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Neural and Behavioral Effects of Social Exclusion on Self-Regulation

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### Abstract

Researchers investigating the effects of social exclusion on neural activity propose there is a common neural framework underlying self-regulatory processes for both social and cognitive behaviors. This study will shed light on the engagement of these processes across social and cognitive task domains by investigating the effects of social exclusion on cognitive task execution. Neural and behavioral activity were measured while participants completed two flanker task sessions with the Cyberball paradigm occurring in between; additionally, half of the participants experienced exclusion during the Cyberball paradigm. Results showed that, similar to previous research, social exclusion led to impairments in subsequent flanker task performance. Further, there was a relationship between neural activity and task behavior. For excluded participants, neural activity during the first flanker task session was associated with neural activity during Cyberball. These findings diverge from previous studies by suggesting that social exclusion via Cyberball doesn't just impair post-error performance in subsequent tasks; rather exclusion impacted overall task performance in the current study.

*Keywords:* social exclusion, self-regulation, ERN, N2

### Neural and Behavioral Effects of Social Exclusion on Self-Regulation

One critical function of the human cognitive system is its ability to override automatic mechanisms in order to behave appropriately based on the situation. This function, termed cognitive control, involves numerous processes that comprise the “ability to orchestrate thought and action in accordance with internal goals” (Miller & Cohen, 2001, p. 167). A subset of cognitive control processes specific to self-regulation are crucial for successful learning and execution of goal-directed behavior (Holroyd & Coles, 2002). Without the coordination of these self-regulatory processes, the human cognitive system would lack the flexibility to perform simple behaviors like detecting when an error has been made, processing feedback related to the error, and adjusting behavior to avoid committing future errors (Gehring, Goss, Coles, Meyer, & Donchin, 1993; Hajcak, Holroyd, Moser, & Simons, 2005; Kerns et al., 2004; Yeung, Botvinick, & Cohen, 2004).

One of the ways researchers have examined self-regulatory processes of cognitive control has been to evaluate how social exclusion impairs self-regulation. Humans are one of the most socially dependent species, with belonging to a social group being critical for physical as well as psychological health (Baumeister & DeWall, 2005). When participants are rejected in the laboratory, they tend to behave more aggressively (Twenge, Baumeister, Tice, & Stucke, 2001), engage in self-destructive and risky behaviors (Twenge, Catanese, & Baumeister, 2002), and report feelings of anxiety, depression, loneliness, frustration, and helplessness (Williams, Cheung, & Choi, 2000). In addition to these negative emotional effects, social exclusion has also been shown to elicit an array of cognitive deficits. Specifically, individuals who have been excluded show impaired cognitive functioning and social self-regulation processes (Baumeister, DeWall, Ciarocco, & Twenge, 2005; Williams, 2007).



Most recently, researchers investigating the impact of social exclusion on neural activity propose there is a common neural framework underlying self-regulatory processes for both social and cognitive behaviors (Eisenberger, 2012; Eisenberger & Lieberman, 2004; Themanson, Ball, Khatcherian, & Rosen, 2014; Themanson, Khatcherian, Ball, & Rosen, 2013). A previous study conducted in our laboratory found that participants performed worse on a cognitive task after being excluded from a social event compared to participants who were included during the social event (Themanson et al., 2014). The neural and behavioral results of this study suggest that implementing self-regulatory control during a social exclusionary event interfered with participants' ability to engage in self-regulatory control during a subsequent cognitive task (Themanson et al., 2014). Thus, the authors proposed that excluded participants exhibited cognitive deficits because the self-regulatory processes implemented during social exclusion and cognitive task execution share a neural framework (Themanson et al., 2014).

The aim of the current study is to shed light on the engagement of self-regulatory cognitive control across social and cognitive task domains by investigating the effects of social exclusionary experiences on subsequent cognitive task execution. This will provide a better understanding of how control processes like self-regulation are implemented during social and cognitive events and inform current theories of cognitive control, specifically the proposal that self-regulatory processes for social and cognitive behaviors are implemented by the same neural framework. This review will begin by describing the role of the dorsal anterior cingulate cortex (dACC) in self-regulation, focusing on how the dominant theories of dACC function have transformed throughout the past decade. Then, the neural and behavioral indices of self-regulation will be discussed, which will lead into an examination of self-regulation during social exclusion. The review will conclude with a description of the current study.

### Theories of dACC Function in Self-Regulation

The rise of cognitive neuroscience has resulted in a surge of research dedicated to exploring the neural mechanisms underlying cognitive control. Numerous studies have confirmed the association between activation of the dorsal anterior cingulate cortex (dACC) and cognitive control processes, but it is not yet clear how this brain region achieves this coordination (Kerns et al., 2004). The dACC is located at the medial surface of the posterior medial frontal cortex and maintains connections with both frontal and limbic areas (Etkin, Egner, & Kalisch, 2011; Wessel, 2012). One of the reasons the field has been unable to converge on a unified theory of dACC function is because of its involvement in such a wide variety of cognitive activities, including language, decision making, learning, imagery, pain processing, and motor control, among others (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Shenhav, Botvinick, & Cohen, 2013).

Two early and influential theories of dACC function include the conflict monitoring hypothesis (Botvinick et al., 2001) and the reinforcement learning hypothesis (Holroyd & Coles, 2002). With their conflict monitoring hypothesis, Botvinick and colleagues (2001) explain that in addition to regulating behavior, control processes must also evaluate information. They propose that the dACC is related to this evaluative aspect of cognitive control. The conflict monitoring hypothesis thus describes an error detection system originating in the dACC that monitors for conflicts and signals for corresponding adjustments to control (Botvinick et al., 2001). In contrast, Holroyd and Coles (2002) present the reinforcement learning hypothesis, which states that the mesencephalic dopamine system delivers error signals to the dACC, triggering the dACC to exert control by modifying behavior. They refer to the error signals as negative reinforcement

learning signals, indicating that these signals train the dACC, which is in accordance with the basic principles of reinforcement learning (Holroyd & Coles, 2002).

Conflict monitoring and reinforcement learning theories remained dominant for several years as they found ample support from neuroimaging studies (Holroyd & Yeung, 2012; Kerns et al., 2004; Rushworth, Behrens, Rudebeck, & Walton, 2007). However, an inability to reconcile these two distinct accounts of dACC function, as well as integrate a variety of other observations regarding the dACC, led researchers to consider different explanations for the role of the dACC in cognitive control (Alexander & Brown, 2011; Hajcak, Moser, Yeung, & Simons, 2005; Holroyd & Yeung, 2012). Most recently, theories have proposed that the dACC determines allocation of control by evaluating the expected values of control (Shenhav et al., 2013) or by selecting options based on high-level behavioral plans (Holroyd & Yeung, 2012).

With their expected value of control (EVC) theory, Shenhav and colleagues (2013) describe the role of the dACC as a decision maker rather than a regulator of behavior. This decision making function involves weighing information of competing tasks to determine their expected values of control (i.e., the quantity or value associated with allocating control), and then selecting which tasks to perform and delegating the appropriate amount of control towards them (Shenhav et al., 2013). At the same time, Holroyd and Yeung (2012) propose the hierarchical reinforcement learning (HRL) theory, which suggests that the dACC is involved in selecting and maintaining long-term action plans, rather than deciding which tasks to perform or executing control. Specifically, they argue that the function of the dACC is related to high-level behavioral plans maintained over extended periods of time, not the regulation of behavior on a trial-by-trial basis as previous theories (including the EVC theory) have assumed (Holroyd & Yeung, 2012). Additionally, the HRL theory supplements previous reinforcement learning theories by

incorporating a hierarchy where options are ranked by value (Holroyd & Yeung, 2012). The authors ultimately assert that the dACC does not monitor for conflict, but rather weighs information about costs and effort as a part of its function of maintaining high-level behavioral plans (Holroyd & Yeung, 2012).

Despite their differences, both the EVC and HRL theories describe the dACC's role in self-regulation as relying on a hierarchy or stratification where processes are ranked as more or less important within a goal directed plan. This implies that the dACC is motivated to implement self-regulatory control to only the most important processes, in accordance with their expected values of control (Shenhav et al., 2013) or an overall behavioral plan (Holroyd & Yeung, 2012). Thus, if self-regulatory processes for social and cognitive behaviors are implemented via a shared neural framework, then the dACC must determine which processes are most valuable and implement control to those tasks, perhaps at the expense of other tasks. Investigating the effects of social exclusionary experiences on subsequent cognitive task execution will provide a better understanding of how social and cognitive behaviors are ranked by the dACC. This study is therefore grounded in the assumption that the role of the dACC in self-regulation involves a value-based hierarchy, but will not attempt to discriminate between the EVC and HRL theories.

### **Neural and Behavioral Indices of Self-Regulation**

Neuroimaging techniques like electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) have revealed several neural and behavioral indices of self-regulatory control processes. Event-related brain potentials (ERPs), which are observed through EEG recordings, have high temporal resolution, allowing researchers to examine changes in brain activity in what is essentially real time. fMRI studies, on the other hand, have high spatial resolution, which provides valuable insight into the activity of specific brain areas. While both

types of evidence are necessary for understanding the mechanisms underlying self-regulation, ERPs are especially useful for examining neural changes from one trial to the next. Accordingly, this project will focus on two ERP components, the error-related negativity (ERN) and the conflict N2, which are known to be associated with the dACC.

**The Error-Related Negativity (ERN).** The ERN is a negative-going deflection seen largest frontocentrally and occurring approximately 50-100 ms after an erroneous response (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring et al., 1993). Studies utilizing source localization techniques trace the generation of the ERN to the dACC, though more advanced techniques have recently suggested that the ERN is actually generated in the posterior cingulate cortex (PCC), which borders the ACC (Agam et al., 2011; Dehaene, Posner, & Tucker, 1994; van Veen & Carter, 2002b). This new evidence describes the PCC as being functionally related to the dACC, coordinating with it to detect errors and adjust behavior (Agam et al., 2011). Thus, even though the ERN may be generated in the PCC, the role of the dACC in implementing self-regulatory behavior is still the same.

