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# What they bring: baseline psychological distress differentially predicts neural response in social exclusion by children's friends and strangers in best friend dyads

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## Abstract

Friendships play a major role in cognitive, emotional and social development in middle childhood. We employed the online Cyberball social exclusion paradigm to understand the neural correlates of dyadic social exclusion among best friends assessed simultaneously. Each child played with their friend and an unfamiliar player. Event-related potentials (ERPs) were assessed via electroencephalogram during exclusion by friend and unfamiliar peer. Data were analyzed with hierarchical linear modeling to account for nesting of children within friendship dyads. Results showed that stranger rejection was associated with larger P2 and positive slow wave ERP responses compared to exclusion by a friend. Psychological distress differentially moderated the effects of friend and stranger exclusion such that children with greater psychological distress were observed to have larger neural responses (larger P2 and slow wave) to exclusion by a stranger compared to exclusion by a friend. Conversely, children with lower levels of psychological distress had larger neural responses for exclusion by a friend than by a stranger. Psychological distress within the dyad differentially predicted the P2 and slow wave response. Findings highlight the prominent, but differential role of individual and dyadic psychological distress levels in moderating responses to social exclusion in middle childhood.

**Key words**: middle childhood; best friend dyads; ostracism; Cyberball; exclusion; anxiety; depression; P2; slow wave

## Introduction

Human beings have a basic need to belong and to form social bonds (Baumeister and Leary, 1995). Among the most prominent social bonds, friendships are driven by reinforcement at a primitive level, keeping account of emotional experiences from past interactions with specific partners over time (emotional bookkeeping) (Brent *et al.*, 2014). Peer relations play an essential role in a child's social, emotional and cognitive development (Newcomb and Bagwell, 1995; Hartup, 1996). When friendships go awry, they can be a source of immense psychological and biological stress (Calhoun *et al.*, 2014). Peer rejection and the absence of preadolescent friendships are predictive of adjustment problems in adulthood (Bagwell *et al.*, 1998).

Middle childhood is the developmental period in which peer relationships become a priority, with children spending an

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increasing amount of time with friends (Hartup, 1996). Friendship relations differ from non-friend peer relations in characteristics such as increased social contact, positive engagement, equality of relationship, increased conflicts, but also improved ability to resolve the conflicts (Furman and Buhrmester, 1985; Newcomb and Bagwell, 1995). Positive friendship relations are associated with decreased peer victimization (Boulton *et al.*, 1999). The nature of friendships also changes through childhood and adolescence. Sullivan (1953) suggested that friendships change from being competitive to being intimate and mutually cooperative during the transition from childhood to adolescence (Sullivan, 1953). Several studies have confirmed this assertion, demonstrating an increase in cooperation, support and intimacy of friendships during this period (Berndt, 1982; Buhrmester, 1990).

When outsiders intrude on a friendship in childhood, some children are especially vulnerable to conflict, tension and jealousy (Asher *et al.*, 1998). Susceptibility to jealousy in such interactions is related to the child's psychological well-being. Children with low self-worth are more likely to perceive intrusion into their friendships and tend to be jealous of such attempts, whereas children with high self-worth tend to endorse feeling less competitive when their friend engages in activities with others (Parker *et al.*, 2005). As well, children and adolescents with low self-worth may show increased surveillance behavior, monitoring their friend's actions, related to the jealousy that they feel in their friendships (Lavallee and Parker, 2009). Inflexibility in accepting a friend's other peer relations and high rumination are associated with surveillance behavior and jealous emotions, all of which further contribute to conflict in the child's friendship along with depressive symptoms and loneliness (Lavallee and Parker, 2009). This finding suggests that children prone to psychological distress may be more strongly engaged by social signals intimating an interpersonal threat to their friendships. Moreover, negative emotions that develop in response to violation of friendship expectations differ among boys and girls with girls being more sad and angry after transgressions in friendship (MacEvoy and Asher, 2012).

## Social exclusion

Social exclusion is common in human relationships across development (Eisenberger *et al.*, 2003; Williams, 2007). In children, continued social exclusion among peer groups is associated with poor academic performance, dysregulated emotion, and loss of physical control (Nesdale and Flesser, 2001; Kim *et al.*, 2005; Schwartz *et al.*, 2008). Peer rejection has been implicated in the development of disruptive behavior problems (Dodge and Pettit, 2003), interpersonal difficulties (Downey *et al.*, 1998), low self-esteem and increased levels of internalizing problems (anxiety and depression) (Deater-Deckard, 2001; Ladd, 2006). While the effects of peer rejection can be diverse, as a process, it tends to be stable in social groups and difficult for a child to overcome (Jiang and Cillessen, 2005).

Continued social exclusion leads to increased need for belongingness in relationships as a physiological necessity. Williams *et al.* (2013) have proposed that individuals keep watch for experiences of social exclusion and acceptance via an adaptive social monitoring system. This system tracks exclusion and acceptance and monitors future social interactions based on previous experiences. Individual differences in psychopathology, especially loneliness and low self-esteem, modify the functioning of the social monitoring system. When the need for belonging is high, biases develop in perceived social interactions as well as greater interpersonal sensitivity. For example, lonely people remember more information about interpersonal characteristics of rejection and are less accurate when interpreting non-verbal cues (Williams *et al.*, 2013).

Social exclusion research in the laboratory commonly uses a standardized computerized task called Cyberball to probe the neural and behavioral effects of ostracism (Williams and Jarvis, 2006). In this task, participants are told they are playing with two or three players via the Internet, passing a virtual ball back and forth. Unbeknownst to the participant, his or her co-players are computer-based and programmed to move from a condition called fair play, where the ball is equally tossed among all players, to exclusion, where the participant is left out of the game (i.e. the other two 'players' pass the ball exclusively to one another). The exclusion phase has been used in event-related potential (ERP) and functional magnetic resonance imaging (fMRI) studies to model ostracism. Studies employing fMRI to measure brain responses during a game of Cyberball reveal that the experience of social exclusion engages neural circuitry relevant to the experience of distress and self-regulation (i.e. ventrolateral prefrontal cortex (PFC), medial PFC, dorsal anterior cingulate cortex, insula, posterior cingulate and medial orbitofrontal cortex) (Eisenberger *et al.*, 2003; Masten *et al.*, 2009; Bolling *et al.*, 2011; Sebastian *et al.*, 2011).

ERPs have been used to probe real-time temporal brain activity during social ostracism in Cyberball (Crowley *et al.*, 2009a,b, 2010; White *et al.*, 2012, 2013; Sreekrishnan *et al.*, 2014; Themanson *et al.*, 2015). Previous ERP studies with Cyberball focused on frontal slow wave responses to exclusion events, with greater negative left frontal/central slow waves tracking greater experienced ostracism distress (Crowley *et al.*, 2009a,b, 2010; White *et al.*, 2013; Sreekrishnan *et al.*, 2014). Despite a strong association between social exclusion and internalizing problems (Zadro *et al.*, 2006; Oaten *et al.*, 2008; Masten *et al.*, 2011) few studies have explored this association in youth.

To date, virtual paradigms used to examine ostracism in previous Cyberball ERP and fMRI studies have mainly focused on social exclusion by strangers (Eisenberger *et al.*, 2003; van Beest and Williams, 2006; Crowley *et al.*, 2010; Jamieson *et al.*, 2010; Bolling *et al.*, 2011; Sebastian *et al.*, 2010, 2011; White *et al.*, 2012, 2013). One exception was a recent study by Sreekrishnan *et al.* (2014) that examined mother–child dyads, within the Cyberball game. They observed that including family members changed the experience of the game. Exclusion by kin (mother or child) was associated with a greater frontal P2 ERP component. The frontal P2 is thought to reflect incidence detection and selective attention (Luck and Hillyard, 1994; Smith *et al.*, 2004; Key *et al.* 2005; Mueller *et al.*, 2008). Exclusion by kin was also associated with a more positive frontal slow wave response compared to exclusion by a stranger (Sreekrishnan *et al.*, 2014). Only brain responses reflecting exclusion by kin (P2, slow wave) were associated with self-reported ostracism distress—neural responses for rejection events by a stranger in this context were unrelated to self-reported ostracism distress. These results highlight how inclusion with familiar others changes the nature of Cyberball in terms of neural responding and corresponding psychological experience. This work has yet to be extended to friendship dyads.

In this study, we investigated neural correlates of exclusion in friendship dyads in a real time environment using Cyberball. Specifically, we compared the ERP neural correlates of exclusion events initiated by a friend *vs* a stranger, as they putatively played Cyberball with a participant. Friends were assessed simultaneously in adjoining electroencephalography (EEG) suites.

