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The effects of social exclusion on the ERN and the cognitive control of action monitoring

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Abstract

The current study investigated the influence of social exclusion, created through the Cyberball paradigm, on cognitive control using neural and behavioral measures of action monitoring. Healthy young adults performed a modified flanker task while their post-error behavior (accuracy, RT) and error-related negativity (ERN) were assessed. Results indicated that excluded participants showed decreased ERN and post-error response accuracy compared to included participants following their social interactions. These findings suggest that a common neural framework may exist for cognitive control processes and that cognitive control allocated toward exclusion-related processing following exclusionary social interactions may disrupt the capability to support self-regulatory action monitoring.

Descriptors: Social exclusion, Cognitive control, Action monitoring, Error-related negativity

Social exclusion leads to alterations in both neural and behavioral activity (Eisenberger, Gable, & Lieberman, 2007; Eisenberger, Lieberman, & Williams, 2003; Themanson, Khatcherian, Ball, & Rosen, 2013) and has been associated with a variety of severe impairments across social, emotional, and cognitive domains (Baumeister, DeWall, Ciarocco, & Twenge, 2005; Baumeister, Twenge, & Nuss, 2002; Eisenberger et al., 2003; Masten et al., 2009; Williams, 2001, 2007), including decreases in self-esteem (Williams, 2001) and increases in depression, anxiety, loneliness, and aggressive social behaviors (MacDonald & Leary, 2005; Williams, 2007; Williams, Forgas, von Hippel, & Zadro, 2005). In relation to cognitive deficits, social exclusion elicits an immediate negative impact on the cognitive functioning of an excluded individual, an occurrence which has been termed cognitive deconstruction (Baumeister et al., 2002; Williams, 2007). This cognitive deconstruction is associated with slower reaction times and overestimation of lapsed time intervals (Twenge, Catanese, & Baumeister, 2003), as well as deficits in social self-regulation, which is critical to ensuring appropriate levels of social inclusion in a given social situation (Baumeister & DeWall, 2005; Baumeister et al., 2002; Williams, 2007). More specifically, the human survival instinct often results in individuals exhibiting selfish tendencies. However, these tendencies can be self-regulated and controlled in exchange for improved social inclusion. In the presence of social exclusion, this function exhibits severe impairments, suggesting that social exclusion may serve to deplete one's capacity to tolerate the attentional effort, motivation, and sacrifices needed for effective social self-regulation (Baumeister & DeWall, 2005; Baumeister et al., 2005).

Given the effects of social exclusion on social self-regulation, it seems plausible that exclusion may also exert an influence on other self-regulatory cognitive control processes, suggesting the impact of exclusion is not domain specific, but more generally influences cognitive control processes across social and cognitive domains, including self-regulatory action monitoring. The aim of the current study was to explore the relationship between the experience of social exclusion and its effects on subsequent cognitive control processes by examining both neural and behavioral indices of cognitive self-regulatory action monitoring before and after social exclusion. No previous research has examined the neural impact of social exclusion on these cognitive processes. Accordingly, we felt the use of both neural and behavioral measures was especially important considering both action monitoring and social exclusion have been associated with similar conflict-related neural processes.

Neural and Behavioral Indices of Action Monitoring

Cognitive control is the "ability to orchestrate thought and action in accord with internal goals," (Miller & Cohen, 2001, p. 167). One core process within cognitive control is action monitoring, or the self-regulatory monitoring of one's behavior to ensure that executed actions match intended outcomes (Gehring & Knight,

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2000). Research suggests that action monitoring is important for learning and goal-directed behavior (Holroyd & Coles, 2002) and is related both to the identification of behavioral errors or conflict and also the subsequent adjustments of behavior to improve subsequent cognitive task performance (Gehring, Goss, Coles, Meyer, & Donchin, 1993; Holroyd & Coles, 2002; Kerns et al., 2004; Yeung, Botvinick, & Cohen, 2004). Importantly, both neural and behavioral indices of action monitoring have been identified.

One neural index of action monitoring, the error-related negativity (ERN), has been identified as a negative-going deflection of the response-locked event-related brain potential (ERP), typically occurring approximately 50 ms following an erroneous response (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring et al., 1993). The ERN has been described as either a reinforcement learning index of error detection (Holroyd & Coles, 2002) or an early indicator of response conflict in association with erroneous task performance (Yeung et al., 2004). Source localization research suggests that the ERN is generated in the anterior cingulate cortex (ACC; Dehaene, Posner, & Tucker, 1994; Herrmann, Römmler, Ehlis, Heidrich, & Fallgatter, 2004; van Veen & Carter, 2002).

Current theories regarding the functionality of the ERN (Holroyd & Coles, 2002; Yeung et al., 2004) suggest that the ERN should be related with error-correcting behavior. To date, this functional characterization of the ERN has been evident in studies showing an association between the ERN and behavioral indices of post-error correction (but see also Hajcak, McDonald, & Simons, 2003). More specifically, increased ERN has been shown to predict increased response slowing and/or increased response accuracy following error commission (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gehring et al., 1993; Themanson, Hillman, & Curtin, 2006; Themanson, Rosen, Pontifex, Hillman, & McAuley, 2012; Yeung et al., 2004). These two behavioral measures reflect the outcome of self-regulatory action monitoring and provide evidence for the overall recruitment, implementation, and effectiveness of self-regulatory cognitive control. Moreover, ACC activity on error and high-conflict trials has been directly related to behavioral adjustments on subsequent task trials. These behavioral adaptations have been associated with enhanced prefrontal cortex (PFC) activation on those same post-error or post-conflict trials, which, in turn, has been related back to ACC activation on the previous task trial (Kerns et al., 2004). It is believed that action monitoring and the cognitive control of behavior is largely accomplished through the interaction between the ACC and the PFC (Garavan, Ross, Murphy, Roche, & Stein, 2002; Kerns et al., 2004).

Additionally, research has shown that numerous variables are related with modulations in ERN amplitude. Those variables associated with larger ERN amplitudes include a task emphasis on accuracy rather than speed (Gehring et al., 1993; Themanson, Pontifex, & Hillman, 2008; Yeung et al., 2004), obsessive-compulsive disorder (Gehring, Himle, & Nisenson, 2000), worry (Hajcak et al., 2003), neuroticism (Boksem, Tops, Wester, Meijman, & Lorist, 2006; Pailing & Segalowitz, 2004), self-efficacy (Themanson, Hillman et al., 2008; Themanson, Pontifex, Hillman, & McAuley, 2011), generalized anxiety disorder (Weinberg, Olvet, & Hajcak, 2010), and negative affect (Hajcak, McDonald, & Simons, 2004; Luu, Collins, & Tucker, 2000; Wiswede, Münte, & Rüsseler, 2009). These studies show that the ERN can be influenced by psychological, motivational, and situational traits and characteristics surrounding the performance of a cognitive task, which suggests that the effects of social exclusion may extend beyond the social domain into cognitive control and self-regulatory action monitoring.

