Published in final edited form as:

J Psychiatr Res. 2020 November ; 130: 1–8. doi:10.1016/j.jpsychires.2020.06.015.

Perceived Burdensomeness and Neural Responses to Ostracism in the Cyberball Task

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Abstract

Previous studies have identified the brain correlates of social pain processing during ostracism. However, the affective response to ostracism may vary according to individual differences in interpersonal needs and subsequent social actions. Despite this relationship, how the neural processes underlying ostracism may be modulated by interpersonal needs to regulate prosocial behaviors remains unknown. Here, in an fMRI study of 64 adults performing the Cyberball task, we quantified ball catching and tossing response time (RT) as a behavioral measure of participants' willingness to seek and reciprocate social interactions. Neural activations to social exclusion were identified and characterized in relation to individual differences in behavioral performance and perceived burdensomeness (PB), a measure of interpersonal needs. The results showed that social exclusion elicited activity in the anterior insula, middle frontal gyrus, postcentral gyrus, and dorsomedial prefrontal cortex, replicating previous studies on ostracism. Importantly, those with higher PB also exhibited greater brain activations to exclusion as well as reduced prosocial behaviors, as reflected by slower ball catching and tossing RT in the Cyberball task. Taken together, these findings suggest that emotional distress in ostracism may increase with PB, resulting in stronger neural responses to social pain and behavioral avoidance of social interactions.

Introduction

Ostracism induces significant emotional distress and threatens the mental well-being of affected individuals (Williams, 2007). A large volume of neuroimaging research has sought to identify the neural processes underlying ostracism (Cacioppo and Cacioppo, 2016). Particularly, studies employing the Cyberball task to simulate social exclusion have reported robust activations in various brain regions including the dorsal anterior cingulate cortex/dorsomedial prefrontal cortex (dACC/dmPFC), middle frontal gyrus (MFG), and anterior insula (AI), (Cacioppo et al., 2013; Rotge et al., 2015; Vijayakumar et al., 2017). As some of these regions have been implicated in nociception, ostracism has subsequently been

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associated with social pain (Eisenberger, 2015; Eisenberger and Lieberman, 2004). However, ostracism does not only elicit hurt feelings (Eisenberger and Lieberman, 2004; MacDonald and Leary, 2005) but also engenders adjustments in social behaviors (Chow et al., 2008; Twenge et al., 2007). The regulation of social behaviors involves cognitive control, a function previously associated with the MFG (Goghari and MacDonald, 2009), AI (Cai et al., 2014), dACC (MacDonald et al., 2000), and other dmPFC regions (Hu et al., 2015; Wang et al., 2018). Thus, it is plausible that the same regions that respond to social pain may also support actions to mitigate ostracism-elicited distress.

Recent imaging work has indeed implicated the MFG, AI, and dACC/dmPFC in the adaptive control of approach and avoidance behaviors in response to motivationally and socially salient events. For instance, the MFG not only shows enhanced activations to emotion-related processing (Grecucci et al., 2013; Ran et al., 2016; Sebastian et al., 2011) but also to goal-directed action and inhibition of action (Le et al., 2019). In the latter study, the MFG activation to monetary loss was further associated with increased avoidance tendency, suggesting the region's modulation of behaviors based on motivational outcomes. Similarly, the dmPFC is known for its role in behavioral regulation in response to fear and negative social feedback (Hoppenbrouwers et al., 2013; Munakata et al., 2011). Emotion processing and cognitive control of goal-directed actions often elicit overlapping activations in the dACC/dmPFC (Buhle et al., 2014; Shackman et al., 2011) and AI (Cromheeke and Mueller, 2014). Thus, these regions likely play a role that extends beyond negative emotion processing to encompass top-down influence on social behaviors during ostracism.