We also examined state measures of distress (ostracism distress) assessed just after Cyberball and trait measures of distress (anxiety and depression composite) assessed before playing Cyberball. As with our previous work-involving familiar others, we predicted that exclusion by a friend would preferentially elicit both a larger frontal P2 response and also a larger frontal slow wave response. We considered that both ostracism distress and psychological distress of the partner may affect the interdependent dyadic ERP measures. We predicted that a state measure, ostracism distress and more longstanding psychological distress would each account for variability in neural response to rejection events. Given the statistical dependency of dyad membership, we examined the effects of psychological measures of both the dyadic members within a hierarchical linear model and the actor-partner independence framework (Kenny and Judd, 1986; Kenny, 1995; Cook and Kenny, 2005).

## Methods

### Participants

Forty-six children (23 best friend same gender pairs; 12 female dyads) 8.92–13.84 years of age (mean = 11.14, s.d. = 1.14) were recruited via mass mailing. In order to participate, dyad members each identified one another as his or her mutual best friend and the friend had to be willing to also partake in the study. The sample identified largely as Caucasian (White, not of Hispanic origin), 91.3%, with 6.5% identifying as Hispanic and 2.2% identifying as Asian. Each participant received 40 US dollars remuneration for his or her participation in the study. The sample was largely middleclass. Eighty-five percent of the sample at or above the median family income for Connecticut ($51 939 in 2013), 8% had between $25 000 and $50 000 and 7% were undeclared. Ninety-seven percent of children lived with their biological mother. Eighty-seven percent of households consisted of married couples. Sixty-eight percent of families had at least one parent with a college or professional degree, 27% had a technical school degree or at least some college and 5% had at least one parent with a high school diploma. Parents provided written informed consent for their child's participation, and each child provided written assent. The Yale University Human Investigative Committee approved this study.

### Procedure

Following consent and assent procedures, child participants were photographed to generate pictures to be used in a Cyberball game as described below. Participants then completed questionnaires about their general distress (anxiety and depression). Next, an EEG sensor net was applied and the Cyberball social exclusion task was administered. Immediately following the Cyberball task, with the EEG net still in place, participants completed a measure of ostracism distress.

### Self-report measures

Children's Depression Inventory (CDI) is a widely used self-report inventory used to assess the severity of depressive symptoms in children and adolescents between the ages of 7–17 years. The instrument contains 28 items scored from 0 to 2 with the range of scores from 0 to 56. It has a high reliability and validity (Kovacs, 1985). Higher scores indicate greater levels of depressive symptoms.

Multidimensional Anxiety Scale for Children (MASC) is a comprehensive self-report instrument used for the assessment of youth anxiety between the ages of 8–19 years. It consists of 39 questions distributed across six domains: Physical Symptoms, Social Anxiety, Harm Avoidance, Separation Anxiety/Phobias, Generalized Anxiety and Obsessive-Compulsive symptoms. Ratings were assessed using a four-point Likert scale. Test-retest reliability using 3-week and 3-month intervals are satisfactory to excellent (March et al., 1997). Convergent and divergent validity has been demonstrated in that shared variance is highest for scales sampling anxiety symptom domains (March et al., 1997).

To evaluate the relative importance of baseline psychological distress on neural markers of social exclusion and to compare baseline psychological distress to ostracism distress post exclusion, we created a composite measure based on the CDI and the MASC (mean of the standardized score for each measure). Anxious and depressive symptoms are examined as a dimensional composite in the child literature (Achenbach and Rescorla, 2001). We created a composite such that trait distress would be represented in our models by one indicator in line with our single indicator of state distress (ostracism distress). Six children were missing self-report depression and anxiety data, but were retained for mixed model analysis. Further supporting our combination of these measures, depression and anxiety scores were moderately related in our sample, $r\,(40) = 0.419$, $P = 0.007$.

Social exclusion distress was assessed with the Need Threat Scale after the task. The Need Threat Scale is a 21-item questionnaire that has been shown to be reliable and valid as an indication of ostracism distress (Williams, 2007; Crowley et al., 2009b, 2010). It has been used in previous neuroimaging research to examine the psychological correlates of social exclusion associated with neural activation (Eisenberger et al., 2003; Lau et al., 2012). We used a revised Need Threat Scale for children. Feelings of distress or threat were assessed along the four dimensions of fundamental psychological needs: belongingness ('I felt like I didn't fit in with the others'), self–esteem ('I felt unsure of myself'), meaningful existence ('I felt invisible') and control ('I felt powerful': reverse-scored). Feelings are rated on a five-point scale from 1 ('Not at all') to 5 ('Extremely'). Higher scores on the Need Threat scale indicate greater distress.

### Cyberball paradigm

Participants sat 60 cm from a 17 inch LCD screen in a dimly lit, sound attenuated room while participating in the Cyberball paradigm. In this game, each participant must throw and receive a virtual ball, along with two-pre-programmed players. Both of the friends played the game simultaneously in different rooms. Each of the participants was told that the two other players in the virtual game were real and they were playing with their friend and a stranger simultaneously. Unbeknownst to the participants, the game is pre-programmed. The game was designed to have two phases: fair play, a series of trials where the ball was evenly thrown among all the participants and exclusion, a series of trials where the ball was only thrown between the pre-programmed players. The play screen was programmed in such a way that each participant's glove is at the bottom center of the screen and the other players' gloves are on opposite sides of the screen next to their pictures. One of the pictures was that of the friend whereas the other was of a gender and race matched photo. In order to choose whom to throw the ball to, the participant used their left or right index finger on the response pad.

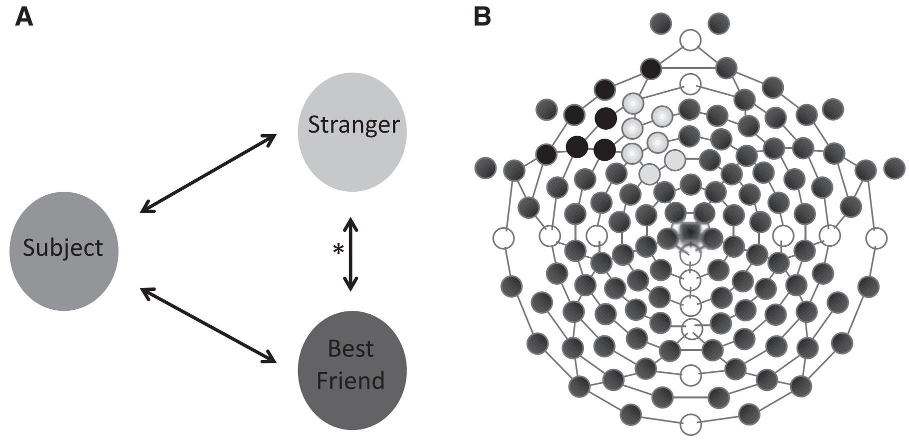


**Fig. 1.** Design of analysis parameters for best friend Cyberball. **(A)** A schematic design of the Cyberball set-up for participants. Each participant 'played' the game against two computerized players, one of they believed was their 'Best Friend' and the other they believed was a 'Stranger'. The game began with a condition of fair play, where the ball could be passed between all players (as indicated by all the arrows), followed by a condition of exclusion, where the ball was passed between the computerized players (as indicated by arrows marked *). **(B)** Frontal left electrodes, white, were chosen to assess rejection-based ERPs.

Authenticity of the game was enhanced with a Google™ page with a 'Cyberball' listing that was linked to a false loading screen. Participants were able to choose different gloves for play, different sound effects for throws and catches and different trajectories the balls were thrown in. Before the game started, the experimenter hinted with a verbal suggestion that 'additional players' were getting ready to play. Participants were debriefed about the falsity of the additional players and the game after the completion of the experiment.

This version of Cyberball contained two conditions, 108 trials (throws) of fair play and 47 trials of exclusion. The game was fixed with a waiting period to receive the ball, waiting 0, 1, 2 or 3 trials before receiving it again (frequency 12, 12, 10 and 2, respectively). Immediately following fair play, the game transitioned into an exclusion phase. In this condition, there were 44 'rejection' events where the ball was thrown between the other players and three 'my turn' events. This resulted in exclusion on 94% of the trials. For the purpose of the analysis, the three 'my turn' events, and the trial following each of these were excluded. Additionally the first 5 trials of the exclusion block were not used. Thus only 36 trials of rejection-based events were examined for analysis, divided into trials initiated by the 'best friend' and trials initiated by an unfamiliar child.

