Case Report

The social pain of Cyberball: Decreased pupillary reactivity to exclusion cues

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ABSTRACT

A heavily investigated topic in the ostracism literature is the manner in which being ostracized impacts immediate psychophysiological reactivity. Despite the prevalence of this research, it is still unclear which psychological mechanism underlies the immediate reaction to cues of ostracism. According to the social-physical pain overlap theory, cues to ostracism induce a social pain response akin to physical pain due to shared neurological substrates between social and physical pain. Alternatively, it is possible that the immediate reaction to ostracism reflects a conflict detection mechanism responding to a violation of the expectation that one should be socially included. In the present studies, we used pupillometry to distinguish the immediate reaction to ostracism in terms of it primarily representing a pain-oriented response or a conflict-detection response. We continuously measured the pupillary reaction during games of Cyberball, which contained social inclusion events (a ball thrown to the participant) and exclusion events (a ball thrown to another player). We find that participants show a diminished pupillary reaction to cues of exclusion but not to cues of inclusion, consistent with the social-physical pain overlap theory.

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Humans face a variety of existential concerns. One of these concerns is reflected in our ubiquitous need to belong to a group (Baumeister & Leary, 1995). Research has consistently demonstrated that people are greatly affected by the loss of acceptance within a group, likely the result of evolutionary pressures to maintain social bonds in order to survive and reproduce. Indeed, research on ostracism—i.e., being ignored and excluded—has shown that being socially excluded subsequently affects one's sense of belonging and also causes a decrease in self-esteem, control, and meaning in life (Williams & Sommer, 1997). This socially painful experience results in the display of various behaviors aimed at restoring social standing, such as pro-social, or even aggressive behavior (for reviews, see Hartgerink, van Beest, Wicherts, & Williams, 2015; Williams, 2009; Williams & Nida, 2011). Taken together, these studies demonstrate the varied impact of ostracism experiences.

Importantly, the psychological impact of ostracism is measured well after the experience of exclusion. In the case of behavioral studies, this delay serves the research question, as it addresses the downstream psychological consequence of the experience of ostracism. In contrast, many self-report studies are focused on people's subjective experience while being ostracized, which brings the validity of retrospective self-assessments into question. This shortcoming has likely—in part—motivated studies assessing the online *physiological* response to the experience of ostracism. Unlike most self-report based studies, the use of psychophysiological and neuroaffective measures allows for an investigation of the *immediate* and continuous reaction to ostracism.

1. Immediate reactions to ostracism: social pain or conflict

One of the most heavily investigated topics in the ostracism literature is how exclusion impacts neural activity. Dozens of studies have been performed in which participants are ostracized while their brain activity was concurrently measured using fMRI technology (for a review, see Cacioppo et al., 2013; Eisenberger, 2012). Many of these studies point towards the involvement of the anterior cingulate cortex (ACC), the anterior insula, and the prefrontal cortex— areas that have been linked to the experience and regulation of emotional distress. Although it is clear from these studies that certain brain areas are active during ostracism, their function remains somewhat ambiguous (also see Rotge et al., 2015).

1.1. Ostracism as social pain

Eisenberger (2015) argues that the involvement of the ACC relates to the experience of social pain, that is, the painful feelings that follow from social rejection, exclusion, or loss. Eisenberger (2012) also cites a substantial portion of fMRI studies that show correlations between

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activity in this region and self-report measures of emotional distress, showing that there is a relationship between the ACC and the experience of social pain, ultimately postulating that this experience of social pain relies on the same neural underpinnings that are involved in the experience of physical pain. This idea stems from Panksepp (1998), who proposed that as animals evolved to become more social, they co-opted the same physiological systems used for physical events to monitor social events (i.e., rejection/ostracism), and is now known as the social-physical pain overlap theory (Eisenberger, 2012).

The social-physical pain overlap theory is also supported by other findings in the literature on ostracism. For instance, research has shown that acetaminophen reduces the emotional experience of social pain (DeWall et al., 2010; Vangelisti, Pennebaker, Brody, & Guinn, 2014) and being socially excluded reduces pain sensitivity, both in terms of higher pain thresholds and higher tolerance (DeWall & Baumeister, 2006). It also has been found that physical pain, like social pain, can threaten basic need satisfaction. Riva, Wirth, and Williams (2011) had participants submerge their hands in cold water or be socially excluded and found that both types of pain produced feelings of being excluded. This also negatively affected their sense of self-esteem, control, and a meaningful existence. Moreover, in spite of the impact of social pain on need satisfaction, it is not always found that being ostracized impacts subsequent mood (DeWall & Baumeister, 2006). In fact, when an effect on mood is found, an absolute interpretation of the results in terms of scale midpoint frequently indicates a neutral state of mind, rather than one of emotional distress (Twenge, Catanese, & Baumeister, 2003). This potentially counterintuitive finding has now been interpreted as one consistent with a numbing reaction caused by the body releasing opioids in response to social pain (for an overview of this idea, see MacDonald & Leary, 2005, but also see Gerber & Wheeler, 2009a; Baumeister, DeWall, & Vohs, 2009; and Gerber & Wheeler, 2009b). This conception is consistent with the previously mentioned brain-imaging studies showing that the brain's response to physical pain and social pain involves common underlying neural circuitry.

1.2. Ostracism as cognitive conflict

Others, however, do not interpret the functions of the ACC is the same manner, and consequently, do not view ACC activation as primarily indicative of pain, social or otherwise. For example, brain activation in the dorsal ACC could also be understood in terms of its function as a conflict monitor (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004; Bush, Luu, & Posner, 2000). Conflicts in information processes, resulting from events such as task errors (i.e., providing an incorrect response during a judgment task), incompatible response tendencies, and trivial expectancy violations (e.g., perceptual anomalies, oddball events) trigger activation in the ACC. Unlike pain, these conflicts in information processing are not experienced as aversive to the extent that social pain is experienced, but rather serve as a benign and frequent signal of any change in the environment, which activates an attentional orienting response (Sokolov, Spinks, Näätänen, & Lyytinen, 2002; Vinogradova, 2001).

Some researchers have suggested that a conflict detection mechanism could play a role in being ostracized because being ostracized is often unexpected, and therefore constitutes a violation of expectations (e.g., Bolling et al., 2011; Kawamoto, Nittono, & Ura, 2013). These expectations can result from prior events, such as one's personal history of being included or excluded, or from our ubiquitous need to belong (Baumeister & Leary, 1995), which motivates us to follow the unwritten rule to err on the side of including others in everyday events. Additionally, research has shown that we tend to hold unrealistically positive self-illusions (Taylor & Brown, 1988), which makes the prospect of being excluded subjectively unlikely. For these reasons, we can expect that expectations play a role in the ostracism experience.

In sum, prior research provides evidence that ostracism may evoke two kinds of psychological responses: a pain-based reaction that results from the shared neural circuitry between physical pain and social pain, and a conflict-based reaction that results from a violation of expectations. It is likely that both of these reactions play a role in the response to ostracism, yet it remains unclear whether these processes differ in their temporal dominance. In the current research we investigate which of these possible reactions takes precedence in the immediate response to cues of being ostracized, using an emerging tool in the ostracism literature—pupillometry.

1.3. Pupillometry

Pupillary reactivity (i.e., changes in pupil size) can serve as an index of neuroeffective arousal. This relationship between pupil size and arousal stems from its association with the locus coeruleus-norepinephrine system (LC-NE). The LC-NE system is believed to play an important role in the regulation of engagement or withdrawal from a task by regulating the release of NE through projections from the LC in the forebrain (Aston-Jones & Cohen, 2005). Research has shown that pupil size correlates with LC activity in monkeys (Rajkowski, Kubiak, & Aston-Jones, 1993 as cited in Gilzenrat, Nieuwenhuis, Jepma, & Cohen, 2010) as well as in humans (Gilzenrat et al., 2010), and work by Beatty and colleagues has demonstrated that pupil reactivity is consistent with LC responses to task-events (Beatty, 1982a, 1982b; Richer & Beatty, 1978). The link between pupil size and the LC-NE system allows researchers to infer a broad range of both cognitive processes (e.g., stimulus identification, working memory maintenance) and emotional processes (e.g., stimulus valence) from the extent of pupil dilation. To illustrate, Bradley, Miccoli, Escrig, and Lang (2008) have shown that the pupil dilates more in response to both positively and negatively valenced pictures, compared to neutral pictures. This response co-varies with skin conductance, thereby demonstrating that the sympathetic nervous system can modulate pupillary reactivity.

Importantly, other research has provided evidence that pupil size can also be used to differentially infer cognitive processes such as conflict detection and emotional processes such as pain. For example, the pupil unilaterally dilates in response to task error and incongruent trials during the Stroop task (Brown et al., 1999; Critchley, Tang, Glaser, Butterworth, & Dolan, 2005; Laeng, Ørbo, Holmlund, & Miozzo, 2011). Similarly, the pupil also responds to violations of expectations (Preuschoff, 't Hart, & Einhäuser, 2011; Raisig, Welke, Hagendorf, & van der Meer, 2010; Raisig, Hagendorf, & van der Meer, 2011; Sleegers, Proulx, & Van Beest, 2015). Sleegers et al. (2015) have shown, for example, that repeated presentations of reverse-colored playing cards (e.g., black two of hearts) lead to a sustained and consistent increase in pupil dilation across dozens of trials. In terms of pupillary response to pain, several studies report a change in pupil size correlated with noxious stimulation and self-reported pain (Ellermeier & Westphal, 1995; Chapman, Oka, Bradshaw, Jacobson, & Donaldson, 1999; Höfle, Kenntner-Mabiala, Pauli, & Alpers, 2008). The pupil dilates in response to pain stimulation, and importantly, appears to *diminish* when the subjective experience of pain is lessened, for example, through hypnosis (Walter, Lesch, Stöhr, Grünbergre, & Gutierrez-Lobos, 2006) or opioids (Connelly et al., 2014). Based on these findings, it seems that pupillary reactivity can serve as an index for physiological arousal in a broad array of cognitive and emotional processes that are likely to play a role during social exclusion.