How individuals react to ostracism has been shown to be dependent, in part, on their interpersonal needs (Richman and Leary, 2009). One's perception and valuation of social relationships can determine the course of action following exclusion. Specifically, ostracized individuals may engage in prosocial behaviors to regain acceptance if they value social bonds and strongly identify with the group (De Cremer and Leonardelli, 2003; Maner et al., 2007). In contrast, those who attach high costs to group membership or have heightened rejection sensitivity are more likely to withdraw from further interactions to minimize future distress (Buckley et al., 2004; DeWall and Bushman, 2011). Instrumental to these decisions is individual differences in perceived burdensomeness (PB), a measure of the feeling that one is a burden or drain on others (Joiner et al., 2002; Van Orden et al., 2012). PB has been associated with higher rejection sensitivity (Brown et al., 2019; Lear et al., 2018), emotional pain (Lear et al., 2018; LeRoy et al., 2018), and negative affect during social exclusion (Chu et al., 2019; Hames et al., 2018; Hollingsworth et al., 2018). Previous research additionally reported a positive link between PB and emotional and behavioral avoidance (Hapenny and Fergus, 2017; Tang and Masicampo, 2018). Thus, those with greater PB may respond more strongly to ostracism and disengage from prosocial activities (Richman and Leary, 2009). Despite the numerous imaging studies of the brain substrates of social exclusion, the neural correlates of PB as well as their relationship with the behavioral responses to ostracism remain unclear.

Here, we sought to address this issue by characterizing the relationship of exclusion-elicited brain activity with social interactions and interpersonal needs. Specifically, we examined fMRI data during the performance of the Cyberball task, a paradigm widely used to study

social exclusion (Cáceda et al., 2019; Cheng et al., 2020; Seidl et al., 2020). The response time (RT) of ball catching and tossing in both inclusion and exclusion scenarios were quantified to determine the effects of ostracism on individual differences in the willingness to seek and initiate interactions. Previous studies have employed RT to assess behavioral responses to ostracism, with speeded and prolonged RT reflective of social approach and avoidance, respectively (Kothgassner et al., 2017; Will et al., 2016a). Behavioral performance in the Cyberball task has been investigated in relation to neural responses to ostracism in our previous work (Wang et al., 2019b) though it remained unclear whether PB also plays a role in modulating the RT. We tested the hypothesis that social exclusion would elicit activations in the AI, dACC/dmPFC, and MFG. Importantly, heightened PB was expected to be associated with enhancement of these regional activities and behavioral evidence of social avoidance.

Materials and Methods

Participants

Sixty-four adults (33 women; age = 47.1 ± 16.3 years, mean $\pm$ SD) participated in the study, including 53 from our previous work (Wang et al., 2020, 2019a). Participants underwent clinical screening and received urine toxicology tests at intake and prior to imaging. All were required to be physically healthy with no major medical illnesses, current use of prescription medications, history of head injury or neurological illness, current or history of axis I disorders, as defined by the Diagnostic and Statistical Manual of Mental Disorders IV, or positive urine test results. Prior to the study, participants signed informed consent according to the protocol approved by the Human Investigation Committee at Yale University.

Assessments and behavioral task

Participants completed the 15-item version of the Interpersonal Need Questionnaire (Van Orden et al., 2012, 2008). The questionnaire assesses two measures including perceived burdensomeness (PB – 6 items) and thwarted belongingness (TB – 9 items). PB refers to the belief that “others would be better off without me” whereas TB accounts for the perceived lack of interpersonal connections or the belief that one does not belong (Hill et al., 2015). Items were rated on a 7-point scale ranging from 1 (not at all true for me) to 7 (very true for me), with positive items reverse coded and higher scores indicating greater severity. The current sample showed average scores of 10.1 ± 6.1 and 26.2 ± 13.7 for PB and TB, respectively.

As social anxiety and depression can impact both the performance and brain responses during the Cyberball task (Heeren et al., 2017; Jobst et al., 2015; Levinson et al., 2013), we assessed these characteristics using the Social Interaction Anxiety Scale (SIAS) (Mattick and Clarke, 1998) and Beck Depression Inventory (BDI) (Beck et al., 1996). The 20-item SIAS evaluates fear of general social interaction, with each item scored from 0 to 4 (3 items are reverse coded) and higher scores indicating greater anxiety. Participants reported an average SIAS score of 31.9 ± 22.4 . The BDI measures depression severity with 21 items each on a scale from 0 to 3, with higher scores indicating greater severity. The current sample

showed an average BDI score of 10.5 ± 11.8 . Both SIAS and BDI scores were used as covariates in subsequent analyses to rule out the influence of social anxiety and depression in the results.