## EEG recording and preprocessing

Standard protocol was used to obtain a high density EEG with a 128 Ag/AgCl electrode system [Electrical Geodesics Incorporated (EGI) Netstation v.4.2 software]. High impedance amplifiers (sampled at 250 Hz: 0.1 Hz high pass, 100 Hz low pass) were utilized with a Cz reference for data acquisition. The baseline impedances of the electrodes were ensured to be <40k Ohms. Stimulus presentation was conducted using E-prime v.2.0 software (Psychology Software Tools, Inc.).

Post-collection processing was conducted per standard procedures including offline low pass filtering at 30 Hz, segmentation between a 100 ms baseline and a 900 ms post-stimulus onset and re-referenced to an average reference. The artifact detection threshold was set at 200 $\mu$V and an eye movement blink threshold of 150 $\mu$V. Ocular Artifact Removal was conducted to remove the eye movements/blinks in all the participants (Gratton *et al.*, 1983). We utilized the left-medial frontal region channel cluster as in our previous Cyberball studies of frontal slow wave negativity (White *et al.*, 2012; Sreekrishnan *et al.*, 2014). EGI Hydrocell net channels 12, 18, 19, 20, 22, 23 and 24 were used for this analysis (Figure 1). ERP's that corresponded to throws between the other players during exclusion were referred to as rejection-based ERPs. We further distinguished these throws between the other players (friend and stranger) during the exclusion phase. A throw by a friend to the stranger (as opposed to the participant) during exclusion was considered a rejection-based ERP of friend. The throw by the stranger to the friend (as opposed to the participant) during exclusion was considered a rejection based ERP of stranger. The number of trials designated, as 'rejection events' were 36, 18 trials for rejection by friend and 18 trials for rejection by stranger. The mean number of trials available for averaging for Friend Rejection were Mean = 13.07; s.d. = 3.88 and Stranger Rejection were Mean = 11.67; s.d. = 3.77.

## Analyses

The rejection based ERP's were analyzed using SPSS v.19 software (SPSS Inc. Chicago, IL, USA). Because the data were collected as best friend dyads, we used a MIXED procedure was to account for the nesting of participants within friendship pairs (dyads). The analysis consisted of 23 (pairs) $\times$ 2 (dyad members) $\times$ 2 conditions (excluder identity: exclusion by a friend or a stranger). We conducted the model accounting for the within dyad and between dyad effects for each individual subject. We analyzed the data using a multilevel model accounting for excluder identity (friend or stranger) nested within each member as well as each member nested within the dyad (Kenny *et al.*, 2006). First, we fit unconditional models for each outcome in order to calculate the intraclass correlation, or degree of variation due to within-dyad variation *vs* between-dyad variations in each outcome (Kenny, 1995). The dependent measures in this analysis were the ERP responses for rejection events delivered by a friend or by a stranger. We fit models for the P2 and the slow wave separately. We then evaluated the effects of pre-existing psychological distress and post-exclusion ostracism distress first for a model including a P2 ERP response and then for a model including a slow wave ERP response.

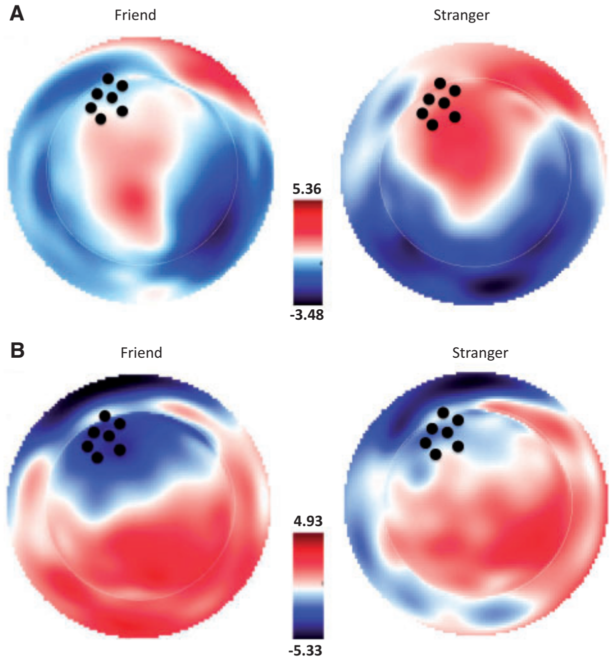


**Fig. 2.** Voltage maps of rejection-based ERPs during Cyberball with frontal left electrodes overlaid (round dots). (A) P2 response at 200 ms for rejection-based ERPs for friend (left) and stranger (right). (B) Slow wave response at 450–900 ms for rejection-based ERPs for friend (left) and stranger (right).

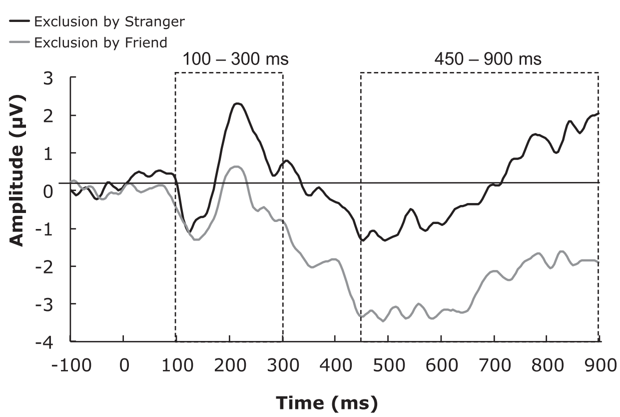


**Fig. 3.** Friend and stranger rejection-based ERPs while playing Cyberball.

Finally, we tested whether dyadic characteristics affected an individual's ERP outcomes. We used the Actor-Partner Interdependence Model (APIM) to assess the relative contribution of each child's reported distress on his or her own and partner's ERP outcomes (Cook and Kenny, 2005), as dyadic contributions are likely in close relationships (Campbell and Kashy, 2002). In the APIM model, the 'actor' effect represents the individual's characteristics on his/her own outcome measure whereas 'partner' effect captures the influence of the characteristics of the partner on the actor's outcome measure (Cook and Kenny, 2005). The interaction of actor and partner characteristics, or actor by partner 'interaction' effects, captures the idea that the effect of actor or partner characteristics depends on the characteristics of the other. Henceforth, we refer to self-reported effects on one's own outcomes as actor effects, the friend's effects as partner effects and the interaction between the two as actor by partner interaction effects.

**Table 1.** Means and s.d.'s of the major study variables separated by gender

| | Female | Male | |
|---|---|---|---|
| | (Mean ± s.d.) | (Mean ± s.d.) | *t*-test (*t*, *P*) |
| Age | 10.86 ± 1.32 | 10.66 ± 1.28 | 0.477, 0.636 |
| Depressive symptoms | 4.86 ± 5.26 | 8.27 ± 7.83 | −1.580, 0.125 |
| Anxiety symptoms | 91.59 ± 13.62 | 87.72 ± 12.27 | 0.944, 0.351 |
| Psychological Distress | −0.048 ± 0.75 | 0.058 ± 0.96 | −0.382, 0.705 |
| Ostracism Score | 67.75 ± 14.97 | 62.56 ± 14.22 | 1.062, 0.296 |

***$P \le 0.001$, two-tailed

**Table 2.** Bivariate correlations between psychological variables and P2 and slow wave for exclusion by friend and stranger

| | Psychological distress | Ostracism score |
|---|---|---|
| | (*r*, *P*) | (*r*, *P*) |
| Exclusion by friend | | |
| P2 | −0.366*, 0.02 | −0.111, 0.517 |
| Slow wave | −0.431**, 0.006 | −0.021, 0.901 |
| Exclusion by stranger | | |
| P2 | 0.481**, 0.002 | −0.199, 0.245 |
| Slow wave | 0.354*, 0.025 | −0.002, 0.989 |

## Results

We calculated descriptive statistics and demographic characteristics of the sample. The means and standard deviations for age, ostracism distress and psychological distress by gender are displayed in Table 1. We focused our analyses on the left frontal cortical region (Figure 1) building on our previous work and examined the P2 and slow wave responses for rejection events (White *et al.*, 2012; Sreekrishnan *et al.*, 2014). Gender was not significantly associated with ERP components, P2 or slow wave across stranger and friend, $rs < 0.12$ or with age, ostracism distress or psychological distress, $rs < .18$, ns. Psychological distress, but not ostracism was associated independently with P2 or slow wave for rejection events by friends or strangers (Table 2). Ostracism distress and psychological distress were not significantly correlated, although this correlation approached statistical significance, $r\ (40) = 0.318$, $P = 0.059$. Because ostracism distress was unrelated to neural response for rejection events by friend and stranger (P2, slow wave), we did not pursue ostracism distress within dyadic analysis and APIM. Figure 2 shows the EEG whole-head current density spline maps of friend and stranger rejection. The plotted ERP waveforms of friend and stranger rejection are shown in Figure 3.