1.4. Pupillometry and social exclusion

Pupillometry is an emerging tool in studies on ostracism, and several studies have used pupillometry in combination with social feedback paradigm (e.g., Silk et al., 2012; Vanderhasselt, Remue, Ng, Mueller, & de Raedt, 2015). In a social feedback paradigm, participants look at photos of other people, who either accept or reject them for a certain

task or provide feedback on the desirability or likability of the participant. These studies show that negative social feedback elicits an increase in pupil dilation, thereby demonstrating the involvement of cognitive and/or emotional processes. Importantly, these studies have not linked pupil reactivity to conflict detection and pain processes, specifically.

Although social feedback paradigms involve a painful social event, this paradigm differs in various respects from another commonly used social exclusion manipulation: Cyberball (Williams, Cheung, & Choi, 2000). Cyberball is a ball tossing game in which three or more people toss a ball amongst each other. In a *belonging* game, participants receive an equal amount of ball tosses as the other players. In an *ostracism* game, participants receive substantially fewer ball tosses from the other players, often after having received a few ball tosses at the start of the session. This ostracism game consequently comprises a prolonged exclusion event, with the same players in a constant context, in which the presence of exclusion is not immediately noticeable. We believe this paradigm has several benefits over social feedback paradigms. First, Cyberball is a prolonged ostracism event in which several players socially exclude the participant. In contrast with other social exclusion paradigms, Cyberball is a holistic ostracism experience that unfolds over time. This temporal component enables researchers to look at the consequences of being ostracized over time, without intervening factors such as the setting, the people involved, and stimuli presented to the participant, as these remain constant. This allows for a more reliable assessment of a potential numbing response in response to the pain of being excluded. It also allows certain predictions to be made, such as the absence of a numbing response at the start of the Cyberball game. Second, the Cyberball paradigm allows us to investigate people's concrete expectations (e.g., the number of ball tosses they expect), thereby enabling us to investigate the role of expectations in ostracism. The Cyberball paradigm thus enables us to investigate what kind of immediate reaction predominates upon receiving a cue that one is being ostracized.

1.5. Hypotheses

As we have noted, it is unclear what kind of reaction predominates in response to cues of ostracism. A first hypothesis is that the immediate reaction to cues of ostracism primarily reflects social pain, based on the social-physical pain overlap theory of ostracism. If it is indeed the case that the social pain activated by cues of ostracism uses the same neural circuitry as those involved in physical pain, we could observe a numbing response due to the release of endorphins that diminish experiences of pain (MacDonald & Leary, 2005). Given that the pupil can be used both as a proxy for sympathetic nervous system arousal in response to pain (Ellermeier & Westphal, 1995; Chapman et al., 1999), and opioid impact on this response (Connelly et al., 2014), we can predict a *decrease* in pupil diameter in response to ostracism cues. Additionally, we can predict that this effect increases over time. As more endorphins are released throughout the course of being excluded, more numbing should take place.

Alternatively, it could be the case that the online reaction primarily reflects a conflict detection process. Ostracism events consist of an initial detection of being ostracized and the subsequent regulation of the emotional distress caused by the ostracism event. Pupillary reactivity can reflect this detection of ostracism in Cyberball due to a probable violation of the expectation that one should be equivalently receiving ball tosses. If the initial response to cues of ostracism is indeed primarily a violation of expectations, we should see an increase in pupil dilation in response to these cues. This is based on the research showing the pupil unilaterally dilates following cognitive conflict induced by a variety of expectancy violations, such as task error and perceptual discrepancies (e.g., Brown et al., 1999; Critchley et al., 2005; Preuschoff et al., 2011; Raisig et al., 2010; Raisig et al., 2011; Sleegers et al., 2015). Since it takes some time to realize one is being excluded during a game of Cyberball, we can additionally predict that this *increase* in pupil dilation appears gradually, once it is clear that each ball toss not received is indeed a signal of being ostracized.

In summary, our investigation of the immediate response to social exclusion could reveal two distinct and divergent outcomes. Either participants show a gradual *decrease* in pupil size (Hypothesis 1) based on the notion that a growing awareness of being ostracized is painful, which evokes a physiological numbing response consistent with the social-physical pain overlap theory (MacDonald & Leary, 2005), or a gradual *increase* in pupil size (Hypothesis 2), based on the notion that the immediate reaction is a detection of conflict—the result of a violation of the expectation that one should be included.

2. Study 1

We set out to investigate the immediate reaction to cues of ostracism using pupillometry and the Cyberball paradigm. We looked for evidence to support Hypothesis 1 (gradually diminished pupil diameter in an ostracism game) or Hypothesis 2 (gradually heightened pupil diameter in an ostracism game). In this first study, all participants started with a game of Cyberball in which they were equally included (belonging game), after which they played another game in which they were generally excluded (ostracism game).

2.1. Method

2.1.1. Participants and design

Thirty-nine participants participated in this study (6 males; 32 females; 1 unknown). The average age was 19.44 (min: 18; max: 25). Participants were rewarded with course credits or €8. The design was a 2 (Cyberball game: belonging/ostracized) within-subjects design, in which participants were first included and then excluded. We report all data exclusions, all manipulations, and all measures in the study.

Since no prior studies have been conducted using pupil dilation as an outcome measure in the Cyberball paradigm, we are unsure about the anticipated effect size of the main effect of interest (i.e., the effect of ostracism on pupil dilation). Hence, we conducted a power analysis, using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), assuming a small to medium effect size. With a repeated measures design and default settings, this resulted in a required sample size of 10 to 32 participants. This sample size is consistent with prior work using pupil dilation as the measure of interest (e.g., Preuschoff et al., 2011; Bradley et al., 2008).

2.1.2. Procedure

Participants were welcomed into the lab and seated in a cubicle. On-screen instructions informed the participant that they were going to participate in several visualization tasks and that their eyes were going to be measured using an eye tracker. They were also informed they could experience feelings common in everyday life, that their participation was voluntary, and that at any moment they could stop the experiment.

After giving their consent, the test leader made sure the participant was seated about half a meter from the eye tracker display (Tobii T60) and the eye tracker was calibrated using the built-in calibration procedure in Tobii's Extensions for E-Prime 2.0. Hereafter, participants played the first Cyberball game.

After the Cyberball game, two filler tasks[2] followed, in counterbalanced order. These tasks included a painting preference task and a snowy pictures task (for more information on these tasks,

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[2] These tasks included a painting preference task (e.g., Landau, Greenberg, Solomon, Pyszczynski, & Martens, 2006) and a snowy pictures task (Whitson & Galinsky, 2008). The results of these tasks were also analyzed but no consistent patterns were found. As with the data and materials from the present studies, the data and materials from these tasks are available upon request.

see the Supplementary files). Afterwards, participants contacted the test leader who asked them to take a short break before contacting the test leader again to start the second part of the experiment.

The second part was identical to the first part, again starting with the Cyberball task, followed by the painting preference task and snowy pictures task. Different than the first part, after the filler tasks, participants were also presented with a fundamental needs questionnaire that was followed by demographic questions and checks. These were administered on average about 5 min after the Cyberball game. They were then debriefed and thanked for their participation.

2.2. Materials

The experiment was designed and administered in E-prime 2.

2.2.1. Cyberball game

Cyberball was presented as a mental visualization game—a common instruction in the Cyberball paradigm. Participants were asked to take a minute and to imagine actually playing a ball tossing game with other people. This was followed by questions about the scene they imagined, such as the color of the ball and where the game takes place. Importantly, we also asked how many ball tosses the participant expected to receive. During these questions information about the game was displayed on the screen. This information included the number of players (3) and the number of total ball tosses (90). After this, the game "connected" to the other players, at which point the participant saw two avatars with common male and female names representing the other players, named Maarten (left player) and Anne (right player) in the inclusion condition and named Lotte (left player) and Thomas (right player) in the exclusion condition. Note that in each game we used common male and female names and that we also changed the order in which the gender was associated to the position of the left or right avatar (also see Fig. 1).

2.2.2. Cyberball event

A Cyberball event was defined as a ball toss, which consists of three components: a baseline period (500 ms), the ball toss animation (900 ms), and the period during which the computer or participant decides whom to toss the ball to (a varying period). The start of the ball toss animation was denoted at the start of an event ($t = 0$). To assure a reliable assessment of pupil size, we extended the standard duration of the Cyberball game to 90 ball tosses in total. Before each ball toss there was a randomly varying period during which the computer (900 to 4300 ms) or participant (determined by participant) considered whom to toss the ball to. This was followed by an animation of the ball being tossed to the selected player. Each ball toss was either to the player (an inclusion event) or not (an exclusion event). During the first game, the participant was equally included (belonging game), thus receiving a total of 30 out of 90 ball tosses during the entire game. In the second game, the player was generally excluded and received only 10 out of the 90 ball tosses (ostracism game). Note that in both the belonging game and the exclusion game, participants experienced both inclusion and exclusion events. This allowed us to directly compare exclusion events across both a belonging and ostracism game. And, also to directly compare inclusion events across both a belonging and ostracism game.