Participants performed a variant of the Cyberball task (Williams and Jarvis, 2006) (Fig. 1A) in which they were instructed to play a ball game via the Internet with two other individuals. Unknown to the participants, the other players were fictitious figures controlled by a computer program. Ball toss, catch, and drop were each accompanied by a distinct sound. Participants were asked to do their best to catch the ball by estimating its arrival time and pressing a button. Responding too early or late would result in a “drop” (see below). Once the ball was received, participants pressed a button to decide which of the two fictitious figures to toss the ball to. There were three different scenarios: (1) passive observation (OB) in which participants were explicitly instructed to simply watch; (2) fair game (FG) in which participants received/tossed the ball approximately 1/3 of the time; and (3) social exclusion (EX) in which participants were tossed the ball approximately 1/12 of the time. There were two sessions per scenario. Each session lasted 8 m, separated by a break and following a fixed order: OB-break (~1 m)-FG-break-EX-break-OB- break-FG-break-EX. A trial started with a ball toss initiated by a fictitious player. The fictitious player was animated to appear to think and look alternately at the participant and the other fictitious player before tossing (2.0 to 16.0 s, uniform distribution). The ball traveled for 3.4 to 6.6 s at different speeds, and the participants were allowed a time window of 2 s to catch the ball if tossed to in FG and EX scenarios. The fictitious player smiled or frowned for 2.4 s, depending on whether the participant caught or dropped the ball (the latter delivered together with a “drop” sound), to end the trial. Two buttons were involved, one for interacting (i.e., receiving and tossing) with one player and the other button for the other player.

Results showed that participants successfully received the ball most of the time in FG, with an average drop rate of $13.6 \pm 17.5\%$. In EX, the participants failed to catch the ball all the time, an outcome controlled by the program without participants’ knowledge. This manipulation established a rationale for the fictitious players to be less willing to interact with the participant. The manipulation and the feedback (i.e., fictitious players frowning) were implemented to induce a strong sense of social isolation. The two fictitious players caught the ball successfully in all scenarios. On average, a trial took 15.8 ± 4.8 s in OB, 14.0 ± 6.7 s in FG, and 15.3 ± 5.4 s in EX. There were approximately 61 trials of observation in OB; 23 trials each of observation, ball tossed to, and from the participant in FG; and 51 trials of observation, and 6 trials each with ball tossed to and from the participant in EX. Data from a subsample of the current group was reported in previous studies (Wang et al., 2019a, 2019b).

Imaging protocol and data preprocessing

Conventional T1-weighted spin echo sagittal anatomical images were acquired for slice localization using a 3T scanner (Siemens Trio, Erlangen, Germany). Anatomical 3D MPRAGE images were obtained with spin echo imaging in the axial plane parallel to the anterior commissure – posterior commissure (AC–PC) line with repetition time (TR) = 1900 ms, echo time (TE) = 2.52 ms, bandwidth = 170 Hz/pixel, FOV = 250×250 mm, matrix =

256 × 256, 176 slices with slice thickness = 1 mm and no gap. Functional blood oxygenation level-dependent (BOLD) signals were acquired using multiband imaging (multiband acceleration factor = 3) with a single-shot gradient echo-planar imaging (EPI) sequence. Fifty-one axial slices parallel to the AC–PC line covering the whole brain were acquired with TR = 1000 ms, TE = 30 ms, bandwidth = 2290 Hz/pixel, flip angle = 62°, FOV = 210 × 210 mm, matrix = 84 × 84, voxel size = 2.5 mm isotropic, and no gap.

Imaging data were preprocessed using SPM12 (Wellcome Trust Centre for Neuroimaging). Images from the first five TRs at the beginning of each run were discarded to ensure steady-state equilibrium between RF pulsing and relaxation. Images of each subject were first realigned (motion corrected) and corrected for slice timing. A mean functional image volume was constructed for individual subject per run from the realigned image volumes. These mean images were co-registered with the high-resolution structural image and then segmented for normalization with affine registration followed by nonlinear transformation. The normalization parameters determined for the structure volume were then applied to the corresponding functional image volumes. Voxel size after normalization was 2.5 mm isotropic. Finally, the images were smoothed with a Gaussian kernel of 4-mm FWHM.

