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Decreased interoceptive accuracy following social exclusion

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Highlights

- We examine the effect of social exclusion on interoceptive accuracy.
- Interoceptive accuracy is measured via a heartbeat perception task.
- Social exclusion is manipulated using the Cyberball paradigm.
- Exclusion decreases heartbeat perception accuracy.

Abstract

The need for social affiliation is one of the most important and fundamental human needs. Unsurprisingly, humans display strong negative reactions to social exclusion. In the present study, we investigated the effect of social exclusion on interoceptive accuracy—accuracy in detecting signals arising inside the body— measured with a heartbeat perception task. We manipulated exclusion using Cyberball, a widely used paradigm of a virtual ball-tossing game, with half of the participants being included during the game and the other half of participants being ostracised during the game. Our results indicated that heartbeat perception accuracy decreased in the excluded, but not in the included participants. We discuss these results in the context of the social and physical pain overlap, as well as in relation to internally versus externally oriented attention.

Keywords: Ostracism; Social exclusion; Social Pain; Cyberball; Interoception; Interoceptive accuracy; Heartbeat perception

1. Introduction

The need for social affiliation is one of the most important and fundamental human needs. From an evolutionary perspective, belonging to social groups carried several advantages in terms of survival, and reproductive opportunities and success (Brewer, 2004). Consequently, it is not surprising that humans display strong negative reactions to social exclusion and rejection. Long-term social isolation and loneliness has been associated with depression and other negative health outcomes such as increased mortality (e.g., Steptoe, Shankar, Demakakos, & Wardle, 2013) and enhanced risk of immune dysregulation (e.g., Jaremka et al., 2013). Even small-scale social rejection in a computerized ball-tossing game, Cyberball (Williams, Cheung, & Choi, 2000; Williams & Jarvis, 2006)—a paradigm developed to study social ostracism in an experimental setting—can impact individual's psychological and physiological state. A few minutes of being Cyber-ostracised can significantly increase negative affect and lower one's sense of belonging, control, meaningful existence and self-esteem (see Williams, 2009 for a review)—independently of factors such as monetary gains and costs associated with ball possession (van Beest & Williams, 2006), or the desirability of the ostracisers (Gonsalkorale & Williams, 2007). Social exclusion has also been found to bring about a significant drop in skin temperature (IJzerman et al., 2012), while both, heart rate deceleration (Gunther Moor, Crone, & van der Molen, 2010) and acceleration (Iffland, Sansen, Catani, & Neuner, 2014) have been observed in response to exclusion.

As Cyberball excluded individuals show increased activation in the dorsal anterior cingulate cortex and the anterior insula (see Eisenberger, 2012a; 2012b)—brain regions associated with the affectively distressing component of physical pain (Rainville, 2002)—it has been suggested that social exclusion constitutes a form of social pain. A close connection exists between the experience of social and physical pain—both in terms of neural correlates (see Eisenberger, 2012a, 2012b for a review) as well as psychological consequences (Riva, Wirth, & Williams, 2011; Riva, Wesselman, Wirth, Carter-Sowell, & Williams, 2014). However, recent research suggests that there is a limit to the social and physical pain overlap. More specifically, Riva, Williams, and Gallucci (2014) have observed that fear of physical pain and fear of social pain selectively affect the experience of physical and social pain, respectively, failing to find an effect of fear of physical pain on the experience social pain and vice versa. Additionally, a recent meta-analysis by Cacioppo et al. (2013) did not indicate a full overlap in the neural networks activated by social rejection and by physical pain, suggesting that the connection between social and physical pain systems might be more complex than previously thought. Consequently, Cacioppo and colleagues suggest that the neural network activated by social exclusion—reliably involving the anterior insula and the anterior cingulate—might be more reflective of “social uncertainty, rumination, distress, and craving rather than social pain per se” (p. 2).

Interoception—the perception of afferent visceral signals—is a key process linking physiological states and emotional experience, and the insula—the central brain region associated with interoception—has been proposed to integrate sensory inputs from the body to bring about feeling states (Craig, 2009). The fact that insula has been consistently found to be activated by social exclusion (Cacioppo et al., 2013; Eisenberger, 2012a, 2012b) suggests that interoceptive accuracy—the accuracy with which an individual perceives own internal signals (directly associated with insula activity (e.g., Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004))—might be affected by this socially distressing experience. Interoceptive accuracy, assessed via heartbeat perception accuracy, has been proposed to be a mediating factor in the subjective experience of emotion (e.g., Pollatos, Kirsch, & Schandry, 2005). Accumulating evidence indicates that individuals with better heartbeat perception accuracy experience emotions more intensely, as indicated by subjective ratings of arousal (e.g., Pollatos, Traut-Mattausch, Schroeder, & Schandry 2007) and patterns of electroencephalographic activity during exposure to emotion-eliciting stimuli (Herbert, Pollatos, & Schandry, 2007). Although, in the past, interoceptive accuracy has been characterized mainly as a stable individual difference variable (e.g., Schandry, 1981), recent research suggests that interoceptive accuracy is also subject to state changes, with heartbeat perception accuracy increasing in conditions characterized by heightened self-focus (Ainley, Tajadura-Jimenez, Fotopoulou, & Tsakiris, 2012; Ainley, Maister, Brokfeld, Farmer, & Tsakiris, 2013) and anxiety (Durlik, Brown, & Tsakiris, 2013).