Ball tosses were randomly determined and could take place throughout the game, thereby assuring that the participant remained involved in the task and also remained unsure about what to expect for each given ball toss. The participant could click on another player's avatar to toss the ball to that player.

We also added a visual frame around the players (see Fig. 1). This extra object can divert the participant's attention from the game and allowed us to investigate where people may divert their attention to during the Cyberball game.

Pupil data was collected using a Tobii T60 eye tracker (Tobii, Stockholm, Sweden). The Tobii T60 is integrated in a 17″ TFT monitor and records at a rate of 60 Hz. Each measurement has a validity indication that ranges from 0 (the system is certain that all data belongs to the
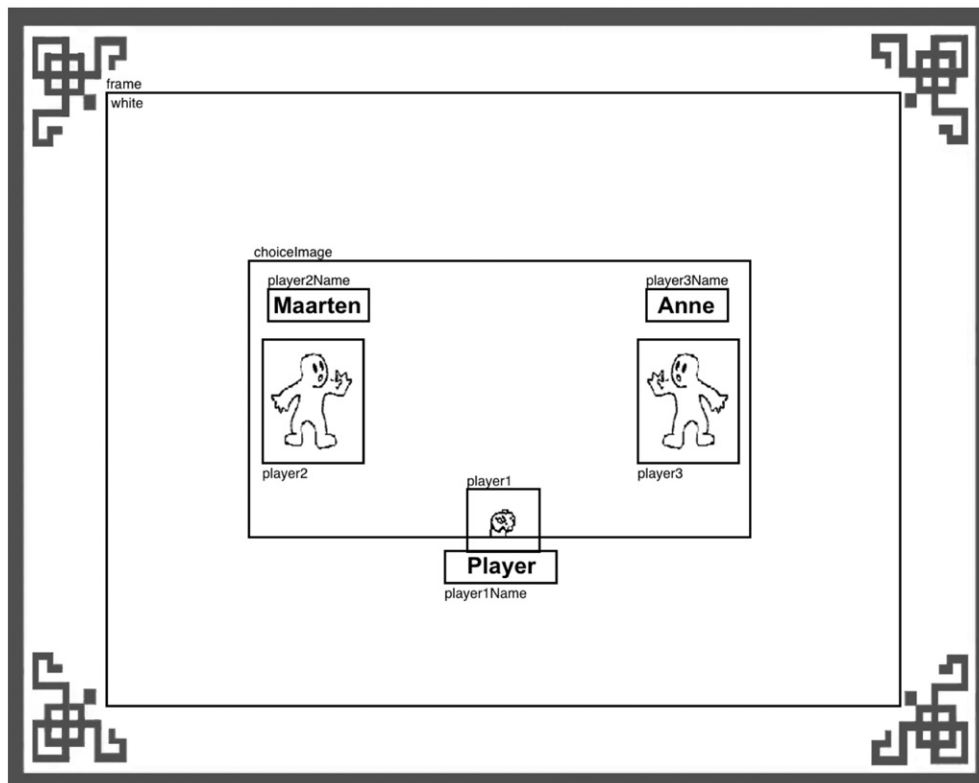

Fig. 1. A depiction of the Cyberball game with its various objects that served as regions of interest (ROIs).

particular eye) to 4 (gaze data is missing or incorrect). Only recordings with a validity score of 0 were used. Pupil size from each eye were averaged together to create a single pupil size score and filtered with a modified repeated median filter (outer width: 25, inner width 15) using the "robfilter" package (Fried, Schettlinger, & Borowski, 2014) in R (R Core Team, 2015). Because the Cyberball task is a black and white task with a continuous sequence of events (i.e., no discrete presentations of stimuli) no light reflex period was present. Missing data (e.g., blinks) were corrected with linear interpolation using the 'zoo' package (Zeileis & Grothendieck, 2005). Hereafter, the pupil size was controlled for baseline differences by subtracting the average pupil size during a 500 ms pre-event (Beatty & Lucero-Wagoner, 2000) period from the subsequent pupil measurements. Events with more than 25% missing data were removed (6.75%), resulting in an average of 84.26 useable trials in the inclusion game and 83.54 in the exclusion game. Additionally, we also used the pupil data to investigate what people looked at on the screen by defining regions of interest (e.g., the players, their names, the area in which the game took place; see Fig. 1). This allowed us to rule out alternative explanations such as participants looking away from the screen and becoming more disinterested in the game as a function of being ostracized or included.

2.2.3. Fundamental needs and mood

The fundamental needs and mood questionnaire consisted of 16 items that measured the participant's need for belonging, self-esteem, meaningfulness, control ($\alpha = 0.84$), and mood ($\alpha = 0.87$) after the Cyberball game (van Beest, Williams, & van Dijk, 2011). Example are: "During the game I had the sense that I belonged", "I had the feeling that I had control over the game.", and "I felt tense during the game.". The questions were answered on a 7-point Likert scale, ranging from 1 "Completely disagree" to 7 "Completely agree" and presented in a fixed order.

2.2.4. Checks and demographics

Before both the belonging and ostracism games we asked participants how many ball tosses they expected to receive (0–90). This question allowed us to assess our assumption that all participants would expect to receive an equal number of ball tosses prior to playing the game, and exclude outliers who did not expect to receive a fair number of ball tosses. After all, if participants expect to receive no ball tosses prior an ostracism game then expectations are not violated when this happens. Alternatively, if participants expect an equal number of ball tosses prior to a belonging game expectation are not violated when this happens.

At the end of the experiment, we also assessed age, gender, whether participants had participated in a Cyberball task before (yes/no), whether they realized the other players were not real (yes/no), and what they thought the research questions were (openended).

2.3. Results

2.3.1. Expectations

Before playing the first Cyberball game (belonging), participants reported expecting to receive an average of 31.46 ($SD = 16.54$) ball tosses, compared to an average of 29.77 ($SD = 12.72$) ball toss

es before playing the second Cyberball game (ostracism). This later average does not differ significantly from expecting an equal number of ball tosses (30 ball tosses, $t(38) = 0.11$, $p = 0.910$), 95% CI [25.65, 33.89], $d = 0.02$, nor from the average expected number of ball tosses before the belonging Cyberball game, $t(38) = 0.98$, $p = 0.335$, 95% CI [−1.81, 5.20], $g_{av} = 0.11$. A total of four participants expected to receive only a few ball tosses (20 or fewer) and were removed from the data analysis, leaving 35 participants.

2.3.2. Gaze durations

We calculated what percentage of time the participants spent looking at each region of interest (ROI) during each of the two Cyberball games and compared these percentages for each ROI with paired t-tests. The findings are displayed in Table 1. To see whether participants did not look away from the Cyberball events, we looked at the time spent in the ROIs surrounding the players. During the *ostracism* Cyberball game, participants looked significantly more at the white area between the frame and the players and marginally significantly more at the frame surrounding the screen. These results point at participants looking more at the fringes of the screen. Notably, there was no significant difference in the amount of missing data, indicating that participants did not look away from the screen during the ostracism experience compared to the belonging experience to any significant extent.

2.3.3. Pupillometry

2.3.3.1. Exclusion events.
To test our main hypotheses, we first looked at the events during which the participant did not receive the ball. In the belonging Cyberball game, these events do not necessarily represent an ostracism cue, as not receiving the ball is part of tossing a ball to each player equally. However, in the ostracism Cyberball game, where these events are more frequent, these events do represent an ostracism cue because they show one is not being included to the same extent as the other player. On these events we performed a repeated measures GLM analysis with Cyberball game (belonging/ostracism) and event period (0 to 2000 s, in 100 ms bins) as within-subject factors, with the average pupil size as the dependent variable (see Fig. 2). This revealed a significant main effect of the Cyberball game, $F(1, 34) = 14.29$, $p = 0.001$, $\eta^2_p = 0.296$. There was a *smaller* pupil size increase upon not receiving a ball in an ostracism Cyberball game ($M = 0.026$ mm, $SE = 0.005$, 95% CI [0.017, 0.036]) compared to not receiving a ball in a belonging game ($M = 0.046$ mm, $SE = 0.007$, 95% CI [0.032, 0.060]). There was also a main effect of the event period, $F(20, 15) = 13.35$, $p < 0.001$, $\eta^2_p = 0.947$. Pupil size increased after a ball was tossed to another player, and decreased after about 600 ms. There was no significant interaction effect, $F(20, 15) = 1.13$, $p = 0.412$, $\eta^2_p = 0.601$.

2.3.3.2. Inclusion events.
We repeated the same analysis for the events that did have the participant as the recipient of a ball toss. The total duration of each event was shorter due to the fact that participants more quickly tossed a ball to another player upon receiving it than the other players were programmed to do, leading to an event period of 0 to 1600 ms. A GLM with Cyberball game (belonging/ostracism) and event period (0 to 1600) did not yield a main effect of the Cyberball game, $F(1, 34) = 0.002$, $p = 0.969$, $\eta^2_p < 0.001$. It did reveal an effect of event period, $F(16, 19) = 14.94$, $p < 0.001$, $\eta^2_p = 0.926$, and an significant interaction effect, $F(16, 19) = 4.24$, $p = 0.002$, $\eta^2_p = 0.781$, see Fig. 3. In both the ostracism and belonging Cyberball games, the pupil size

Table 1
Percentage of time spent looking at each region of interest, during a belonging or ostracism Cyberball game in Study 1.