Researchers have used a variety of cognitive tasks to investigate the ERN and discover several of its characteristics. For instance, the ERN is affected by factors like motivation and context, such that when participants are instructed to focus on accuracy over speed, and when participants commit a larger error, the magnitude of the ERN is increased (Hajcak, McDonald, & Simons, 2004; Holroyd & Coles, 2002). Additionally, larger ERNs are observed when participants are certain they have responded erroneously compared to when they are unsure about whether they have made an error (Scheffers & Coles, 2000). Task engagement shares a similar positive correlation as perception of response accuracy; the more engaged the participant during the task, the larger the ERN (Luu, Collins, & Tucker, 2000).

In accordance with these findings, the ERN is understood to represent some form of error processing, though there are still disagreements regarding its specific functionality (Yeung et al., 2004). Current theories suggest that the ERN's role in self-regulation is related to error-correcting behavior, which is examined by looking at post-error trials (Holroyd & Coles, 2002; Yeung et al., 2004). For example, after participants make an error, they will implement self-regulatory control in order to ensure that the next trial is not an error. The ERN is associated with this cognitive control process, which is crucial for ensuring that one's behaviors align with internal goals (Themanson et al., 2014). This theory of ERN function is supported by observations that increased ERN amplitude is correlated with longer response time and increased response accuracy after an error trial (Botvinick et al., 2001; Gehring et al., 1993; Themanson, Hillman, & Curtin, 2006; Themanson, Rosen, Pontifex, Hillman, & McAuley, 2012; Yeung et al., 2004). Response time and accuracy are behavioral measures that are useful for providing information about the implementation and effectiveness of cognitive control (Themanson et al., 2014).

The function of the ERN in self-regulation can be further illustrated with the Eriksen flanker task (Eriksen & Eriksen, 1974). In this task, participants are instructed to indicate the central target letter of a letter string. The central target letter ("H" or "S") is flanked on both sides by letters that create either congruent trials ("HHHHH" or "SSSSS") or incongruent trials ("SSHSS" or "HSHHH"). The current study utilized a modified version of the flanker task as the cognitive task because it allows for the assessment of self-regulation. For example, this task induces high conflict in the incongruent trials because the flanking stimuli indicate the incorrect response, meaning both the correct and incorrect response compete for the participant's attention (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999). In other words, the participant must exert



more control to respond correctly (Rueda, Posner, & Rothbart, 2005). Behaviorally, this means participants tend to be faster on incongruent trials that were preceded by an incongruent trial as opposed to a congruent trial (Kerns et al., 2004; van Veen & Carter, 2002a). When the preceding trial was a high conflict situation, participants recruit additional control, reducing conflict on the current trial (Kerns et al., 2004). In accordance, studies have found reduced ACC activation on incongruent trials preceded by incongruent trials than on incongruent trials preceded by congruent trials (Botvinick et al., 1999; Kerns et al., 2004).

While the current study did not examine self-regulatory control processes in terms of congruent or incongruent trials, the function of the ERN in self-regulation can be thought of in a similar way. The ERN is activated after a participant commits an error, and normally this activation assists the participant in making sure the next trial of the task is not an error, much like when a previous high conflict trial reduces conflict on the current trial (Kerns et al., 2004). In accordance, research has found that increased ERN amplitude is correlated with longer response time and increased response accuracy after an error trial (Botvinick et al., 2001; Gehring et al., 1993; Themanson et al., 2006; Themanson et al., 2012; Yeung et al., 2004). However, participants who have been socially excluded may exhibit impairments in self-regulation, which means that after they commit an error, they would have decreased ERN amplitude, and would not be as efficient at making sure the next trial is not an error. This study therefore focused on ERN amplitude as well as response accuracy on trials that occur after an error trial (post-error trials), with impairments to self-regulation defined as decreased ERN amplitudes and reduced response accuracy on post-error trials. In other words, the decreased ERN amplitude is the neural indicator of the impaired self-regulatory processes, whereas the reduced response accuracy on post-error trials is the behavioral indicator.

**The Conflict N2.** The conflict N2, or anterior N2, is a subcomponent of the N200 characterized by a negative-going deflection seen largest frontocentrally and peaking approximately 250-350 ms following stimulus presentation (Clayson & Larson, 2012; Folstein & Van Petten, 2008; van Veen & Carter, 2002b). The conflict N2 represents the detection of conflict that occurs without action errors or error feedback (Themanson et al., 2014). For example, the conflict N2 has been demonstrated in tasks that involve response inhibition, such as the Stroop task, and tasks that involve response conflict, such as the flanker task (Braver, Barch, Gray, Molfese, & Snyder, 2001; Clayson & Larson, 2013). Both the ERN and conflict N2 are thought to be generated in nearby regions of the ACC and both are thought to be indices of conflict monitoring (van Veen & Carter, 2002b; Yeung et al., 2004). However, the ERN is only elicited after an incorrect response, whereas the conflict N2 is observed in both correct and incorrect trials (Yeung et al., 2004). Thus, the conflict N2 is thought to be an index of conflict monitoring, specifically reflecting the conflict-related activity that occurs before the response on correct trials (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; Yeung et al., 2004).

In relation to the flanker task, the amplitude of the conflict N2 is more negative on incongruent trials relative to congruent trials (Folstein & Van Petten, 2008; van Veen & Carter, 2002b; Yeung et al., 2004). Incongruent trials in the flanker task represent high response conflict situations, and corresponding increases in conflict N2 amplitude are seen in other tasks which elicit such situations, like the oddball and go/no-go paradigms (Clayson & Larson, 2012; Iannaccone et al., 2015; Yeung et al., 2004). Taken together, these results suggest that the conflict N2 is a correlate of response conflict monitoring while the ERN is a correlate of error processing (Clayson & Larson, 2012; Iannaccone et al., 2015; Nieuwenhuis et al., 2003; Yeung



et al., 2004). Therefore, the amplitude of the conflict N2 varies according to the degree of response conflict that occurs before a response has been made, but the ERN is dependent on factors related to error processing (Holroyd & Coles, 2002; Yeung et al., 2004). This means that the conflict N2, in addition to being activated by cognitive tasks such as the flanker task, can be activated by tasks that do not necessarily require a behavioral response, such as a social task. Accordingly, the conflict N2 has also been shown to reflect conflict as a result of social exclusion (Themanson et al., 2013).

This study measured the conflict N2 during the social task to examine the relationship between neural activity during the cognitive task (ERN) and the social task (conflict N2). The ERN and conflict N2 are both indices of self-regulation, and previous research suggests that there is a shared neural framework underlying the implementation of self-regulation for social and cognitive behaviors. To the degree that participants display increased conflict N2 amplitudes during a social task, which reflects greater levels of self-regulatory processes, then they would be expected to display decreased ERN amplitudes during a subsequent cognitive task. This would support the proposal, as put forth by Themanson et al. (2014), that self-regulatory control implemented during the social exclusionary event interfered with participants' ability to implement self-regulatory control during the cognitive task.

### **Self-Regulation during Social Exclusion**

In order to produce feelings of ostracism in the laboratory, Williams, Cheung, and Choi (2000) developed a social interaction paradigm called Cyberball. In this paradigm, participants believe they are playing a ball-tossing game online with other people. In reality, the other players are part of the computer program (Williams et al., 2000). Cyberball task sessions can either be inclusionary (e.g., the participant receives about half of the throws from the other players) or

exclusionary (e.g., the participant initially receives about half of the throws but is then no longer thrown the ball for the remainder of the session). This paradigm is successful in producing feelings of ostracism; the negative effects of exclusion elicited by Cyberball have been found to be comparable in strength to in-person situations of exclusion (Williams, 2007; Zadro, Williams, & Richardson, 2004).

Using Cyberball and other social interaction paradigms, researchers have examined how social exclusion modulates neural activity in terms of dACC activation with both fMRI and ERP technologies. When participants are excluded during a social interaction, there is greater activation of the dACC compared to inclusive interactions, and this activation is positively correlated with self-reported levels of social distress (Eisenberger, Lieberman, & Williams, 2003). ERP research has demonstrated that following social exclusion, participants exhibit decreased ERN amplitudes and post-error response accuracy on a cognitive task (Themanson et al., 2014). These findings suggest that excluded participants display impairments in self-regulation because the self-regulatory control processes activated during social exclusion share a neural framework with those activated during cognitive task performance (Themanson et al., 2014).

Themanson et al. (2013; 2015) also found that the conflict N2 is activated by specific acts of exclusion, even when those acts occur during an overall inclusionary interaction. The presence of the conflict N2 to exclusionary events during inclusionary interactions indicates that control-related dACC activation is a sensitive process that responds generally to undesired events (Themanson et al., 2014; Themanson et al., 2013; Themanson et al., 2015). Moreover, a study utilizing the go/no-go paradigm found that when participants were excluded, they showed larger conflict N2 amplitudes on high response conflict trials compared to included participants (Otten

& Jonas, 2013). This enhancement of the conflict N2 indicates that excluded individuals actually have a heightened sensitivity to deal with errors (Otten & Jonas, 2013). Otten and Jonas (2013) therefore propose that the experience of social exclusion does not simply lead to a general depletion of cognitive control processes, but rather causes the cognitive system to modify resource allocation in accordance with a shifting of priorities.

Overall, these modulations in dACC activation suggest that the experience of social exclusion involves a reallocation of self-regulatory control processes via a shared neural framework (Themanson et al., 2014). Such reallocation due to social exclusion is thought to result in deficits during subsequent cognitive task performance because negative social feedback is more motivationally salient than negative feedback without the social context (Boksem, Kostermans, & De Cremer, 2011; Boksem, Ruys, & Aarts, 2011). Thus, processes related to dealing with the experience of social exclusion are considered more important than activating control processes following erroneous responses in a subsequent cognitive task (Themanson et al., 2014). In accordance with these findings, the current study explored how social and cognitive behaviors are ranked by the dACC by activating self-regulatory control processes during a social exclusionary event and a cognitive task.