The present study investigated the stability of interoceptive accuracy, measured via heartbeat perception accuracy, in response to Cyberball social exclusion. As social exclusion has been found to bring about increased activity in the anterior insula (Cacioppo et al., 2013; Eisenberger 2012a, 2012b), which, in turn, has been associated with enhanced interoceptive accuracy (e.g., Critchley et al., 2004), we hypothesized that social exclusion during the Cyberball game would bring about increased interoceptive accuracy—as reflected by an increase in heartbeat perception accuracy from pre- to post-Cyberball in excluded, but not included individuals. As previous research has found heartbeat perception accuracy to be directly associated with the intensity of emotional experience (e.g., Pollatos et al., 2007), we hypothesized that the increase in heartbeat perception accuracy from pre- to post-Cyberball in the excluded individuals will be positively correlated with the self-reported distress following the exclusion. Lastly, potential moderating effects of baseline heartbeat perception accuracy and sex were examined in the present study. Previous research has found that individuals with lower baseline heartbeat perception accuracy, categorized with median splits, experienced greater subjective reactions to social exclusion (Werner, Kerschreiter, Kindermann, & Duschek, 2013), and greater enhancement in accuracy due to self-focus (Ainley et al., 2012). Additionally, some studies have found sex differences in interoceptive accuracy with males being more accurate than females (Cameron, 2001). Consequently, we included baseline heartbeat perception accuracy, and sex as a between-subjects factors in our analyses.

2. Material and Methods

2.1 Participants

64 (43 female; Mean age = 21.31; *SD* = 2.86) students at Royal Holloway, University of London took part in the experiment in compensation for £5. The sample size was based on previous research investigating state changes in heartbeat perception accuracy (e.g., Durlik, Brown, & Tsakiris, 2014). Participants were randomly assigned to one of two conditions so that half of the participants were in the experimental condition (*N* = 32) where they were excluded while playing Cyberball and the other half of the participants were in the control condition (*N* = 32) where they were included while playing Cyberball. All participants were non-psychology students who were naïve to the Cyberball paradigm.

2.2 Cyberball

The computerized ball tossing game (Williams et al., 2000) consisted of 30 ball tosses in total, between the participant and 2 computerized players. Participants were asked to pose for a photograph to be taken. They were told the photograph would be displayed in a box beside their avatar, while they played the game, for the other participants to see. Photographs of the computerized players: Player 1 and Player 3 were taken from The Center for Vital Longevity Face Database (obtained from: http://agingmind.utdallas.edu/stimuli/facedb/). Player 2 was the participant, and the photograph of the participant was not visible on the screen during the game in order not to increase participants self-focus, which has been found to enhance heartbeat perception accuracy (Ainley et al., 2012, 2013). In the included condition the tosses were distributed equally among the three players with the participant receiving the ball on one third of the tosses (10 tosses in total), while in the excluded condition the participant received the ball 2 times, at the very beginning of the game (once from Player 1 and once from Player 2), after which the participant was excluded from the game while the ball was passed only between Player 1 and Player 3 for the remainder of tosses (28 tosses). Cyberball 4.0 (Williams, Yeager, Cheung, & Choi, 2012) was administered through the online survey software Qualtrics (www.qualtrics.com), using the script obtained on www.cyberball.wikispaces.com.

2.3 Post-Cyberball Questionnaire

The post-Cyberball questionnaire was based on previous studies utilizing the Cyberball paradigm (e.g., Williams et al., 2002; Zadro, Boland, & Richardson, 2006) and assessed four fundamental needs (with five items per need): Belonging, Control, Meaningful existence and Self-esteem. Eight items retrospectively assessed positive and negative affect during the game. Additionally, participants reported how “ignored” and “excluded” they felt during the game, and estimated the percentage of total throws they think they received during the game. All items, except for the last one, were rated on a continuous 5-point scale ranging from ‘not at all’ to ‘extremely’.

2.4 Heartbeat Perception Accuracy Task

Interoceptive accuracy was assessed via heartbeat perception, using the Mental Tracking Method (Schandry, 1981). Participants were instructed to lightly place the heels of their hands on the heart rate sensor that was attached to the desk in front of them. Participants were asked to mentally count their heartbeats from the moment they received an audio cue signaling the start of the trial, until they received an otherwise identical cue signaling the end of the trial, and then to verbally report to the experimenter the number of heartbeats they have counted. Every participant was first presented with a 10-second training trial (during the first assessment only), and then with a pseudo-randomized block of 35-second, 25-second, and 45-second trials, with 20-second pauses in between the trials. Note that in small samples, where randomization often does not result in comparable distributions of conditions across groups, a pseudo-random order can increase procedural comparability between groups (Wolk, Sutterlin, Koch, Vogele, & Schulz, 2014). During the whole duration of the task, participants' true heart rate was monitored using the POLAR RS800CX heart rate monitor (Polar Electro Oy, Kempele, Finland sampling rate of 1000 Hz). Signals were analyzed by the Polar ProTrainer 5 software (version 5.40.172), which relies on the HRV analysis software of the University of Kuopio, Finland (Niskanen, Tarvainen, Ranta-aho, & Karjalainen, 2004). The software's filtering process corrects for missed beats and false positives using median and moving average based filtering methods (polar.com/en/support/Polar_ProTrainer_5). POLAR products have excellent construct validity and instrument reliability, measuring heart rate, and R-R interval data on par with electrocardiogram recorded data (e.g., Kingsley, Lewis, & Marson, 2005; Nunan et al., 2008; Quintana, Heathers, & Kemp, 2012; Weippert, Kumar, Kreuzfeld, Arndt, & Rieger, 2010). Throughout the task, participants were not permitted to take their pulse, or to use any other strategy such as holding their breath. No information regarding the length of the individual trials or feedback regarding participants' performance was given. All participants performed the heartbeat accuracy task twice: at baseline and after the Cyberball game.