We conducted paired samples *t*-tests to identify the ERP differences between rejection by strangers *vs* friends on both P2 and slow wave ERP's. Results showed significantly larger P2 ERPs for rejection by strangers compared to friends $t\ (79.3) = 2.057$, $P = 0.043$ (means = 3.585 $\mu$V *vs* 1.944 $\mu$V; Figure 4A). Similarly for slow wave, results showed significantly higher slow wave ERPs for rejection by strangers compared to friends $t\ (90) = 2.538$, $P = 0.013$ (Means = 0.153 $\mu$V *vs* −2.573 $\mu$V; Figure 4B).

The intraclass correlations (ICC) for unconditional models of P2 and slow wave revealed coefficients of 0.11 and 0.03

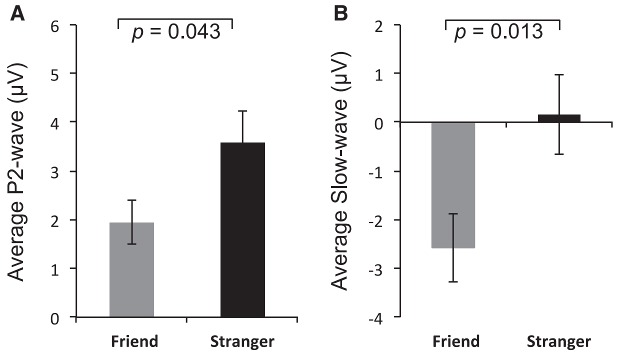


Fig. 4. (A) Average P2-wave amplitude ($\mu$V), 100–300 ms, of rejection-based ERPs for friend and stranger Participants showed a significantly positive wave for rejection-based ERPs for strangers than friends $t$ (79.3) = 2.057, P = 0.043. (B) Average slow-wave amplitude ($\mu$V), 450–900 ms, of rejection-based ERPs for friend and stranger Participants showed a significantly negative slow wave for rejection-based ERPs for friends than strangers during exclusion $t$ (90) = 2.538, P = 0.013.

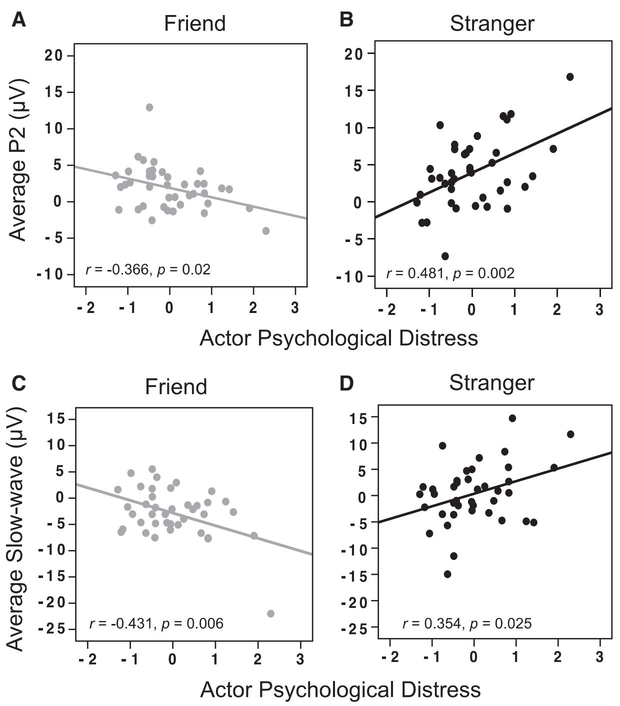


Fig. 5.(A and B) Scatter plot of *self-rated* ('Actor') psychological distress scores against average P2 wave for rejection-based ERPs for friend (left) and stranger (right). There was a significant negative correlation for friend ($r$ (40) = −0.366, P = 0.02), where greater distress correlated with a more negative slow-wave and significant positive correlation for rejection by stranger ($r$ (40) = 0.481, P = 0.002) with greater distress associated with a positive P2 wave.(C and D). Scatter plot of self-rated ('*Actor*') psychological distress against average slow-wave for rejection-based ERPs for friend (left) and stranger (right). There was a significant correlation for friend ($r$ = −0.431, P = 0.006), where greater distress correlated with a more negative slow-wave and a significant correlation for strangers ($r$ = 0.354, P = 0.025) with greater distress associated with a positive slow-wave.

respectively, suggesting a small proportion of the outcome variance was due to within-dyad variation *vs* individual level variation. Especially the P2 (ICC = 0.11) showed substantive variation due to dyad level characteristics, violating the assumption of independence. Such a violation can bias standard error estimation, supporting the choice of dyadic modeling to appropriately account for interdependence due to friendship pairs. Thus there was statistical evidence that multilevel modeling accounting for the nesting of measures within persons within dyads was appropriate (Kenny *et al.*, 2006).

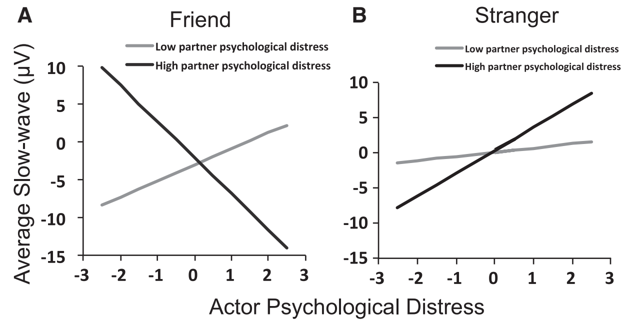


Fig. 6. (A and B) Plots of self-rated ('Actor') Psychological distress on the horizontal axis plotted against Average slow wave on the vertical axis. Having a friend ('Partner') with high (+1.5 s.d.) *vs* low (−1.5 s.d.) distress for exclusion by friend (6A) and exclusion by stranger (6B).

## P2 and slow wave association with actor's psychological distress

We conducted mixed model analyses to assess the effect of one's own psychological distress (actor effect) and the excluder identity as predictors of P2 and slow wave response (Table 3). In this model, the intercept was significant at 2.89 ($CI_{95}$ = 2.07, 3.72). The P2 response for exclusion by stranger was 2 units higher than exclusion by a friend ($CI_{95}$ = −3.53, −0.47). Also, the interaction of actor psychological distress and identity of excluder was significantly associated with P2 response ($\gamma = -3.98$, $CI_{95}$ = −5.83, −2.14). Similarly, the slow wave response of actor's own psychological distress showed the intercept was significant at −1.24 ($CI_{95}$ = −2.24, −0.24). Slow wave response for exclusion by stranger was 3.18 units higher than exclusion by friend ($CI_{95}$ = −5.18, −1.18). The interaction of actor's psychological distress and identity of excluder was significantly associated with slow wave ($\gamma = -4.99$, $CI_{95}$ = −7.52, −2.47). Although a majority of our sample was in the middle childhood range (8.92–11.99 years, 74%) we considered age as a factor in an exploratory fashion (Supplementary Table A). While age accounted for variability in the P2 model, the effects for Excluder Identity and Actor Distress × Excluder identity remained significant and comparable to the models without age for both the P2 and slow wave models (Table 3 *vs* Supplementary Table A).

## P2 and slow wave friend and stranger rejection ERP's correlations with actor psychological distress

We examined the correlations of P2 and slow wave ERP associations with actor psychological distress. Actor psychological distress was negatively associated with P2 responses upon rejection by a friend $r$ (40) = −0.366, P = 0.020 (Figure 5A), but was positively associated on rejection by a stranger $r$ (40) = 0.481, P = 0.002 (Figure 5B). On Fisher's r to z transformation, the difference between the correlation coefficients for exclusion by stranger and friend was significant, z (40) = 3.91, P < 0.001.

Resembling the pattern of results for P2, actor psychological distress was negatively correlated with slow wave response for rejection by a friend $r$ (40) = −0.431, P = 0.006 (Figure 5C), was positively associated for rejection by a stranger $r$ (40) = 0.354, P = 0.025 (Figure 5D). On Fisher's $r$-to-z transformation, the correlation coefficients for exclusion by stranger and friend were significantly different z (40) = 3.57, P = 0.004.