### **Current Study**

Recent theories of cognitive control describe a hierarchy where processes are ranked by value (Holroyd & Yeung, 2012; Shenhav et al., 2013). The dACC plays a crucial role in this function by delegating control to some processes over others, but the specific mechanisms are currently unknown. In addition to a lack of consensus regarding how the dACC implements control, there is a gap in the literature in describing which processes are regarded as the most valuable, particularly across task domains. Exploring the impact of social exclusion on self-

regulatory control processes will help describe where social and cognitive tasks fall in the hierarchy, and further explore how self-regulatory cognitive control is implemented across social and cognitive tasks.

The current study aimed to replicate the results of a previous investigation by this laboratory. Themanson and colleagues (2014) found that participants who were excluded via the Cyberball paradigm exhibited decreased ERN amplitudes and post-error response accuracy on a subsequent flanker task compared to participants who were included. The reduced ERN amplitudes and response accuracy on post-error trials reflected the impairments in self-regulation as a result of social exclusion, specifically the participants' decreased ability to correct errors (Themanson et al., 2014).

However, the study did not measure neural activity during the Cyberball paradigm (Themanson et al., 2014). Previous research indicates that the conflict N2 is activated by specific events of exclusion, such as not being thrown the ball during the Cyberball paradigm (Themanson et al., 2013). Since greater amplitudes of conflict N2 during Cyberball represent an overall exclusionary experience, participants who are excluded during Cyberball have greater conflict N2 amplitudes than participants who are included (Themanson et al., 2013). Thus, excluded participants in separate studies utilizing Cyberball have exhibited both increased conflict N2 activity during Cyberball and decreased ERN activity during a subsequent flanker task relative to included participants (Themanson et al., 2014; Themanson et al., 2013). In order to demonstrate if there is a relationship between the conflict N2 and the ERN, this study included the measurement of neural activity during Cyberball. I expected that increased conflict N2 activity during Cyberball, which would indicate greater levels of self-regulatory processes in response to the experience of exclusion, would be correlated with decreased ERN activity during

the subsequent flanker task, which would indicate the impairments in implementing self-regulatory processes as a result of social exclusion.

In this experiment, neural and behavioral measures were collected from participants during the completion of a cognitive task (i.e., flanker task) and a social task (i.e., Cyberball paradigm), with one session of the flanker task occurring before the Cyberball paradigm and one session occurring after. Participants were randomly assigned to be included or excluded during the Cyberball paradigm. The ERN was measured during the flanker task while the conflict N2 was measured during the Cyberball paradigm. Additionally, response time and accuracy were recorded for every trial of the flanker task. I hypothesized that participants who were excluded during the Cyberball paradigm would exhibit greater impairments in self-regulatory control processes than participants who were included during the Cyberball paradigm, which would be shown through decreased ERN amplitudes and post-error response accuracy during the subsequent flanker task. I also hypothesized that conflict N2 activity during the Cyberball paradigm and ERN activity during the subsequent flanker task would be related, such that larger (more negative) conflict N2s would be correlated with smaller (more positive) ERNs.

## Methods

### Participants

Twenty-six participants between the ages of 18 and 27 were recruited from psychology courses at Illinois Wesleyan University (see Table 1 for demographic characteristics of the participants). Seven participants were dropped from analysis due to either excessive EEG artifacts or not performing above 50% in each flanker task session, resulting in a sample size of 19 participants (12 females, 7 males). Prior to their arrival, participants were randomly assigned to an inclusion ( $n = 10$ ) or exclusion ( $n = 9$ ) condition. Participants were awarded course credit

towards a research experience requirement in exchange for their participation; no other compensation was provided. The study was approved by the Institutional Review Board at Illinois Wesleyan University.

### Measures

**Self-report assessments.** Participants completed four questionnaires before and after the Cyberball paradigm in order to assess the impact of the social interaction on affect, anxiety, depression, and social needs fulfillment. The first three questionnaires consisted of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988), the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), and the Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996). All of these measures are well-established in their reliability and validity. The PANAS accurately captures participants' feelings of negative and positive affect, and is also correlated with other measures of mood and related constructs (Watson et al., 1988). The STAI has high reliability and validity and is able to differentiate between high stress and low stress situations (Metzger, 1976). Finally, the BDI-II has high concurrent validity and internal consistency (Storch, Roberti, & Roth, 2004).

Participants also completed the Needs-Threat Scale, a brief needs and feelings assessment that has been used in previous social exclusion research, before and after the Cyberball paradigm (NTS; Williams et al., 2000; Zadro et al., 2004). The NTS evaluates the impact of social interaction on four basic social needs, including self-esteem, control (over oneself and one's environment), belongingness, and meaningful existence, as well as mood (Williams, 2007; Williams et al., 2000; Williams et al., 2002). The instructions provided to participants for the PANAS and NTS both varied slightly depending on when they were administered. Before the Cyberball paradigm, the PANAS and NTS asked participants to report the feelings they had

“right now” and used the present tense “feel.” After the Cyberball paradigm, the PANAS and NTS instructed participants to represent how they “felt” during the game. The NTS after Cyberball also included the manipulation check questions used by Zadro et al. (2004). Specifically, participants were asked to indicate, on a scale from one (not at all) to seven (extremely), how often they had the following thoughts during the game: “I was ignored” and “I was excluded” (Zadro et al., 2004). Additionally, participants were instructed to estimate the percentage of throws they received during the game (Zadro et al., 2004).

In addition to the assessments mentioned above, participants also completed a set of preliminary questionnaires including a brief demographics questionnaire, the Edinburgh handedness inventory (Oldfield, 1971), the rejection sensitivity questionnaire (RSQ; Downey & Feldman, 1996), the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983), the Social Phobia and Anxiety Inventory (SPAI; Beidel, Borden, Turner, & Jacob, 1989) and a brief personality assessment (IPIP; <http://ipip.ori.org>) based on the Big Five personality factors (Goldberg et al., 2006). These questionnaires were used as part of a larger study to assess whether individual differences in demographics, anxiety, and personality have any significant associations with the neural and behavioral measures. They will not be further discussed in this paper.

**Cognitive performance assessment.** In order to assess cognitive performance, participants completed a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974). The stimuli were 4 cm high white symbols (“<” and “>”) presented on a black background. The central target stimulus was flanked by two symbols on both sides such that each trial was considered either congruent (“<<<<<” or “>>>>>”) or incongruent (“<<◇<<” or “>>◇>>”). Participants were instructed to press a button on a controller pad to indicate the direction of the



central target stimulus. Stimuli were presented on the screen for 80 ms with an inter-trial interval (ITI) varying between 1000, 1200, or 1400 ms. The dynamic ITI inhibits participants from developing a rhythm of responding and thus ensures they remain engaged throughout the task. The congruent and incongruent trials were equally probable and randomly ordered. The task began with a practice block of 20 trials, followed by two blocks of 300 trials each. There was a brief rest period between each block and the two blocks were counterbalanced across participants. Each participant completed two flanker sessions with the Cyberball paradigm occurring in between for a total of 600 trials per flanker session and 1200 trials overall.

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 flanker trials across task sessions. To calculate RT and accuracy for each participant, three types of trial categories were created: error trials, matched-correct trials, and post-error trials (Themanson et al., 2014). Since error trials tend to have faster RTs than correct trials (Falkenstein, Hoormann, & Hohnsbein, 2001; Yeung et al., 2004), average ERP waveforms for error trials were matched with correct trial waveforms (i.e., matched-correct trials) based on RT. This matching ensures that any variations in the timing of processing due to the differences in response latency observed in error trials and correct trials are removed. Moreover, post-error response accuracy was computed for each participant using correct trials that occur after an error trial (post-error trials). In sum, there were four scores analyzed for the flanker task: response time (RT), response accuracy, post-error response time (post-error RT), and post-error accuracy.

**Neuroelectric assessment.** An electroencephalogram (EEG) was used to measure neuroelectric activity occurring during the Cyberball paradigm and flanker task. The EEG was recorded from 64 sintered Ag-AgCl electrodes (10 mm) arranged in a 10-10 system montage



(Chatrian, Lettich, & Nelson, 1985) on a lycra electrode cap (Neuro, Inc., El Paso, TX).

Administration of the EEG cap followed the guidelines of the Society for Psychophysiological Research (Picton, 2000). The electrodes were prepared using Quik gel (Neuro, Inc., El Paso, TX). Impedance levels for all electrodes were kept under 10 k $\Omega$ . The electrode AFz was utilized as the ground electrode and the average mastoids served as references to eliminate non-brain signals. Four electrodes placed above and below the left orbit and near the outer canthus of each eye monitored vertical and horizontal bipolar electrooculographic activity. The raw EEG signal was digitized, amplified, and filtered in DC mode (763  $\mu$ V/bit resolution) using a Neuroscan Synamps2 bioamplifier (Neuro, Inc., El Paso, TX). An analog-to-digital converter was used to digitize the signal continuously with a 500 Hz sampling rate. In order to capture the neural activity on the computer, signals were amplified by a gain of 10. A 70 Hz low-pass filter with a 60 Hz notch filter eliminated signals too large to be coming from the brain as well as signals coming from non-biological electrical devices. Neuroscan scan software (v 4.3.1) was used to record EEG activity and Neuroscan Stim software (v 2.0) was used to present stimuli and record behavioral responses.

Offline EEG processing included eye blink correction, baseline correction, low-pass filtering, and artifact rejection. Eye blink correction occurred using a spatial filter (Compumedics Neuroscan, 2003). For the baseline correction, the average activity for each event, consisting of an epoch preceding the presentation of the first task-related image, was removed to allow for amplitude comparisons across participants and electrode sites. The creation of epochs varied for each task. For the flanker task, response-locked epochs ran from -100 ms to 0 ms relative to the behavioral response. For the Cyberball paradigm, stimulus-locked epochs ran from -900 ms to 0 ms relative to the inserted marker. Low-pass filtering at 30 Hz (24dB/octave) eliminated signals

with frequencies higher than 30 Hz. In order to remove artifacts, epochs with signals exceeding  $\pm 75\mu\text{V}$  were rejected.