2.5 Procedure

Upon arrival to the lab, participants were given information about the study that was essential to provide informed consent, but that did not disclose the real objectives of the experiment. After the participants signed an informed consent form, the experiment begun. Participants were seated at a desk in front of a computer and begun by providing basic demographic information. Then, participants were instructed to lightly place the heels of their hands on the heartbeat sensor attached to the desk in front of them, and completed the first heartbeat perception accuracy task (approximately 3 minutes prior to playing Cyberball), which served as a baseline interoceptive accuracy measure. After a photograph of the participant was taken using a web-camera connected to the computer, participants read the standard Cyberball instructions (see Williams and Jarvis, 2006). Participants were told that they would be playing the game with other students currently online on the University of London network. Participants then played the game for about 2-3 minutes, during which they were either included or excluded by the other two players (see ‘Experimental Design’ for further details). Once the game came to an end, participants started the heartbeat perception accuracy task for the second time (within 1 minute after finishing the Cyberball game). Then, participants completed the post-Cyberball questionnaire. The heartbeat perception accuracy task was administered before the post-Cyberball questionnaire, due to a potentially short-lived fluctuation in heartbeat perception accuracy (e.g., Antony, Meadows, Brown, & Barlow, 1995). The entire experiment was administered using the online survey software Qualtrics (www.qualtrics.com). Upon completion of the experiment, participants were fully debriefed.

2.6 Data Analysis

2.6.1 Heartbeat perception accuracy scores

Heartbeat perception accuracy (HPA) scores were calculated according to the standard formula used in research on cardiac interoceptive accuracy (e.g., Fustos, Gramman, Herbert, & Pollatos, 2013; Pollatos, Fustos, & Critchley, 2012; Werner et al., 2013):

$1/3 \Sigma (1-(|\text{actual heartbeats} - \text{reported heartbeats}|) / \text{actual heartbeats})$.

In the present study, Cronbach's α for the HPA task (based on the perception accuracy scores of the three intervals) was $\alpha = .94$ for the first assessment and $\alpha = .93$ for the second assessment. In line with previous research (e.g., Ainley et al., 2012; Durlik, Cardini, & Tsakiris, 2014; Pollatos & Schandry, 2008; Suzuki, Garfinkel, Critchley, & Seth, 2013; Werner et al., 2013), we categorized individuals into two groups, consisting of 30 persons with lower baseline HPA (*M* = .44, *SD* = .09) and 29 persons with higher baseline HPA (*M* = .76, *SD* = .12), using a median split on the baseline HPA score (median = .57).

2.6.2 Post-Cyberball Questionnaire

Items belonging to each of the four need subscales were summed (negative items were first reverse scored) to create four total scores of Belonging, Control, Meaningful Existence, and Self-Esteem. Items assessing positive affect and items assessing negative affect were summed to create total positive affect and negative affect scores, respectively. The two items assessing how ignored and how excluded the participants felt were summed.

2.6.3 Data exclusions

In order to ensure that individuals experienced the manipulation as intended, an outlier analysis was performed on manipulation check scores—i.e., retrospective reports of exclusion, and mood (positive and negative affect) during the game. Cases with scores 2 standard deviations above/below group mean on either exclusion or total mood scores were excluded from the main analysis, as they reported experiencing the game in an atypical manner in comparison to the vast majority of the sample (for example, reporting feeling highly included in the excluded condition, or reporting feeling highly excluded in the included condition). Three cases were excluded from the excluded group (reports of exclusion 2 standard deviations below the condition mean), and 2 cases were excluded from the included group (negative mood 2 standard deviations above the condition mean) with 59 cases remaining in total (29 in the excluded condition and 30 in the included condition).

2.6.4 Statistical analyses

Manipulation check analyses tested for differences in post-Cyberball questionnaire scores between the included and excluded groups. Where the scores were normally distributed, independent samples t-tests were computed, and where the scores were not normally distributed, Mann-Whitney U tests were computed. Independent samples t-tests and

Mann-Whitney U tests were also used to test for potential differences in post-Cyberball questionnaire scores between excluded male and female individuals, and between excluded individuals who had lower baseline HPA versus higher baseline HPA. The effect of social exclusion versus inclusion on HPA scores, and on heart rate was examined using two 2 x 2 x 2 x 2 mixed ANOVAs, each with a within-subject factor of Time (baseline, post-cyberball) and between-subjects factors of Condition (excluded or included), Sex (male, female), and HPA group (lower HPA, higher HPA). Pearson's *r* (where both variables were normally distributed) and Spearman's *ρ* (where one or both variables were not normally distributed) correlation coefficients were computed to examine the associations between changes in HPA, changes in HR, and post-Cyberball questionnaire subscales.

3. Results

First, we tested the effect of the Cyberball manipulation on self-reported manipulation check measures. Mann-Whitney U tests were conducted to test for differences in the post-Cyberball questrionnaire subscales, as they were not normally distributed across all participants (with the exception of the Self-Esteem and positive affect subscales, which were normally distributed across all participants, allowing for the use of independent samples t-tests). Bonferroni corrections for multiple comparisons were applied throughout the analysis. Participants in the exclusion condition reported significantly lower sense of Belonging (U = 39.000, $Z = -6.018$, $p < .001$), Control ($U = 109.000$, $Z = -4.956$, $p < .001$), Meaningful existence (U = 76.000, $Z = -5.462$, $p < .001$), and Self-Esteem ($t\ (57) = -5.403$, $p < .001$) after the Cyberball game than participants in the inclusion condition. Moreover, participants in the exclusion condition reported feeling significantly more negative affect (U = 100.500, $Z = -5.103$, $p < .001$) and significantly less positive affect ($t\ (57) = -6.053$, $p <.001$) during the game than participants in the inclusion condition. Lastly, participants in the exclusion condition reported feeling significantly more excluded during the game (U = 10.500, $Z = -$

6.549, $p < .001$) than participants in the inclusion condition, and estimated that they received a significantly lower percentage of total throws during the game (U = .000, Z = - 6.639, $p <$ .001) than participants in the inclusion condition. Overall, the included and excluded groups differed significantly on all of the self-reported measures (see Table 1 for means and standard deviations), confirming that our manipulation was successful.

