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RESEARCH

Both first-hand and vicarious social ostracism reduces sense of agency and body ownership: evidence from explicit and implicit measures

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Abstract
Previous findings revealed that social ostracism reduces people's sense of agency and body ownership, and vicarious ostracism reduces agency. Given theoretical claims that other's and own behavior may be cognitively represented similarly, we compared the impact of first-hand and vicarious social ostracism on agency and ownership, using both explicit and implicit measures. Participants were separated into target group and observer group, to experience first-hand or vicarious ostracism or inclusion. We used a virtual Cyberball game to induce social ostracism or inclusion; and virtual hand illusion, where participants could freely control a virtual hand by moving their real hands, for agency and ownership measurements. Findings show that, both first-hand and vicarious ostracism reduced agency and ownership in both explicit and implicit measures. While the implicit measures were affected by first-hand and vicarious experience equally, the explicit measures showed a stronger reduction of agency and ownership for first-hand than for vicarious experience.

Keywords Sense of ownership · Sense of agency · Social ostracism · Virtual hand illusion

Introduction

It is important for human beings to belong to and to be accepted by a social group, and to build positive and stable social relationships with other group members (Baumeister & Leary 1995). And yet, social ostracism, in which social relationships are denied or cut off, people are explicitly or implicitly excluded from a group, is a common phenomenon (Williams 2001). The experience of being ignored by others or even actively excluded from social interactions is often perceived as a threat to our basic needs, including aspects of a sense of belonging, control, self-esteem, and meaningful existence (Williams 2009).

When thinking about the relationship between this experience and one's felt self, it seems that being involved in social interactions with others can be considered as fundamental for what has been called the "narrative self", which is a chronic, coherent, and continuous self-construct emerging from and maintained by stories about the past and future of and including oneself. While, interestingly for our purposes, researchers have recently begun to consider the possibility that, ostracism might also affect the immediate experience of oneself—the so-called "minimal self", which represents how one experiences oneself in the here and now (Gallagher 2000). The minimal self is often studied by focusing on two of its core aspects, the sense of agency (SoA)—i.e., the experience of controlling one's own body to make movements, of being the cause of an action and its consequences in the external world (Haggard et al. 2002; Moore & Fletcher 2012; Moore & Obhi 2012); and the sense of ownership (SoO)—the experience of owning and living inside a body (Botvinick & Cohen 1998).

With regard to the relationship between SoA and ostracism, one previous study (Malik & Obhi 2019) found that ostracism, induced by asking participants to recall memories of past ostracism experiences, reduces SoA. The authors did not measure the explicit SoA (by directly asking participants the felt degree that they can control an action to make

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a tone), but only used an implicit and indirect SoA task (by asking participants to estimate the temporal interval between the press-key action and a consequent tone), even though it may be assumed that converging explicit and implicit results is more convincing (Haggard 2017); and their method to induce social ostracism may not be so reliable (Sun et al. 2023), as the recalled ostracism/inclusion events may be different from what really occurred (Baumeister et al. 2007) and may not optimally fit to what the researchers intended (Loftus & Pickrell 1995). With regard to the relationship between SoO and ostracism, previous findings suggest that being ostracized may induce the experience of one's own body as a mere tool (Ataria 2015), which may cause a kind of disownership and thus reduce SoO. Most importantly for our current study, Sun et al. (2024) found that social ostracism induced by a virtual Cyberball game reduces SoA and SoO in both explicit and implicit measures.

While all these findings refer to the (obviously distressing) first-person experience of ostracism, there is evidence that observing others being ostracized is also distressing (Wesselmann et al. 2009, 2013; Williams 2009). In one study (Masten et al. 2010), participants witnessed a three-player Cyberball game, in which the target player was socially included or ostracized, after which the participants exhibited certain behavior and brain patterns that were similar to people with first-hand experience of ostracism. Indeed, watching a friend being social ostracized activates the same pain network that is coded for first-hand experience (Beeney et al. 2011). Importantly and related to the current study, in one study vicarious ostracism was found to reduce the SoA in both explicit and implicit measures (Sun et al. 2023).