**Table 3.** Parameter estimates for Dyadic Multilevel models of P2 response and slow wave as a function of psychological distress and excluder identity in best friend dyads

| P2 response | Estimate | (SE) | $t^a$ | $P^b$ | $CI_{95}{}^c$ | |
|---|---|---|---|---|---|---|
| | | | | | Lower | Upper |
| Intercept | 2.89 | 0.39 | 7.41 | <0.001*** | 2.07 | 3.72 |
| Excluder identity | −2.00 | 0.73 | −2.74 | 0.013* | −3.53 | −0.47 |
| Actor distress | 0.70 | 0.47 | 1.48 | 0.145 | −0.25 | 1.66 |
| Actor distress* excluder identity | −3.98 | 0.91 | −4.37 | <0.001*** | −5.83 | −2.14 |
| **Slow wave** | **Estimate** | **(SE)** | $t^a$ | $P^b$ | $CI_{95}{}^c$ | |
| | | | | | Lower | Upper |
| Intercept | −1.24 | 0.49 | −2.52 | 0.016* | −2.24 | −0.24 |
| Excluder identity | −3.18 | 0.98 | −3.23 | 0.003* | −5.18 | −1.18 |
| Actor distress | −0.02 | 0.63 | −0.04 | 0.968 | −1.28 | 1.23 |
| Actor distress* excluder identity | −4.99 | 1.26 | −3.95 | <0.001*** | −7.52 | −2.47 |

[a]Degrees of freedom are 18.14 for tests of intercepts for P2 and 36.78 for the tests of intercepts for slow wave;
[b]All *P*-values are two tailed except in the case of variances, where one-tailed *P*-values are used (because variances are constrained to be non-negative);
[c]Confidence intervals for variances were computed using the Satterthwaite method;
[d]Covariances for intercepts of P2 and slow wave were estimated but not reported for the sake of simplicity.
*$P \leq 0.05$, two-tailed;
**$P \leq 0.01$, two-tailed;
***$P \leq 0.001$, two-tailed.

Table **4**. Parameter estimates for Dyadic Multilevel models of P2 response and slow wave as a function of psychological distress (of the actor, partner and the interaction of the actor and partner) and excluder identity in best friend dyads

| P2 response | Estimate | (SE) | $t^a$ | $P^b$ | $CI_{95}{}^c$ | |
|---|---|---|---|---|---|---|
| | | | | | Lower | Upper |
| Intercept | 2.94 | 0.39 | 7.42 | 0.001*** | 2.10 | 3.77 |
| Excluder identity | −1.87 | 0.71 | −2.60 | 0.018* | −3.38 | −0.35 |
| Actor distress | 0.75 | 0.52 | 1.44 | 0.154 | −0.29 | 1.80 |
| Actor distress*excluder identity | −3.37 | 0.99 | −3.38 | 0.001*** | −5.37 | −1.37 |
| Partner distress | 0.64 | 0.52 | 1.24 | 0.219 | −0.39 | 1.69 |
| Partner distress*excluder identity | −0.02 | 0.99 | −0.02 | 0.979 | −2.02 | 1.97 |
| Actor*partner distress | −0.37 | 0.41 | −0.88 | 0.387 | −1.24 | 0.50 |
| Actor*partner distress*excluder identity | −1.12 | 0.75 | −1.49 | 0.154 | −2.71 | 0.46 |
| **Slow wave** | **Estimate** | *(SE)* | $t^a$ | $P^b$ | $CI_{95}{}^c$ | |
| | | | | | *Lower* | *Upper* |
| Intercept | −1.15 | 0.42 | −2.70 | 0.011** | −2.03 | −0.28 |
| Excluder identity | −2.81 | 0.85 | −3.27 | 0.002*** | −4.55 | −1.06 |
| Actor distress | 0.30 | 0.67 | 0.44 | 0.655 | −1.04 | 1.65 |
| Actor distress*excluder identity | −3.27 | 1.35 | −2.41 | 0.019* | −5.97 | −0.56 |
| Partner distress | 0.20 | 0.67 | 0.30 | 0.759 | −1.14 | 1.56 |
| Partner distress*excluder identity | 0.22 | 1.35 | 0.16 | 0.867 | −2.47 | 2.93 |
| Actor*partner distress | −0.70 | 0.45 | −1.57 | 0.126 | −1.62 | 0.20 |
| Actor*partner Distress*excluder identity | −3.18 | 0.90 | −3.53 | 0.001*** | −5.01 | −1.35 |

[a]Degrees of freedom are 17 for tests of intercepts for P2 and 34 for the tests of intercepts for slow wave;
[b]All *P*-values are two tailed except in the case of variances, where one-tailed *P*-values are used (because variances are constrained to be non-negative);
[c]Confidence intervals for variances were computed using the Satterthwaite method;
[d]Covariances for intercepts of P2 and slow wave were estimated but not reported for the sake of simplicity.
*$P \leq 0.05$, two-tailed;
**$P \leq 0.01$, two-tailed;
***$P \leq 0.001$, two-tailed.

## P2 and slow wave association with partner psychological distress

Mixed model analyses were conducted to identify the effect of partner's psychological variables on P2 and slow wave. Partner's psychological distress was not independently or interactively associated with P2 or the slow wave.

## P2 and slow wave association with actor by partner interaction for psychological distress

To identify the effect of dyadic psychological distress on P2 and slow wave, we included actor, partner and actor by partner psychological distress and excluder identity as predictors of P2 and slow wave (Table 4). In the model predicting P2, the intercept for

P2 response was significant at 2.94 ($CI_{95} = 2.10, 3.77$). The actor by partner interaction for psychological distress and excluder identity, however, was not significantly associated with P2 response ($\gamma = -1.12$, $CI_{95} = -2.71, 0.46$). The intercept for slow wave analysis was significant at −1.15 ($CI_{95} = -2.03, -0.28$). In contrast to the P2 analysis, the actor by partner interaction for psychological distress and excluder identity was significantly associated with slow wave ($\gamma = -3.18$, $CI_{95} = -5.01, -1.35$). To probe the significant actor by partner interaction on slow wave further, we plotted the actor and partner psychological distress with slow wave ERP separately for friend (Figure 6A) and stranger rejection (Figure 6B). As is shown in Figure 6, for children with low distress friends (low partner psychological distress), distress and slow wave were positively associated in the friend condition, and slightly positively associated in the stranger condition (grey line). For children with high distress friends, the association of their own distress and slow wave was negative in the friend condition, but positive in the stranger condition (black line). Overall these findings indicate that the level of psychological distress a friend brings to the dyad does matter in considering the association between slow wave response to rejection events (across friend and stranger) and the psychological distress a child brings to the situation.

## Discussion

We examined the neural correlates of social exclusion in best friend dyads and the moderating role of psychological distress and ostracism distress. We observed significant differences in neural responses upon rejection by stranger and friend, but the direction of the observed differences was contrary to our predictions—exclusion by a stranger was associated with a markedly greater P2 and more positive slow wave response in the left frontal region compared to exclusion by a friend. Moreover, we observed that actor psychological distress was associated with a greater neural response (P2, slow wave) for rejection by a stranger than for rejection by a friend. Actor by partner interaction psychological distress differentially accounted for variability in neural responses to rejection, indicating a dyadic effect.

First, we found that rejection by a stranger elicited a significantly greater P2 and slow wave ERP response than rejection by friend. The P2 response appears in preferential processing (context and intensity) of unique stimuli (Luck and Hillyard, 1994; Key *et al.*, 2005). The larger P2 we observed here likely reflects greater engagement of attentional resources for exclusion events by a stranger compared to exclusion events by a friend. The differences observed between stranger and friend rejection on P2 also emerged for the frontal slow wave. Left frontal slow waves were observed for exclusion events in previous Cyberball studies (Crowley *et al.*, 2009a,b, 2010; Sreekrishnan *et al.*, 2014). In previous work, frontal negative slow waves were observed in anticipation of noxious stimuli such as aversive noise (Regan and Howard, 1995; Crowley *et al.*, 2009a) and shocks (Baas *et al.*, 2002). Additionally, studies have shown that slow wave amplitude is correlated to task difficulty especially to memory processing (Birbaumer *et al.*, 1990; Rosler *et al.*, 1997). The more negative slow wave response observed for exclusion by friend may reflect the more aversive nature of the event (Crowley *et al.*, 2009a,b, 2010; Sreekrishnan *et al.*, 2014).