Neural Activity During Social Exclusion

As indicated above, researchers have examined neural responses to social exclusion (Eisenberger et al., 2003, 2007; Themanson et al., 2013). Neuroimaging studies utilizing fMRI methodologies have shown greater ACC and right ventral prefrontal cortex (RVPFC) activation during exclusionary interactions compared to inclusionary interactions, with self-reported feelings of social distress following exclusion positively correlated with ACC activation during exclusion (Eisenberger et al., 2003). Conversely, RVPFC activation was negatively correlated with both social distress and ACC activation during exclusion (Eisenberger et al., 2003), suggesting that the RVPFC is activated to suppress exclusion-related ACC activation and disrupt one's feelings of distress in response to exclusion (Eisenberger et al., 2003; Eisenberger & Lieberman, 2004).

Recently, research utilizing ERPs has helped clarify this pattern of neural activity associated with social exclusion (Themanson et al., 2013). This research examined exclusion-related ACC activation through measurement of the anterior, or conflict, N2 component. Similar to the ERN, the conflict N2 is maximal over frontocentral recording sites and is believed to be a psychophysiological index of conflict monitoring that originates from the ACC (van Veen & Carter, 2002; Yeung et al., 2004). Scalp recordings of this component reflect the detection of conflict that occurs without action errors or error feedback, including conflict associated with the inhibition of action (Braver, Barch, Gray, Molfese, & Snyder, 2001), response conflict (Clayson & Larson, 2012), and conflict derived from being excluded from an ongoing social interaction (Themanson et al., 2013). This study revealed that the conflict N2 was activated by the specific act or moment of being excluded from a social interaction, even if the individual was largely included throughout the entirety of the social exchange. This finding is consistent with theories of conflict monitoring and cognitive control (Botvinick et al., 2001; Braver, Gray, & Burgess, 2007; Yeung et al., 2004) that suggest action monitoring occurs throughout task engagement and indicates that conflict-based ACC activation reflects a more general and sensitive process that is broadly activated by any undesired event (Themanson et al., 2013). Further, this finding corroborates studies associating greater ACC-based conflict monitoring activation with social exclusion (Eisenberger et al., 2003, 2007).

Current Study

The current study was designed to assess the potential relationship between social exclusion and cognitive self-regulatory action monitoring. To achieve this goal, neural (ERN) and behavioral (post-error accuracy and post-error RT) indices of action monitoring were obtained while participants completed a modified Eriksen flanker task both before and after engaging in a computerized social task (Cyberball; Williams, Cheung, & Choi, 2000), which was manipulated to either include or exclude the participants. We hypothesized that socially excluded participants would exhibit decreased ERN amplitude and post-error response accuracy and a shortened reaction time in post-error trials when compared to participants who were fully included in the social interaction. These results would extend the impact of social exclusion to include a more general degradation of self-regulatory cognitive control functioning on both neural and behavioral levels, beyond previous research specifically examining behavioral indicators of social self-regulation (Baumeister et al., 2005). Further, we hypothesized that alterations in ERN amplitude across task sessions would be associated with changes in the post-error behavioral measures across testing sessions (Themanson et al., 2012), which would suggest that changes in ERN activation are related with changes in self-regulatory behavior following social exclusion. These findings, when combined with previous studies associating greater ACC (Eisenberger et al., 2003) and conflict N2 (Themanson et al., 2013) activation with social exclusion, would suggest that social exclusion may disrupt subsequent action monitoring capabilities through the reallocation of cognitive control processes implemented by the same self-regulatory neural framework.

Method

Participants

Twenty-nine undergraduate students between the ages of 18 and 21 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 were randomly assigned to either an exclusion group or an inclusion group. Participants ($n = 1$) with fewer than six errors in either task session (i.e., before Cyberball, after Cyberball) were discarded from the analyses (Olvet & Hajcak, 2009; Pontifex et al., 2010), as were participants ($n = 2$) with excessive noise and artifacts obtained during ERP data collection and participants who did not perform above 50% accuracy during each flanker task session ($n = 3$), resulting in a sample size of 23 participants (11 females, 12 males). The study was approved by the Institutional Review Board of Illinois Wesleyan University.

Assessments and Procedures

Preliminary assessments and procedure. After obtaining informed consent, each participant completed the Edinburg Handedness Inventory (Oldfield, 1971) and a demographics questionnaire. Immediately after completing these measures, participants were told they were going to complete both a cognitive (flanker task) and social (Cyberball) task on the computer while their neural activity was recorded, with the social task occurring between sessions of the cognitive task to break up the repetitive nature of the cognitive task. Participants completed two blocks of the flanker task (described below) while having their neuroelectric activity measured in accordance with the guidelines of the Society for Psychophysiological Research (Picton et al., 2000). Following this initial flanker task session, participants completed a brief need-threat scale (NTS) and feelings assessment that has been used in previous social exclusion research (Williams et al., 2000; Zadro, Williams, & Richardson, 2004) and the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). After completing these measures, participants completed two blocks of the Cyberball paradigm (described below), with the NTS and PANAS administered immediately after each Cyberball paradigm, and then the participants completed two more blocks of the flanker task. The NTS and PANAS administered before the first Cyberball task instructed participants to represent the feelings they have “right now” and used the present tense “feel” while the NTS and PANAS used after each Cyberball block asked participants to report how they “felt” during the game, and the NTS included the manipulation check questions used by Zadro et al. (2004). Throughout the process of testing, participants were monitored by the experimenter, ensuring they adhered to proper testing protocol. After the completion of the final block of the flanker task, participants were debriefed on the goals of the experiment and allowed to ask any questions they had about the study.