In view of the available evidence, it makes sense to consider the possibility that people represent first-person and vicarious ostracism in rather similar ways, as is suggested by the Theory of Event Coding (TEC, Hommel et al. 2001) and its extensions to self- and other-representation (Hommel 2018) and social phenomena (Kim & Hommel 2019). TEC theory emphasizes that different cognitive representations (event files), which are cognitively coded in terms of the perception and action features, can overlap to a degree if they share common features, irrespective of whether these files are self- or other- related (Hommel 2018; 2019). It seems that experiencing ostracism in first-hand or just observing other's being ostracized would create two integrated events representation (event files) comprising shared features codes related to similar ostracism perception and action, as discussed in previous studies (Wesselmann et al. 2009; Masten et al. 2010; Meyer et al. 2013). Thus it makes sense that observed ostracism in others-event files can overlap and have similar effect than ostracism in self-event files, and influence one's perceived SoA and SoO.

Thus, the present study was motivated by the question how similar these representations might be, and what it implies for the effect of (vicarious) ostracism on perceived SoA and SoO. Accordingly, we directly compared the impact of first-person and vicarious experience of ostracism on explicit and implicit measures of SoA and SoO. Like Sun et al. (2023), we induced ostracism or inclusion by means of a VR Cyberball game.

For explicit measures of perceived agency (Ma et al. 2019; Moore & Obhi 2012; Saito et al. 2015) and body ownership (Botvinick & Cohen 1998), we employed questionnaires as common in studies of the rubber hand illusion (RHI; Botvinick & Cohen 1998; Ehrsson et al. 2004) and the virtual hand illusion (VHI; Slater et al. 2008; Sanchez-Vives et al. 2010) in the current study. In VHI, participants wear immersive virtual reality (VR) head-mounted displays (HMD); dataglove and wrist sensors to track their hand movements (which translate movement data of their real hand into movements of the virtual hand); and see a virtual hand that coincides with the real position of their real hand. According to previous findings, when they can voluntarily and freely control the virtual hand, participants report the feeling that they can cause or control the movement and action effect of it, i.e., the SOA; and that the virtual hand belongs to them, i.e., the SoO.

In contrast to explicit measures, implicit measures are thought to reflect non-conscious aspects of SoA and SoO. As some researchers proposed that, implicit SoA is often and widely assessed by means of the so-called intentional or temporal binding (IB; Haggard et al. 2002) task (Imaizumi & Tanno 2019; Lafleur, Soulières, & D'Arc, 2020). The IB effect that this task generates consists in a subjective compression (under-estimation) of the temporal interval between the onsets of one's self-produced voluntary action and its consequent effect/event (Ebert & Wegner 2010; Haggard et al. 2002; Wiesing & Zimmermann 2024). Even though we also note that some other researchers criticized the connection between IB and agency (e.g., Suzuki et al. 2019; Kirsch et al. 2019; Gutzeit et al. 2023; Kong et al. 2024). It was suggested that, the temporal binding effect may be better interpreted as related to causal beliefs (e.g., Hoerl et al. 2020) or multisensory integration (e.g., Klaffehn et al. 2021), but rather than action intention. And implicit SoO is often assessed by means of the proprioceptive drift of the real hand (Liepelt et al. 2017) and skin conductance responses (SCR) to apparent threats to the virtual hand (Ehrsson et al. 2007; Ma & Hommel 2013).

From previous studies, we can see that the relationship between SoA and SoO has been highly debated. Depending on the various experimental designs and manipulations, also different measurements, some studies showed that they correlate very tightly, while some studies demonstrate the

