences in neural activity across the duration of social exclusion experiences, with larger N2 and P3b amplitudes for exclusionary events earlier in the exclusion process compared to later in the exclusion process (Themanson et al., 2013). Accordingly, we conducted similar two-level repeated-measures ANOVAs for the N2 and P3b in

the first informational image to examine the potential alterations in neural activation to ETs over the course of the exclusion process. Following the conclusion of the initial inclusionary phase of the exclusion block, the remaining ET trials were examined in 20-trial blocks across time (time: first 20 ETs and second 20 ETs) for each component separately. These analyses revealed no difference for the N2, $F(1,54) = .1$, $MSE = .44$, $p = .78$, partial $\eta^2 = .01$, suggesting no modulation of the anterior N2 over the course of the exclusion process. However, an effect for the P3b was present, $F(1,54) = 12.0$, $p = .001$, $MSE = 1.22$, partial $\eta^2 = .18$, indicating larger (more positive) P3b amplitudes to exclusionary events earlier ($M(SD) = 1.5(1.8) \mu V$) compared to later ($M(SD) = .8(1.3) \mu V$) in the exclusion process (see Figure 4). Further, analyses were conducted to examine the relationships between alterations in the N2

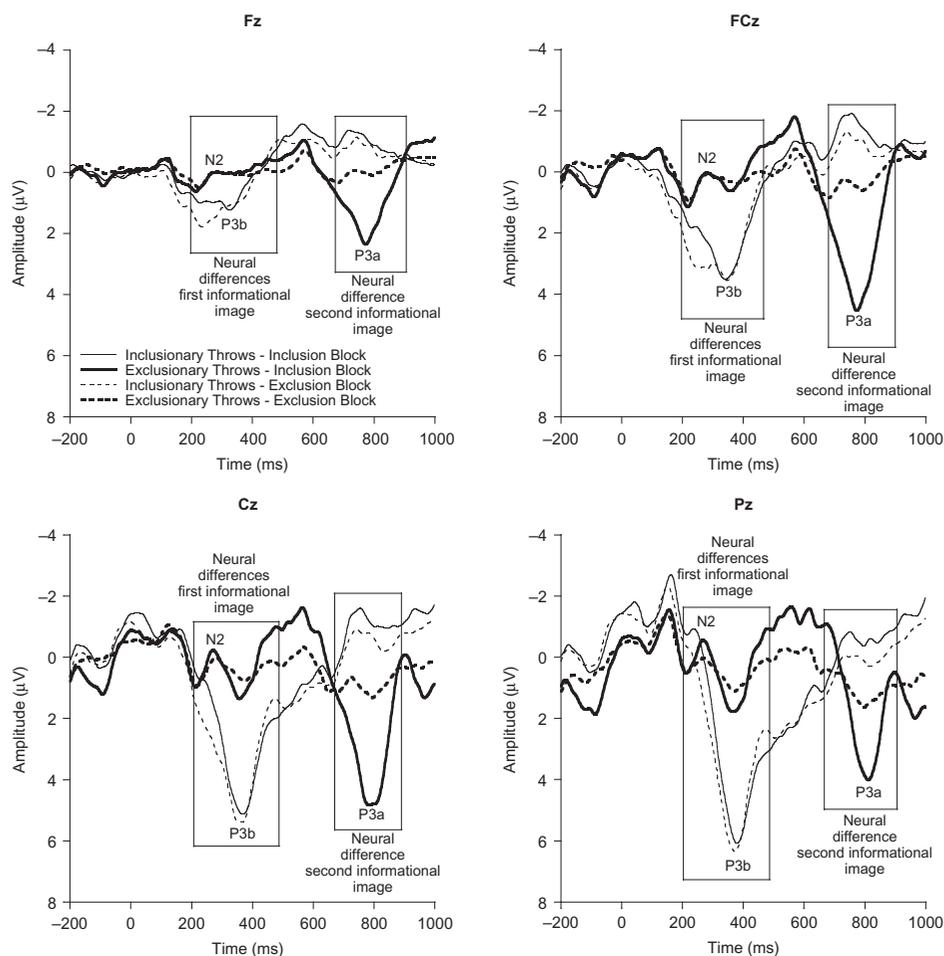


Figure 3. Grand-averaged stimulus-locked ERP waveforms during Cyberball for the inclusion and exclusion blocks (solid and dotted, respectively) for inclusionary throws (thin lines) and exclusionary throws (thick lines) at the Fz, FCz, Cz, and Pz electrode sites. Relative to inclusionary throws, exclusionary throws are characterized by larger N2 amplitude and smaller P3b amplitude to the first informational image as well as larger P3a amplitude to the second informational image. Additionally, P3a amplitude to exclusionary throws in the second informational image was larger during the inclusion block compared to the exclusion block. No differences were present for either task block or informational image in regard to inclusionary throws.