Cognitive assessment. Participants completed a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974) utilizing stimuli in the form of 4-cm-high white symbols (< and >) presented on a black screen that were either congruent (<<<<< or >>>>>) or incongruent (<<><< or >><>>) with the central target stimulus. The central target stimulus pointing to the right (>) required a right-handed response, and the central target symbol pointing to the left (<) required a left-handed response. Participants viewed a series of these flanker stimuli presented focally on a computer monitor at a distance of 1 m, and each array of five stimuli subtended 13.5° of the horizontal visual angle and 3.4° of the vertical visual angle when presented on the computer monitor. Stimuli were presented for 80 ms with an intertrial interval varying between either 1,000, 1,200, or 1,400 ms for each trial. The trials were grouped into two task blocks, with 20 practice trials before the first block and a brief rest period between blocks. Each block contained 300 trials, and participants completed two blocks of the task during each session. Accordingly, a total of 600 flanker trials were completed both before (T1) and after (T2) the Cyberball paradigm. Participants were instructed to respond to stimuli as quickly and accurately as possible. Congruent and incongruent trials were equiprobable and randomly ordered within each task block. Finally, the two blocks were counterbalanced across participants in the task sessions both before and after the Cyberball paradigm.

Behavioral assessment. Behavioral data were collected on response time (i.e., time in ms from the presentation of the stimulus) and response accuracy (i.e., number of correct and error responses) for all trials across task blocks. Multiple additional behavioral measures of accuracy and RT were calculated for each participant (Themanson, Hillman et al., 2008; Themanson, Pontifex et al., 2008; Themanson et al., 2011, 2012). Specifically, these measures were calculated for (a) error trials, (b) matched-correct trials (the subset of correct trials matched to specific error trials based on RT), (c) correct trials following an error trial (post-error trials), and (d) correct trials following a matched-correct trial (post-matched-correct trials). Each participant’s post-error behavior (accuracy, RT) was compared to his or her post-matched-correct behavior to examine whether behavioral differences obtained in the present investigation were due specifically to error-related adjustments in cognitive control.

Social exclusion manipulation. Following the completion of the first flanker session, participants were told they would be playing a computerized game of “catch” (Cyberball; Williams et al., 2000) over the internet with two other undergraduate participants who were located at nearby universities. Participants were told that there was no ultimate goal of the game. Instead, the game served the purpose of allowing the researchers to record neural activity while the participants were engaged in a social task. In reality, the other players in the game were part of the Cyberball program (Williams et al., 2000), and their actions were controlled by the computer program. Blocks of the Cyberball task were designed to either include or exclude the participant by altering a preprogrammed sequence of throws. Each participant was randomly assigned to either the “inclusion” or “exclusion” group prior to the experiment. For the included participants ($n = 11$; 5 female, 6 male), they completed two blocks of the Cyberball task where they had a 50% chance of receiving the ball from the computerized players throughout the course of the two blocks. For the excluded participants ($n = 12$; 6 female, 6 male), the first block of the task was identical to the inclusion group (described above). However, in the second block of the task (the exclusion block), the participant had the same 50% chance of receiving the ball until receiving a total of 10 throws from the other participants. Following this initial inclusionary phase, the participant was no longer included in any of the remaining approximately 50 throws in the block. In each block, the Cyberball game was set for 80 throws, with the computerized players waiting between 2–3 s after receiving the ball to make a throw to enhance the sense that the player was actually playing the game and making a choice about which other player should receive the ball.

Neural 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 a ground electrode (AFz) on the forehead. The sites were referenced online to an electrode at the midpoint between Cz and CPz, and eye movements were monitored using vertical and horizontal bipolar electrooculographic activity (EOG) recorded by Ag-AgCl electrodes placed above and below the right orbit and near the canthus of each eye. Impedances were kept below 10 kΩ for all electrodes. A Neuroscan SynAmps2 bioamplifier (Neuro Inc., El Paso, TX), with a 24-bit A/D converter and ± 200 mV input range, was used to continuously digitize (500 Hz sampling rate), amplify (gain of 10), and filter (70 Hz low-pass filter, including a 60 Hz notch filter) the raw EEG signal in DC mode (763 μV/bit resolution). Neuroscan Scan software (v 4.3.1) was used to record EEG activity, and Neuroscan Stim (v 2.0) was used to control stimulus presentation, timing, and measurement of behavioral response time and accuracy.

Offline processing of the response-locked flanker ERP included eye blink correction using a spatial filter (Compumedics Neuroscan, 2003), rereferencing to average mastoids, creation of response-locked epochs (–400 ms to 1,000 ms relative to the behavioral response), low-pass filtering (30 Hz; 24 dB/octave), baseline correction (the average activity in the 100-ms preresponse time window was subtracted from each data point in the filtered waveforms), and artifact rejection (signals that exceeded ±75 μV after all other offline processing steps were rejected). Average ERP waveforms for correct trials were matched to error trial waveforms on response time and number of trials to protect against differential artifacts of the stimulus-related activity overlapping with the response-locked ERP activity (Coles, Scheffers, & Holroyd, 2001). Matching (described above for the assessment of post-error behavior) involved selecting individual correct trials for each participant, without replacement, that matched the response time for each of the error trials for that individual. This procedure removes artifacts that may exist in the timing of processing due to differences in response latency for correct and error trials, and results in an equal number of matched-correct trials and error trials for each individual to compare differences across accuracy conditions. The ERN amplitude was quantified as the average amplitude between 0–100 ms postresponse. The data for each participant was then outputted in ASCII format so that it could be analyzed statistically in SPSS 21.0.

Table 1. *Mean (SD) Values for Participant Demographics and Overall Task Performance Data by Group (Inclusion, Exclusion)*

Variable	Inclusion group	Exclusion group
# of participants	11 (5 female, 6 male)	12 (6 female, 6 male)
Age	18.5 (.9)	18.7 (.9)
T1 reaction time (ms)	402.3 (35.7)	392.6 (63.1)
T1 response accuracy (% correct)	88.1 (7.8)	85.8 (8.2)
T2 reaction time (ms)	385.2 (28.5)	377.5 (61.2)
T2 response accuracy (% correct)	89.9 (6.3)	84.6 (11.3)

Note. T1 = First flanker testing session (pre-Cyberball); T2 = Second flanker testing session (post-Cyberball).