discrepancy. For example, in some studies using VHI paradigm, correlations between the explicit measures of SoA and SoO are often high; as also the correlations between the implicit measures of SoA and SoO; whereas correlations between the explicit and implicit measures of each sense are often weak or absent (Qu et al. 2021a, b; Ma & Hommel 2015; Ma et al. 2021). Also in one active-robotic hand study (Caspar et al. 2015), the authors mentioned that the perceived SoO towards the active alien hand may facilitate SoA. While in some studies using classical RHI paradigm, more dissociation between the two explicit measures was found (Kalckert & Ehrsson 2012). However, in another study the several specific implicit measures correlated positively (Pyasik et al. 2018). It is thus possible that the stronger SoA in active RHI/VHI paradigm may contribute to body awareness and stronger SoO (Tsakiris et al. 2006). Nevertheless, all studies suggest that the available measures rely on both overlapping and non-overlapping top-down and bottom-up representations and processes, and likely to differ with regard to the weight and type of information involved (Pyasik et al. 2018; Qu et al. 2021a, b). In general, implicit measures seem to integrate more low-level multisensory information; while explicit judgments rely more on high-level reasoning based on knowledge, belief, and context (Synofzik et al. 2008; Lafleur et al. 2020).

Taken altogether, we aimed to compare explicit and implicit measures of SoA and SoO, specifically the questionnaire, SCR and IB task, after self-experienced or just observed social inclusion and ostracism. We combined a VR Cyberball game, which has been shown to be comparable to real life Cyberball games regarding ostracism experience (Kassner et al. 2012), for social inclusion and ostracism scenarios; and a VHI paradigm for SoO and SoA. From previous findings, we considered that the effect of ostracism on SoA and SoO may well be stronger with first-hand than with vicarious experience (Giesen & Echterhoff 2018), but still we assumed that even in the vicarious condition a significant effect would be found. Because we expected that, similar to the effect of vicarious ostracism on SoA, vicarious ostracism reduces SoO as well, because of the tight relationship between SoA and SoO; and according to what TEC implies, people may cognitively represent the event files of self and other being ostracized similarly; also to previous evidence that similar feeling and physiological reactions were shown to self-perceived and observed ostracism. We also considered the possibility that implicit and explicit measures are differently affected, as the social context may induce top-down effects that might influence explicit measures more strongly than implicit ones.

Method

Participants

Sixty females (mean age = 20.58, SD = 1.55, range: 18–23 years) participated. In order to control for possible gender effects, only female participants were recruited because females tend to be influenced by social exclusion more strongly (Benenson et al. 2013). The sample size was determined using a-priori G*power analysis (Faul et al. 2007): F tests, "ANOVA: fixed effects, special, main effects and interactions" was used, power was set to be as 0.8, and α to be 0.05, numerator df to be 1, number of groups to be 2, the effect size (partial $\eta 2 \geq 0.12$) was set according to previous related studies (Malik & Obhi 2019; Sun, Hommel, Ma, 2023; Sun et al. 2024), and the needed total sample size is sixty. All participants in this study individually provided informed consent and received reward for their participation. The study was approved by the southwest university ethics committee (H24021). We set exclusion criteria as in previous studies: the reported temporal intervals data of one participant need to covary monotonically with actual action-tone interval (Caspar et al. 2015; Pyasik et al. 2018), and none participants were excluded as outlier.

Design

The experiment had a two-factorial mixed design, in which the role of the participants as ostracism target or observer varied between participants; and the social scenario, ostracism or inclusion, varied within participants. The dependent variables were SoA and SoO questionnaires to assess agency and ownership explicitly, the IB effect obtained in the temporal interval estimation task (Ma et al. 2019; Sun et al. 2024) to assess implicit SoA, and SCR to assess implicit SoO (Ma et al. 2021; Sun et al. 2023; Qu et al. 2021a, b). The sequence of the two social scenario conditions was fully counterbalanced across participants.

Virtual environment and apparatus

We adopted VHI paradigm and used the same VR equipment as in a previous study (Qu et al. 2021a, b). Participants were immersed in the virtual environment through an HTC Vive head mounted display (HMD). The VR software Vizard was used to create a VR environment and three VR avatars, in addition to a virtual hand module. Participants wore a right-hand data glove (Manus, 12 sensors, record frequency 200HZ, latency around 5 ms) and an HTC Vive orientation tracker to record the movements and orientation of their hands and finger joints. The real hand movement

data was translated to the virtual hand, so that its motion was fully consistent with participants' real hand movement.