Insert Table 1

Note that there were no significant differences between excluded male and female individuals, and between excluded individuals who had lower baseline HPA and higher baseline HPA, as indicated by *p*-values above .05 on a series of Mann-Whitney U tests, and independent sample t-tests.

We proceeded to test for differences in HPA from pre- to post-Cyberball in the excluded and included groups. It should be noted that HPA scores at baseline were not significantly different in the included and excluded groups (t (57) = 1.235, p = .222, 95% CI [-.038, .16]). Baseline and post-Cyberball HPA scores were both normally distributed, and were analyzed in a 2 x 2 x 2 x 2 mixed ANOVA with a within-subject factor of Time (baseline, post-Cyberball) and between-subjects factors of Condition (excluded or included), Sex (male, female), and HPA group (lower HPA, higher HPA). The results revealed a significant interaction effect of Time and Condition on HPA scores (F (1, 51) = 7.017, p = .011, η^2_p = .121, 95% CI [-.098, -.014]). Pairwise t-tests revealed a significant difference in HPA from baseline to post-Cyberball only in the excluded group, where HPA decreased significantly from baseline to post-Cyberball (t (28) = 2.468, p = .020, Cohen's d = .203, 95% CI [-.073, .007]) and no significant difference in HPA from baseline to post-Cyberball in the included group (t (29) = -.466, p = .644, 95% CI [-.024, .038]). See Figure 1 for a graphical depiction of the interaction effect of Time and Condition on HPA.

Insert Figure 1

There was no main effect of Sex on HPA (F (1, 51) = .018, p = .895), and Sex did not moderate the interaction effect of Time and Condition on HPA (F (1, 51) = 1.475, p = .230). HPA group also did not moderate the interaction effect of Time and Condition on HPA (F (1, 51) = .987, p = .325)

In order to test whether differences in HPA between the included and excluded groups were due to differences in heart rate, heart rate was analyzed in a 2 x 2 x 2 x 2 mixed ANOVA with a within-subject factor of Time (baseline, post-Cyberball) and between-subjects factors of Condition (excluded or included), Sex (male, female), and HPA group (lower HPA, higher HPA). The results revealed a significant effect of Time on heart rate (F (1, 51) = 7.049, p = .011, η^2_p = .121, 95% CI [-1.975, -.274]), as participants decreased in average heart rate from baseline to post-Cyberball. Importantly, there was no significant interaction effect of Time and Condition (F (1, 51) = 2.067, p = .157, 95% CI [-2.918, .483]), indicating that all participants' heart rates decreased by a comparable degree, suggesting that the heart rate decrease was not due to the manipulation, but rather was brought about by a habituation to the lab setting. There was no main effect of Sex (F (1, 51) = .178, p = .675), and no interaction effect of Time, Condition, and Sex (F (1, 51) = 2.040, p = .159) on average heart rate. Although there was a significant main effect of HPA group on average heart rate (F (1, 51) = 16.591, p < .001, η^2_p = .245), there was no interaction effect of Time, Condition, and HPA group (F (1, 51) = .569, p = .454) on average heart rate.

In order to examine whether the decrease in HPA from pre- to post-Cyberball in the excluded group was associated with heart rate change or Post-Cyberball measures, Pearson's *r* correlation coefficients were computed for analyses where both variables were normally distributed, and Spearman's *ρ* correlation coefficients were computed for analyses where one or both variables were not normally distributed. Variables which were not normally distributed within the excluded group included the Control subscale, self-reported exclusion, and the perceived percentage of throws received. Change in HPA in the excluded group was not significantly correlated with any of the variables. See Table 2 for correlation coefficients.

Insert Table 2

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4. Discussion

In the current study, we utilized the Cyberball paradigm to investigate the effect of social exclusion on interoceptive accuracy, as measured via heartbeat perception accuracy (HPA). Because previous research found that social exclusion increases activity in the anterior insula (Cacioppo et al., 2013; Eisenberger 2012a, 2012b), and because anterior insula activation has been associated with enhanced interoceptive accuracy (e.g., Critchley et al., 2004), we hypothesized that social exclusion during the Cyberball game would bring about increased HPA. Contrary to our hypothesis, we found that HPA decreased from pre- to post-Cyberball in excluded individuals. There were no differences in self-report measures evoked by social exclusion between males and females, nor between individuals with low versus high baseline HPA. Change in HPA was not due to change in heart rate—included and excluded individuals decreased in heart rate to the same extent, whereas HPA changed only in the excluded group. Also, the change in HPA was not significantly associated with any of the post-Cyberball questionnaire subscales. It should be noted that it was essential to administer the post-Cyberball questionnaire after the heartbeat counting task due to a potentially short lived effect of social exclusion on HPA, in comparison to the established robust effect of social exclusion on the post-Cyberball questionnaire measures. However, it is possible that due to a delay in the administration of the post-Cyberball questionnaire, the self-reports were more reflective rather than reflexive, which could, in turn, potentially account for the lack of a correlation between changes in HPA and self-reported affect after the game. Nevertheless, past research indicates that situational changes in HPA do not necessarily have to be accompanied by changes in subjective emotional experience (Durlik, Brown, & Tsakiris, 2014). Overall, our results suggest that social rejection decreases individual ability to detect cardiac interoceptive signals.