Statistical Analyses

Initial analyses were conducted utilizing mixed model analyses of variance (ANOVA). Follow-up analyses utilized univariate ANOVA and two-tailed paired samples t tests with Bonferroni correction. An experiment-wise alpha level of $p \leq .05$ was set for all analyses prior to Bonferroni correction. The analytical approach utilized in the current study was based on recommendations of the Society for Psychophysiological Research (Vasey & Thayer, 1987). For the ERN, an omnibus analysis using a 2 (Accuracy: error, correct) × 4 (Site: Fz, FCz, Cz, Pz) × 2 (Time: T1/pre-Cyberball, T2/post-Cyberball) multivariate repeated measures ANOVA was conducted first to verify that these data conformed to the expected topography and accuracy effects (Rodríquez-Fornells, Kurzbuch, & Münte, 2002). Then, the ERN was analyzed using 2 (Time: T1, T2) × 2 (Group: inclusion, exclusion) mixed model ANOVAs. Overall response accuracy and RT were also examined for the flanker task using the same 2 × 2 mixed model ANOVA structure. Post-error accuracy and post-error RT for the flanker task were analyzed separately using 2 (Time: T1, T2) × 2 (Group: inclusion, exclusion) × 2 (Accuracy: post-error, post-matched-correct) mixed model ANOVAs. For the Cyberball measures, the NTS and PANAS were examined in 3 (Time: baseline, after block 1, after block 2) × 2 (Group: inclusion, exclusion) mixed model ANOVAs, and manipulation check measures were examined in 2 (Time: after block 1, after block 2) × 2 (Group: inclusion, exclusion) mixed model ANOVAs to verify the expected pattern of behavioral findings associated with social inclusion and exclusion.

Results

Flanker Task Performance

Table 1 provides demographic data and overall task performance data by session for each group. The omnibus ANOVA for overall response accuracy during the flanker task revealed no significant time or group effects, indicating that overall response accuracy was not significantly influenced by time, membership in either the inclusion or exclusion group, or their interaction. The ANOVA for overall RT did reveal a significant time effect, $F(1,21) = 18.8$, $p < .001$, partial $\eta^2 = .47$, indicating that flanker task RT was faster for all participants, regardless of Cyberball group membership, during the second flanker session ($M = 381.2$ ms, $SD = 47.5$) compared to the first flanker session ($M = 397.2$ ms, $SD = 51.0$). These findings suggest that an overall practice effect is evident for the

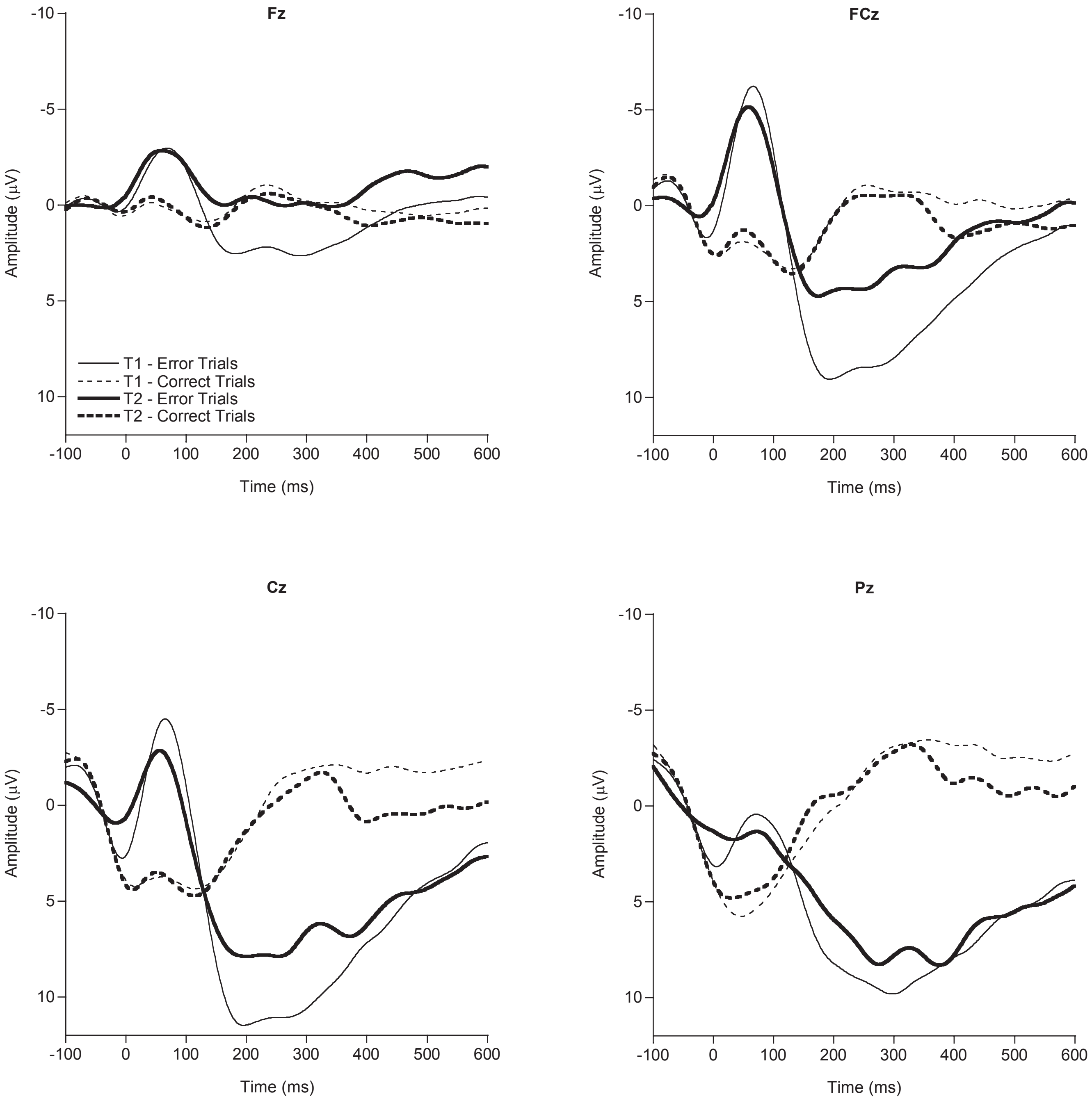

Figure 1. Grand-averaged response-locked waveforms for all participants on both T1 (pre-Cyberball) and T2 (post-Cyberball) error trials and correct trials during the flanker task at the Fz, FCz, Cz, and Pz electrode sites.

repeated completion of the flanker task (rather than a speed-accuracy tradeoff), with task accuracy remaining intact over time while RT is improved over time.