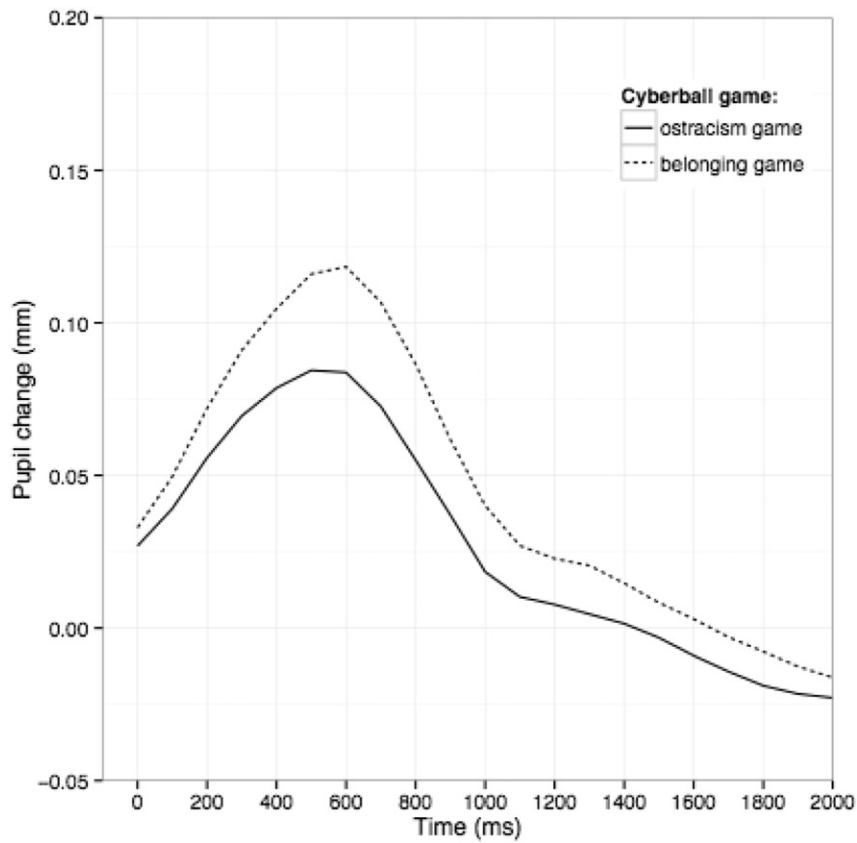| ROI	Inclusion		Exclusion		t (34)	p
	M	SD	M	SD		
Frame	0.31	0.60	1.83	5.02	1.782	0.084
Player 1	7.07	3.48	4.97	2.97	− 0.235	0.815
Player 1 name	0.38	0.38	1.03	0.78	− 3.432	0.002
Player 2	29.00	5.42	30.66	6.69	4.722	0.000
Player 2 name	0.60	0.66	0.95	1.19	1.902	0.066
Player 3	30.38	7.41	28.38	7.79	2.921	0.006
Player 3 name	0.63	1.01	0.97	1.58	− 1.887	0.068
White area	0.47	0.79	1.08	1.64	2.575	0.015
Choice image	21.18	5.44	20.42	6.65	2.702	0.011
Missing data	9.98	8.75	9.71	5.55	− 0.748	0.459

Fig. 2. Change in pupil size during exclusion events in two games of Cyberball—first a belonging game, followed by an ostracism game (Study 1).
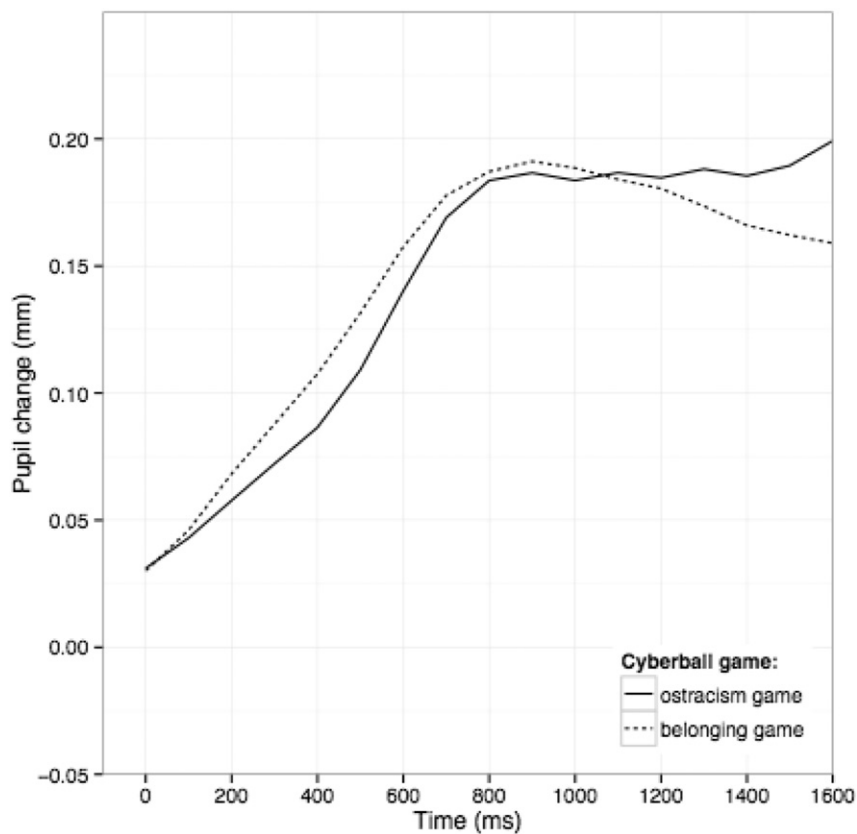

Fig. 3. Change in pupil size during inclusion events in two games of Cyberball—first a belonging game, followed by an ostracism game (Study 1).

increased rapidly upon seeing the ball being tossed to the participant, but slowly decreased soon after when playing a belonging game, while it remained somewhat level in an ostracism game.

2.3.3.3. Effect across the duration of a Cyberball game. Above we analyzed the overall pupillary change in response to both inclusion and exclusion events (i.e., across all ball tosses). We anticipated that it might take participants some moments to realize that they are being excluded, so the decrease in pupil size should be more pronounced as a function of the time that has passed playing the Cyberball game. Additionally, this should not be the case in the belonging game. Hence, we performed two planned comparisons. We combined the average pupil change into three event bins of 30 events each and conducted a two 3 (Cyberball period: event 1 to 30/event 31 to 60/event 61 to 90) repeated-measures analyses). This revealed an effect of event bin during the ostracism game, $F(2, 68) = 9.50$, $p < 0.001$, $\eta^2_p = 0.218$, but not during the belonging game, $F(2, 66) = 0.72$, $p = 0.491$, $\eta^2_p = 0.021$.[3] Additionally, we conducted three separate t-tests to compare the average pupil size change in response to exclusion events between the two Cyberball games, per event bin. During the first 30 ball tosses, there was no statistically significant difference between the belonging game and the ostracism game, $t(34) = 1.50$, $p = 0.151$. In the later two bins (events 31 to 60 and events 61 to 90), the difference was statistically significant, $t(34) = 3.48$, $p = 0.001$ and $t(33) = 2.29$, $p = 0.028$, respectively. These results are consistent with Hypothesis 1; we see that after the first bin there is a substantial decrease in average pupil size in response to an exclusion event during the ostracism Cyberball game ($M_{\text{event 1 to 30}} = 0.088$ mm, $SD_{\text{event 1 to 30}} = 0.040$; $M_{\text{event 31 to 60}} = 0.060$ mm, $SD_{\text{event 31 to 60}} = 0.036$, $M_{\text{event 61 to 90}} = 0.049$ mm, $SD_{\text{event 61 to 90}} = 0.013$), while it remains constant during the belonging Cyberball game ($M_{\text{event 1 to 30}} = 0.096$ mm, $SD_{\text{event 1 to 30}} = 0.047$; $M_{\text{event 31 to 60}} = 0.081$ mm, $SD_{\text{event 31 to 60}} = 0.051$; $M_{\text{event 61 to 90}} = 0.085$ mm, $SD_{\text{event 61 to 90}} = 0.059$).

2.3.4. Fundamental needs

To test whether the ostracism manipulation induced self-reported threat to needs and decrease in mood, t-tests were performed between the average scores of the fundamentals needs sub-scales and the midpoint of the response-scale (4). Results show that all but mood differed from the mid-point (see Table 2) in a manner consistent with feeling ostracized.

2.3.5. Checks

Six participants (15.4%, 1 missing) reported having experience with the Cyberball paradigm[4] and 19 participants (47.5%, 2 missing) did not believe the participants they were playing with were real participants.

2.4. Discussion

We found that participants showed a gradually decreased pupillary reaction to exclusion events in a game of Cyberball in which they were generally ostracized (ostracism game), but not when they were equally included (belonging game). For inclusion events, no such difference in pupillary dilation was observed relative to either version of the game. Additionally, we found that mood was not affected by being excluded. These findings are in support of Hypothesis 1. That is, the results

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[3] We also performed a 2 (Cyberball condition: belonging/ostracism) × 3 (Cyberball period: event 1 to 30/event 31 to 60/event 61 to 90) to test for a possible interaction effect. This revealed a main effect of ostracism, $F(1, 33) = 12.80$, $p = 0.001$, $\eta^2_p = 0.279$ and of event bin, $F(2, 66) = 5.60$, $p = 0.006$, $\eta^2_p = 0.145$, but not a significant interaction, $F(2, 32) = 1.57$, $p = 0.223$, $\eta^2_p = 0.089$.