Imaging data modeling

As with previous work (Gunther Moor et al., 2012; Wang et al., 2019a; Will et al., 2016b), a general linear model (GLM) was constructed for each subject, with the onsets of ball tossing and catching in each trial convolved with a canonical hemodynamic response function (HRF) and with the temporal derivative of the canonical HRF and entered along with realignment parameters as regressors in the model. Regressors were defined for three distinct events – tossing, receiving, and observation (of ball toss between the two fictitious players) – and were analyzed separately for the inclusion and the exclusion game. Thus, the following events were examined: FO – fair game observation, FR – fair game receiving, FT – fair game tossing, EO – exclusion observation, ER – exclusion receiving, and ET – exclusion tossing.

To assess the brain responses to exclusion, we employed the contrast $EO + ER + ET > FO + FR + FT$. We included all events (i.e., observation, receiving, and tossing) as participants likely felt ostracized throughout the entire scenario of EX. While participants did receive and toss the ball during EX, these events induced sense of exclusion as they happened infrequently and featured negative feedback in the form of a frowning face in disapproval of participants' performance. Further, this contrast allowed us to examine whether brain regions associated with social exclusion may also modulate interactive behavior (i.e., ball catching and tossing).

We identified and removed runs with significant motion (> 3-mm translation peak-to-peak movement and/or 1.5-degree rotation). Additionally, volumes with frame-to-frame displacement exceeding 0.5 mm and/or rotation >1.5° were deemed outliers and removed from analysis. No subject with more than 20% volumes identified as outliers and thus all subjects were included in the analysis.

Head motions in 6 dimensions were entered in the GLM. Serial autocorrelation was corrected by a FAST model and the data were high-pass filtered (1/128 Hz cutoff) to remove low-frequency signal drifts. Contrast images were used in second-level, group analyses, and the results were assessed with a threshold of voxel $p < 0.001$, uncorrected, in combination with a cluster $p < 0.05$, corrected for family-wise error of multiple comparisons, minimum cluster size $k = 74$, according to current reporting standards (Eklund et al., 2016). All activations were reported in MNI coordinates.

Finally, to examine the relationships between brain activations and individual differences in task performance and PB, we extracted the parameter estimates (β contrast) of regional activities defined from the exclusion contrast (see Results) for correlation with RT and PB scores. In particular, we focused on the dACC/dmPFC and MFG per our hypothesized roles of these prefrontal cortical structures in both emotional processing and regulation of approach and avoidance behaviors. Again, we minimized the influence of age, sex, SIAS, and BDI scores by including these variables as covariates in the correlations.

Results

Behavioral findings

The reaction time (RT) of participants catching a ball was calculated by subtracting the time when the ball was thrown by a fictitious player from the time when the participant pressed the button to catch the ball. The RT of participants throwing a ball was calculated by subtracting the time when the participant received the ball from the time when the participant threw the ball. RT was computed separately for the FG and EX sessions (Fig. 1B–C). Results showed that participants were faster at catching but slower in tossing the ball in the EX relative to FG scenarios (p 's $< .001$).

Next, we examined the relationship between task performance and individual differences in interpersonal needs, controlling for age, sex, SIAS scores, and BDI scores. PB scores showed a significant positive correlation with the average RT of ball catching and tossing during EX (i.e., mean [ER + ET] RT) ($r = .34$, $p = .007$, Fig. 1D). TB scores were not significantly correlated with mean [ER + ET] RT, ER RT or ET RT (p 's $> .05$). Thus, greater sense of burdensomeness was associated with reduced prosocial behaviors as measured by the willingness to seek and initiate social interactions.