Some additional offline processing was necessary for each task. In order to protect against stimulus-related activity that may overlap with the response-locked ERP activity in the flanker task, average ERP waveforms for correct trials were matched to average ERP waveforms for error trials based on response time and number of trials (Coles, Scheffers, & Holroyd, 2001). This creates averages based on the same number of trials and where the responses are occurring at the same time point with the averages so that no differences exist between stimulus-locked activities on these response-locked averages. The ERN amplitude was quantified as the average amplitude between 0-100 ms post-response for error trials. For the Cyberball paradigm, the neural responses to social inclusion (receiving the ball) and exclusion (not receiving the ball) were quantified and average waveforms were created. The data from each participant was outputted in ASCII format to be analyzed in SPSS 22.0.

### **Experimental Manipulation**

**Cyberball Paradigm.** In the Cyberball paradigm, participants played a computerized game of catch in which they pressed a button on a controller pad to throw a ball either to a player on the left or right side of the screen. The current study employed a cover story similar to that used previously by this laboratory (Themanson et al., 2014; Themanson et al., 2013; Themanson et al., 2015). Participants were told they were playing the game over the internet with two research participants from other universities conducting separate EEG studies. The other universities named were University of Illinois and Illinois State University, used for their geographic proximity and familiarity to the participants. In reality, the game was a computer

program, and the two computerized players were programmed to behave according to the type of condition, evoking either social inclusion or social exclusion (Williams et al., 2000).

The Cyberball paradigm involved one block of 120 throws in which the participant was either included or excluded. Participants were randomly assigned to the inclusion or exclusion condition prior to the start of the experiment. In the inclusion condition, the probability that the participant received the ball on each throw was 50%. In the exclusion condition, the participant was “included” (i.e., the participant had a 50% chance of receiving the ball on each throw) until they received 30 throws. Once the participant received 30 throws, which occurred after approximately 60-70 throws, the participant did not receive another throw for the duration of the block.

### **Procedure**

Each participant completed one two-hour session. Once participants arrived to the laboratory, they read a description of the experiment and provided their informed consent. A research assistant delivered the cover story and answered any questions the participants had. Participants then completed the preliminary questionnaires which were used to determine whether individual differences have any significant associations with the neural and behavioral measures. At this time, participants also completed the pre-PANAS, STAI, BDI-II, and NTS. Following completion of all assessments, participants were prepared for neuroelectric data collection. During preparation, participants were reminded of EEG protocol (i.e., sit still and in a relaxed position, keep feet flat on the floor, focus eyes on the computer screen, do not blink excessively). Participants were instructed on the flanker task as soon as targeted levels of electrical impedance were observed.

All participants completed the Cyberball paradigm in between two flanker task sessions. Half of the participants experienced inclusion and half experienced exclusion during the Cyberball paradigm. After the social task, participants completed the post-PANAS, STAI, BDI-II, and NTS. Finally, all participants underwent a second flanker task session. Once participants completed the second flanker task, a research assistant removed the cap and provided the debriefing. Participants were notified of the random assignment to their condition and were assured that the social interaction they experienced was not real in order to prevent the exclusion from distressing them after they left the laboratory. To ensure adherence to EEG protocol, participants were monitored by a research assistant for the duration of the session.

### **Statistical Analyses**

Initial analyses consisted of mixed-model ANOVAs and bivariate correlations. Follow-up analyses consisted of univariate ANOVAs, bivariate correlations, two-tailed independent-samples and paired-samples *t* tests with Bonferroni correction. Prior to Bonferroni correction, the alpha level for all analyses was set at  $p \leq .05$ . For the flanker task, analyses used omnibus 2 (Time: T1, T2)  $\times$  2 (Group: inclusion, exclusion) mixed-model ANOVAs to examine the ERN at the site where it is maximal. Overall response accuracy and RT were analyzed using omnibus 2 (Time: T1, T2)  $\times$  2 (Group: inclusion, exclusion) mixed-model ANOVAs. Post-error response accuracy and RT were analyzed using 2 (Time: T1, T2)  $\times$  2 (Group: inclusion, exclusion) mixed model ANOVAs. Neural activity during the Cyberball paradigm was analyzed using omnibus 2 (Group: inclusion, exclusion)  $\times$  2 (Throw Type: inclusionary throw, exclusionary throw) mixed-model ANOVAs separately at the Fz, FCz, Cz, and Pz electrode sites for the first informational image within each throw type. Additionally, bivariate correlations were calculated for the conflict N2 during the Cyberball paradigm and the ERN during T1 and T2 of the flanker task.

Individual variables related to affect, anxiety, and depression were considered for their potential influence on neural and behavioral measures.

## Results

### Self-Report Assessments

Participant scores on the PANAS, STAI, and BDI-II did not differ significantly between the inclusion and exclusion groups at baseline,  $t's(17) \leq 1.43$ ,  $p's \geq .271$ . Separate 2 (Time: pre-Cyberball, post-Cyberball)  $\times$  2 (Group: inclusion, exclusion) mixed model ANOVAs were conducted on the self-report assessments (PANAS, STAI, BDI-II, NTS) to determine how the Cyberball paradigm impacted affect, anxiety, depression, and needs fulfilment across groups (see Table 2). The omnibus ANOVA for the STAI showed a significant Time  $\times$  Group interaction,  $F(1,17) = 4.66$ ,  $p = .045$ , partial  $\eta^2 = .215$ . Follow-up analyses revealed a significant increase in STAI scores for the exclusion group from the first flanker session ( $M = 36.89$ ,  $SD = 9.91$ ) to the second flanker session ( $M = 41.11$ ,  $SD = 11.05$ ),  $t = -2.99$ ,  $p = .017$ , while no significant effect was present from the first flanker session ( $M = 37$ ,  $SD = 10.00$ ) to the second flanker session ( $M = 33.20$ ,  $SD = 10.95$ ) for the inclusion group,  $t = 1.09$ ,  $p = .305$ . There were no significant results for the PANAS and BDI-II.

Omnibus analyses for the NTS revealed a significant Time  $\times$  Group interaction for the meaningful existence subscale,  $F(1,17) = 6.21$ ,  $p = .023$ , partial  $\eta^2 = .268$ . Follow-up analyses revealed no significant effects for either group,  $t's \leq 2.11$ ,  $p's \geq .064$ , but the exclusion group had increased meaningful existence scores from pre-Cyberball ( $M = 2.78$ ,  $SD = .48$ ) to post-Cyberball ( $M = 3.11$ ,  $SD = .63$ ), while the inclusion group had decreased meaningful existence scores from pre-Cyberball ( $M = 3.02$ ,  $SD = .97$ ) to post-Cyberball ( $M = 2.64$ ,  $SD = .85$ ). Additionally, there was a main effect of time for the self-esteem subscale,  $F(1, 17) = 5.35$ ,  $p =$

.034, partial  $\eta^2 = .239$ , indicating that self-esteem scores for both groups decreased from pre-Cyberball ( $M = 4.19$ ,  $SD = 1.16$ ) to post-Cyberball ( $M = 3.66$ ,  $SD = .90$ ). There were no significant results for the belonging, control, and mood subscales. Finally, for the NTS manipulation check variables,  $t$  tests found that excluded participants showed significantly greater reporting of being ignored/excluded in comparison to included participants,  $t(17) = -2.77$ ,  $p = .013$ . Excluded participants also reported significantly lower levels of estimated percent of throws received in comparison to included participants,  $t(17) = 8.29$ ,  $p \leq .001$ .

### Flanker Task Performance

Table 3 provides the overall task performance data by session for each group. The omnibus ANOVA for overall response time (RT) during the flanker task revealed a significant time main effect,  $F(1,17) = 4.5$ ,  $p = .05$ , partial  $\eta^2 = .21$ , with faster times during the second flanker session ( $M = 403.97$ ,  $SD = 48.45$ ) compared to the first ( $M = 414.37$ ,  $SD = 41.99$ ). The analysis found no significant group effects. The omnibus ANOVA for overall response accuracy (% correct) during the flanker task revealed a significant Time  $\times$  Group interaction,  $F(1,17) = 5.04$ ,  $p = .038$ , partial  $\eta^2 = .23$ . Follow-up analyses looking at response accuracy across time for each group revealed a significant increase in response accuracy for the inclusion group from the first session ( $M = 73.08$ ,  $SD = 23.89$ ) to the second session ( $M = 85.99$ ,  $SD = 12.47$ ),  $t = 2.3$ ,  $p = .05$ , while no significant improvement was present from the first session ( $M = 80.16$ ,  $SD = 14.4$ ) to the second session ( $M = 77.53$ ,  $SD = 16.15$ ) for the exclusion group,  $t = .7$ ,  $p = .50$  (see Figure 1). These results corroborate findings from the previous study (Themanson et al., 2014) that suggest an overall practice effect occurs with repeated completion of the flanker task. Excluded participants in this study thus demonstrated impairments to overall response accuracy, with

impairments defined as not exhibiting the improved performance that is expected from the practice effect.

For post-error RT, analyses revealed a significant time main effect,  $F(1,17) = 19.21, p < .005$ , partial  $\eta^2 = .531$ , indicating that both the inclusion and exclusion groups had faster post-error response times at T2 ( $M = 402.71, SD = 56.95$ ) compared to T1 ( $M = 434.84, SD = 46.78$ ), which was also reported in the previous study (Themanson et al., 2014). There were no significant group effects. The omnibus ANOVA for post-error response accuracy showed no significant time main effect,  $F(1,17) = .485, p = .496$ , partial  $\eta^2 = .028$ , or Time  $\times$  Group interaction,  $F(1,17) = .173, p = .683$ , partial  $\eta^2 = .01$ . This is in contrast with previous findings (Themanson et al., 2014), in which excluded participants demonstrated a decrease in post-error accuracy over time. These results, which found that excluded participants had impairments to overall response accuracy but not post-error trials specifically, suggest that social exclusion generally disrupts overall task performance rather than simply disrupting post-error performance in subsequent cognitive tasks (see Table 3).