and P3b from inclusion to the initial stage of the exclusion process and changes in self-report measures from the inclusion block to the exclusion block. The findings replicated previous results (Themanson et al., 2013), with alterations in P3b correlated with changes in positive affect, $r = -.39$, $p = .003$, and changes in the feelings of control subscale of the NTS, $r = -.36$, $p = .007$. No other correlations were significant for the P3b, r 's $\leq .20$, p 's $\geq .15$, or the N2 component, r 's $\leq -.23$, p 's $\geq .09$.

Second informational image

The omnibus analysis for the P3 revealed main effects of Block, $F(1,54) = 11.7$, $MSE = 6.84$, $p = .001$, partial $\eta^2 = .18$; Throw, $F(1,54) = 78.4$,

$MSE = 11.0$, $p < .001$, partial $\eta^2 = .59$; and Site, $F(3,52) = 11.7$, $MSE = 4.47$, $p < .001$, partial $\eta^2 = .40$; and two-way interactions of Block \times Throw, $F(1,54) = 38.5$, $MSE = 6.69$, $p < .001$, partial $\eta^2 = .42$; Block \times Site, $F(3,52) = 8.3$, $MSE = 2.0$, $p < .001$, partial $\eta^2 = .32$; and Throw \times Site, $F(3,52) = 19.1$, $MSE = 2.62$, $p < .001$, partial $\eta^2 = .52$, which were modified by a three-way interaction of Block \times Throw \times Site, $F(3,52) = 11.6$, $MSE = 1.56$, $p < .001$, partial $\eta^2 = .40$. Decomposition of this interaction revealed a significant Block effect at FCz, $F(1,54) = 18.1$, $MSE = 2.58$, $p < .001$, partial $\eta^2 = .25$, and Cz, $F(1,54) = 13.3$, $MSE = 2.56$, $p = .001$, partial $\eta^2 = .20$, with larger P3 in the inclusion block compared to the exclusion block regardless of the throw