[4] Excluding these participants did not substantially impact the results (e.g., the effect of ostracism on pupil size during exclusion events remained, $F(1, 27) = 8.66$, $p = 0.007$).

Table 2
Difference average fundamental needs scale and sub-scales from midpoint and descriptives from Study 1 (N = 34).

Scale	Statistics	M (SD)
Belonging	$t = -14.05$, $p < 0.001$	1.91 (0.88)
Control	$t = -11.28$, $p < 0.001$	1.97 (1.06)
Self esteem	$t = -2.01$, $p = 0.052$	3.41 (1.72)
Meaning	$t = -4.18$, $p < 0.001$	3.11 (1.27)
Mood	$t = 0.26$, $p = 0.798$	4.05 (1.31)
All combined	$t = -3.07$, $p = 0.004$	3.44 (1.08)

are consistent with a numbed reaction towards exclusion events that fits with the social-physical pain overlap theory. The findings do not support Hypothesis 2, or a conflict-based reaction due to a violation of the expectation that one should be equally included.

3. Study 2

In Study 2 we continued to test the two hypotheses by including a manipulation to further disentangle our two competing hypotheses. For this purpose, we selected value affirmation. Recent research has shown that beliefs, such as religious convictions, can serve as a buffer and mute neurophysiological activity in response to expectancy violations (Inzlicht, McGregor, Hirsh, & Nash, 2009; Inzlicht & Tullett, 2010; Sleegers et al., 2015). For example, Inzlicht and Tullett (2010) primed participants with their religious affiliation before performing a Stroop task and subsequently found decreased activity in the ACC as measured by error related negativity (ERN), compared to those who were not primed. Similarly, Sleegers et al., 2015 found that participants who strongly affirmed their moral beliefs decreased pupillary dilation in response to reverse-colored playing cards. These findings indicate that the affirmation of values can mute the physiological response to cognitive conflicts following from expectancy violations such as task error and perceptual anomalies. In contrast, studies have shown that self-affirmation has no buffer effect on the negative effects of ostracism (Dingwall, 2011; Howell & Shepperd, 2016; and see Williams, 2009). Consequently, if the pupillary reactivity in response to cues of ostracism similarly reflects a conflict detection process, then we should expect a muted pupillary response as a function of value affirmation, which would support the hypothesis that pupillary reactivity following ostracism cues reflects an underlying conflict detection mechanism. Alternatively, if we fail to find an effect of value affirmation and again find a decreased pupillary reactivity in response to ostracism cues, this would constitute a further lack of support for a conflict detection hypothesis.

We also changed the design of Study 2 to address some methodological trade-offs present in Study 1. In Study 1, participants always played the belonging game first, and the ostracism game second. To address potential ordering effects, we changed this order in Study 2 by having participants first play the ostracism game first and then the belonging game. Moreover, in order to better track the self-reported effects of our ostracism manipulation, we administered the fundamental needs and mood questionnaire twice, after each game, together with an additional questionnaire that measures anxiety caused by a state of uncertainty. This was added to gain more insight into the self-reported consequences of the ostracism experience. Previous research has shown that anxiety is an important construct related to how people cope with uncertainty arousing experiences (e.g., McGregor, Prentice, & Nash, 2013), with uncertainty likely to play a role in ostracism as there is often an initial an element of uncertainty. We can therefore expect that being ostracized causes an increase in anxious uncertainty. The fundamental needs and mood scale does not include any items related to felt anxious uncertainty, so we extended our design by adding a questionnaire specifically designed to measure this possibility.

3.1. Method

3.1.1. Participants and design

Seventy-one participants participated in this study (14 males; 56 females; 1 unknown). The average age was 19.57 (min: 17; max: 24). Participants were rewarded with course credits. The design was a 2 (Cyberball game: belonging/ostracism) × 2 (values prime: present/absent) mixed design with ostracism as a within-subjects factor and the prime as a between-subjects factor. Participants were excluded in the first game and equally included in the second game. A power analysis on a between subjects test for the effect of the values prime on pupil dilation revealed a required sample size ranging between 34 (medium effect) and 122 (small effect).

3.1.2. Procedure

The procedure was identical to the first study, except that half the participants were primed with a questionnaire on various controversial topics immediately prior to the first Cyberball game, which allowed them to affirm their values. This questionnaire was framed as being part of a different experiment. After filling in this questionnaire, participants contacted the test leader and the procedure identical to Study 1 would commence.

3.2. Materials

The same material was used as in Study 1, except for some key differences noted below.

3.2.1. Pupillometry

Pupil data was prepared identical to that in Study 2. Events with more than 25% missing data were removed (3.17%), resulting in an average of 86.34 useable trials in the inclusion game and 87.90 in the exclusion game.

3.2.2. Values prime

To buffer the potential negative impact of ostracism, half of the participants were presented with a values prime before the start of the experiment. To this end, participants indicated to what extent they agreed or disagreed with various controversial topics (e.g., gay rights, nuclear energy, multiculturalism; see Sleegers et al., 2015).

3.2.3. Anxious uncertainty

Anxious uncertainty was measured after each Cyberball game, after the administration of the fundamental needs (after exclusion: $\alpha = 0.71$, after inclusion: $\alpha = 0.78$) and mood questionnaire (after exclusion: $\alpha = 0.88$, after inclusion: $\alpha = 0.66$). Participants were asked to what extent they felt certain emotions related to anxious uncertainty (e.g., conflicting, concerned, nervous) on the same 7 point Likert scale (after exclusion: $\alpha = 0.87$, after inclusion: $\alpha = 0.81$), following McGregor, Zanna, and Holmes (2001) and McGregor, Nash, Mann, and Phills (2010).

3.2.4. Checks and demographics

We again assessed how many ball tosses participants expected to obtain prior to playing both Cyberball games and used this to exclude outliers. We also assessed age, gender, and experience with similar tasks. This time, we did not assess whether participants realized that the other players were fake. We feared that presentation biases likely motivated many participants to indicate that that they were not fooled, regardless of what they believed over the course of the experiment.

3.3. Results

3.3.1. Expectations

Before playing the ostracism Cyberball game, participants reported expecting to receive an average of 29.48 ($SD = 7.16$) ball tosses. This

average does not differ significantly from expecting an equal number of ball tosses (30 ball tosses, $t(65) = 0.584$, $p = 0.561$, 95% CI [27.72, 31.25], $d = 0.07$). This time, however, expectations did change between conditions. Before the belonging Cyberball game, participants expected on average 24.54 ($SD = 10.4$) ball tosses. This was a significant change from the expectations before the ostracism Cyberball game, $t(63) = 3.389$, $p < 0.001$, 95% CI [-8.16, -2.62], $g_{av} = 0.55$, as well as significantly different from expecting an equal number of ball tosses (30), $t(66) = 4.30$, $p < 0.001$, 95% CI [22.00, 27.07], $d = 0.48$. There were also nine participants who already expected to be excluded at the start of the experiment (expected to receive 20 ball tosses or less). They were subsequently removed from data analysis, leaving 63 participants.

3.3.2. Values prime

To investigate the effect of the values prime buffering the impact of ostracism cues on pupillary reactivity, and find support for Hypothesis 2, we looked at whether the presence or absence of the values prime impacted the average pupil change during exclusion events in the ostracism Cyberball game. The average pupil change in the values prime condition was 0.024 ($SE = 0.005$, 95% CI [0.014, 0.034]) while the average pupil change in the no values prime condition was 0.021 ($SE = 0.005$, 95% CI [0.011, 0.031]). A GLM-repeated measures with the values prime as a between-subjects factor and event period (0 to 2000, in 100 ms bins) as within-subject factor revealed an effect of event period, $F(20, 36) = 18.70$, $p < 0.001$, $\eta^2_p = 0.912$, but no main effect of the prime, $F(1, 55) = 0.23$, $p = 0.634$, $\eta^2_p = 0.004$, nor a significant interaction with event period, $F(20, 36) = 1.50$, $p = 0.348$, $\eta^2_p = 0.390$. Hence, the values prime did not seem to have an impact on the average pupil change.

Additionally, all pupil analyses from the next sections were performed with the presence or absence of the prime as a between-subjects factor. These analyses also failed to reveal a main effect or show any interactions between the prime and the variables of interest (all Fs < 1). As a result, both the prime condition and the no prime conditions were collapsed to increase the sample size and therefore achieve higher power.

3.3.3. Gaze durations

We again looked at whether participants maintained their attention throughout the Cyberball games by recording where they looked at during each game (see Table 3). We found a difference in the amount of missing data between conditions, $t(56) = -1.97$, $p = 0.054$, in that there was more missing data during the belonging condition than during the ostracism condition. Participants also spent more time looking at the frame in the ostracism condition compared to the belonging condition, $t(56) = 2.82$, $p = 0.007$. Taken together, these results point at some disengagement of participants during the belonging game, while participants remained attentive during the ostracism game.

Table 3
Percentage of time spent looking at each region of interest, during a belonging or ostracism Cyberball game in Study 2.