### Neural Measures

**Flanker Task.** The omnibus ANOVA for ERN amplitude at the FCz electrode site during the flanker task revealed a significant Time  $\times$  Group interaction,  $F(1,17) = 5.02, p = .039$ , partial  $\eta^2 = .23$ . Follow-up analyses looking at ERN amplitude across time for each group revealed no significant change in ERN amplitude for the inclusion group from T1 ( $M = -2.5, SD = 2.46$ ) to T2 ( $M = -2.83, SD = 2.57$ ),  $t = .6, p = .55$ , while there was a significant decrease in ERN amplitude from T1 ( $M = -2.92, SD = 1.85$ ) to T2 ( $M = -1.35, SD = 1.89$ ) for the exclusion group,  $t = 2.3, p = .05$  (see Figure 2). In other words, excluded participants had significantly decreased levels of self-regulatory control during the second flanker session compared to the first



flanker session, while included participants had no significant change to their levels of self-regulatory control from the first to the second flanker session.

**Cyberball Paradigm.** The omnibus ANOVA for conflict N2 amplitude at the FCz electrode site during the Cyberball paradigm revealed a significant main effect for throw type,  $F(1,17) = 19.89, p \leq .001$ , partial  $\eta^2 = .54$ , with larger conflict N2 amplitudes for exclusionary throws ( $M = -.63, SD = 1.98$ ) compared with inclusionary throws ( $M = 1.68, SD = 2.40$ ). There were no effects for group, indicating that even the inclusion group exhibited larger conflict N2 amplitudes for exclusionary throws (see Figure 3). These results confirm that this study observed behavior typically found during Cyberball (Themanson et al., 2013), specifically that conflict N2 amplitude was enhanced for exclusionary throws, demonstrating the high levels of conflict that occur on exclusionary throws in comparison to inclusionary throws.

**Relationship between Conflict N2 and ERN.** The bivariate correlations between ERN amplitude in both flanker sessions and conflict N2 amplitude during Cyberball were calculated to determine the relationship between these neural indicators of self-regulatory cognitive control. The results showed no significant correlation between conflict N2 amplitude and ERN amplitude at T2,  $r = .108, N = 19, p = .661$ , as well as no significant correlation between conflict N2 amplitude and ERN at T1,  $r = .085, N = 19, p = .729$ . Bivariate correlations between ERN amplitude in both flanker sessions and conflict N2 amplitude during Cyberball were then calculated separately for the inclusion and exclusion groups. There was a strong and marginally significant inverse correlation between conflict N2 amplitude and ERN amplitude at T1 for the exclusion group,  $r = -.615, N = 9, p = .078$ , indicating that as ERN values in the first flanker session become less negative, conflict N2 values become more negative (see Figure 4). In other



words, lower levels of self-regulatory control in the first flanker session were related to higher levels of self-regulatory control during Cyberball.

After finding this marginally significant relationship between the conflict N2 and ERN at T1 for the exclusion group, follow-up analyses were conducted to determine if the conflict N2 was related to any other variables (see Table 4 and 5). The analyses found a strong, but not significant, inverse correlation between conflict N2 amplitude and response accuracy at T2 for the exclusion group,  $r = -.530$ ,  $n = 9$ ,  $p = .142$ , indicating that as conflict N2 values become more negative, representing higher levels of self-regulatory control, overall response accuracy in the second flanker session increases (see Figure 5).

### Discussion

The current investigation explored how self-regulatory cognitive control is implemented across social and cognitive tasks by assessing the neural and behavioral effects of social exclusion on subsequent cognitive task execution. This study aimed to replicate the results of a previous investigation by this laboratory (Themanson et al., 2014) as well as report on the relationship between the ERN and conflict N2. Findings offered support for previous research demonstrating that social exclusion impairs self-regulatory control processes via a shared neural framework (Themanson et al., 2014). In line with this theory, I found that excluded participants had decreased ERN amplitudes and impairments to overall task performance during the second flanker task. These impairments to overall task performance, as opposed to impairments in post-error trials specifically, suggest that social exclusion leads to more general impairments in self-regulatory control processes than previously found (Themanson et al., 2014).

While this study did not find a relationship between conflict N2 activity during Cyberball and ERN activity during the second flanker session, there was a marginally significant inverse

correlation between conflict N2 activity during Cyberball and ERN activity during the first flanker session for the exclusion group, such that increased (more negative) ERN amplitudes in the first flanker session were related with decreased (more positive) conflict N2 amplitudes during Cyberball. In other words, participants who displayed greater amounts of self-regulatory control during the first flanker session had less conflict N2 activation to exclusionary throws during Cyberball. This finding supports the proposal that control-related dACC activation for social and cognitive behaviors is implemented by a shared neural framework, as implementing greater levels of self-regulation during a cognitive task interfered with the ability to implement it during a subsequent social task. Follow-up analyses also found a strong, but not significant, inverse correlation between conflict N2 amplitude and response accuracy during the second flanker session for the exclusion group. This finding suggests social exclusion may have resulted in numbing effect, such that participants who were more severely affected by the exclusion (as indicated by the conflict N2) ignored it during the second flanker session, allowing them to get a larger percent correct.

### **Impairments in Self-Regulation**

One of the goals of this study was to replicate the finding that social exclusion leads to impairments in self-regulatory control processes (Themanson et al., 2014). I hypothesized that participants who were excluded during the Cyberball paradigm would exhibit greater impairments in self-regulation than included participants, which would be shown through decreased ERN amplitudes and post-error response accuracy during the second flanker session. In the current study, excluded participants exhibited decreased ERN amplitudes during the second flanker session. They did not, however, demonstrate significant impairments in post-error response accuracy, which previous research shows is an important indicator of impairments in

self-regulatory control processes following social exclusion (Williams, 2007). The ERN's role in self-regulation is currently theorized to be related to error-correcting behavior (Holroyd & Coles, 2002; Yeung et al., 2004) and studies have found that increased ERN amplitude is correlated with increased response accuracy on post-error trials (Botvinick et al., 2001; Gehring et al., 1993; Themanson et al., 2006; Themanson et al., 2012; Yeung et al., 2004). Thus, impairments to self-regulation would result in decreased ERN amplitudes and impaired response accuracy on post-error trials.

The absence of impairments in post-error response accuracy for excluded participants is a deviation from previous results (Themanson et al., 2014), but it does not necessarily indicate that there were no impairments to self-regulatory control. This is because the results also show that excluded participants demonstrated impairments in overall response accuracy during the second flanker session. The flanker task requires self-regulation on incongruent trials because the participant sees both the correct and incorrect response and must exert control in order to choose the correct behavior (Botvinick et al., 1999; Rueda et al., 2005). Even though the current study did not observe impairments in post-error response accuracy, there is still evidence of impairments to self-regulation because of the diminished overall response accuracy. Instead of impacting post-error trials specifically, these findings suggest that social exclusion leads to more general impairments in self-regulatory control processes than previously found (Themanson et al., 2014).

Another interpretation of these results, however, may be that excluded participants exhibited impairments in overall task performance as opposed to post-error response accuracy because they were disengaged from the task. This idea is supported by the fact that the ERN has a positive correlation with task engagement, such that the more engaged the participant during

the task, the larger the ERN (Luu et al., 2000; Tops & Boksem, 2010). If participants disengaged from the experiment following their social exclusion, they would have decreased ERN amplitudes during the second flanker session, as was found in the current study. Further, excluded participants did not have impairments in post-error trials, as was expected, but they did have a decrease in overall response accuracy during the second flanker session. The latter finding could be indicative of general task disengagement due to previous exclusion instead of more specific impairments in self-regulation, as previous research in this laboratory found that included and excluded participants exhibited the same levels of overall task performance in the second flanker task (Themanson et al., 2014).

Additional research is needed to disentangle the effects of impaired self-regulation from potential task disengagement following social exclusion. It is also possible that the current study did not find significant impairments in post-error response accuracy because of the small sample size, which weakened statistical power. Notably, both the current study and the previous study (Themanson et al., 2014) found evidence of impairments in self-regulation following social exclusion, whether it was through decreased overall task performance or decreased post-error response accuracy (Themanson et al., 2014).

### **Relationship between Conflict N2 and ERN**

In order to extend the findings of the previous study (Themanson et al., 2014) to include an examination of the relationship between the ERN and conflict N2, this study recorded neural activity during the Cyberball paradigm. The conflict N2 is believed to represent the detection of conflict that occurs without behavioral errors or error feedback (Themanson et al., 2014; van Veen & Carter, 2002b; Yeung et al., 2004), and previous research has demonstrated that conflict N2 activity is enhanced during exclusionary interactions within the Cyberball paradigm

(Themanson et al., 2013). The current study also found significantly larger conflict N2 amplitudes for exclusionary throws compared with inclusionary throws, indicating that this investigation observed behavior typically found during Cyberball. Ultimately, conflict N2 activity during Cyberball should be related with ERN activity during the second flanker session because the self-regulatory control processes activated during social exclusion share a neural framework with those activated during cognitive task performance (Themanson et al., 2014).

As such, I hypothesized that increased (more negative) conflict N2 activity during Cyberball would be correlated with decreased (more positive) ERN activity during the second flanker session. In other words, greater levels of self-regulatory processes during Cyberball as a result of exclusionary experiences would be correlated with lower levels of self-regulatory processes during the second flanker session. The results surprisingly found no significant relationship between conflict N2 activity during Cyberball and ERN activity during the second flanker session. This finding is inconsistent with previous research that found enhanced conflict N2 activity during exclusionary interactions in Cyberball (Themanson et al., 2013) and decreased ERN activity during a post-flanker task for participants who were previously excluded (Themanson et al., 2014). Low statistical power may have contributed to the lack of significant results. Future research should continue to explore the connections between the conflict N2 and ERN given the broad literature supporting their similar functionality (Holroyd & Coles, 2002; Themanson et al., 2014; Themanson et al., 2013; Yeung et al., 2004).