Flanker Action Monitoring Measures

ERN. Figure 1 provides grand-averaged waveforms by accuracy (error, correct) and time of flanker task (T1/pre-Cyberball, T2/post-Cyberball) at the Fz, FCz, Cz, and Pz electrode sites. The omnibus analysis revealed significant accuracy, $F(1,22) = 77.0$, $p < .001$, partial $\eta^2 = .78$, and site, $F(3,20) = 20.5$, $p < .001$, partial $\eta^2 = .76$, main effects. However, these were modified by the expected significant two-way Accuracy × Site interaction, $F(3,20) = 64.4$, $p < .001$, partial $\eta^2 = .91$. Post hoc Bonferroni-corrected t tests revealed the largest accuracy effect at FCz, $t(22) = 12.0$, $p < .001$, and other significant effects at Fz, Cz, and Pz, $ts(22) \geq 5.2$, $ps \leq .001$. Additionally, average ERN was maximal at FCz ($M = -3.2$, $SD = 2.6$) compared to Fz ($M = -1.9$, $SD = 1.5$), Cz ($M = -1.3$, $SD = 3.4$), and Pz ($M = 1.8$, $SD = 2.8$). Accordingly, all subsequent ERN analyses used area scores from the waveforms at FCz.

Figure 2 provides grand-averaged waveforms by group (inclusion, exclusion) and time of flanker task (T1, T2) at FCz. The

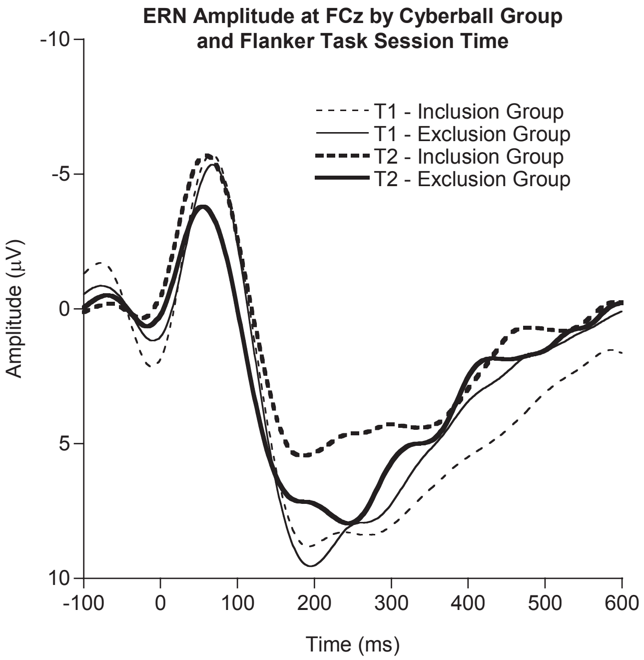

Figure 2. Grand-averaged response-locked waveforms for the inclusion and exclusion participant groups on both T1 (pre-Cyberball) and T2 (post-Cyberball) error trials during the flanker task at the FCz electrode site.

omnibus ANOVA revealed a significant Time × Group interaction effect, $F(1,21) = 4.6$, $p = .04$, partial $\eta^2 = .18$, indicating that ERN values in the inclusion group (T1: $M = -3.5$, $SD = 2.7$; T2: $M = -3.6$, $SD = 2.3$) got more negative over time, while the ERN values from the exclusion group (T1: $M = -3.5$, $SD = 3.3$; T2: $M = -2.2$, $SD = 2.8$) became more positive over time (see Figure 3a). Follow-up Bonferroni-corrected t tests showed a significant time effect for excluded participants, $t(11) = 4.0$, $p = .002$, and no significant effect for included participants, $t(10) = .2$, $p = .87$, indicating that the exclusion group showed a significant decrease in ERN amplitude between T1 and T2 while the inclusion group showed no change in ERN over time.

Post-error accuracy. The omnibus ANOVA revealed a significant Time × Group interaction, $F(1,21) = 4.3$, $p = .05$, partial $\eta^2 = .17$, as well as a significant Accuracy × Group interaction, $F(1,21) = 4.2$, $p = .05$, partial $\eta^2 = .17$. However, these two-way interactions were modified by a significant three-way Time × Accuracy × Group interaction, $F(1,21) = 5.8$, $p = .02$, partial $\eta^2 = .22$. Decomposition of this interaction into Time × Accuracy interactions for each group revealed different effects. Specifically, a time effect was observed for the inclusion group, $F(1,10) = 9.2$, $p = .01$, partial $\eta^2 = .48$, with greater post-trial response accuracy (% correct) in the second session (T2: $M = 91.9$, $SD = 5.1$) compared to the first session (T1: $M = 86.5$, $SD = 7.5$) regardless of whether the responses occurred following error trials or matched-correct trials. No other effects were significant. For the exclusion group, a significant Time × Accuracy effect was observed, $F(1,11) = 5.4$, $p = .04$, partial $\eta^2 = .33$. Follow-up Bonferroni-corrected t tests showed no significant time effects for either post-error response accuracy, $t(11) = 1.6$, $p = .14$, or post-matched-correct response accuracy, $t(11) = 1.5$, $p = .15$. However, post-error accuracy for the exclusion group decreased from T1 ($M = 85.6$, $SD = 6.0$) to T2 ($M = 76.0$, $SD = 22.5$), while post-matched-correct accuracy increased from T1 ($M = 85.8$, $SD = 7.5$) to T2 ($M = 89.3$, $SD = 7.5$). Combined, these findings indicate that a specific decrease in post-error accuracy was observed over time