In the VR Cyberball game scene, when being the target, a participant saw and controlled the virtual hand in the virtual environment, with two other avatars standing nearby. At first the virtual ball was held by the virtual hand, and the participant could choose to pass the ball to one of the two avatars, this avatar then passed the ball back to the participant or to the other avatar. There were 40 pass rounds in total. In the inclusion condition, participants and avatars received the ball equally often but, in the ostracism condition, the participant would receive the ball in the first two rounds only, after which the two avatars would only pass the ball to each other.

When being the observer, participant saw the virtual hand in the virtual environment, and three other avatars nearby. The ball was at first in the hands of one avatar, who would be the target. Participants were told that they would observe a ball passing game among three best friends. The ball passing behavior and receiving percentage of each avatar in the Cyberball avatars was preprogrammed. Participants only needed to observe the virtual environment and the avatars from a bystander viewpoint (Wesselmann et al. 2009). The passing game comprised of 40 ball passes in total. In the inclusion condition, each avatar received the ball in one third of the total passes. In the ostracism conditions, the target avatar received the ball only twice in the beginning but was ignored thereafter by the other two avatars.

Procedure

When participants arrived in the laboratory, the experimenter helped them to put on the HMD, the data glove on their right hand, the orientation Vive tracker on their right wrist; and the SCR electrodes on their left hand fingers. Participants were then asked to freely move or rotate their right hand and fingers while watching the corresponding movement of the virtual hand for two minutes.

After that, three time estimation trials, two Cyberball passing game experiences/observations, questionnaires and threat phase, were interleaved: participants needed to perform a time estimation task that served as baseline IB; then to experience/observe a Cyberball passing game in which (vicarious) ostracism or inclusion occurred; followed by a second time estimation task. Participants rated their perceived exclusion or inclusion about themselves/target avatar, and estimated the ball passes percentage themselves/target avatar received. Then a virtual knife appeared and cut the virtual hand while the corresponding SCR data were recorded. At last, participants filled in the questionnaire to indicate their explicit SoO and SoA; and the Affect Grid scale (Russell et al. 1989) to indicate their subjective affective valence and arousal, as the target or observer.

There was a five-minute break between the two experimental conditions for relaxation and to prevent possible interference between conditions. Thereafter, participants were again to freely move their right hand and fingers for two minutes and to experience/observe another Cyberball passing game in which (vicarious) inclusion or ostracism occurred; etc.

Note that, it is possible that participants in the target and inclusion conditions need to react more by moving their virtual hand to pass the ball in the Cyberball game, i.e., make more hand movement, than in the observer or ostracism conditions. We thus not only constantly asked participants to freely move and control the virtual hand during the Cyberball game; but also asked participants to freely practice to move or rotate their real hand and watch the corresponding virtual hand movement for two minutes, before the Cyberball game, as stated above. Because, we can see from two previous papers (Pfister et al. 2021; Finotti et al. 2023), in which the active RHI was used, participants on average start experiencing illusory ownership of the rubber hand very soon with the visuo-tactile-motor stimulation, and show steep increase within 90 s. After that, the ownership feeling became stable. Thus we may infer that, the ownership feeling already went to a high level in the practice period, it cannot increase significantly with extra movements in the latter Cyberball game. Similar inference was made for explicit agency, as we can see from previous studies (Kalckert & Ehrsson 2012; Ma et al. 2021), after a 2 min practicing, agency scores in VHI paradigm are usually very high already.

Measurements

Manipulation check

The manipulation of ostracism was checked by asking participants to rate two questions assessing the subjective feeling of the ostracism target on a Likert scale from 1 to 7: "I felt that I was included" or "I felt that I was excluded", when the participant was the target; and "I felt target avatar was included" or "I felt target avatar was excluded", when the participant was the observer. Responses to the first question were reversed in score and then the average of the two questions was computed. Also, participants were asked to estimate the percentage the participant received the ball in the game, when the participant was target; or the percentage the target avatar received the ball, when the participant was observer.

Affect grid

To measure participants' subjective affective state after social ostracism or inclusion, we used the two-dimensional Affect Grid (Russell et al. 1989). The horizontal axis represents affective valence, and the vertical axis represents perceived arousal. Participants were asked to rate their mood in terms of valence and arousal whenever the affect grid appeared in the virtual environment during the experiment.