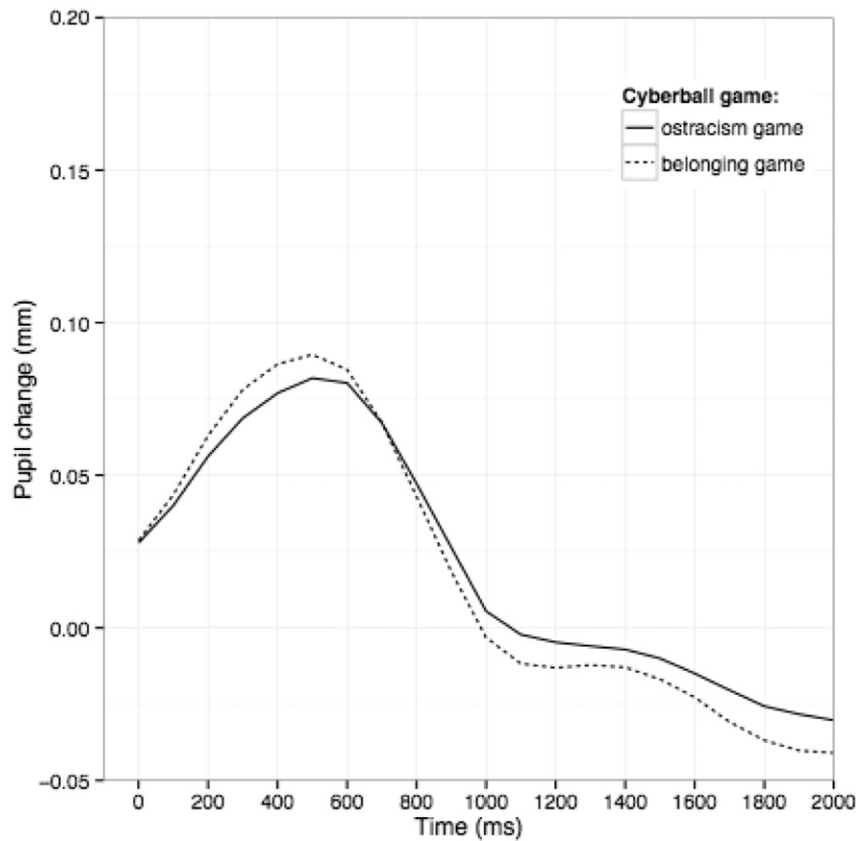| ROI	Inclusion		Exclusion		t (56)	p
	M	SD	M	SD		
Frame	0.32	0.43	0.72	0.98	2.82	0.007
Player 1	6.59	3.38	5.72	3.70	−1.77	0.082
Player 1 name	0.55	1.74	0.57	0.74	0.072	0.943
Player 2	28.80	6.86	27.53	7.31	−1.31	0.197
Player 2 name	0.83	1.55	0.93	1.17	0.46	0.648
Player 3	30.70	5.00	32.24	6.41	2.06	0.044
Player 3 name	0.74	1.31	0.71	0.60	−0.14	0.889
White area	0.87	3.25	0.98	1.95	0.50	0.618
Choice image	21.81	6.24	23.09	8.71	1.21	0.229
Missing data	8.77	5.40	7.51	3.23	−1.97	0.054

Fig. 4. Change in pupil size during exclusion events in two games of Cyberball—first an ostracism game, followed by a belonging game (Study 2).

3.3.4. Pupillometry

3.3.4.1. Exclusion events. Identical to Study 1, we investigated pupillary reactivity during events in which the ball was not thrown to the participant. A repeated measures GLM analysis was performed with Cyberball game (ostracism/belonging) and event period (0 to 2000 s, in 100 ms bins) as within-subject factors, with average pupil change as the dependent variable. This did not reveal a main effect of the Cyberball game, $F(1, 56) = 0.932$, $p = 0.338$, $\eta^2_p = 0.016$. It did reveal an effect of event period, $F(20, 37) = 19.32$, $p < 0.001$, $\eta^2_p = 0.913$, and an interaction effect between the Cyberball game and event period, $F(20, 37) = 1.92$, $p = 0.042$, $\eta^2_p = 0.510$.

Visual inspection (see Fig. 4) showed that the pupil size change in the ostracism game is smaller than in the belonging game at the start of a ball toss, but reverses after about 700 ms. In fact, a separate analysis on the initial event period reveals a significant difference, $F(1, 56) = 4.02$, $p = 0.05$, $\eta^2_p = 0.067$. Pupillary reactivity to a ball toss of which participants were not the receiver was smaller in an ostracism game ($M = 0.063$ mm, $SE = 0.003$, 95% CI [0.056, 0.070]) compared to a belonging game ($M = 0.069$ mm, $SE = 0.004$, 95% CI [0.062, 0.077]). After this moment, the pupil size in the ostracism game seems to remain larger than in the belonging game, and a separate analysis across this event period confirms a significant effect of the Cyberball game, $F(1, 56) = 4.00$, $p = 0.05$, $\eta^2_p = 0.067$. The pupil change is now larger in the ostracism game condition ($M = -0.014$ mm, $SE = 0.004$, 95% CI [-0.022, -0.005]) than in the belonging game condition ($M = -0.02$ mm, $SE = 0.006$, 95% CI [-0.035, -0.012]).

3.3.4.2. Inclusion event. We again repeated the same analysis for events in which the participant received the ball: A repeated measures GLM analysis with Cyberball game (ostracism/belonging) and event period (0 to 1600 s, in 100 ms bins) as within-subject factors, with average pupil change as the dependent variable. This revealed a main effect of the Cyberball game, $F(1, 55) = 61.11$, $p < 0.01$, $\eta^2_p = 0.526$, an effect of event period, $F(16, 40) = 44.55$, $p < 0.001$, $\eta^2_p = 0.947$, as well as an interaction, $F(16, 40) = 11.05$, $p < 0.001$, $\eta^2_p = 0.815$, see Fig. 5. Pupil size increased quickly in the first second, but increased even more in the ostracism game, after which the pupil size slowly decreased in both conditions.

3.3.4.3. Effect across the duration of a Cyberball game. We again tested for an effect of time across the entire Cyberball game, as it might take participants some moments to realize they are being excluded. Given the findings that revealed a difference between being included and excluded in pupillary reactivity in the initial phase of an event (0–700 ms) and the later phase of an event, we specifically focused on this event period across the duration of a Cyberball game. Identical to Study 1, we performed two planned comparisons, which revealed an effect of event bin during both the ostracism game, $F(2, 112) = 36.39$, $p < 0.001$, $\eta^2_p = 0.394$, and the belonging game, although the effect is smaller during the belonging game, $F(2, 112) = 9.71$, $p < 0.001$, $\eta^2_p = 0.148$.[5] Separate paired *t*-tests reveal that there is no significant difference between the two Cyberball games in response to exclusion events during the first 30 ball tosses, $t(56) = 0.99$, $p = 0.326$. However, during the next 30 ball tosses this difference is significant, $t(56) = 2.13$, $p = 0.037$, but not during the last 30 ball tosses, $t(56) = 1.51$, $p = 0.137$. In summary, it appears that the average pupil size decreases both during the ostracism game and the belonging game, but this decrease was relatively faster in the ostracism game (ostracism: $M_{\text{event 1 to 31}} = 0.085$ mm, $SD_{\text{event 1 to 31}} = 0.038$; $M_{\text{event 31 to 60}} = 0.058$ mm, $SD_{\text{event 31 to 60}} = 0.027$; M_{event}

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[5] A 2 (Cyberball condition: belonging/ostracism) × 3 (Cyberball period: event 1 to 30/event 31 to 60/event 61 to 90) repeated-measures analysis revealed no main effect of ostracism, $F(1, 56) = 1.94$, $p = 0.169$, $\eta^2_p = 0.033$, a main effect of event bin, $F(2, 112) = 34.63$, $p < 0.001$, $\eta^2_p = 0.382$, and an interaction effect, $F(2, 112) = 3.81$, $p = 0.025$.
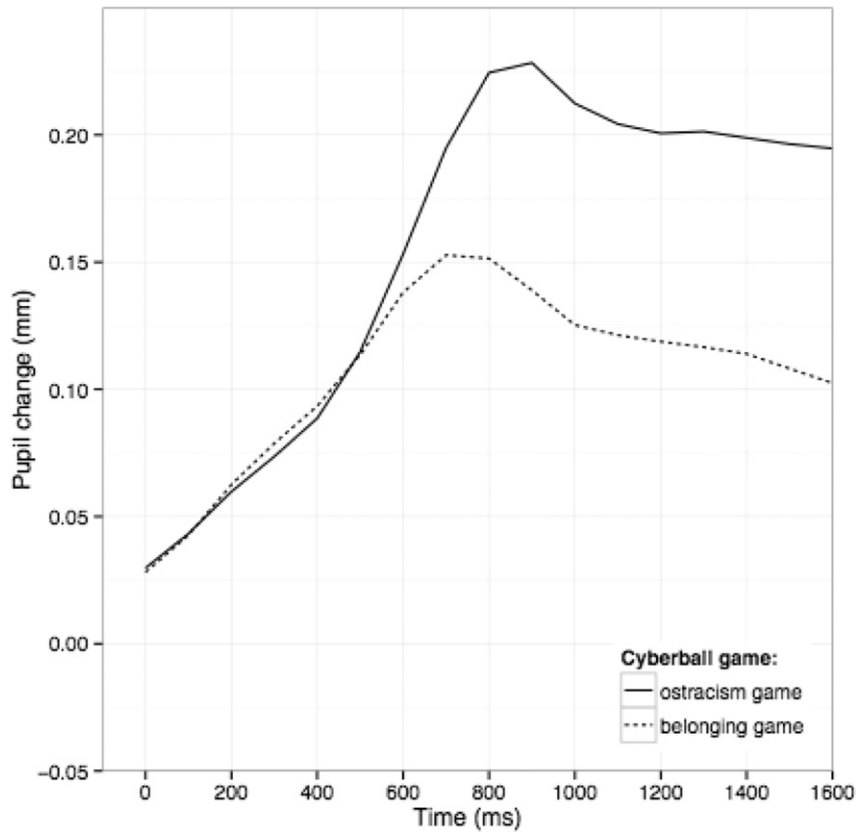
Fig. 5. Change in pupil size during inclusion events in two games of Cyberball—first an ostracism game, followed by a belonging game (Study 2).