It is interesting to note that the greater P2 and slow wave response observed on stranger exclusion when compared to exclusion by friend are in contrast to our previous findings—rejection events delivered by kin were associated with greater amplitude of neural response when compared to those by a stranger (Sreekrishnan *et al.*, 2014). The unexpected direction of the results led us to reflect on how the dynamics of a friend-stranger pairing differs fundamentally from a kin-stranger pairing. In this study, the addition of a stranger to an existing friend dyad creates a unique situation, fundamentally different from kin based situations such as mother–child bonds. Whereas mother–child bonds are more or less stable in middle childhood, friendships wax and wane across development (Hartup, 1996). The greater uncertainty in this paradigm may tilt motivated attention for some youth toward perceived intrusion by a stranger (surveillance behavior). Previous studies have documented that perceived social isolation in children leads to increased surveillance behaviors and heightened sensitivity to social threats (Parker *et al.*, 2005; Cacioppo and Hawkey, 2009; Lavallee and Parker, 2009). Second, social competition is a prominent feature in peer relations in childhood (Berndt, 1982; Fonzi *et al.*, 1997; Schneider *et al.*, 2005). In social situations that involve strangers, people make an active attempt to present themselves in a positive light to the stranger (Vohs *et al.*, 2005). This is because friends already have pre-existing knowledge of one another whereas strangers do not. In contrast, social competition is a not a prominent characteristic in mother–child bonds where strangers are concerned. In the present study, exclusion by a stranger may engage more attention allocation and post exclusion processing than exclusion by a friend, either because of heightened surveillance behavior, due to enhanced social competition in this version of Cyberball, or possibly some combination of these factors. The pattern of ERP effects related to psychological distress favor the surveillance interpretation as discussed next.

Psychological distress, but not ostracism distress of the child, was uniquely associated with rejection based ERP's. The greater an individual's trait psychological distress, the more likely they showed a larger neural response (P2 and slow wave) to exclusion by the stranger. Perhaps, individuals with greater levels of baseline psychological distress engage in more surveillance behavior, reflecting their perception of a threat by individuals moving in on their friendships. Previous work has shown that low self-esteem and loneliness are associated with an overactive social monitoring system that is biased towards enhanced sensitivity but misidentification of social cues (Gardner *et al.*, 2000, 2005). Specifically, lonely children tend to harbor cognitive biases, expect social rejection and also overreact to social rejection (Qualter *et al.*, 2013). Also, among individuals with high distress, social rejection is associated with hypervigilance to socially threatening stimuli and with difficulty disengaging from the threatening stimuli (Qualter *et al.*, 2013). In children with high distress in our study, we propose that hypervigilance to social rejection by stranger presents as the heightened neural response to these events. Relatedly, the presence of psychopathology is associated with attachment insecurity in middle childhood, with insecurity extending to social relationships (Cassidy *et al.*, 2013). For example, socially withdrawn and anxious children avoid conflict even with their known peers and have difficulties in friendships (Garmezy and Rutter, 1988). On the other end of the continuum, participants with low psychological distress, and possibly greater attachment security, may place more emphasis on friends. Even in our unselected sample, the more 'well adjusted' children (lower psychological distress), showed stronger neural responding (P2) for rejection events by best friends, suggesting greater attention engagement in their best friend's behaviors.

We examined the actor by partner psychological distress within dyads, finding that dyadic psychological distress was associated with slow wave neural response. In terms of this psychological distress-slow wave finding, it is useful to consider dyadic effects (plots in Figure 6A and B) against main effects (scatter plots in Figure 5c and d). Children with 'higher distress' friends appear to be driving the main effects. That is, the regression lines for high partner distress and slow wave ERPs (black lines, Figure 6A and B) resemble the scatter plots of these data (Figure 5C and D), whereas children whose friends have lower psychological distress (grey lines, Figure 6A and B) show a pattern opposite to the main effect in the case of 'Friend' and show a weak to no relationship in the case of 'stranger'. High psychological distress (high actor and partner psychological distress) in the dyad was associated with a relatively more negative slow wave for exclusion by friend (Figure 6A) and a relatively more positive slow wave when excluded by stranger (Figure 6B). Two conclusions can be drawn from the dyad-level effect (combined distress levels in the dyad). First, the dyadic distress levels within a child friendship matters in Cyberball. Best friends who are members of high psychological distress dyads show greater differential responsivity to exclusion across friends and strangers. Second, and building on our previous work finding that greater negative frontal slow waves in Cyberball are associated with more experienced distress generally (Crowley *et al.*, 2009a,b, 2010; Sreekrishnan *et al.*, 2014), our data indicate that high psychological distress dyads show greater negative frontal slow waves for rejection by a friend and reduced negative frontal slow waves for exclusion by a stranger. Data suggest that when both members of a dyad bring high levels of psychological distress to the interaction, they are more responsive to rejection by a friend with a pattern of frontal negative slow wave consistent with greater distress.

This is the first study to examine the ERP based neural correlates of social rejection in best friend dyads using Cyberball. The results highlight the unique neural response to social rejection upon exclusion by a best friend *vs* a stranger and the prominent and differential role of psychological distress individually and at the dyadic level in moderating the neural response. This study confirms the P2 and slow wave responses as reliable neural responses for friend rejection in middle childhood. Our previous work with stranger exclusion in Cyberball and ERPs (Crowley *et al.*, 2009b, 2010) did not identify P2 responses for rejection events. Potentially, the presence of known others and their higher salience more strongly engages attention mechanisms in the frontal region as indexed by P2. The direction of the effect observed on ERP appears to be specific to the type of the relationship, kin *vs* friend relationship, and the underlying psychological distress. Moreover, not only the individual's distress but also the combined psychological distress levels in friend pairs affect the brain responses in social exclusion.

## Limitations and direction for future research

The issue of sample size frequently arises as a study limitation. In the context of the APIM framework, the number of predictors emerging from a dyadic model compounds sample size issues. In this study, the single examined predictor (psychological distress) led to seven regression terms (Table 4). There are myriad other relevant variables that could be considered within the APIM framework, some of which we suggest below. A sample larger than ours ($n = 46$) would be needed to explore multiple predictors.

Based on our study design, findings are limited to psychological distress, ostracism distress and their individual and dyadic effects on neural response to social exclusion. In the absence of previous work examining social exclusion in the context play with a friend and a stranger, we administered the widely used measure of global ostracism distress (Need Threat for assessing control, belonging, meaningful existence, self-esteem), predicting this self-report would track neural response to rejection events. Our data suggest that psychological distress, but not global ostracism distress tracks neural response when social exclusion involves a friend or a same age/gender stranger. Providing discriminant validity for the psychological distress-rejection event effects, exploratory analysis (see correlation Supplementary Table B) shows that neither psychological distress, nor ostracism distress were related to P2 or slow wave responses when the throws were to the participant in fair play (see Supplementary Figure A for inclusion event ERPs).

Two potential factors come to mind that may have contributed to the lack of findings for ostracism distress in this study. First, the measure of global distress does not distinguish between thoughts and emotions about the friend and the thoughts and emotions about the stranger. Clearly our neural response data show that response to friend and stranger are distinguishable. Second, the type of measure could reflect the differential cognitions and emotions that a participant might have for the friend and stranger, respectively. For instance, it could be that factors such as trust and betrayal are more relevant for understanding social exclusion in the context of a friendship. For instance, betrayal of friendship, as in violation of friendship expectations, is associated with increase in negative emotions especially differentially among boys and girls (MacEvoy and Asher, 2012). On the other hand, issues of jealousy, surveillance behavior (Lavallee and Parker, 2009) and interpersonal threat could be more predictive of neural response to the stranger's behavior. These points suggest modifications of the best friend Cyberball paradigm post-assessment that could be useful in future research.

The transition from childhood to adolescence is accompanied by pubertal changes and accompanying brain, hormonal and social relationship changes (Blakemore, 2008, 2012; Forbes and Dahl, 2010; Crone and Dahl, 2012; Peper and Dahl, 2013). Puberty is associated with physical, affective and emotional changes, differentially in males and females (Dahl, 2004; Peper and Dahl, 2013). In this period, affective and cognitive processes are integrated and the associated mentalizing processes lead to developing a sense of self and have been linked to positive and negative appraisals and underlying motivations (Dahl, 2004; Blakemore, 2008, 2012). The heightened social consciousness and social evaluation is observed more in adolescents than children (Somerville, 2013). Despite some understanding of these changes, pubertal and gender-based associations and relationships in neural development are less well understood and need further study (Somerville, 2013). Herein, we did not assess pubertal status or hormonal factors likely to be relevant in the childhood to adolescent transition. We did consider age in an exploratory fashion, finding that although age accounted for significant variance in the model for the P2, the Excluder Identity and Actor Distress* Excluder Identity effects remained statistically significant (supplementary materials). With a larger sample size, and sampling more broadly across the teenage years, pubertal assessments are clearly warranted as they may bear on factors that affect self-regulation, identity and interaction with peers (Crosnoe, 2000; Rose and Rudolph, 2006).