The decrease in HPA observed in the present study contradicts studies indicating increased activity in the insula—the interoceptive centre of the brain (Craig, 2009)—in response to social exclusion (see Cacioppo et al., 2014). The HPA decrease observed in the current study can, however, be explained using previous research on the nature of social exclusion and its physiological and behavioural effects. One possibility is that decreased accuracy in detecting interoceptive signals might reflect a numbing response to social exclusion. A recent study by Hsu and colleagues (2013) indicates that social rejection can activate an endogenous opioid system that alleviates physical pain, reflected by μ-opioid receptor system activity along the neural pathway consisting of the ventral striatum, amygdala, midline thalamus, periaqueductal gray, anterior insula and anterior cingulate cortex. Additional evidence for numbing effects of socially painful experiences comes from a series of experiments by DeWall and Baumeister (2006) who show that anticipated aloneness can bring about decreased sensitivity to physical pain—as reflected by higher pain thresholds, and higher pain tolerance in the experimental condition (Experiment 1-4)—as well as lesser emotional sensitivity—as reflected by lesser empathizing with another person's physical and social pain—and decreased affective forecasting. In line with these results, it could be suggested that, in the present study, individuals experienced social pain during the game, which then induced a pain-induced analgesic response. This hypothesis would also be in line with studies showing an inverse relationship between HPA and pain thresholds or pain tolerance levels (Pollatos, Fustos, & Critchley, 2012). Nevertheless, it should be considered that DeWall and Baumeister used a different social exclusion paradigm than the present study, and studies investigating the effect of Cyberball exclusion on physical pain perception suggest that there is a heightening, rather than numbing, of physical pain following social pain (Eisenberger, Jarcho, Lieberman, & Naliboff, 2006). Bernstein and Claypool (2012) suggest that exclusion severity might determine whether hyper- or hypo-sensitivity to physical pain follows, with pain sensitization being associated with exclusion of lesser severity, and pain numbing being associated with highly severe exclusion. As there was no measure of physical pain in the present experiment, we cannot ascertain whether our participants experienced physical pain numbing or heightening following social exclusion, and future studies should investigate the relationship between interoceptive and pain processing changes following social exclusion.

As threat captures and holds attention (e.g., Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004), one could argue that the decrease in HPA following Cyberball exclusion results from a lack of availability of attentional resources necessary to perform the task, which, instead, are deployed to process the social threat of the exclusion. Consequently, an alternative explanation of the HPA decrease following social exclusion observed in the present study is a switch from relying on the predictive control system to relying on the reactive control system of the brain (Tops, Boksem, Luu, & Tucker, 2010; Tops, Boksem, Quirin, IJzerman, & Koole, 2014). Tops and colleagues (2010, 2014) propose that the predictive control system—associated with the posterior medial-dorsal cortical system—processes familiar information and guides behavior in familiar and highly predictable environments, while the reactive control system—tied to the anterior temporal-ventrolateral prefrontal cortical system—processes novel, and salient stimuli in unpredictable environments. Tops and colleagues argue that the predictive system, being guided by internal models of self and others, is essential for internally directed cognition and self-reflection, and consequently, being able to access one's own state, whereas the reactive system is guided by the experiential mode which is focused on the here and now, with environmental cues directing ongoing evaluation of action progress. As social exclusion constitutes a highly salient and threatening situation in which individuals must become more vigilant of the surroundings, it likely activates the reactive control system. This is supported by research on the effects of social exclusion on thermoregulation, which shows that socially excluded individuals show decreased skin temperature, most likely due to the reactive system increasing core body temperature, and decreasing skin temperature and blood flow to the extremities (see IJzerman et al., 2012). Consequently, in the present study, the social exclusion could have triggered a shift from predictive to reactive control, which could have caused attention to be oriented externally rather than internally, resulting in decreased accuracy in detecting internal bodily signals such as heart beats.

Finally, decreased self-focus and increased other-focus could be used to explain the results of the present study. As social isolation constitutes a threat to the organism, socially rejected individuals are likely to engage in behavioral patterns aimed at reestablishing social bonds following rejection. For example, Lakin, Chartrand and Arkin (2008) have observed that after being excluded in a Cyberball game, individuals tend to mimic a stranger to a larger degree than those who did not experience the social rejection. Further, Hess and Pickett (2010) show that individuals excluded during the Cyberball game have reduced memory for self-related social behaviours, and increased memory for other-related social behaviours, as compared to individuals included in the game. Overall, these results suggest that social exclusion brings about a decrease in self-focus, and an increase in other-focus. While nonconscious mimicry and other affiliation-increasing behaviours inherently rely on disengaging from the self and reengaging with the other, some researchers have suggested that decreased self-focus in an emotionally painful situation might also serve as a defense strategy in which the individual protects him or herself from aversive self-awareness (e.g., Twenge, Catanese & Baumeister, 2003), which can bring about distressing thoughts about the self, in light of the socially painful situation (e.g., Heatherton & Baumeister, 1991). However, Hess and Pickett (2010) highlight that by disengaging from the self, the individual can simultaneously avoid the distress brought about by social failure, while freeing attentional resources, which can then be allocated to others and the external world, with the aim to increase affiliation and improve the likelihood of social success in the future. As past research shows that conditions characterized by heightened self-focus are associated with enhanced HPA (Ainley et al., 2012; Ainley et al., 2013), it is likely that the decrease in HPA following social exclusion observed in the present study reflects decreased self-focus and increased other-focus following the exclusion. Of course, it should be noted that in the present study we did not measure other-focus. While it is likely that social exclusion during the Cyberball game brought about a decrease in self-focus, which in turn resulted in poorer HPA, the exact nature of the mechanism behind this effect posits a topic for future investigation.