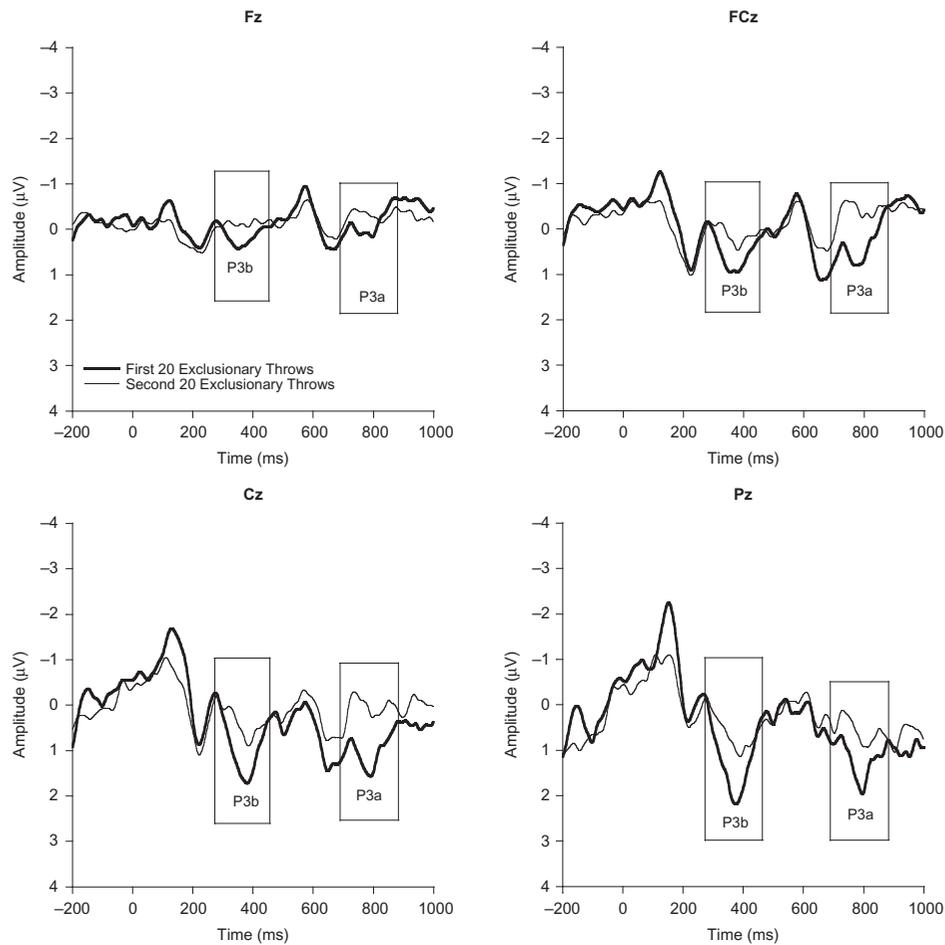


Figure 4. Grand-averaged stimulus-locked waveforms during Cyberball for the first 20 (thick lines) and second 20 (thin lines) exclusionary throws in the exclusion block following the initial inclusionary phase at the Fz, FCz, Cz, and Pz electrode sites. The first 20 exclusionary throws are characterized by larger P3b amplitude to the first informational image and larger P3a amplitude to the second informational image when compared to the second 20 exclusionary throws.

type at these two sites. Further, a significant Throw effect was present at each site, $F's(1,54) \geq 29.8$, $p's < .001$, partial $\eta^2 \geq .36$, indicating that P3 was larger for ETs compared to the ITs regardless of task block. Specifically, across task blocks, the P3 to ETs was largest at Cz ($M = 1.9 \mu\text{V}$, $SD = 1.6$), followed by Pz ($M = 1.6 \mu\text{V}$, $SD = 1.4$), FCz ($M = 1.4 \mu\text{V}$, $SD = 1.4$), and Fz ($M = .6 \mu\text{V}$, $SD = 1.1$). Lastly, similar Block \times Throw interactions were observed at each site, with the largest interaction at FCz, $F(1,54) = 52.6$, $MSE = 2.21$, $p < .001$, partial $\eta^2 = .49$, followed by the interactions at Cz, $F(1,54) = 31.4$, $MSE = 3.05$, $p < .001$, partial $\eta^2 = .37$, Fz, $F(1,54) = 19.3$, $MSE = 1.78$, $p < .001$, partial $\eta^2 = .26$, and Pz, $F(1,54) = 12.2$, $MSE = 2.63$, $p = .001$, partial $\eta^2 = .18$. Follow-up analyses indicated larger P3 amplitude to ETs in the inclusion block compared to the exclusion block at each site,

$F's(1,54) \geq 9.1$, $p's \leq .004$, partial $\eta^2 \geq .14$. No difference in P3 amplitude was present across task blocks for the ITs at any site. Given the topographic distribution of the P3 to this second informational image, as well as the context in which this component is maximal, this component is best characterized as a P3a component (Polich, 2007). Subsequent analyses use the P3a at the Cz site given that is the location where the P3a is maximal (see Figure 3).