One area worthy of further exploration in the context of social exclusion among friends is relationship quality. Via the APIM, our results demonstrate the role of combined distress levels in dyadic relationships. Previous work demonstrated the significant role of attachment type and security in close relationships (Hazan and Shaver, 1987; Ainsworth, 1989; Shaver and Fraley, 2000). Future work could characterize attachment classification of dyad members, considered within the APIM and their likely role in social rejection in adolescence (White *et al.*, 2012, 2013). Assessing attachment patterns could shed light on why children with greater levels of trait distress respond more strongly to rejection events by strangers whereas children low in psychological distress are more responsive to their friends. Further, attention mechanisms such as threat bias (Bar-Haim *et al.*, 2007; Cisler and Koster, 2010) and interpretive biases (Taghavi *et al.*, 2000) and social information processing patterns (Spencer *et al.*, 2013) may account for neural response differences in social exclusion we report here.

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## References

Achenbach, T.M., Rescorla, L.A. (2001). *ASEBA School-Age Forms & Profiles*. Burlington: ASEBA.

Ainsworth, M.D.S. (1989). Attachments beyond infancy. *American Psychologist*, **44**(4),709–16.

Asher, S.R., Parker, J.G., Walker, D.L. (1998). Distinguishing friendship from acceptance: Implications for intervention and assessment. In: Bukowski, W.M., Newcomb, A.F., Hartup, W.W. editors. *The company they keep: Friendship in childhood and adolescence*, pp. 366–405, New York, NY: Cambridge University Press; US.

Baas, J.M.P., Kenemans, J.L., Bocker, K.B.E., Verbaten, M.N. (2002). Threat-induced cortical processing and startle potentiation. *Neuroreport*, **13**(1), 133–7.

Bagwell, C.L., Newcomb, A.F., Bukowski, W.M. (1998). Preadolescent friendship and peer rejection as predictors of adult adjustment. *Child Development*, **69**(1), 140–53.

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M.J., van Ijzendoorn, M.H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. *Psychological Bulletin*, **133**(1), 1–24.

Baumeister, R.F., Leary, M.R. (1995). The need to belong: desire for interpersonal attachments as a fundamental human motivation. *Psychological Bulletin*, **117**(3),497–529.

Berndt, T.J. (1982). The features and effects of friendship in early adolescence. *Child Development*, **53**(6), 1447–60.

Birbaumer, N., Elbert, T., Canavan, A.G.M., Rockstroh, B. (1990). Slow potentials of the cerebral-cortex and behavior. *Physiological Reviews*, **70**(1), 1–41.

Blakemore, S.-J. (2008). The social brain in adolescence. *Nature Reviews Neuroscience*, **9**(4), 267–77.

Blakemore, S.-J. (2012). Imaging brain development: the adolescent brain. *NeuroImage*, **61**(2),397–406.

Bolling, D.Z., Pitskel, N.B., Deen, B., *et al.* (2011). Dissociable brain mechanisms for processing social exclusion and rule violation. *NeuroImage*, **54**(3), 2462–71.

Boulton, M.J., Trueman, M., Chau, C., Whitehand, C., Amatya, K. (1999). Concurrent and longitudinal links between friendship and peer victimization: implications for befriending interventions. *Journal of Adolescence*, **22**(4), 461–6.

Brent, L.J., Chang, S.W., Gariepy, J.F., Platt, M.L. (2014). The neuroethology of friendship. *Annals of the New York Academy of Sciences*, **1316**, 1–17.

Buhrmester, D. (1990). Intimacy of friendship, interpersonal competence, and adjustment during preadolescence and adolescence. *Child Development*, **61**(4), 1101–11.

Cacioppo, J.T., Hawkey, L.C. (2009). Perceived social isolation and cognition. *Trends in Cognitive Sciences*, **13**(10), 447–54.

Calhoun, C.D., Helms, S.W., Heilbron, N., Rudolph, K.D., Hastings, P.D., Prinstein, M.J. (2014). Relational victimization, friendship, and adolescents' hypothalamic-pituitary-adrenal axis responses to an in vivo social stressor. *Development and Psychopathology*, **26**(3), 605–18.

Campbell, L., Kashy, D.A. (2002). Estimating actor, partner, and interaction effects for dyadic data using PROC MIXED and HLM: a user-friendly guide. *Personal Relationships*, **9**(3), 327–42.

Cassidy, J., Jones, J.D., Shaver, P.R. (2013). Contributions of attachment theory and research: a framework for future research, translation, and policy. *Development and Psychopathology*, **25**(4), 1415–34.

Cisler, J.M., Koster, E.H.W. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: an integrative review. *Clinical Psychology Review*, **30**(2), 203–16.

Cook, W.L., Kenny, D.A. (2005). The actor-partner interdependence model: a model of bidirectional effects in developmental studies. *International Journal of Behavioral Development*, **29**(2), 101–9.

Crone, E.A., Dahl, R.E. (2012). Understanding adolescence as a period of social–affective engagement and goal flexibility. *Nature Reviews Neuroscience*, **13**(9), 636–50.

Crosnoe, R. (2000). Friendships in childhood and adolescence: the life course and new directions. *Social Psychology Quarterly*, **63**(4), 377–91.

Crowley, M.J., Wu, J., Bailey, C.A., Mayes, L.C. (2009a). Bringing in the negative reinforcements: the avoidance feedback-related negativity. *Neuroreport*, **20**(17), 1513–7.

Crowley, M.J., Wu, J., McCarty, E.R., David, D.H., Bailey, C.A., Mayes, L.C. (2009b). Exclusion and micro-rejection: event-related potential response predicts mitigated distress. *Neuroreport*, **20**(17), 1518–22.

Crowley, M.J., Wu, J., Molfese, P.J., Mayes, L.C. (2010). Social exclusion in middle childhood: rejection events, slow-wave neural activity, and ostracism distress. *Social Neuroscience*, **5**(5-6), 483–95.

Dahl, R.E. (2004). Adolescent brain development: a period of vulnerabilities and opportunities. Keynote address. *Annals of the New York Academy of Sciences*, **1021**(1), 1–22.

Deater-Deckard, K. (2001). Annotation: recent research examining the role of peer relationships in the development of psychopathology. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **42**(5), 565–79.

Dodge, K.A., Pettit, G.S. (2003). A biopsychosocial model of the development of chronic conduct problems in adolescence. *Developmental Psychology*, **39**(2),349–71.

Downey, G., Freitas, A.L., Michaelis, B., Khouri, H. (1998). The self-fulfilling prophecy in close relationships: rejection sensitivity and rejection by romantic partners. *Journal of Personality and Social Psychology*, **75**(2),545–60.

Eisenberger, N.I., Lieberman, M.D., Williams, K.D. (2003). Does rejection hurt? An FMRI study of social exclusion. *Science*, **302**(5643),290–2.

Fonzi, A., Schneider, B.H., Tani, F., Tomada, G. (1997). Predicting children's friendship status from their dyadic interaction in structured situations of potential conflict. *Child Development*, **68**(3), 496–506.

Forbes, E.E., Dahl, R.E. (2010). Pubertal development and behavior: hormonal activation of social and motivational tendencies. *Brain and Cognition*, **72**(1), 66–72.

Furman, W., Buhrmester, D. (1985). Childrens perceptions of the personal relationships in their social networks. *Developmental Psychology*, **21**(6), 1016–24.

Gardner, W.L., Pickett, C.L., Brewer, M.B. (2000). Social exclusion and selective memory: how the need to belong influences memory for social events. *Personality and Social Psychology Bulletin*, **26**(4), 486–96.

Gardner, W.L., Pickett, C.L., Jefferis, V., Knowles, M. (2005). On the outside looking in: loneliness and social monitoring. *Personality and Social Psychology Bulletin*, **31**(11), 1549–60.

Garmezy, N., Rutter, M. (1988). *Stress, Coping, and Development in Children*, Baltimore: Johns Hopkins University Press.

Gratton, G., Coles, M.G.H., Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, **55**(4),468–84.

Hartup, W.W. (1996). The company they keep: friendships and their developmental significance. *Child Development*, **67**(1), 1–13.

Hazan, C., Shaver, P. (1987). Romantic love conceptualized as an attachment process. *Journal of Personality and Social Psychology*, **52**(3), 511–24.

Jamieson, J.P., Harkins, S.G., Williams, K.D. (2010). Need threat can motivate performance after ostracism. *Personality and Social Psychology Bulletin*, **36**(5), 690–702.

Jiang, X.L., Cillessen, A.H.N. (2005). Stability of continuous measures of sociometric status: a meta-analysis. *Developmental Review*, **25**(1), 1–25.

Kenny, D.A. (1995). The effect of nonindependence on significance testing in dyadic research. *Personal Relationships*, **2**(1), 67–75.

Kenny, D.A., Judd, C.M. (1986). Consequences of violating the independence assumption in analysis of variance. *Psychological Bulletin*, **99**(3), 422–31.