4.1 Conclusions

To conclude, our results show that social exclusion brings about a less accurate perception of signals arising from the inner body, specifically heart beats. Several explanations of the results observed in the present study exist including a numbing response, a shift from predictive to reactive control, and a decrease in self-focus and increase in other-focus. Consequently, future research should aim to distinguish between aforementioned alternative hypotheses by carefully designing studies that investigate the effect of social exclusion on interoceptive accuracy and on physical pain, and attention, while carefully delineating the neural mechanisms of these changes. Additionally, as HPA has been established to be a valid measure of interoceptive accuracy across modalities (e.g., Herbert, Muth, Pollatos, & Herbert, 2012), it is likely that our results reflect a reduced ability to detect interoceptive signals in general, following social exclusion. Nevertheless, further research should aim to investigate this effect in other interoceptive modalities.

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References

Ainley, V., Maister, L., Brokfeld, J., Farmer, H., & Tsakiris, M. (2013). More of myself: Manipulating interoceptive awareness by heightened attention to bodily and narrative aspects of the self. *Consciousness and cognition, 22*(4), 1231-1238. doi: 10.1016/j.concog.2013.08.004

Ainley, V., Tajadura-Jimenez, A., Fotopoulou, A., & Tsakiris, M. (2012). Looking into myself: Changes in interoceptive sensitivity during mirror self-observation. *Psychophysiology, 49*(11). doi: 10.1111/j.1469-8986.2012.01468.x

Antony, M. M., Brown, T. A., Craske, M. G., Barlow, D. H., Mitchell, W. B., & Meadows, E. A. (1995). Accuracy of heartbeat perception in panic disorder, social phobia and nonanxious subjects. *Journal of Anxiety Disorders, 9*(5), 355-371. doi: 10.1016/0887-6185(95)00017-i

Bernstein, M. J., & Claypool, H. M. (2012). Social Exclusion and Pain Sensitivity: Why Exclusion Sometimes Hurts and Sometimes Numbs. *Personality and Social Psychology Bulletin, 38*(2), 185-196. doi: 10.1177/0146167211422449

Brewer, M. B. (2004). Taking the social origins of human nature seriously: Toward a more imperialist social psychology. *Personality and Social Psychology Review, 8*(2), 107-113. doi: 10.1207/s15327957pspr0802_3

Cacioppo, S., Frum, C., Asp, E., Weiss, R. M., Lewis, J. W., & Cacioppo, J. T. (2013). A Quantitative Meta-Analysis of Functional Imaging Studies of Social Rejection. *Scientific Reports, 3*. doi: 10.1038/srep02027

Cameron, O. G. (2001). Interoception: The inside story - A model for psychosomatic processes. *Psychosomatic Medicine, 63*(5), 697-710.

Craig, A. D. (2009). How do you feel - now? The anterior insula and human awareness. *Nature Reviews Neuroscience, 10*(1), 59-70. doi: 10.1038/nrn2555

Critchley, H. D., Wiens, S., Rotshtein, P., Ohman, A., & Dolan, R. J. (2004). Neural systems supporting interoceptive awareness. *Nature Neuroscience, 7*(2), 189-195. doi: 10.1038/nn1176

DeWall, C. N., & Baumeister, R. F. (2006). Alone but feeling no pain: Effects of social exclusion on physical pain tolerance and pain threshold, affective forecasting, and interpersonal empathy. *Journal of Personality and Social Psychology, 91*(1), 1-15. doi: 10.1037/0022-3514.91.1.1

Durlik, C., Brown, G., & Tsakiris, M. (2013). Enhanced interoceptive awareness during anticipation of public speaking is associated with fear of negative evaluation, *Cognition & Emotion*. doi: 10.1080/02699931.2013.832654

Durlik, C., Cardini, F., & Tsakiris, M. (2014). Being watched: The effect of social self-focus on interoceptive and exteroceptive somatosensory perception. *Consciousness and Cognition, 25,* 42-50. doi: 10.1016/j.concog.2014.01.010

Eisenberger, N. I. (2012a). Broken Hearts and Broken Bones: A Neural Perspective on the Similarities Between Social and Physical Pain. *Current Directions in Psychological Science, 21*(1), 42-47. doi: 10.1177/0963721411429455

Eisenberger, N. I. (2012b). The pain of social disconnection: examining the shared neural underpinnings of physical and social pain. *Nature Reviews Neuroscience, 13*(6), 421-434. doi: 10.1038/nrn3231

Eisenberger, N. I., Jarcho, J. M., Lieberman, M. D., & Naliboff, B. D. (2006). An experimental study of shared sensitivity to physical pain and social rejection. *Pain, 126*(1-3), 132-138. doi: 10.1016/j.pain.2006.06.024

Fustos, J., Gramann, K., Herbert, B. M., & Pollatos, O. (2013). On the embodiment of emotion regulation: interoceptive awareness facilitates reappraisal.*Social Cognitive and Affective Neuroscience, 8*(8), 911-917. doi: 10.1093/scan/nss089

Gonsalkorale, K., & Williams, K. D. (2007). The KKK won't let me play: Ostracism even by a despised outgroup hurts. *European Journal of Social Psychology, 37*(6), 1176-1186. doi: 10.1002/ejsp.392

Gunther Moor, B. G., Crone, E. A., & van der Molen, M. W. (2010). The Heartbrake of Social Rejection: Heart Rate Deceleration in Response to Unexpected Peer Rejection. *Psychological Science, 21*(9), 1326-1333. doi: 10.1177/0956797610379236

Heatherton, T. F., & Baumeister, R. F. (1991). Binge eating as escape from self-awareness. *Psychological Bulletin, 110*(1), 86-108. doi: 10.1037//0033-2909.110.1.86

Herbert, B. M., Muth, E. R., Pollatos, O., & Herbert, C. (2012). Interoception across Modalities: On the Relationship between Cardiac Awareness and the Sensitivity for Gastric Functions. *Plos One, 7*(5). doi: 10.1371/journal.pone.0036646