Imaging findings

Brain activations to Exclusion and their relationship with interpersonal needs

The exclusion contrast $EO + ER + ET > FO + FR + FT$ showed significant activations in the bilateral but predominantly right-hemispheric anterior insula/inferior frontal cortex (AI/IFC), dmPFC which also included dACC (referred to as dACC/dmPFC from here on), right middle frontal gyrus (MFG), left thalamus, right supramarginal gyrus, bilateral occipital cortices, and bilateral pre and postcentral gyrus (PrCG and PoCG) (Fig. 2, Table 1). The reverse contrast did not show any significant activations.

Relationship of brain activations with task performance and social needs

In an ROI analysis, we investigated the relationship between regional activations to social exclusion and measures of interpersonal needs and task performance. The parameter estimates were extracted for each region with significant activation to exclusion. As stated in our hypothesis, we focused on the dACC/dmPFC and right MFG, both of which showed a significant positive relationship with PB (dACC/dmPFC: $r = .34$, $p = .007$, Fig. 3A; MFG: $r = .33$, $p = .009$, Fig. 3B). Additionally, PB was significantly correlated with activity in the left thalamus ($r = .37$, $p = .004$, Fig. 3C). The left PoCG also exhibited a negative relationship with the difference in average ball catching and tossing RT between EX and FG scenarios (i.e., mean [ER + ET] minus mean [FR + FT]) ($r = -.31$, $p = .016$). To ensure robustness of the correlation results, we applied bootstrapping to each correlation and found that all relationships remained significant (p 's $< .019$).

Discussion

Using the Cyberball task, we replicated previous findings that social exclusion elicited activations from the dACC/dmPFC, AI, and MFG. Their activity was positively correlated with individual differences in PB scores, indicating that heightened feeling of burdensomeness predicted greater neural responses to ostracism. Behaviorally, PB scores were also positively associated with ball catching/tossing RT in the exclusion scenario, suggesting that those with greater interpersonal needs may be more likely to withdraw from social interactions in response to ostracism, as reflected by reduced willingness to seek and initiate social activities. Together, these findings extend the literature of social neuroscience by highlighting the behavioral and neural correlates of PB in the Cyberball task.

Neural responses to social exclusion

We found increased activation to social exclusion in multiple regions including the dACC/dmPFC, AI/IFC, and MFG. The involvement of these regions in emotional distress during social exclusion was supported by both recent imaging findings from studies examining ostracism and previous work on pain processing mechanisms. Specifically, various fMRI studies have identified their activations during the performance of the Cyberball task (Eisenberger et al., 2003; Gunther Moor et al., 2012; Nishiyama et al., 2015; Onoda et al., 2010; Preller et al., 2016; Rudolph et al., 2016). As individuals subjected to the Cyberball exclusion manipulation reported a strong sense of rejection and negative emotions (Fung and Alden, 2017; Kraines et al., 2018), it stands to reason that these regions may support the pain response in ostracism. Indeed, the dACC, AI, and MFG have all been implicated in nociception. For instance, MFG connectivity with the periaqueductal gray modulates pain and pain relief (Wager et al., 2007). Circumscribed lesioning (Foltz and White, 1968) and deep brain stimulation (Boccard et al., 2014) of the dACC have been performed to treat chronic pain. The AI and dmPFC (including the dACC) activate strongly to noxious stimuli (Rémy et al., 2003; Wager et al., 2013) and this activation tracks pain intensity (Büchel et al., 2002). It is worth noting that these regions appear to be particularly sensitive to the affective component of the nociceptive signals (Rainville, 2002). As those who experience ostracism often describe the event as “painful”, it is proposed that the evolutionarily older neural mechanisms for nociception may have been co-opted to support the complex response

to social exclusion (Eisenberger, 2012; Eisenberger and Lieberman, 2004; MacDonald and Leary, 2005).

We also observed enhanced activation to social exclusion in the PrCG and PoCG. While not typically associated with emotional processing, these regions may be recruited in the Cyberball task, as reported in a recent meta-analysis (Vijayakumar et al., 2017), due to their role in motor planning and action (Kato and Izumiyama, 2015; Yousry et al., 1997). Indeed, in a post-hoc analysis, we observed that the left PoCG activity was negatively correlated with the RT difference between exclusion and fair game. This finding suggests the potential utility in quantifying RT of ball receiving and tossing to fully explore the behavioral and neural processes during social interaction in the Cyberball task.