Similar to the analysis for the first informational image, a two-level repeated-measures ANOVA was conducted for the P3a in the second informational image to assess the potential changes in P3a activation to ETs over the duration of the social exclusion experience. This analysis revealed a significant effect for changes in the P3a over the course of the exclusionary social interaction, $F(1,54) = 8.5$, $MSE = 2.48$, $p = .005$, partial $\eta^2 = .14$, with larger P3a earlier

($M(SD) = .9(2.4) \mu V$) compared to later ($M(SD) = .1(1.9) \mu V$) during the exclusionary social interaction (see Figure 4).

Relationship between neural measures and self-report assessments

Given the pattern of block effects for both the P3a to the second informational image and the self-report assessments, with changes present across the two Cyberball task blocks, an analysis was conducted to determine the potential nature of the relationships between exclusion-specific neural and behavioral processes over time. A measure was calculated obtaining the degree of change in the P3a at Cz to ETs from the inclusionary block to the exclusionary block. Specifically, this measure subtracted P3a amplitude to ETs in the exclusion block from the P3a amplitude to ETs in the inclusion block (i.e., P3a amplitude for inclusion block—P3a amplitude for exclusion block). Similarly, change scores were calculated for the self-report assessments from block to block, with exclusion block scores subtracted from inclusion block scores (inclusion block score—exclusion block score). Correlational analyses revealed that the decrease in the P3a for ETs in the second informational image across task blocks was positively correlated with the decrease in the percentage of the time participants felt included in the interaction ($r = .33, p = .015$) and negatively correlated with participants' self-reported increases in NA ($r = -.32, p = .016$), state anxiety ($r = -.39, p = .003$), and depressive symptoms ($r = -.28, p = .041$) from inclusion block to exclusion block, such that a greater decrease in the P3a amplitude from inclusion to exclusion was associated with a greater increase in these negative consequences of exclusion (see Table 1). No significant relationships were present between changes in the full

needs scale of the NTS and changes in the P3a across task blocks, $r = .1, p = .482$. Taken together, these results indicate that exclusion is a dynamic process (Williams et al., 2005) with alterations in the neural response to exclusionary events over the course of ongoing social interactions. Further, these changes in neural activity are sensitive to the larger context, or macro-level, of the social interactions. Finally, patterns of neural activity associated with the allocation of attention to exclusionary experiences are related with self-reported changes in negative feeling states following exclusion.

DISCUSSION

The current study provides evidence for ongoing differences in neural activation to specific events within social interactions. Specifically, during the first informational image for exclusionary events (ETs), we found greater ACC-related activation, indexed by the anterior N2, and a lesser degree of task-relevant attentional allocation, indexed by the P3b, compared to inclusionary events (ITs). These findings were present regardless of the larger context of the social interactions, which replicates previous research (Themanson et al., 2013). During the second informational image, findings revealed larger P3a amplitudes for ETs compared to ITs across social interactions (inclusion, exclusion) as well as greater P3a amplitudes for ETs in the inclusionary interaction compared to the exclusionary interaction. Finally, the modulation of the P3a from inclusion to exclusion was associated with the modulation of self-reported increases in state anxiety, NA, and depressive symptoms from inclusion to exclusion. These findings show that exclusion is a dynamic process with multiple ongoing neural responses to both micro-level (i.e., exclusionary

TABLE 1

Correlations among measures of change in the P3a at Cz to exclusionary throws (second informational image), BDI-II, state anxiety (measured via the STAI), and negative affect (measured via the PANAS), and the percentage of time the participants felt included in the interaction, across testing sessions

Variable	1	2	3	4	5	6
1. Δ P3a at Cz	—					
2. Δ BDI-II	-.28*	—				
3. Δ STAI	-.39**	.44**	—			
4. Δ NA	-.32*	.42**	.65**	—		
5. Δ % Included	.33*	-.15	-.21	-.28*	—	
6. Δ NTS	.10	-.44**	-.36**	-.25	.46**	—

Notes: Δ = change across task sessions (T2–T1); STAI = state anxiety scale in the STAI; NA = negative affect scale in the PANAS; % Included = percentage amount the participant felt they were included in the interaction; NTS = full scale score on the NTS.