$_{61\ to\ 90} = 0.053$ mm, $SD_{event\ 61\ to\ 90} = 0.028$; belonging: $M_{event\ 1\ to\ 31} = 0.080$ mm, $SD_{event\ 1\ to\ 31} = 0.036$; $M_{event\ 31\ to\ 60} = 0.069$ mm, $SD_{event\ 31\ to\ 60} = 0.036$; $M_{event\ 61\ to\ 90} = 0.060$ mm, $SD_{event\ 61\ to\ 90} = 0.037$).

3.3.4.4. Fundamental needs and mood. The fundamental needs and mood questionnaire was administered twice in this study, after each Cyberball game. Results showed that participants experienced an increase in their fundamental needs, as well as elevated mood, after the belonging game compared to after the ostracism game (see Table 4). We also compared the average scores on each of the scales administered after the ostracism Cyberball game to the neutral mid-point (4) and found that all scores fell significantly below the mid-point, except for mood, which was found to be significantly *greater* than 4 ($M = 4.29$, $SD = 0.91$, $t(56) = 2.43$, $p = 0.018$, 95% CI [0.052, 0.533] see Table 5).

3.3.4.5. Anxious uncertainty. We performed an identical analysis on the results of the anxious uncertainty scale, and found that participants expressed more anxious uncertainty after being excluded ($M = 2.07$, $SD = 0.72$) compared to being included ($M = 1.80$, $SD = 0.57$), $t(56) = 4.50$, $p < 0.001$, 95% CI [0.15, 0.39]). These scores were significantly below the mid-point (exclusion: $t(56) = 20.30$, $p < 0.001$; inclusion: $t(56) = 28.87$, $p < 0.001$, 95% CI [−2.12, −1.74]).

3.3.4.6. Checks. Two participants (2.78%) reported having experience with the Cyberball paradigm.[6]

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[6] Excluding these participants did not substantially impact the results (e.g., the effect of ostracism on pupil size during exclusion events in the 0 to 600 ms period remained, $F(1, 54) = 4.28$, $p = 0.043$).

4. Comparison between Study 1 and 2

Given that we conducted two similar studies, we performed additional analyses in which the responses to the Cyberball game that participants played first (*belonging* in Study 1, *ostracism* in Study 2) can be compared between the two studies. This controls for any ordering effects caused by having just participated in a Cyberball game. This analysis was done by performing a repeated-measures GLM with the 100 ms time bins as repeated measure and study (belonging first/ostracism first) as between-subjects factor. This revealed a significant effect of study (i.e., ostracism), $F(1, 90) = 13.57$, $p < 0.001$, $\eta^2_p = 0.131$, event period, $F(20, 71) = 25.92$, $p < 0.001$, $\eta^2_p = 0.880$, and an interaction effect, $F(20, 71) = 1.86$, $p = 0.029$, $\eta^2_p = 0.344$. Pupil size increased upon not receiving the ball, although in Study 2 (ostracism), this change in pupil size was consistently smaller ($M = 0.021$ mm, $SE = 0.004$, 95% CI [0.012, 0.029]) than in Study 1 (belonging; $M = 0.046$ mm, $SE = 0.005$, 95% CI [0.035, 0.057]), see Fig. 6.[7]

5. Discussion

In Study 2 we again found that participants showed a gradually decreased pupillary reaction to exclusion events in an ostracism game of Cyberball compared to a belongingness game of cyberball. This lends additional support to the hypothesis that a social-physical pain overlap mechanism underlies the pupillary response to cues of ostracism. We

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[7] We also repeated the analyses for the prime and no prime conditions separately and find largely consistent results in each condition, as well as some differences. Notably, separate analyses during the 0–700 ms and 700+ time period did not reveal significant effects of ostracism, potentially the result of a smaller effect of ostracism due to ordering effects and the loss of power. Importantly, the effect of ostracism remained in the between study comparison, in both the prime and no prime condition.

Table 4
Difference in fundamental needs, its sub-scales and mood, and the anxiety questionnaire between the belonging and ostracism condition in Study 2 (N = 57).

Scale	Statistics	M (SD) inclusion	M (SD) exclusion
Belonging	t = 27.20, p < 0.001	6.10 (0.66)	1.98 (0.67)
Control	t = 15.82, p < 0.001	5.10 (1.00)	2.01 (0.91)
Self esteem	t = 11.53, p < 0.001	5.52 (0.76)	3.20 (1.23)
Meaning	t = 10.98, p < 0.001	5.82 (0.79)	4.29 (1.34)
Mood	t = 11.54, p < 0.001	5.82 (0.52)	4.29 (0.91)
Fundamental needs and mood combined	t = 16.66, p < 0.001	5.74 (0.48)	3.63 (0.74)
Anxious uncertainty	t = 4.50, p < 0.001	1.80 (0.57)	2.07 (0.72)

also did not find any moderating effects of primed values on pupillary reactivity, a null effect which failed to support the hypothesis that exclusion is primarily experienced as an expectancy violation.

Although we obtained a similar pattern of results between the two studies, the pattern was not identical. In Study 1 we found a decreasing average pupil size across the duration of an exclusion event. In Study 2 we found this trend to occur at the beginning of the event, during the period in which a ball is tossed to another player, but before it is clearly visible to where the ball is being tossed. Possibly, this different pattern of results may be caused by the order in which participants played the belonging or ostracism games. Research on ostracism has shown that threats to people belonging evoke a variety of emotional and motivational responses. One of these responses is an enhanced state of vigilance during which there is a stronger concern for preventing further losses of social connection (Molden, Lucas, Gardner, Dean, & Knowles, 2009). Possibly as a result of having just played the ostracism game, Study 2 participants became more wary and were specifically impacted by the uncertain period during which a ball was tossed. The higher average pupil size change after a ball was tossed in the subsequent belonging game could indicate a higher level of arousal, therefore reflecting this state of increased vigilance for social cues. Alternatively, but relatedly, it could have been the case that due to the initial acceptance in Study 1, an expectation of inclusion was established, which was violated in the subsequent ostracism game, thereby increasing the severity of the ostracism experience. Severity of ostracism has been related to numbing (Bernstein & Claypool, 2012), with more numbing when the ostracism experience is severe. This could also potentially explain the difference between Study 1 and Study 2.

6. General discussion

In two experiments we tested two possible hypotheses that link pupillary reactivity to the experience of ostracism. Based on prior theorizing, we argued that ostracism necessarily consists of an initial detection of the fact one is being ostracized, and emotion regulatory processes to deal with the distressing event that is the ostracism experience. We hypothesized that pupillary reactivity could reflect either a social-physical pain overlap process which would be reflected in decreased pupillary

reactivity, or an conflict detection process which would be reflected in increased pupil dilation in response to exclusion events. In two studies we demonstrated that the pupil dilates to a lesser extent in response to exclusion events in a game during which the participant is generally ostracized (ostracism game), compared to the same event during a game in which the participant is equally included (belonging game), thereby supporting the social-physical pain overlap theory of ostracism.

6.1. Social-physical pain overlap theory

Being ostracized is a painful experience akin to being physically hurt. Researchers in the field of ostracism have suggested that this analogy is more than just a metaphorical way of speaking. The experience of social pain seems to rely on some of the same neural underpinnings that are also involved in the experience of physical pain, as supported by neuroimaging studies (for an overview, see Cacioppo et al., 2013; Eisenberger, 2012), studies on pain sensitivity after a belonging threat, (DeWall & Baumeister, 2006), and studies in which analgesics reduce the emotional experience of social pain (DeWall et al., 2010; Vangelisti, Pennebaker, & Brody, 2014). We have shown that this diminished response to ostracism might also be reflected in the pupil. The pupil can reflect a variety of cognitive and emotional processes, some of which are related to sympathetic nervous system arousal (Bradley et al., 2008) the experience of pain (Ellermeier & Westphal, 1995; Chapman et al., 1999; Höfle et al., 2008; Walter et al., 2006), and diminished pupillary dilation as a function of opioid impact on pain response (Connelly et al., 2014),

One alternative line of evidence for the social-physical pain overlap theory is that self-reports of experienced distress as a result of being ostracized often show no effects on mood, i.e., a numbing effect, whereby an absolute interpretation of the results in terms of its scale frequently indicates a neutral state of mind rather than one of emotional distress (Twenge et al., 2003). In both our studies, we find no significant impact of ostracism on mood in terms of a significant decrease towards the lower end of the response-scale. We do find differences in fundamental needs and anxious uncertainty depending on whether participants were included or excluded. These results lend some support to the social-physical pain overlap theory, although it is unclear why we observe only a numbing effect of ostracism on mood. It is possible that self-report responses can be affected by unrelated factors such as demand characteristics, making it harder to detect numbing effects that follow from the social-pain overlap theory. Or alternatively, it is possible that fundamental needs items do not tap into the affective component associated with a pain response. Instead, fundamental needs items tap more into a factual/affective response to being ostracized. For example, the item "I feel excluded" is likely to be immediately impacted upon noticing that one is being excluded, not just because one *feels* excluded but also simply because one *is* excluded. Immediately following the ostracism experience, the latter remains true, so even though a defensive numbing response took place, it remains true that one was excluded, making it likely that participants report feeling excluded, despite already coping with the experience due to the defensive numbing response. If this is indeed the case, our pupillometry findings further bolster the advantages of using physiological measures to investigate

Table 5
Difference from neutral mid-point (4) of fundamental needs, its sub-scales and mood, and the anxiety questionnaire administered after the ostracism Cyberball game in Study 2 (N = 57).