Herbert, B. M., Pollatos, O., & Schandry, R. (2007). Interoceptive sensitivity and emotion processing: An EEG study. *International Journal of Psychophysiology, 65*(3), 214-227. doi: 10.1016/j.ijpsycho.2007.04.007

Hess, Y. D., & Pickett, C. L. (2010). Social rejection and self- versus other-awareness. *Journal of Experimental Social Psychology, 46*(2), 453-456. doi: 10.1016/j.jesp.2009.12.004

Hsu, D. T., Sanford, B. J., Meyers, K. K., Love, T. M., Hazlett, K. E., Wang, H., … Zubieta, J. K. (2013). Response of the mu-opioid system to social rejection and acceptance. *Molecular Psychiatry, 18*(11), 1211-1217. doi: 10.1038/mp.2013.96.

Iffland, B., Sansen, L. M., Catani, C., & Neuner, F. (2014). Rapid heartbeat, but dry palms: reactions of heart rate and skin conductance levels to social rejection. *Frontiers in Psychology, 5*. doi: 10.3389/fpsyg.2014.00956

Ijzerman, H., Gallucci, M., Pouw, W. T. J. L., Weissgerber, S. C., Van Doesum, N. J., & Williams, K. D. (2012). Cold-blooded loneliness: Social exclusion leads to lower skin temperatures. *Acta Psychologica, 140*(3), 283-288. doi: 10.1016/j.actpsy.2012.05.002

Jaremka, L. M., Fagundes, C. P., Glaser, R., Bennett, J. M., Malarkey, W. B., & Kiecolt-Glaser, J. K. (2013). Loneliness predicts pain, depression, and fatigue: Understanding the role of immune dysregulation. *Psychoneuroendocrinology, 38*(8), 1310-1317. doi: 10.1016/j.psyneuen.2012.11.016

Lakin, J. L., Chartrand, T. L., & Arkin, R. M. (2008). I am too just like you - Nonconscious mimicry as an automatic behavioral response to social exclusion. *Psychological Science, 19*(8), 816-822. doi: 10.1111/j.1467-9280.2008.02162.x

Kingsley, M., Lewis, M. J., & Marson, R. E. (2005). Comparison of Polar 810 s and an ambulatory ECG system for RR interval measurement during progressive exercise. *International Journal of Sports Medicine, 26*(1), 39-44. doi: 10.1055/s-2004-817878

Koster, E. H. W., Crombez, G., Van Damme, S., Verschuere, B., & De Houwer, J. (2004). Does imminent threat capture and hold attention? *Emotion, 4*(3), 312-317. doi: 10.1037/1528-3542.4.3.312

Minear, M. & Park, D.C.(2004). A lifespan database of adult facial stimuli. Behavior Research Methods, Instruments, & Computers. 36, 630-633.

Niskanen, J. P., Tarvainen, M. P., Ranta-Aho, P. O., & Karjalainen, P. A. (2004). Software for advanced HRV analysis. *Computer Methods and Programs in Biomedicine, 76*(1), 73-81. doi: 10.1016/j.cmpb.2004.03.004

Nunan, D., Jakovljevic, D. G., Donovan, G., Hodges, L. D., Sandercock, G. R. H., & Brodie, D. A. (2008). Levels of agreement for RR intervals and short-term heart rate variability obtained from the Polar S810 and an alternative system. *European Journal of Applied Physiology, 103*(5), 529-537. doi: 10.1007/s00421-008-0742-6

Pollatos, O., Fustos, J., & Critchley, H. D. (2012). On the generalised embodiment of pain: how interoceptive sensitivity modulates cutaneous pain perception. *Pain, 153*(8), 1680-1686. doi: 10.1016/j.pain.2012.04.030

Pollatos, O., Kirsch, W., & Schandry, R. (2005). Brain structures involved in interoceptive awareness and cardioafferent signal processing: A dipole source localization study. *Human Brain Mapping, 26*(1), 54-64. doi: 10.1002/hbm.20121

Pollatos, O., & Schandry, R. (2008). Emotional processing and emotional memory are modulated by interoceptive awareness. *Cognition & Emotion, 22*(2), 272-287. doi: 10.1080/02699930701357535

Pollatos, O., Traut-Mattausch, E., Schroeder, H., & Schandry, R. (2007). Interoceptive awareness mediates the relationship between anxiety and the intensity of unpleasant feelings. *Journal of Anxiety Disorders, 21*(7), 931-943. doi: 10.1016/j.janxdis.2006.12.004

Quintana, D. S., Heathers, J. A. J., & Kemp, A. H. (2012). On the validity of using the Polar RS800 heart rate monitor for heart rate variability research.*European Journal of Applied Physiology, 112*(12), 4179-4180. doi: 10.1007/s00421-012-2453-2

Rainville, P. (2002). Brain mechanisms of pain affect and pain modulation. *Current Opinion in Neurobiology, 12*(2), 195-204. doi: 10.1016/s0959-4388(02)00313-6

Riva, P., Wesselmann, E. D., Wirth, J. H., Carter-Sowell, A. R., & Williams, K. D. (2014). When Pain Does Not Heal: The Common Antecedents and Consequences of Chronic Social and Physical Pain. *Basic and Applied Social Psychology, 36*(4), 329-346. doi: 10.1080/01973533.2014.917975

Riva, P., Williams, K. D., & Gallucci, M. (2014). The relationship between fear of social and physical threat and its effect on social distress and physical pain perception. *Pain, 155*(3), 485-493. doi: 10.1016/j.pain.2013.11.006