* $p < .05$; ** $p < .01$.

events) and macro-level (i.e., exclusionary interactions) social exclusion. These neural activations are consistent with temporal models of the exclusion process (Williams, 2009), with N2 activation reflecting the initial detection and reflexive stages, where individuals' detect social exclusion begin to experience the pain, conflict, and NA associated with exclusion, and the P3 activation (both P3b and P3a) indexing the reflective stage of the exclusion process where attention is directed toward the exclusionary experience in an attempt to regulate the pain and control future behavior to meet fundamental needs. Further, the pattern of results provides new evidence for the nature of self-regulatory control toward exclusion, and how that process unfolds over the course of an exclusionary event, which has not been possible given the limitations of other studies on social exclusion.

Neural activity during first informational image

Similar to previous research (Crowley et al., 2010; Themanson et al., 2013), the anterior N2 was activated quickly in response to the specific act of being excluded from a social interaction, even if the individual was largely included throughout the social exchange. This finding suggests that ETs elicit immediate neural activation and that these exclusion-related processes are sensitive and broadly engaged processes (Williams, 2009) activated by any undesired event during an interaction, not just in response to the unpleasant conclusion of a social exchange (Themanson et al., 2013). This result is consistent with the theories of dACC activation, suggesting that the dACC is activated in response to conflict among ongoing processes or events (Botvinick et al., 2001; Yeung et al., 2004), exclusion-related distress or pain (Eisenberger & Lieberman, 2004), unexpected predicted outcomes (Brown, 2013), or the control of processes and outcomes that have a high expected value (Shenhav et al., 2013) or are superordinate compared to other action plans (Holroyd & Yeung, 2012).

With regard to the P3b in the first informational image, it exhibited smaller amplitude for ETs compared to ITs, confirming previous findings from this methodology of examining social exclusion (Themanson et al., 2013). This result appears to diverge from other fMRI and ERP findings suggesting greater self-regulatory attentional control toward exclusion when compared to inclusion (Crowley et al., 2010; Eisenberger et al., 2003). However, this finding makes sense in the context of this

methodology. In the current study, once participants perceive that they are going to receive the throw (an inclusionary event; IT), they must update their representation of the game dynamics and prepare their motor response (i.e., determine to whom they are going to throw the ball, prepare their button response, etc.). These processes are not needed in response to exclusionary events (ETs), but all of these processes require control processes that would be reflected by the P3b; these are task-relevant processes requiring a revision of the task environment (Donchin, 1981) including categorizing events (Polich & Kok, 1995) and updating working memory (Donchin & Coles, 1988). Accordingly, for the first informational image, our findings suggest that ETs elicit greater conflict-related activation to evaluate the undesired event, while ITs elicit greater attentional allocation to begin processing their subsequent task-related action.

Unlike previous studies (Crowley et al., 2010; Themanson et al., 2013), the present investigation found no difference in P3b amplitudes to ETs from the inclusion block to the exclusion block. This divergence from previous findings may be due to the extended duration of the exclusionary interaction in the present study. Similar to the previous research (Themanson et al., 2013), the current study showed a decrease in P3b amplitudes over the course of the exclusionary interaction, with a significant drop in P3b amplitude after the first 20 exclusionary events. In the current study, the exclusion manipulation lasted for approximately 80–90 ETs to obtain a greater number of trials for averaging each of the event types (ETs, ITs) in each of the task blocks (inclusion, exclusion). This exclusion duration is almost twice as long as the exclusion manipulation in previous research, which lasted for approximately 50 consecutive ETs (Themanson et al., 2013). Accordingly, there are a significantly greater number of trials after the first 20 trials included in the average waveforms for ETs in the exclusion block of the present investigation. This would further attenuate the overall P3b amplitude for the first informational image in response to ETs in the exclusion block and minimize the effect that was evidenced in the shorter exclusion manipulations used previously (Crowley et al., 2010; Themanson et al., 2013). Evidence for this habituation and desensitization of ERPs has been found in other areas of P3b research (Rule, Shimamura, & Knight, 2002) and has been suggested for other exclusion-related ERP effects (Crowley et al., 2010). It is important to note that the decrease in P3b amplitude over the course of the exclusion may not reflect habituation. Rather, the decrease may be an index of the depletion of self-regulatory attentional systems, resulting in social