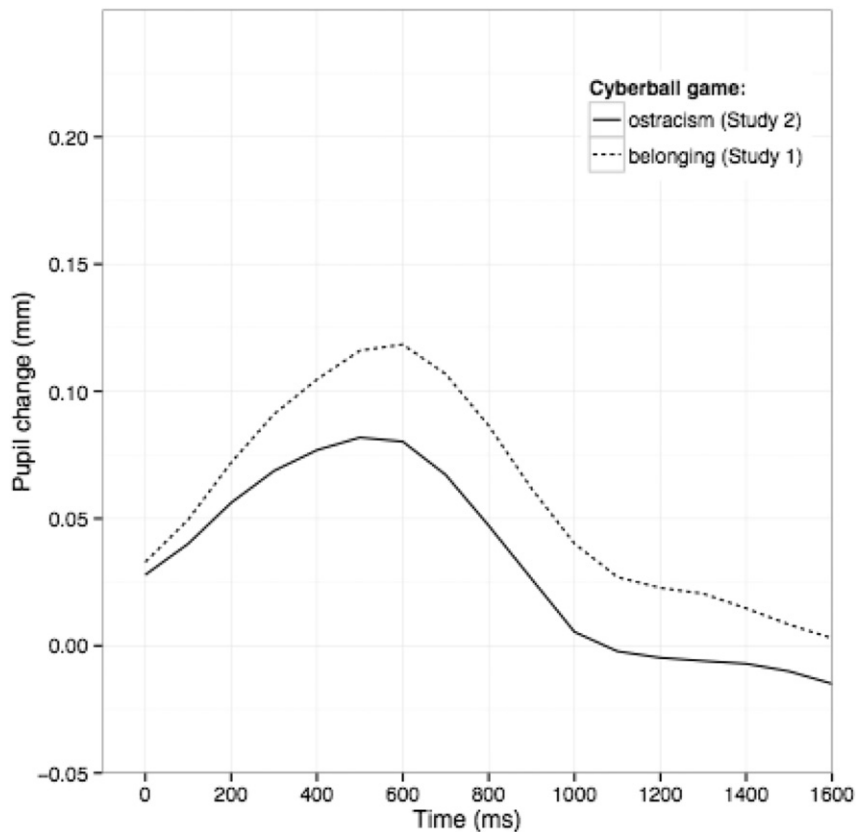| Scale	Statistics	M (SD) exclusion
Belonging	t = 22.58, p < 0.001	1.98 (0.67)
Control	t = 16.54, p < 0.001	2.01 (0.91)
Self esteem	t = 4.89, p < 0.001	3.20 (1.23)
Meaning	t = 3.21, p = 0.002	4.29 (1.34)
Mood	t = 2.43, p = 0.018	4.29 (0.91)
Fundamental needs and mood combined	t = 3.71, p < 0.001	3.63 (0.74)
Anxious uncertainty scale	t = 20.30, p < 0.001	2.07 (0.72)

Fig. 6. Change in pupil size during exclusion events in two games of Cyberball—the belonging Cyberball game from Study 1 vs. the ostracism Cyberball game from Study 2.

ostracism, which circumvent some of the limitations of self-report measures.

6.2. Conflict detection

We proposed that exclusion events could initially cause an increase in pupillary reactivity, possibly reflecting a conflict detection mechanism (e.g., Brown et al., 1999; Preuschoff et al., 2011; Smallwood et al., 2011; Sleegers et al., 2015) based on the violation of the expectation that one will be equally included in social interactions. We did not find any discrete evidence of a conflict detection mechanism. Pupillary reactivity was found to decrease, rather than increase, in response to exclusion events, and we did not find an effect of value affirmation prior to the exclusion experience, which has previously been shown to buffer pupil reactivity following expectancy violations (Inzlicht & Tullett, 2010; Inzlicht et al., 2009; Sleegers et al., 2015). However, we acknowledge the possibility of an early conflict detection mechanism in detecting ostracism. That is, it could still be the case that conflict detection plays a role, but that the numbing response that we observed overshadowed a conflict-based response. Possibly, and we concur that this remains an empirical question, the type of experience is likely to be of great importance in how people respond, even in terms of initial physiological reactions. It has already been demonstrated that the severity of the threat can impact the numbing response, with more severe threats inducing a numbing response whereas less severe threats can cause increased sensitivity to threat (Bernstein & Claypool, 2012). Other potentially aversive experiences such as task error or trivial violations of expectations might noticeably elicit physiological changes consistent with a conflict response, but fail to elicit a more downstream coping response such as the numbing effect. Future research could be focused on comparing different types of aversive experiences and how they elicit unique physiological changes.

6.3. Alternative explanations

A possible alternative explanation for our findings is that pupil sizes decreases because the participants became bored. However, we do not believe that this is a viable alternative explanation, insofar as there was no evidence for general disengagement on the part of the participants during the ostracism games. First, we also did not observe any increases in missing data during the ostracism Cyberball game compared to the belonging Cyberball game. Second, the diminished pupillary response in the ostracism game was associated only with exclusion events, as we saw no decreased pupillary reactivity during events in which participants received a ball toss and only observed it during ostracism-specific events. If participants were generally disengaged, we would have predicted a decreased pupillary response to both exclusion and inclusion events in the ostracism game. Finally, we observed a similar pattern of results in two studies, despite reversing the order in which they were included or excluded. If the decreased pupillary reactivity was due to boredom, we should have observed the decreased pupillary reactivity in the belonging game in Study 2, as this was the second Cyberball game they played. Instead we observed more numbing during the ostracism game, which was presented first.

6.4. Limitations

A potential limitation arises from the fact that pupillary reactivity can be linked to a variety of cognitive and emotional processes. Although several studies have shown the size of the pupil to be related to the experience of physical pain (Ellermeier & Westphal, 1995; Chapman et al., 1999), we have not directly demonstrated such a relationship in the present studies. Future research could provide further support by for example manipulating the presence and absence of opioids such as acetaminophen before participants play the Cyberball

game. If the decreased pupil dilation is indeed a result of a numbing response, then this might be enhanced under the influence of pain suppressing drugs such as acetaminophen.

6.5. Future directions

In our two studies we used pupillometry as a proxy for physiological arousal. Our findings contribute to the ostracism literature that so far has revealed a syndrome of sympathetic nervous system arousal findings. It has been shown that being ostracized can increase blood pressure (Stroud, Tanofsky-Kraff, Wilfley, & Salovey, 2000), cortisol levels (Blackhart, Eckel, & Tice, 2007), and skin conductance (Kelly, McDonald, & Rushby, 2012). It has also been demonstrated that being ostracized decrease one's skin temperature (IJzerman et al., 2012) and skin temperature in the face area (Paolini, Alparone, Cardone, van Beest, & Merla, 2016). We contribute to this literature by showing that also the pupil indicates the involvement of sympathetic nervous system arousal in the ostracism experience. It is possible to combine these measurement techniques, for example by combining pupillometry with other proxies for arousal such as the galvanic skin response (Bradley et al., 2008). To gain a more comprehensive insight into how people respond to ostracism events, future research could combine physiological measures to provide convergent evidence on the underlying defense mechanisms.

Pupillometry can also be used as a tool to potentially bolster existing models of ostracism. Recent development in eye tracker technology have made eye tracking an affordable and easy-to-use tool. This tool is, as demonstrated by the present research, applicable to the investigation of ostracism. Heretofore immediate responses to ostracism are measured using self-report measures such as the fundamental needs scale (e.g., Van Beest et al., 2011) or a negative affect dial (Wesselmann, Wirth, Mroczek, & Williams, 2012) that is tuned during the ostracism experience. These measures rely on the ability of participants to accurately introspect their affective responses to being ostracized. Physiological measures such as pupillometry do not rely on this ability also record more immediate responses to ostracism cues than self-report measures. The use of pupillometry could provide new insights for models that make specific predictions about immediate reactions to ostracism cues, such as William's need-threat model of ostracism, which makes the prediction that reflexive responses to ostracism are less likely to be moderated by external factors. The absence of an effect of our value affirmation could perhaps be seen as initial support for this prediction, although it must also be noted that the value affirmation test might be somewhat underpowered.

As mentioned in the Introduction, Silk and colleagues (2012) have demonstrated an increase in pupil dilation following rejection. In the present paper, we demonstrated a decrease in pupil size in response to an ostracism cue. We believe a reason for this discrepancy is likely to be the paradigm of choice. A game of Cyberball is a single event in which the players remain constant throughout the game. The ostracism cues (i.e., not being on the receiving end of a ball toss) actually represent a single holistic ostracism experience. Following a realization that one is being excluded, defensive mechanisms such as a pain response can become active to cope with the experience. In contrast, the paradigm of Silk and colleagues consisted of receiving repeated rejections from multiple people. Importantly, Silk and colleagues randomized acceptance and rejection blocks, thus potentially interfering with a numbing response as acceptance blocks could alleviate the negative experience resulting from the rejection blocks. This, however, remains conjecture and the literature would benefit from a future investigation of this possibility.

7. Conclusion

Across two studies we demonstrated a decreased pupillary reaction to cues of ostracism in the Cyberball paradigm. This response was found to be consistent with a numbing response based off of the social-physical pain overlap theory rather than a conflict detection response.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jesp.2016.08.004.

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