Riva, P., Wirth, J. H., & Williams, K. D. (2011). The consequences of pain: The social and physical pain overlap on psychological responses. *European Journal of Social Psychology, 41*(6), 681-687. doi: 10.1002/ejsp.837

Schandry, R. (1981). Heartbeat perception and emotional experience. *Psychophysiology, 18*(4), 483-488. doi: 10.1111/j.1469-8986.1981.tb02486.x

Steptoe, A., Shankar, A., Demakakos, P., & Wardle, J. (2013). Social isolation, loneliness, and all-cause mortality in older men and women. *Proceedings of the National Academy of Sciences of the United States of America, 110*(15), 5797-5801. doi: 10.1073/pnas.1219686110

Suzuki, K., Garfinkel, S. N., Critchley, H. D., & Seth, A. K. (2013). Multisensory integration across exteroceptive and interoceptive domains modulates self-experience in the rubber-hand illusion. *Neuropsychologia, 51*(13), 2909-2917. doi: 10.1016/j.neuropsychologia.2013.08.014

Tops, M., Boksem, M. A. S., Luu, P., & Tucker, D. M. (2010). Brain substrates of behavioral programs associated with self-regulation. *Frontiers in Psychology, 1*. doi: 10.3389/fpsyg.2010.00152

Tops, M., Boksem, M. A. S., Quirin, M., Ijzerman, H., & Koole, S. L. (2014). Internally directed cognition and mindfulness: an integrative perspective derived from predictive and reactive control systems theory. *Frontiers in Psychology, 5*. doi: 10.3389/fpsyg.2014.00429

Twenge, J. M., Catanese, K. R., & Baumeister, R. F. (2003). Social exclusion and the deconstructed state: Time perception, meaninglessness, lethargy, lack of emotion, and self-awareness. *Journal of Personality and Social Psychology, 85*(3), 409-423. doi: 10.1037/0022-3514.85.3.409

van Beest, I., & Williams, K. D. (2006). When inclusion costs and ostracism pays, ostracism still hurts. *Journal of Personality and Social Psychology, 91*(5), 918-928. doi: 10.1037/0022-3514.91.5.918

Weippert, M., Kumar, M., Kreuzfeld, S., Arndt, D., Rieger, A., & Stoll, R. (2010). Comparison of three mobile devices for measuring R-R intervals and heart rate variability: Polar S810i, Suunto t6 and an ambulatory ECG system. *European Journal of Applied Physiology, 109*(4), 779-786. doi: 10.1007/s00421-010-1415-9

Werner, N. S., Kerschreiter, R., Kindermann, N. K., & Duschek, S. (2013). Interoceptive Awareness as a Moderator of Affective Responses to Social Exclusion. *Journal of Psychophysiology, 27*(1), 39-50. doi: 10.1027/0269-8803/a000086

Williams, K. D. (2009). Ostracism: A temporal need-threat model. In M. P. Zanna (Ed.), *Advances in Experimental Social Psychology, Vol 41* (Vol. 41, pp. 275-314).

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). CyberOstracism: Effects of being ignored over the Internet. *Journal of Personality and Social Psychology, 79,* 748-762.

Williams, K. D., Govan, C. L., Croker, V., Tynan, D., Cruickshank, M., & Lam, A. (2002). Investigations into differences between social- and cyberostracism. *Group*

Dynamics-Theory Research and Practice, 6(1), 65-77. doi: 10.1037//1089-2699.6.1.65

Williams, K. D., & Jarvis, B. (2006). Cyberball: A program for use in research on interpersonal ostracism and acceptance. *Behavior Research Methods, 38*(1), 174-180. doi: 10.3758/bf03192765

Williams, K.S., Yeager, D.S., Cheung, C.K.T., & Choi, W. (2012). Cyberball (version 4.0) [Software].

Wölk, J., Sütterlin, S., Koch, S., Vögele, C., & Schulz, S. M. (2014). Enhanced cardiac perception predicts impaired performance in the Iowa Gambling Task in patients with panic disorder. *Brain and Behavior, 4* (2) 238-246. doi: 10.1002/brb3.206

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), 692-697. doi: 10.1016/j.jesp.2005.10.007

Tables and Figures

Tables

Table 1. Means and standard deviations of the post-Cyberball questionnaire scores in the two conditions.

	Excluded group (*N* = 29)	**Included group (*N* = 30)**
Belonging	9.86 (3.56)	18.93 (3.44)
Control	8.76 (3.23)	14.30 (3.40)
Meaningful existence	12.10 (4.03)	19.17 (2.82)
Self-Esteem	12.52 (3.16)	16.87 (3.03)
Negative affect	10.86 (3.50)	5.93 (2.05)
Positive affect	9.17 (3.02)	13.50 (2.45)
Feeling excluded	8.28 (1.60)	3.1 (1.16)
Perceived percentage of throws received	7.62 (3.5)	31.10 (6.49)

Note: The two groups differ significantly on all scores at alpha = .001 level (2-tailed).

Table 2. Correlations between change in heartbeat perception accuracy (change in HPA), change in heart rate, and post-Cyberball questionnaire scores in excluded participants.

Variable 1	**Variable 2**
	Change in HPA
Change in heart rate	-.248
Belonging	.014
Control	.015
Meaningful existence	.054
Self-Esteem	.075
Negative effect	.262
Positive affect	-.045
Feeling excluded	-.204
Perceived percentage of throws received	-.132

*Note: * correlation is significant at alpha = .05 level, ** correlation is significant at alpha = .01 level (2-tailed). Also, note that Spearman's ρ correlations were calculated for Control, Feeling Excluded, and Percentage of throws as these were not normally distributed. N = 29.*

Figures

Figure 1. Mean heartbeat perception accuracy scores at baseline and post-Cyberball in the excluded and the included groups along with respective standard errors of means.