cognitive deficits hypothesized in cognitive deconstruction (Baumeister et al., 2002). Further, this decrease in P3b may result from a general process of task disengagement on the part of the participants. As participants experience more exclusion and they do not have to actively participate in the social interaction, they may remove themselves from attending to the Cyberball task and simply stop processing the ongoing interaction. Based on the nature of the current study, the present data cannot adequately examine which explanation is most likely as they all could potentially elicit the observed reductions in P3b amplitudes over the course of exclusion.

Neural activity during second informational image

As hypothesized, results indicated that greater attentional allocation was present to ETs in the second informational image during both blocks of the Cyberball paradigm. This result indicates that additional attentional processing is present and ongoing for exclusionary events compared to inclusionary events. Specifically, exclusionary events are associated with additional top-down orienting processes, indexed by the P3a, that are not present to inclusionary events, regardless of the nature of the interaction. These orienting processes may reflect the dynamic methodology used in the current Cyberball paradigm (Themanson et al., 2013), as multiple stimulus images providing the same information to the participant in order to create each “event” within the social interactions. The use of multiple informational images may create an opportunity for the participants to verify or confirm the nature of the social event with the repetition of the information in the second informational image. These processes appear to be unique to ETs, which is consistent with ERP research using more traditional single-image methodologies (Crowley et al., 2009, 2010). Further, a larger attention-related orienting response of the P3a in the second frame of ETs in the inclusionary interactions would be expected as ETs within an exclusionary interaction would not require the same degree of secondary attentional orienting. Further, given the repeated nature of these exclusionary events during exclusionary interactions compared to inclusionary interactions, this finding supports previous fMRI findings showing enhanced patterns of neural activation in response to social exclusion (Eisenberger et al., 2003). The fMRI research aggregated the neural activity associated with these ETs over the duration of the entire social interaction, whereas the present investigation shows that

this result may have been due to the increased frequency of attentional responses to ETs that present in exclusionary, but not inclusionary, interactions. Additionally, the present investigation allows for a more precise examination of the nature of neural reactivity to social exclusion. Rather than just a general characterization, the findings revealed that in addition to an initial exclusion-related reaction (i.e., larger N2 in first informational image) to an exclusionary event, there is a later orienting response, indexed by the P3a in the second informational image, which focuses attention on being excluded from a social interaction. These combined ERP effects are consistent with current theories detailing the temporal dynamics associated with being the target of social exclusion (Williams, 2009).

In addition to the finding of greater P3a amplitudes to ETs compared to ITs for the second informational image across task blocks, we also found that these P3a amplitudes to ETs were larger in the inclusionary interaction compared to the exclusionary interaction. This effect is most likely due to the nature of the P3a component. The P3a is known to be sensitive to novel and orienting stimuli and will habituate to repeated stimulus presentations (Polich, 2007; Simons, Graham, Miles, & Chen, 2001). In the current social interactions, the ETs were novel and infrequent within the inclusionary block, which would be associated with larger P3a amplitude across exclusionary events. Conversely, in the exclusionary block, the ETs were the predominate event within the task session, which would lead to the habituation of the P3a resulting in a diminished P3a amplitude to ETs within the exclusionary block. This is supported by the changes in the amplitude of the P3a to ETs over the course of the ongoing exclusion, with larger amplitudes exhibited earlier, compared to later, in the exclusion process. Although these changes in P3a may provide evidence for the known habituation effect for the P3a, this reduction in P3a amplitude over time may also reflect cognitive deconstruction (Baumeister et al., 2002) or a general disengagement from the task as the process of exclusion continues. In spite of this average amplitude difference, the repeated nature of the ETs within the exclusion block compared to the inclusion block indicates that an overall greater degree of neural activity would be present during social exclusion compared to inclusion. This replicates previous findings during social exclusion across ERP (Crowley et al., 2010) and fMRI (Eisenberger et al., 2003, 2007) methodologies.