Explicit ownership and agency questionnaire

In line with an earlier study (Ma et al., 2019a; Qu et al. 2021a, b), we used an adapted Chinese version of the RHI/VHI questionnaire. We presented participants with eight questions to assess perceived SoA (Q1–4), and SoO (Q5–8). For each statement, participants responded by choosing a score on a 7-point (1–7) Likert scale, 1 indicating "strongly disagree", 4 indicating "uncertain", and 7 indicating "strongly agree". SoO scores are the average of the Q5-8; and SoA scores are the average of the Q1-4 for each condition.

The statements were:

Q1. The movement of the virtual hand in the virtual environment was caused by me.

Q2. I can control the virtual hand.

Q3. The virtual hand in the virtual environment followed my wishes.

Q4. When I make movements with my own hand, I expect the virtual hand to do the same movements with me.

Q5. I felt as if I was looking at my own hand when I was looking at this virtual hand.

Q6. I felt as if the virtual hand were my own hand.

Q7. I felt as if the virtual hand were a part of my body.

Q8. It seemed my right hand was at the same location as where the virtual hand was.

The time estimation task

The Libet-style time estimation task in the virtual environment (Ma et al. 2019; Qu et al. 2021a, b) was similar to previous non-virtual versions (Haggard et al. 2002; Ruess et al. 2018a, b; Saito et al. 2015). Participants in the virtual environment saw a virtual clock and its pointer, also the virtual hand and a virtual button (see Fig. 1). Participants were asked to press a real space bar freely with their real fingers on a real keyboard, which was placed in front of their real hand. We mapped the virtual button to the real keyboard, thus when participants pressed and released the real space bar with their real hand, the virtual hand were seen to press the virtual button, which went down and up. Importantly, pressing the space bar would cause the virtual pointer to start moving from zero clockwise. With each press, the virtual clock pointer always rotated from zero to zero at a speed of 1200 ms for a round. At a random time point between 600 and 1000 ms after the space bar was pressed, the computer generated a tone. Participants were asked to report the position of the pointer when the tone was played. The time estimation task for baseline, inclusion, exclusion comprised ten IB trials each (Ma et al. 2019; Qu et al. 2021a, b).