Perceived burdensomeness, regional activity, and task performance

The current work shows that greater brain activity during ostracism was positively correlated with PB scores, suggesting that the regional responses to social exclusion are modulated by interpersonal needs. Increased PB may have heightened the feeling of the social pain experienced during ostracism which in turn enhanced the regional activity. Commonly implicated in mental health, including suicidality (Joiner et al., 2002; Van Orden et al., 2006; Zhornitsky et al., 2020), PB has been demonstrated to predict the degree of social and emotional pain (Lear et al., 2018; LeRoy et al., 2018; Ribeiro and Joiner, 2009). Yet, little is known about the neural correlates of PB and the role of such correlates in ostracism. By highlighting the relationship between the neural processes of social pain and PB, the current findings add to the literature of social emotion research.

It should be noted that while activity in different regions was modulated by both PB and social exclusion, they may be involved in different aspects of ostracism. Whereas the dACC/dmPFC has been directly implicated in pain response (Lieberman and Eisenberger, 2006) with increasing pain eliciting greater activation (DeWall et al., 2010), the MFG may play a role in the top-down modulation of pain signal (Lorenz et al., 2003; Wager et al., 2007). As the MFG has been associated with cognitive control of social information (Weissman et al., 2008) and the regulation of pain signal (Lorenz et al., 2003), the region likely supports the mitigation of the affective reactions to social pain. Nevertheless, it remains to be clarified whether these regional activities reflect pain experience (DeWall et al., 2010; Lieberman and Eisenberger, 2006) or a mechanism to down-regulate pain (Lorenz et al., 2003; Wager et al., 2007; Weissman et al., 2008).

We showed that individuals with greater PB scores were slower in catching and tossing the ball, indicating reduced motivation to seek and reciprocate interaction during social exclusion. These findings extend previous reports associating PB with rejection sensitivity (Brown et al., 2019; Lear et al., 2018) by establishing a behavioral correlate of PB. The current work also found increased PB with higher neural responses to exclusion. Thus, individuals who perceived themselves to be burdensome and unworthy of inclusion may adopt an avoidance strategy to minimize future rejections. Indeed, those with heightened PB engage less in social interaction (Opperman et al., 2015) and report higher social isolation (Ahmadpanah et al., 2017) in real life. In contrast, increases in social contact and support have been demonstrated to reduce PB (Allan et al., 2018).

As heightened PB has been linked to greater stress reactivity (Buitron et al., 2016), it is plausible that the stronger emotional demand during the exclusion condition may have prolonged ball tossing and catching RT via reduced cognitive control. Previous research has provided evidence for impaired cognitive control under stress which can lead to poorer task performance (Steinhauser et al., 2007). While we cannot rule out this possibility, given that social exclusion selectively increased ball tossing RT but decreased catching RT, it appears unlikely that the relationship between PB and RT was driven primarily by stress. Furthermore, those with elevated PB are more likely to engage in avoidance processing (Hapenny and Fergus, 2017) and social withdrawal (Hill et al., 2019) as they regard themselves as a liability and burden to others and unworthy of inclusion. Ostracism serves to confirm this belief, further motivating disengagement from social interactions, as manifested in increased RT in the current work. Taken together, there is likely an inter-relationship between PB, brain activity during ostracism, and behaviors such that those with a greater sense of burdensomeness may exhibit more robust brain responses to social exclusion, which subsequently leads to avoidance of prosocial acts to reduce further distress.

Limitations of the study and conclusions

A number of limitations need to be considered for the study. First, although post-scan briefing confirmed frustration during the exclusions session in all participants, some did suspect that they were simply playing a computer game. Nevertheless, an earlier behavioral study showed that social exclusion elicited negative cognitive and affective responses even if the participants were told that they were interacting with a computerized player (Zadro et al., 2004). Second, while PB predicted both neural and behavioral responses to exclusion, we did not observe a significant relationship for TB, a measure of the need to belong. In the current sample, social exclusion elicited an avoidance strategy which is more directly related to PB (Hapenny and Fergus, 2017). Thus, it is plausible that the behavioral tendency following to ostracism may have driven the PB relationships. Finally, although we included age, sex, SIAS score and BDI score as covariates in data analyses, we cannot completely rule out the influences of these variables on the current findings. Individual differences in interpersonal needs likely interact with these variables in important ways that warrant additional investigation.