Furthermore, our findings indicate that the change in the top-down allocation of attention to exclusionary events, indexed by the P3a modulation to ETs from inclusion to exclusion in the second informational

image, is associated with self-reported increases in state anxiety, NA, and depressive symptoms from inclusion to exclusion. This supports previous findings showing that modulations of the P3 were related with alterations in self-reported social distress during exclusion (Themanson et al., 2013) and suggests that the degree of change in neural activity indexing attentional orienting to an undesired event or stimulus is related to the degree of change in self-reported increases in negative emotional states including anxiety, NA, and feelings of depression. Accordingly, this finding provides evidence that the explicit awareness, or perception of being excluded and the related allocation of attention to exclusionary experiences are linked with the negative consequences of exclusion. This relationship may be due to the underregulation (Baumeister & Heatherton, 1996) of one's responses to the exclusion as limited self-regulatory attentional processes are directed toward the exclusionary events and away from other self-regulatory processes. These findings show that similar to how exclusion can work in real-world interactions (Williams, 2001), any event or series of events that elicits attentional changes toward exclusion-related processes may also lead to negative outcomes for the individual's cognitive and emotional states.

Limitations and future directions

Although our analyses were able to examine multiple aspects of specific events within social interactions and determine the extent to which patterns of neural activation were independently associated with those specific events, it is important to mention the limitations of the current study. Notably, the restrictive nature of the exclusionary interaction limits the strength of the findings. Future research should utilize a variety of exclusionary interactions to more completely assess the relationships between neural measures of conflict-related activation and attentional allocation, and self-reported behavioral measures of social distress, anxiety, and NA. Further, future studies should investigate individual differences to uncover important variables and characteristics that may moderate exclusion-related effects on neural and behavioral measures present during social interactions. Finally, the repeated-measures nature of the methodology, with multiple self-report assessments examining participants' feelings regarding social exclusion, may have accounted for a portion of the self-report assessment findings following exclusion as participants were asked to reflect upon their social standing immediately prior to being excluded from a social interaction. Although this procedural difference

may have enhanced the self-reported effects of exclusion, the pattern of self-report findings from the current study is similar to other research that only assesses self-reported needs following the entire experimental protocol (Zadro et al., 2004). Further, the present protocol was able to uncover evidence for the beneficial influence of social inclusion on negative feeling states in addition to examining the consequences of social exclusion.

Summary

The current investigation offers new evidence into the ongoing nature of neural activity that is present during social exclusion. By examining ERPs to exclusionary events, we have shown that each moment of exclusion is associated with conflict-based neural activation and later orienting attentional responses regardless of the context of the larger social interaction. This provides a clearer understanding of what processes are engaged during social exclusion as the repeated activation of these neural circuits has been evidenced at the level of the interaction in hemodynamic research (Eisenberger et al., 2003, 2007), but never at this level of specificity. Further, we showed that alterations in orienting attentional processes toward exclusionary events are associated with self-reported increases in negative feeling states, including state anxiety, NA, and depressive feelings. These results show that the attentional processing and self-reported consequences of social exclusion are continually developing and are not just the summated outcome of an interaction. Therefore, these data provide a more precise and explicit understanding of the ongoing neural processes activated in response to social exclusion, including the allocation of attention toward exclusionary events, and the more general costs of exclusion on self-regulation and other attention-related cognitive processes (Baumeister et al., 2002, 2005; Themanson et al., 2013, 2014), which are not present in response to inclusionary events or interactions.

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