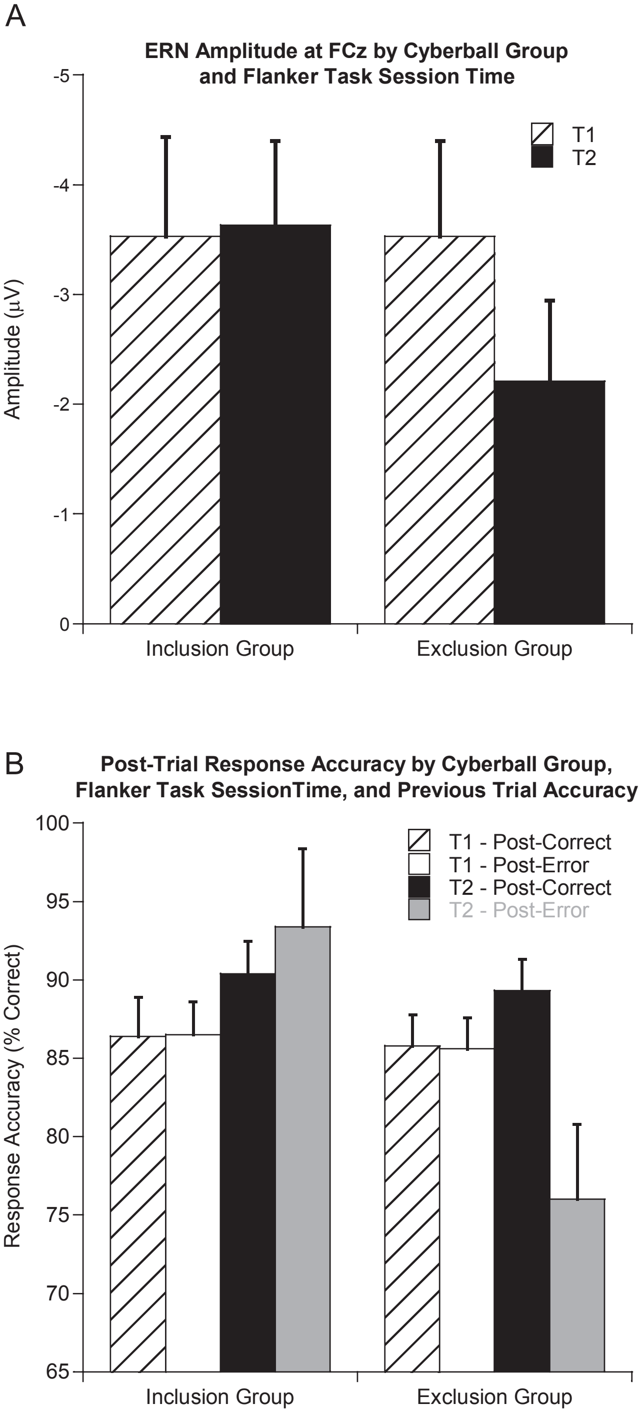

Figure 3. A: Mean ERN amplitudes for the inclusion and exclusion participant groups on both T1 (pre-Cyberball) and T2 (post-Cyberball) error trials during the flanker task at the FCz electrode site. B: Mean post-trial response accuracy values (% correct) on post-error trials and post-matched-correct trials for the inclusion and exclusion participant groups on both T1 (pre-Cyberball) and T2 (post-Cyberball) flanker task performances.

Table 2. *Mean (SD) Scale/Subscale Scores on the PANAS and NTS for All Participants by Group and Time of Measurement (Pre-Cyberball, Post-Cyberball Block 1, Post-Cyberball Block 2)*

	Inclusion group			Exclusion group		
	Pre-	Post-B1	Post-B2	Pre-	Post-B1	Post-B2
Variable	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*
PANAS-PA	28.5 (8.1)	25.4 (8.3)	23.9 (5.9)	27.1 (4.1)	24.3 (4.3)	*15.9 (5.6)*
PANAS-NA	13.5 (3.1)	12.8 (2.6)	12.3 (3.4)	15.7 (6.2)	13.5 (5.7)	14.3 (4.6)
NTS-Belonging	4.1 (.5)	4.2 (.7)	4.2 (.3)	3.7 (1.0)	4.2 (.7)	*2.4 (.8)*
NTS-Self-esteem	3.7 (.4)	3.5 (.6)	3.5 (.5)	3.7 (.6)	3.5 (.6)	*2.4 (.5)*
NTS-Meaningful existence	4.3 (.5)	4.0 (.7)	4.2 (.4)	3.9 (.8)	4.1 (.5)	*2.5 (.9)*
NTS-Control	3.2 (.4)	3.3 (.4)	3.3 (.7)	3.1 (.5)	3.6 (.5)	*1.9 (.7)*
NTS-Mood	4.2 (.4)	3.9 (.5)	3.9 (.4)	3.9 (.5)	3.9 (.6)	*2.9 (.6)*
Extent felt ignored/excluded	N/A	1.6 (1.0)	1.6 (.7)	N/A	1.3 (.6)	*3.8 (1.0)*
Estimated % of throws received	N/A	37.2 (7.1)	33.9 (7.5)	N/A	41.2 (15.8)	*9.5 (6.5)*

Note. Italicized numbers in the "Post-B2" column for the exclusion group represent scale scores that significantly differed from previous scores for that group in pairwise comparisons. All scores in that assessment were different from previous scores except for the NA scale in the PANAS. PANAS = Positive and Negative Affect Schedule; NTS = need-threat scale.

for the exclusion group (see Figure 3b). All other measures of post-trial response accuracy either increased significantly (i.e., both measures for the inclusion group) or simply increased (i.e., post-matched-correct accuracy for the exclusion group) over time.

Post-error RT. The omnibus ANOVA revealed a significant time main effect, $F(1,21) = 8.3$, $p = .01$, partial $\eta^2 = .28$, as well as a significant accuracy main effect, $F(1,21) = 30.8$, $p < .001$, partial $\eta^2 = .60$. These results indicate that all post-trial RTs were significantly faster at T2 ($M = 382.5$ ms, $SD = 51.0$ ms) compared to T1 ($M = 398.4$ ms, $SD = 50.2$ ms), regardless of group membership (inclusion, exclusion) and accuracy (post-error, post-matched-correct) and that post-trial RTs were significantly faster following matched-correct trials ($M = 375.4$ ms, $SD = 45.9$ ms) compared to error trials ($M = 405.5$ ms, $SD = 55.1$ ms) regardless of group membership and task session (T1, T2). No group effects were revealed in the analysis of post-error RT.

Relation between ERN and post-error accuracy. The bivariate correlation between changes in ERN and changes in post-error accuracy over time was calculated across participant groups to determine whether changes in the ERN were associated with alterations in post-error response accuracy across the flanker task sessions. The correlation was significant, $r = -.44$, $p = .04$, suggesting that as ERN changes to be more negative (larger) across task sessions, post-error accuracy changes to be greater (more accurate) across task sessions. This shows that the changes in the two metrics are related for all of the participants, corroborating previous research (Themanson et al., 2012) and provides evidence that the decrease in ERN for the exclusion group across sessions was associated with the decrease in post-error response accuracy across sessions.

Cyberball Measures

Omnibus analyses revealed the expected Time × Group effects for all scales in the NTS, $F\text{s}(2,20) \geq 5.8$, $p\text{s} \leq .01$, partial $\eta^2 \geq .37$, as well as the manipulation check measures, $F\text{s}(1,21) \geq 20.8$, $p\text{s} \leq .001$, partial $\eta^2 \geq .50$. Examining pairwise comparisons between different Cyberball blocks and baseline measures for the NTS revealed that measures taken following the second Cyberball block (exclusion) were significantly different from all other measurements on all scales for the exclusion group, $t\text{s}(11) \geq 4.1$, $p\text{s} \leq .002$. For the inclusion group, no significant differences were present across measurements on the NTS (baseline, after block 1, after block 2), $t\text{s}(10) \leq 1.5$, $p\text{s} \geq .16$. These results suggest that the social exclusion manipulation experienced by the exclusion group resulted in a significant decrease in all needs fulfillment and positive mood compared to baseline reports and measures taken following social inclusion for either participant group. For the manipulation check measures (e.g., extent ignored/excluded) in which there was no baseline measurement, data obtained following the exclusion block for the exclusion group showed significantly greater reporting of being ignored/excluded in comparison to the inclusion block, $t\text{s}(11) \geq 6.3$, $p\text{s} \leq .001$. The inclusion group showed no difference in the reporting of these measures following either Cyberball task block, $t\text{s}(10) \leq .9$, $p\text{s} \geq .36$. Table 2 provides mean scores (*SD*) for each subscale/measure by group and time of measurement.