Kenny, D.A., Kashy, D.A., Cook, W.L. (2006). *Dyadic Data Analysis*. New York: Guilford Press.

Key, A.P.F., Dove, G.O., Maguire, M.J. (2005). Linking brainwaves to the brain: An ERP primer. *Developmental Neuropsychology*, **27**(2), 183–215.

Kim, Y.S., Koh, Y.J., Leventhal, B. (2005). School bullying and suicidal risk in Korean middle school students. *Pediatrics*, **115**(2),357–63.

Kovacs, M. (1985). The children's depression, inventory (CDI). *Psychopharmacology Bulletin*, **21**(4),995–8.

Ladd, G.W. (2006). Peer rejection, aggressive or withdrawn behavior, and psychological maladjustment from ages 5 to 12: an examination of four predictive models. *Child Development*, **77**(4), 822–46.

Lau, J.Y.F., Guyer, A.E., Tone, E.B., *et al.* (2012). Neural responses to peer rejection in anxious adolescents: contributions from the amygdala-hippocampal complex. *International Journal of Behavioral Development*, **36**(1), 36–44.

Lavallee, K.L., Parker, J.G. (2009). The role of inflexible friendship beliefs, rumination, and low self-worth in early adolescents' friendship jealousy and adjustment. *Journal of Abnormal Child Psychology*, **37**(6), 873–85.

Luck, S.J., Hillyard, S.A. (1994). Electrophysiological correlates of feature analysis during visual-search. *Psychophysiology*, **31**(3), 91–308.

MacEvoy, J.P., Asher, S.R. (2012). When friends disappoint: boys' and girls' responses to transgressions of friendship expectations. *Child Development*, **83**(1), 104–19.

March, J.S., Parker, J.D.A., Sullivan, K., Stallings, P., Conners, C.K. (1997). The multidimensional anxiety scale for children (MASC): factor structure, reliability, and validity. *Journal of the American Academy of Child and Adolescent Psychiatry*, **36**(4), 554–65.

Masten, C.L., Eisenberger, N.I., Borofsky, L.A., *et al.* (2009). Neural correlates of social exclusion during adolescence: understanding the distress of peer rejection. *Social Cognitive and Affective Neuroscience*, **4**(2), 143–57.

Masten, C.L., Eisenberger, N.I., Borofsky, L.A., McNealy, K., Pfeifer, J.H., Dapretto, M. (2011). Subgenual anterior cingulate responses to peer rejection: a marker of adolescents' risk for depression. *Development and Psychopathology*, **23**(1), 283–92.

Mueller, V., Brehmer, Y., von Oertzen, T., Li, S.C., Lindenberger, U. (2008). Electrophysiological correlates of selective attention: a lifespan comparison. *BMC Neuroscience*, **9**, 21.

Nesdale, D., Flesser, D. (2001). Social identity and the development of children's group attitudes. *Child Development*, **72**(2), 506–17.

Newcomb, A.F., Bagwell, C.L. (1995). Children's friendship relations: a meta-analytic review. *Psychological Bulletin*, **117**(2), 306.

Oaten, M., Williams, K.D., Jones, A., Zadro, L. (2008). The effects of ostracism on self-regulation in the socially anxious. *Journal of Social and Clinical Psychology*, **27**(5), 471–504.

Parker, J.G., Low, C.M., Walker, A.R., Gamm, B.K. (2005). Friendship jealousy in young adolescents: individual differences and links to sex, self-esteem, aggression, and social adjustment. *Developmental Psychology*, **41**(1), 235–50.

Peper, J.S., Dahl, R.E. (2013). The teenage brain surging hormones—brain-behavior interactions during puberty. *Current Directions in Psychological Science*, **22**(2), 134–9.

Qualter, P., Rotenberg, K., Barrett, L., *et al.* (2013). Investigating hypervigilance for social threat of lonely children. *Journal of Abnormal Child Psychology*, **41**(2), 325–38.

Regan, M., Howard, R. (1995). Fear conditioning, preparedness, and the contingent negative-variation. *Psychophysiology*, **32**(3), 208–14.

Rose, A.J., Rudolph, K.D. (2006). A review of sex differences in peer relationship processes: potential trade-offs for the emotional and behavioral development of girls and boys. *Psychological Bulletin*, **132**(1), 98.

Rosler, F., Heil, M., Roder, B. (1997). Slow negative brain potentials as reflections of specific modular resources of cognition. *Biological Psychology*, **45**(1–3), 109–41.

Schneider, B.H., Woodburn, S., del Toro, M.D.P., Udvari, S.J. (2005). Cultural and gender differences in the implications of competition for early adolescent friendship. *Merrill-Palmer Quarterly-Journal of Developmental Psychology*, **51**(2), 163–91.

Schwartz, D., Gorman, A.H., Dodge, K.A., Pettit, G.S., Bates, J.E. (2008). Friendships with peers who are low or high in aggression as moderators of the link between peer victimization and declines in academic functioning. *Journal of Abnormal Child Psychology*, **36**(5), 719–30.

Sebastian, C., Viding, E., Williams K.D, Blakemore S.J. (2010). Social brain development and the affective consequences of ostracism in adolescence. *Brain and Cognition*, **72**(1),134–45.

Sebastian, C.L., Tan, G.C.Y., Roiser, J.P., Viding, E., Dumontheil, I., Blakemore, S.-J. (2011). Developmental influences on the neural bases of responses to social rejection: implications of social neuroscience for education. *NeuroImage*, **57**(3),686–94.

Shaver, P.R., Fraley, R.C. (2000). Attachment theory and caregiving. *Psychological Inquiry*, **11**(2), 109–14.

Smith, J.L., Johnstone, S.J., Barry, R.J. (2004). Inhibitory processing during the Go/NoGo task: an ERP analysis of children with attention-deficit/hyperactivity disorder. *Clinical Neurophysiology*, **115**(6), 1320–31.

Somerville, L.H. (2013). The teenage brain sensitivity to social evaluation. *Current Directions in Psychological Science*, **22**(2),121–7.

Spencer, S.V., Bowker, J.C., Rubin, K.H., Booth-Laforce, C., Laursen, B. (2013). Similarity between friends in social information processing and associations with positive friendship quality and conflict. *Merrill-Palmer Quarterly*, **59**(1), 106–31.

Sreekrishnan, A., Herrera, T.A., Wu, J., *et al*. (2014). Kin rejection: social signals, neural response and perceived distress during social exclusion. *Developmental Science*, **17**(6),1029–41.

Sullivan, H.S. (1953). *The Interpersonal Theory of Psychiatry*. New York: Norton.

Taghavi, M.R., Moradi, A.R., Neshat-Doost, H.T., Yule, W., Dalgleish, T. (2000). Interpretation of ambiguous emotional information in clinically anxious children and adolescents. *Cognition & Emotion*, **14**(6), 809–22.

Themanson, J.R., Schreiber, J.A., Larsen, A.D., Dunn, K.R., Ball, A.B., Khatcherian, S.M. (2015). The ongoing cognitive processing of exclusionary social events: evidence from event-related potentials. *Social Neuroscience*, **10**(1), 55–69.

van Beest, I., Williams, K.D. (2006). When inclusion costs and ostracism pays, ostracism still hurts. *Journal of Personality and Social Psychology*, **91**(5), 918–28.

Vohs, K.D., Baumeister, R.F., Ciarocco, N.J. (2005). Self-regulation and self-presentation: regulatory resource depletion impairs impression management and effortful self-presentation depletes regulatory resources. *Journal of Personality and Social Psychology*, **88**(4),632–57.

White, L.O., Wu, J., Borelli, J.L., *et al*. (2012). Attachment dismissal predicts frontal slow-wave ERPs during rejection by unfamiliar peers. *Emotion*, **12**(4),690–700.

White, L.O., Wu, J., Borelli, J.L., Mayes, L.C., Crowley, M.J. (2013). Play it again: neural responses to reunion with excluders predicted by attachment patterns. *Developmental Science*, **16**(6),850–63.

Williams, K.D. (2007). Ostracism. *Annual Review of Psychology*, **58**, 425–52.

Williams, K.D., Forgas, J.P., Von Hippel, W. (2013). *The Social Outcast: Ostracism, Social Exclusion, Rejection, and Bullying*, New York, NY: Taylor & Francis.

Williams, K.D., Jarvis, B. (2006). Cyberball: a program for use in research on interpersonal ostracism and acceptance. *Behavior Research Methods*, **38**(1), 174–80.

Zadro, L., Boland, C., Richardson, R. (2006). How long does it last? The persistence of the effects of ostracism in the socially anxious. *Journal of Experimental Social Psychology*, **42**(5), 692–7.