Although there was no significant correlation between conflict N2 activity and ERN activity during the second flanker task, there was a strong, but not significant, inverse correlation between ERN activity during the first flanker session and conflict N2 activity during Cyberball. Excluded participants who displayed increased (more negative) ERN activity during the first

flanker session had decreased (more positive) conflict N2 activity during Cyberball. However, inspection of the scatterplot suggests that two outlying data points may be responsible for the strong correlation; additionally, the data points are unevenly scattered, which is difficult to interpret with the small sample size ( $n=9$ ) (see Figure 4). While they should be considered tentatively as the correlation failed to reach significance and the scatterplot does not show a strong, linear correlation, there are two plausible explanations for this relationship.

First, this data may offer support for the theory that control-related dACC activation for social and cognitive behaviors is implemented by a shared neural system. This theory suggests that the control processes engaged during the cognitive task and the social task share a neural framework (Themanson et al., 2014). Therefore, the amount of self-regulatory control processes activated during the first flanker session (as indicated by the ERN) interfered with the implementation of such processes during the Cyberball paradigm (as indicated by the conflict N2). Second, it is also possible that participants with greater ERN activation experienced a general loss of sensitivity to conflict as a result of the flanker task. This fatigued or overwhelmed conflict monitoring system would then lead to decreased conflict N2 activation during Cyberball.

Although this correlation is a novel finding, a related situation is seen in a previous study, which found that while participants were excluded via Cyberball, their conflict N2 activation was reduced over time (Themanson et al., 2013). In other words, as the exclusionary event went on, participants' high levels of self-regulatory control decreased over time. The authors theorized that this effect was due to a depletion of self-regulatory control processes or a desensitization to the exclusion (Themanson et al., 2013), similar to the current explanations for the relationship between the ERN during the first flanker session and the conflict N2. Accordingly, if self-regulatory processes do fatigue over time, this may be an explanation for why participants with



more ERN activation during the first flanker session in the current study displayed less conflict N2 activation during the Cyberball paradigm. However, for socially excluded participants, this pattern would be expected to continue to the second flanker session, with greater N2 activation in Cyberball associated with less ERN activation in the second flanker session – a finding that was not evident in the data. Clearly, more research on the relationship between the ERN and conflict N2 is needed to understand the roles of these two indices of self-regulatory cognitive control.

### **Relationship between Conflict N2 and Response Accuracy**

This study also found a strong but not significant correlation between conflict N2 activity and overall response accuracy. For excluded participants, conflict N2 activity during Cyberball and overall response accuracy during the second flanker session were inversely correlated, such that as conflict N2 values become more negative, response accuracy increases. In other words, participants who had enhanced conflict N2 activity during Cyberball, representing higher levels of self-regulatory processes, had greater response accuracy (larger percent correct) during the second flanker session. This correlation is in contrast to the previous study, which found no effects for response accuracy (Themanson et al., 2014).

It is possible that participants who were more severely affected by the exclusion ignored it during the second flanker session, allowing them to get a larger percent correct. There is emerging evidence that more severe social exclusion results in a numbing effect, much in the same way severe physical pain does (Bernstein & Claypool, 2012; DeWall & Baumeister, 2006). This is supported by findings that participants who are rejected in a laboratory setting respond with detachment and emotional indifference (Baumeister, Twenge, & Nuss, 2002; DeWall & Baumeister, 2006; Gardner, Pickett, & Brewer, 2000; Twenge et al., 2001; Zadro et al., 2004), as well as evidence suggesting that social pain and physical pain may share a neural basis

(Eisenberger & Lieberman, 2004; MacDonald & Leary, 2005). Thus, according to this theorized relationship between social and physical pain, participants who had enhanced conflict N2 activity during Cyberball in this study were so severely affected by the exclusion that they did not even attend to it, and instead directed their resources to self-regulatory control processes during the subsequent cognitive task, leading them to have greater response accuracy.

However, the study that determined more severe social exclusion results in a numbing effect was actually using the Cyberball paradigm as a less severe paradigm to compare with a highly severe paradigm (Bernstein & Claypool, 2012). In that study, Cyberball resulted in hypersensitivity to physical pain whereas the highly severe paradigm resulted in hyposensitivity to physical pain, i.e. a numbing effect (Bernstein & Claypool, 2012). Therefore, it is questionable that a Cyberball-based form of social exclusion would be so severe as to cause a numbing effect. Future studies should investigate this potential numbing effect and continue to explore the characteristics of the conflict N2 as it relates to situations of social exclusion.

### **Cyberball Measures**

Looking to the self-report assessments, excluded participants reported feeling significantly more ignored/excluded during the Cyberball paradigm than included participants, and they also reported significantly lower levels of estimated percent of throws received compared to included participants. These results demonstrate that participants in the exclusion group indeed felt excluded from the Cyberball paradigm. In addition, both included and excluded participants reported significantly lower scores on the self-esteem subscale of the NTS from pre-Cyberball to post-Cyberball. Finally, excluded participants reported significantly higher scores on the STAI from pre-Cyberball to post-Cyberball, while included participants reported no



significant changes. This is in line with previous research which found that social exclusion leads to increased anxiety (Baumeister et al., 2002).

However, participants in the exclusion group did not have significant differences in their scores on the PANAS; BDI-II; and the meaningful existence, belonging, control, and mood subscales of the NTS following social exclusion. These findings diverge from the previous study (Themanson et al., 2014), which found significant changes in the PANAS and all subscales of the NTS. While Themanson et al. (2014) did not utilize the BDI-II, other research on social exclusion has found that it leads to decreased mood (Williams et al., 2002). It is possible that this study did not yield the expected findings because of low statistical power; however, several studies have demonstrated that social exclusion does not always lead participants to report significantly different emotional states from included or control participants (Baumeister et al., 2002; DeWall & Baumeister, 2006; Gardner et al., 2000; Twenge et al., 2002; Zadro et al., 2004). Additionally, excluded participants in the current study may have underreported their negative feelings due to the social desirability bias, which can influence how excluded participants represent their emotional states on self-report assessments (DeWall & Baumeister, 2006).

### **Limitations and Future Directions**

Although the data provide novel insights into multiple aspects of social exclusion's effect on self-regulatory cognitive control, it is important to address the limitations of this study. There was a relatively small sample size which may have impacted the results. The sample size was further limited by complications with participant data (i.e., excessive EEG artifacts or not performing above 50% in each flanker task session), which caused seven participants to be dropped from analysis, thus weakening the statistical power. Additionally, since participants

were recruited from psychology courses at a small, predominantly Caucasian university, participant demographics were considerably homogeneous. Neural and psychological research shows that the effects of social exclusion are moderated by whether the excluding individuals are racial in-group members or racial out-group members (Bernstein, Sacco, Young, Hugenberg, & Cook, 2010; Goodwin, Williams, & Carter-Sowell, 2010; Krill & Platek, 2009; Masten, Telzer, & Eisenberger, 2011), which indicates that members of racial minority groups may react differently than Caucasian participants to the experimental manipulation of this study. In order to improve on the generalizability of the current findings, this study should be replicated with a larger and more diverse sample.

This study was also limited by the social exclusion paradigm that was used. Cyberball has many strengths: it is simple, it is known to elicit negative effects of social exclusion that are comparable in strength to in-person situations of exclusion (Williams, 2007; Zadro et al., 2004), and it elicits these negative effects even when participants are told they are playing the game against a computer (as opposed to real people) (Zadro et al., 2004). That being said, the experience of being excluded from a game of catch on a computer screen does not encompass the full spectrum of social interactions that occur outside of the laboratory. Future studies should use different social exclusion paradigms to determine if the patterns seen in Cyberball generalize to a variety of other social tasks. In addition, the ERN is known to be sensitive to task engagement (Luu et al., 2000), and there is a possibility that excluded participants in the current study generally disengaged after being excluded. This would've contributed to the decreased ERN amplitudes that were observed during the second flanker session. Including a questionnaire to assess participants' engagement would allow future studies to get a better understanding of the role task disengagement plays after social exclusion.

**Summary**

Overall, this study corroborates previous research on the impact of social exclusion on self-regulatory control processes and current theories of control-related dACC activation. These theories propose that the dACC implements self-regulatory control to only the most important processes, in accordance with their expected values of control or an overall behavioral plan (Holroyd & Yeung, 2012; Shenhav et al., 2013). Following this assumption, research shows that activating self-regulatory control processes during social exclusion leads to impairments in self-regulation during a subsequent cognitive task (Themanson et al., 2014), as the current study also finds. This suggests that not only are social behaviors ranked higher than cognitive behaviors by the dACC, but that the self-regulatory processes implemented during social exclusion and cognitive task execution share a neural framework.

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Table 1.

*Demographic Characteristics of Participants*

Characteristic	<i>N</i>	%
Group		
Included	10	52.6
Excluded	9	47.4
Gender		
Male	7	36.8
Female	12	63.2
Age		
18	8	42.1
19	7	36.8
20	1	5.3
21	2	10.5
27	1	5.3
Ethnicity		
African American	0	0
Asian	3	15.8
Hispanic	1	5.3
Caucasian	16	84.2
Other	0	0



Table 2.