In relation to the PANAS, the Positive Affect (PA) subscale showed a similar Time × Group interaction effect, $F(2,20) = 4.4$, $p = .03$, partial $\eta^2 = .31$. Examining pairwise comparisons between different Cyberball blocks and baseline measures for the PA subscale revealed that measures taken following the second Cyberball block (exclusion) were significantly different from all other measurements on all scales for the exclusion group, $t\text{s}(11) \geq 5.1$, $p\text{s} \leq .001$. For the inclusion group, no significant differences were present across measurements on the PA subscale of the PANAS, $t\text{s}(10) \leq 2.4$, $p\text{s} \geq .04$. Finally, the Negative Affect (NA) subscale showed no Time × Block effect, $F(2,20) = 1.1$, $p = .36$, partial $\eta^2 = .10$, suggesting NA was not influenced by the social exclusion manipulation (see Table 2).

Discussion

The current study found that social exclusion has a negative effect on cognitive control processes as measured through both neural and behavioral indices of action monitoring. As hypothesized, the ERN and post-error response accuracy were both decreased for individuals following social exclusion compared to those who had been fully included in a social interaction, while no differences existed between the groups prior to the social manipulation. Further, the changes in these two metrics were correlated with one another across the flanker task sessions, with decreased (less negative) ERN associated with decreased (less positive) post-error accuracy. Taken together, these data suggest that the self-regulatory control implemented in response to social exclusion may utilize the same neural framework as action monitoring processes employed during cognitive task performance, which leads to the disruption of action monitoring processes following social exclusion.

Cognitive and Social Action Monitoring

The ERN is a neural response that has been linked to the process of self-regulatory action monitoring (Gehring et al., 1993; Holroyd & Coles, 2002; Themanson et al., 2012; Yeung et al., 2004). Functionally, the ERN is theorized to be associated with subsequent improvements in performance (e.g., improved post-error accuracy) as enhanced cognitive control is implemented to alter behavior in accord with desired goals following errors or conflict (Holroyd & Coles, 2002; Yeung et al., 2004). This self-regulatory control process is vital to ensuring that executed behaviors match intended goals during cognitive task execution (Gehring & Knight, 2000). The ERN is believed to be generated in the ACC (Dehaene et al., 1994: van Veen & Carter, 2002), and the action monitoring system is reliant upon the interactions between the ACC and the PFC to regulate post-error behavior (Garavan et al., 2002; Kerns et al., 2004).

A similar internal monitoring system has been proposed to serve a social function. Williams and colleagues (Williams et al., 2005) have suggested that humans developed social self-regulation, involving the analysis of cognitive, emotional, and behavioral cues, to aid in the detection of social exclusion. Given the import of social group membership to human survival, if an individual's inherent need to be socially accepted is not fulfilled, social self-monitoring allows the individual to implement control over selfish tendencies in exchange for improved social inclusion (Baumeister & DeWall, 2005; Baumeister et al., 2002; Williams, 2007). This social system relies upon the ACC as a social conflict-based neural alarm, and the RVPFC is activated to regulate the conflict and social distress resulting from exclusion (Eisenberger & Lieberman, 2004; Eisenberger et al., 2003, 2007). Using ERPs, the ACC activation can be indexed by the anterior, or conflict, N2 (Folstein & van Petten, 2008), which has been evidenced in response to exclusionary events during social interactions in other social exclusion research (Themanson et al., 2013) and has been theorized to reflect the same neural processes as the ERN (Yeung et al., 2004). Following social exclusion, social self-regulation has been shown to be impaired, suggesting that exclusion disrupts the control processes needed for effective self-regulation of healthy behaviors (Baumeister et al., 2005; Twenge, Catanese, & Baumeister, 2002), aggressiveness (Buckley, Winkel, & Leary, 2004; Twenge, Baumeister, Tice, & Stucke, 2001), and prosocial behavior (Twenge, Baumeister, DeWall, Ciarocco, & Bartels, 2007).

Integration of Neural Control Processes

We observed associated decreases in both ERN and post-error accuracy in the flanker task for participants who were previously excluded from a social interaction. The combined neural and behavioral deficits in the present investigation suggest that the previously noted effects of social exclusion on cognitive function (Baumeister & DeWall, 2005; Baumeister et al., 2002; Williams, 2007) can be observed on a neural level, with decreased ACC-based activation of the ERN following exclusion. This is a novel finding considering previous research was limited to behavioral measures. Additionally, our findings show self-regulatory action monitoring is among the processes that are negatively impacted by social exclusion, evidenced by the decreased ability to correct erroneous task performance, expanding our understanding of the cognitive impact of social exclusion. Findings from a number of studies may seem to question this effect as research has shown that negative affect, worry, neuroticism, and anxiety (among other characteristics) have been associated with greater ERN amplitude (Boksem et al., 2006; Hajcak et al., 2003, 2004; Luu et al., 2000; Pailing & Segalowitz, 2004; Weinberg et al., 2010). However, explanations of these effects have been grounded in trait associations with the ERN, leading some researchers to suggest that the ERN could be a heritable, state-independent endophenotype for psychopathology (Olvet & Hajcak, 2008). By comparison, the present study suggests social exclusion exerts a transient, or statelike, effect on the ERN and action monitoring processes. This effect is dissociable from the trait-based influences on the ERN. For example, the baseline correlation between negative affect and ERN amplitude in the present study is similar in magnitude ($r = .36$) to the correlations ($r = .35$; $r = .46$) detailed by Luu et al. (2000) in their examination of the relationship between trait negative affect and two measures of ERN amplitude, suggesting that the present findings are consistent with previous research examining trait influences on the ERN.