In conclusion, our work not only replicated previous findings of dACC/dmPFC, AI, and MFG responses to social exclusion in the Cyberball task but also showed an association between these neural correlates and interpersonal needs. Those with heightened PB exhibited greater brain activations to exclusion and enhanced motivation to disengage from social interactions, putatively to avoid further emotional distress. These new findings extended our previous studies demonstrating the neural correlates of self-initiated action and physiological responses during social exclusion. These findings may also provide implications for the understanding of behavioral responses to ostracism and potential intervention to lessen its detrimental impacts on mental health.

Acknowledgements and disclosures

The study was supported by NIH grants MH113134, AA021449 and DA023248. The NIH was otherwise not involved in conceptualization of the study, data collection or analysis, interpretation of the findings, or in the decision to publish these results. We declare no conflicts of interest in the current work.

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Figure 1:

Task schematic and behavioral performance. **(A)** Cyberball task. OB: observation; FG: fair game, with equal shares of catch and toss; EX: exclusion with $\sim 1/12$ ball toss to and from the participant and 0% catch. The ratios indicate the approximate % of ball toss among players. **(B-C)** Behavioral data (mean $\pm$ S.E.) showed that participants were faster at catching (left) but slower in tossing (right) the ball in the EX relative to FG scenarios. ** $p < .001$. **(D)** Perceived burdensomeness (PB) showed a positive relationship with RT of ball catching and tossing during the exclusion scenario. Abbreviations: FR – receiving during fair game, ER – receiving during exclusion, FT – tossing during fair game, ET – tossing during exclusion. Scatterplot here and in the other figures show partial correlations in which regression residuals were used after the effects of sex, age, SIAS, and BDI scores had been removed.

Figure 2:

Brain activations to social exclusion. Exclusion from the game elicited activations in the bilateral but predominantly right-hemispheric anterior insula/inferior frontal cortex, dmPFC which also included dACC, right middle frontal gyrus, left thalamus, right supramarginal gyrus, bilateral occipital cortices, bilateral pre and postcentral gyrus. Threshold: voxel-level $p = .001$ (uncorrected) and cluster-level $p = .05$ (corrected for familywise error). Color scale indicates t statistics.

Figure 3:

Relationship between neural activity during exclusion and individual differences in perceived burdensomeness (PB). PB was positively associated with activity of (A) dACC/dmPFC, (B) right MFG, and (C) left thalamus. Note that, as we conducted partial correlations, the plots show the correlation of the residuals after the effects of SIAS, BDI, age, and sex had been removed.

Table 1:

Activations to social exclusion

Region	MNI coordinates (mm)			Voxel T	Cluster k
	x	y	z		
AI	48	22	-12	6.85	242
	48	16	-4	5.53	
	45	9	-2	5.36	
IFC	-55	9	0	5.57	100
AI	-50	16	-7	5.28	
Supramarginal gyrus	-34	22	-7	4.19	261
	55	-28	28	6.08	
	65	-28	26	5.48	
Precentral gyrus	60	-21	46	4.28	230
Occipital cortex	40	-71	-17	5.78	
	50	-64	-20	4.57	
Thalamus	-40	-76	-14	4.95	87
	-32	-78	-17	4.78	
	-10	-14	8	4.27	
dACC/dmPFC	2	29	36	5.54	374
	8	12	60	5.05	
	2	9	48	4.83	
Precentral gyrus	-35	-8	66	5.16	184
	-40	-16	56	5.00	
	52	-33	50	3.57	
Middle frontal gyrus	52	9	40	5.13	220
	38	-1	63	5.06	
	45	2	53	4.74	
Postcentral gyrus	-48	-34	38	4.91	101
	-60	-28	46	4.68	
	-50	-36	48	4.27	
	40	-44	56	4.64	

Abbreviations: AI – anterior insula, dmPFC – dorsomedial prefrontal cortex, IFC – inferior frontal cortex