*Mean (SD) Scale and/or Subscale Scores on the PANAS, NTS, BDI-II, and STAI for all participants by group and time measurement (Pre-Cyberball, Post-Cyberball)*

Variable	Inclusion Group		Exclusion Group	
	Pre- <i>M (SD)</i>	Post- <i>M (SD)</i>	Pre- <i>M (SD)</i>	Post- <i>M (SD)</i>
PANAS-PA	19.60 (9.29)	19.50 (9.65)	24.00 (7.33)	18.33 (5.81)
PANAS-NA	12.20 (2.30)	12.30 (2.26)	13.33 (4.00)	14.22 (5.31)
BDI-II	10.60 (15.09)	6.30 (6.55)	9.78 (8.89)	12.22 (8.74)
STAI-State Anxiety	37.70 (10.00)	33.20 (10.95)	36.89 (9.91)	<i>42.11 (11.05)</i>
NTS-Self-esteem	4.02 (1.32)	3.72 (.82)	4.38 (1.00)	<i>3.60 (1.01)</i>
NTS-Control	3.58 (.66)	3.00 (.71)	3.67 (.63)	3.38 (.57)
NTS-Mood	3.33 (.66)	3.35 (.69)	3.46 (.53)	3.33 (.65)
NTS-Belonging	2.36 (.56)	2.56 (.50)	2.71 (.58)	2.88 (.92)
NTS-Meaningful existence	3.02 (.97)	2.64 (.85)	2.78 (.48)	3.11 (.63)
Extent felt ignored/excluded	N/A	1.70 (1.06)	N/A	3.67 (1.95)*
Estimated % of throws received	N/A	34.30 (4.64)	N/A	14.7 (5.68)*

*Note.* Italicized numbers in the "Post-" column represent scale scores that significantly differ from previous scores for that group. Asterisked numbers represent exclusion group scores that significantly differ from the inclusion group. PANAS = Positive and Negative Affect Schedule; BDI-II = Beck Depression Inventory; STAI = State-Trait Anxiety Inventory; NTS = Needs-Threat Scale.

Table 3.

*Mean (SD) Values for Response Time and Response Accuracy Data by Group (Inclusion, Exclusion)*

Variable	Inclusion Group	Exclusion Group
Number of Participants	10 (5 female, 5 male)	9 (7 female, 2 male)
T1 Response time (ms)	411.13 (38.06)	417.98 (48.07)
T2 Response time (ms)	400.86 (42.92)	407.43 (56.42)
T1 Response accuracy	73.08 (23.89)	80.16 (14.40)
T2 Response accuracy	85.99 (12.47)	77.53 (16.15)
T1 Post-error RT (ms)	424.50 (40.05)	446.33 (17.76)
T2 Post-error RT (ms)	391.73 (54.33)	414.91 (60.49)
T1 Post-error RA	77.62 (21.63)	81.62 (15.47)
T2 Post-error RA	81.10 (17.71)	82.50 (13.03)

*Note.* Italicized numbers in each column represent scores from the second flanker session that significantly different from scores from the first flanker session for that measure. T1 = first session of flanker task (pre-Cyberball); T2 = second session of flanker task (post-Cyberball); RT = response time; RA = response accuracy.

Table 4.

*Correlation Matrix for Study Variables for Inclusion Group*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. RT T1	1										
2. RA T1	.146	1									
3. Post-error RT T1	.630	.138	1								
4. Post-error RA T1	-.098	.903**	.046	1							
5. RT T2	.879**	.103	.678*	-.159	1						
6. RA T2	-.041	.682*	-.004	.688*	-.120	1					
7. Post-error RT T2	.664*	.167	.732*	.043	.715*	.130	1				
8. Post-error RA T2	-.003	.507	.172	.683*	-.272	.765**	.091	1			
9. ERN T1	.702*	-.395	-.312	-.392	.548	-.224	.353	.005	1		
10. ERN T2	.757*	-.046	.307	-.163	.738*	-.072	.316	-.119	.793**	1	
11. N2 Exclusionary Throws	.439	.172	.289	.199	.364	-.140	.412	.104	.375	.177	1

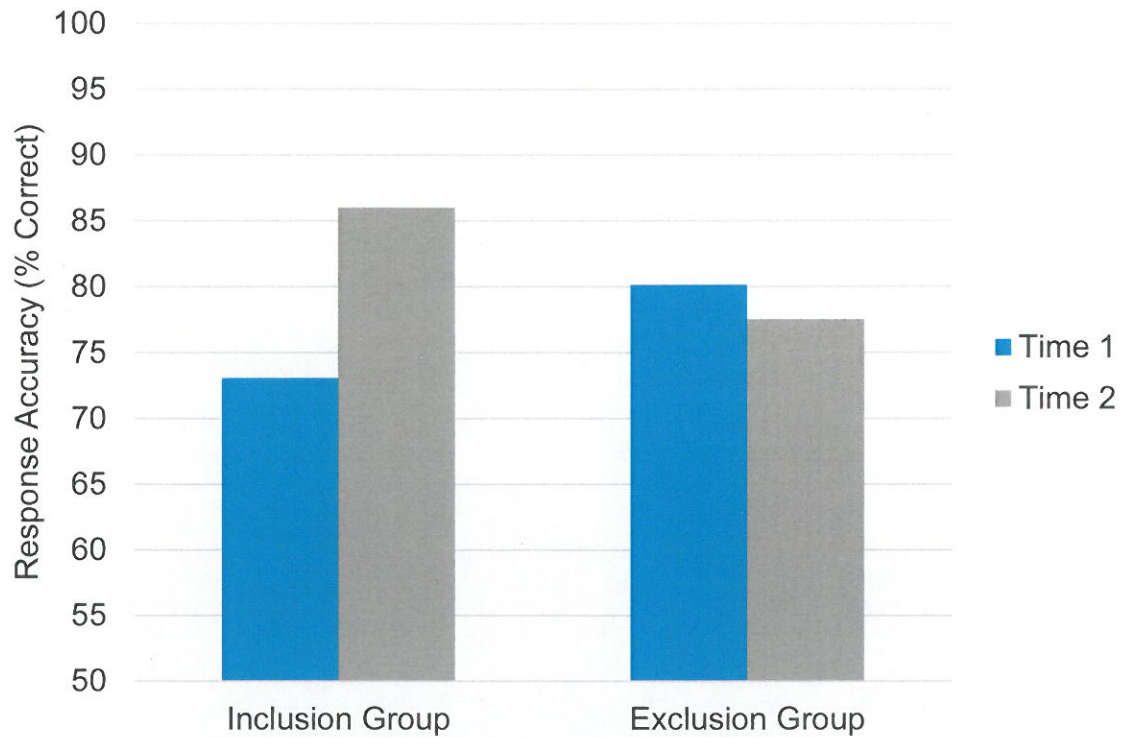
*Note.* \* Correlation significant at .05 level (2-tailed) \*\* Correlation significant at .01 level (2-tailed). RT = response time; RA = response accuracy; T1 = first session of flanker task (pre-Cyberball); T2 = second session of flanker task (post-Cyberball).

Table 5.

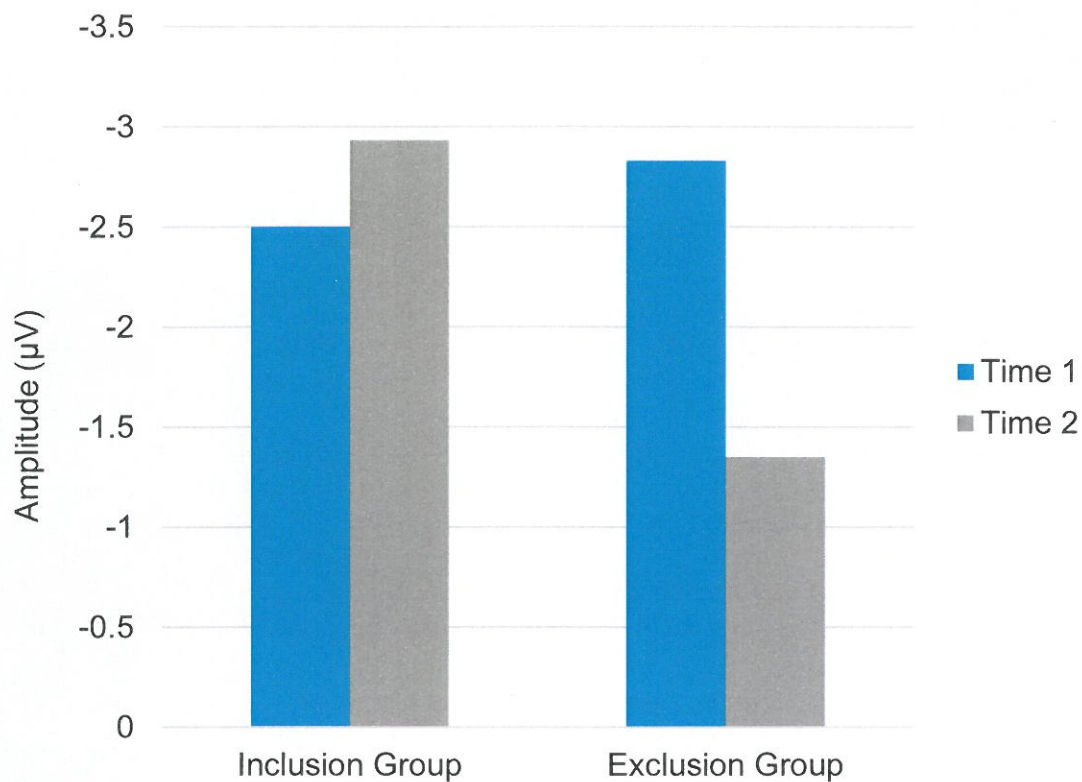
*Correlation Matrix for Study Variables for Exclusion Group*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. RT T1	1										
2. RA T1	.423	1									
3. Post-error RT T1	.945**	.364	1								
4. Post-error RA T1	.239	.963**	.194	1							
5. RT T2	.921**	.348	.928**	.216	1						
6. RA T2	.395	.745*	.375	.711*	.327	1					
7. Post-error RT T2	.945**	.350	.912**	.180	.966**	.284	1				
8. Post-error RA T2	.288	.684*	.296	.759*	.260	.820**	.171	1			
9. ERN T1	-.514	-.246	-.518	-.099	-.534	-.016	-.676*	.152	1		
10. ERN T2	.081	.115	-.054	.049	-.269	.213	-.233	.159	.405	1	
11. N2 Exclusionary Throws	-.233	-.228	-.181	-.141	-.129	-.661	-.060	-.283	-.352	-.474	1