In addition to previous trait effects on the ERN, the present findings also appear to diverge from the literature examining negative affective state influences on the ERN. Recent research has generally shown an increase in ERN associated with increases in negative affective states or negative social contexts and influences (Boksem & De Cremer, 2010; Boksem, Kostermans, & De Cremer, 2011; Boksem, Ruys, & Aarts, 2011; Pfabigan et al., 2013; Unger, Kray, Mecklinger, 2012; Wiswede et al., 2009; Wu, Zhou, van Djik, Leliveld, & Zhou, 2011; but see also Clayson, Clawson, & Larson, 2012; Larson, Gray, Clayson, Jones, & Kirwan, 2013, for other outcomes). Explanations for these findings have related modulations in ERN to alterations in the motivational salience and subjective importance of erroneous task performance, with enhanced ERN in conditions where errors are more salient or meaningful due to negative social or affective consequences. In contrast to those studies, the present research provides meaningful negative social feedback via social exclusion in the Cyberball paradigm. This social feedback is associated with an active response by the cognitive control system (Eisenberger et al., 2003; Eisenberger & Lieberman, 2004) and is also separate from the flanker task and the assessment of the ERN in this study. We believe that social exclusion, and the motivated need to attend to exclusion with cognitive control processes (Eisenberger et al., 2003; Eisenberger & Lieberman, 2004; Themanson et al., 2013), may decrease the requisite motivation and attentional control needed for proper error-related action monitoring during the subsequent flanker task. Given that social exclusion is associated with a number of severe consequences across social, emotional, and cognitive domains (Baumeister et al., 2002, 2005; Williams, 2001, 2007), the cognitive control of exclusion may act as a superordinate control goal (Holroyd & Yeung, 2012), which is more motivationally salient and valuable (Shenhav, Botvinick, & Cohen, 2013) to the individual than the goal of monitoring and correcting performance errors in the subsequent flanker task in our paradigm. This would disrupt the normal capabilities of the error monitoring system, leading to a reduced ERN and a related decrease in post-error accuracy for excluded participants in the flanker task. This interpretation fits with evidence that social negative feedback carries greater motivation salience compared to errors without social content (Boksem, Kostermans et al., 2011; Boksem, Ruys et al., 2011) and with research on the ACC showing enhanced ACC activation directed toward exclusion-related self-regulatory processes (Eisenberger & Lieberman, 2004). Further, this outcome is consistent with the existing literature regarding motivational and subjective error salience influences on the ERN (Clayson et al., 2012; Hajcak, Moser, Yeung, & Simons, 2005; Larson et al., 2013; Pfabigan et al., 2013), with more motivationally salient errors associated with greater ERN and less salient errors associated with smaller ERN. Finally, this interpretation corresponds with recent theoretical developments in ACC activation based upon hierarchical reinforcement learning (Botvinick, Hiv, & Barto, 2009), which state that the ACC supports the selection of control options based upon superordinate, extended action plans (Holroyd & Yeung, 2012) or upon the expected value of control (Shenhav et al., 2013).

Additionally, the present findings indicate that self-regulatory action monitoring processes are not domain-specific operations unique to either social or cognitive issues. Rather, self-regulatory control appears to be more generic and generalized, with the same neural framework utilized to implement cognitive control to achieve desired outcomes regardless of the social (Eisenberger & Lieberman, 2004; Eisenberger et al., 2003, 2007) or cognitive (Botvinick et al., 2001; Holroyd & Coles, 2002; Holroyd & Yeung, 2012; Yeung et al., 2004) nature of behavior. While this common cognitive control framework permits efficient neural functioning across a variety of self-regulatory problems, this shared system allows for social or emotional influences on subsequent cognitive self-regulatory processes as observed in the current study, and the reciprocal potential for cognitive influences on subsequent social self-regulation. These influences may be especially apparent in circumstances where the control processes are responding to aversive and motivational experiences. In the present study, this effect was observed for social exclusion through robust self-reported decreases in PA and all needs measures by the NTS following the second Cyberball block (exclusion) for the excluded group. For error commission, research has shown that errors prime defensive motivational responses (Hajcak & Foti, 2008) and are sensitive to motivational manipulations (Hajcak et al., 2005). These characteristics are common to social exclusion and post-error monitoring, but they differentiate these self-regulatory processes from other control processes, like navigating difficult task conditions (i.e., incongruent trials in the flanker task), and may help to explain why the self-regulation of errors was sensitive to the exclusion manipulation.

An alternative explanation may be that excluded individuals generally disengaged from the experimental procedure following their exclusion. This would reduce the ERN in the second flanker task session, as research has demonstrated a positive relationship between task engagement and the ERN (Luu et al., 2000; Tops & Boksem, 2010), with greater engagement associated with larger ERN amplitudes. In the current study, it is difficult to determine whether excluded participants were disengaged from the task. While it is true that they were not actively participating during their social exclusion, they did exhibit the same levels of overall task performance in the second flanker session as included participants. Additionally, they reported significant changes in their PA and NTS scores following the exclusion, suggesting that they were focusing their attention on the proceedings during the exclusion, which is consistent with some definitions of engagement (Tops & Boksem, 2010). Clearly, future research is needed to better choose among these possibilities.

Limitations and Future Directions

Although the current data present an interesting depiction of the effects of social exclusion on neural and behavioral indices of self-regulation, it is important to note the limitations of this study. The relatively small sample size, complications with participant data (i.e., the presence of excessive artifacts in ERP data, performance issues during the flanker task), and the poor spatial resolution of ERPs each limit the strength of the findings. Accordingly, replication in a larger sample is needed. However, because the findings in the present investigation are consistent with patterns observed in previous research examining action-monitoring processes (Themanson et al., 2012; Yeung et al., 2004) and responses to social exclusion (Themanson et al., 2013), we believe we have assessed reliable associations between neural and behavioral cognitive control processes. Further, future studies should examine a broader array of cognitive control processes as well as more variable social interactions. This would help to obtain a more comprehensive understanding of the interaction between different cognitive control processes and how those effects are manifested through neural or behavior measures.

Conclusion

In summary, social exclusion negatively impacted both neural and behavioral indices of self-regulatory action monitoring processes during subsequent cognitive task execution. More specifically, following computerized social interactions we found decreased ERN and post-error response accuracy for excluded participants compared to included participants while no group differences were present prior to the social interaction manipulation. Further, changes in ERN and post-error accuracy across task sessions were correlated. This corroborates previous research (Themanson et al., 2012) and suggests that the influence of social exclusion was consistent for both neural and behavioral indices of action monitoring. These combined results provide evidence for a generalized neural cognitive control framework that is responsive to self-regulatory needs regardless of their nature. Accordingly, we conclude that occurrences of social exclusion may serve to deplete the motivation and attention required for effective action monitoring as cognitive control is allocated toward exclusion-related processing and away from other self-regulatory control mechanisms.

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