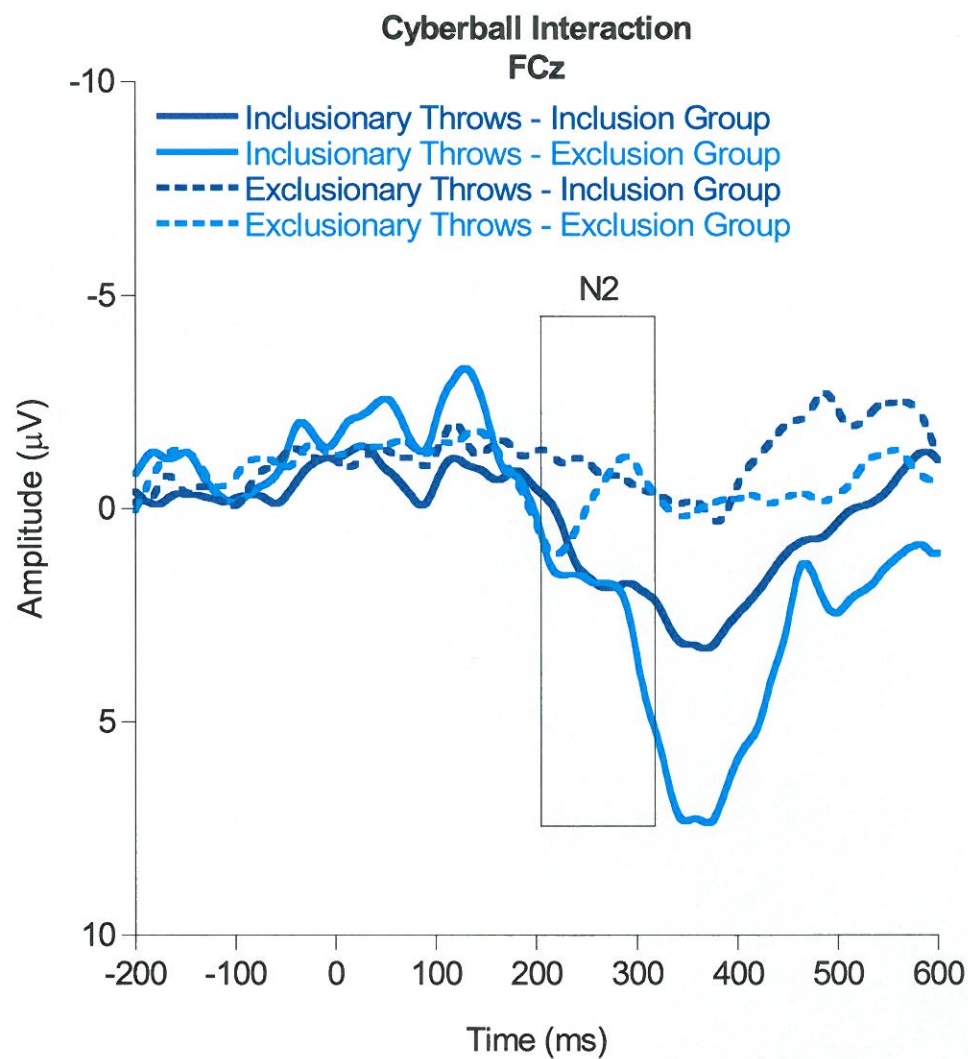
*Note.* \* Correlation significant at .05 level (2-tailed) \*\* Correlation significant at .01 level (2-tailed). RT = response time; RA = response accuracy; T1 = first session of flanker task (pre-Cyberball); T2 = second session of flanker task (post-Cyberball).



*Figure 1.* Mean overall response accuracy values (% correct) for the inclusion and exclusion participants groups on both T1 (pre-Cyberball) and T2 (post-Cyberball) flanker task sessions.

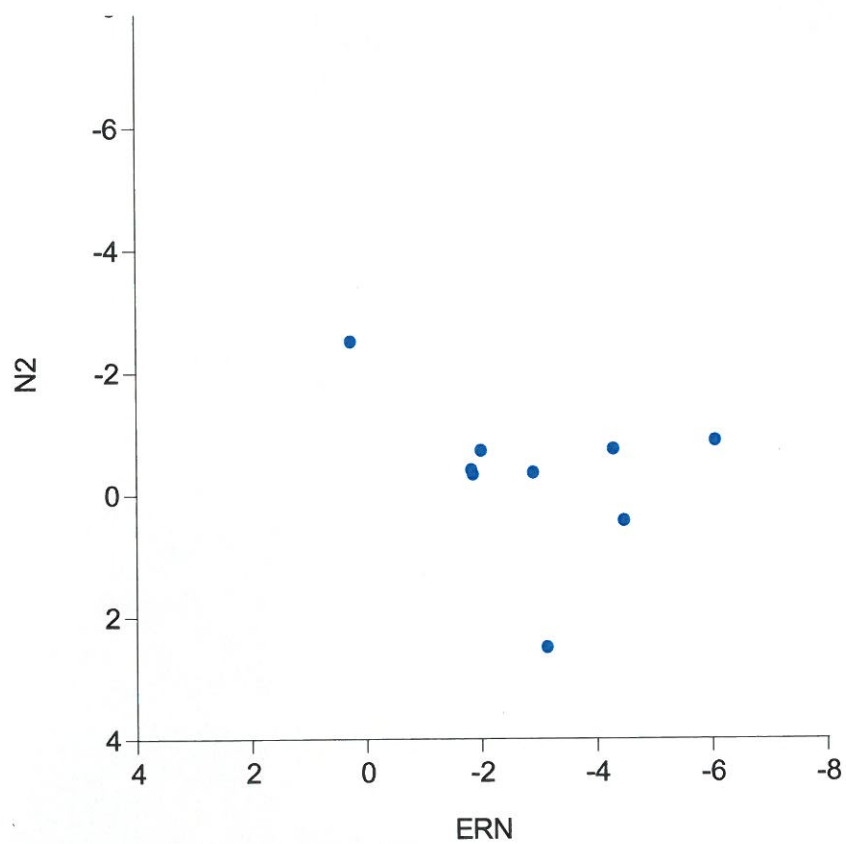


*Figure 2.* Mean ERN amplitudes for the inclusion and exclusion participant groups on both T1 (pre-Cyberball) and T2 (post-Cyberball) of the flanker task at the FCz electrode site.

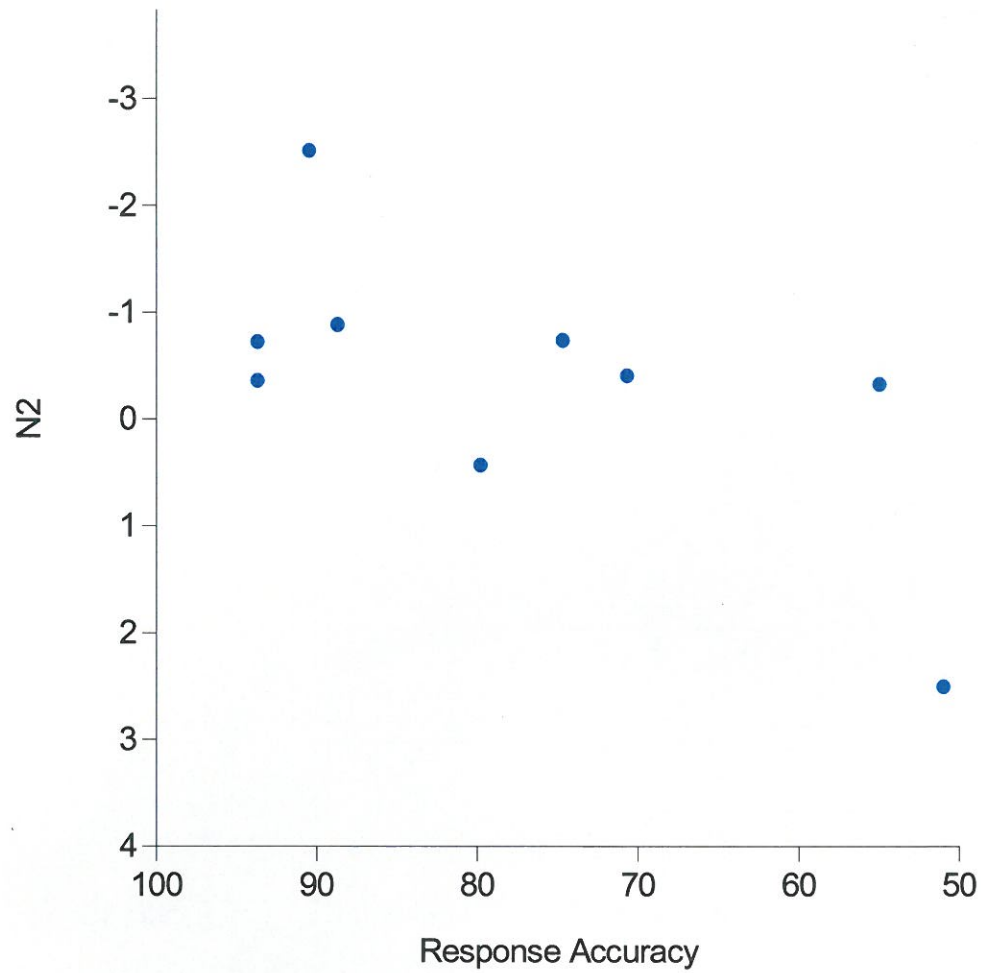


*Figure 3.* Grand-averaged stimulus locked conflict N2 waveforms during Cyberball for inclusionary throws (solid line) and exclusionary throws (dotted line) for the inclusion and exclusion groups (dark blue and light blue, respectively) at FCz.





*Figure 4.* Scatterplot for correlation between ERN amplitudes during the first flanker session and conflict N2 amplitudes during Cyberball for the exclusion group.



*Figure 5.* Scatterplot for correlation between conflict N2 amplitudes during Cyberball and response accuracy (% correct) during the second flanker session for the exclusion group.