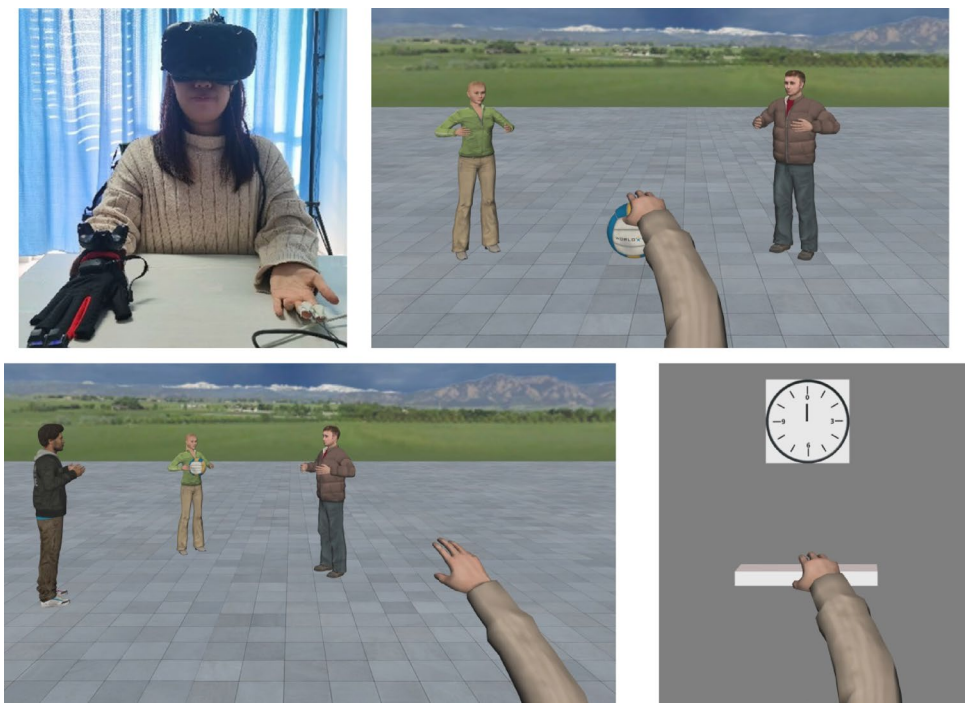

Fig. 1 (upper left) The front view of a participant wearing the HMD, dataglove and wrist tracking sensor, also the SCR electrodes; (upper right) the VR Cyberball passing game, participants as the target; (lower left) the VR Cyberball passing game, participants as the observer; (lower right) the IB task

Note that our time estimation task actually only measures the effect-binding effect (similar to Ruess et al. 2018a, b), without the action-binding effect. While in many studies, researchers measured the IB effect by asking participants to verbally report the temporal interval between action and tone, thus measured the IB effect which include both action-binding and effect-binding (Haggard et al. 2002; Caspar et al. 2015; Pyasik et al. 2018). We have five reasons for this.

First, inspired by the previous ostracism studies (Williams 2009), we can read their questionnaire about control deprivation following ostracism, which specifies to the perceived control over one's environment, but not over one's body actions. For example, the questions are like: "I felt that I had control over the Cyberball game"; or "I felt that I could alter things during the game". Thus effect-binding effect may be optimal for us than total binding and action-binding effect in the current study. Second, as previous study (Haggard et al. 2002; Ruess et al. 2018a, b) showed, when participants only need to report the onset time of the tone after the voluntary action, effect-binding effect is sufficient to reflect action-tone interval compression itself; and specifically explains how felt SoA influences our perception of the effects of action (McEneaney 2013). Third, we note that one meta-analysis study reported a positive correlation of action-binding and effect-binding across different studies (Tanaka et al. 2019). Fourth, it seems that some researchers proposed conflicting evidence and suggest that temporal binding originates not from action intention, but rather from sensory integration and temporal prediction (Kong et al. 2024; Krisch et al., 2019), or predictively attentional resources redirection processes (Schwarz & Weller 2023; Gutzeit et al. 2023). And fifth, in one study (McEneaney 2013) the authors asked participants to use mouse to click on the screen to induce a flash, to simulate human–computer interaction, instead of the key-press action in real physical environments; which is similar to our experimental design, as we asked participants to press virtual keys in virtual environment. And McEneaney (2013) found that the shifted temporal amount in effect-binding is bigger than which in action-binding, thus we may infer that at least in current study, effect-binding may itself generate more pronounced temporal interval compression. Thus in our time estimation task we preferred to only measure the effect-binding, to reduce possible confounding and gain clear cut findings.

Skin conductance response (SCR)

As previous findings show, the ownership illusion comes with increased concern for the owned effector, as indicated by increases in SCR when the virtual hand is threatened (Ehrsson et al. 2007). During the threat phase of each condition, we presented a virtual knife on top of the virtual hand, and it would go down to cut the virtual hand, and then back to the original position, wait for 10 s, then cut again. In total, the knife cut the virtual hand four times in each social scenario condition. For each cut, we defined a latency onset window between 1 and 8 s after the stimulus/event onset, namely when the virtual knife cut the virtual hand; and with the skin conductivity before event onset serving as SCR baseline (Ma & Hommel 2015). Then we calculated the magnitude of the event-induced SCR by subtracting SCR baseline from the peak amplitude of the SCR during the time window, then computed the log(magnitude + 1) per cut (Figner & Murphy 2011). Lastly the average of the four cut-induced SCR, so to avoid possible noise, was taken as the SCR result in a specific social scenario condition for each participant (Qu et al. 2021a, b).

Result

To control the familywise error rate, all below reported p values were adjusted with the Holm-Bonferroni correction (Paulet al. 2013). For our interest, we run one-tailed Spearman correlational analysis between the four measures of SoA and SoO. Only correlation between SoA and IB effect when participants' role is observer was found to be significant, correlation coefficient = 0.412, $p = 0.012$; correlation between SoA and IB effect when target was near to significant, correlation coefficient = 0.267, $p = 0.077$; but the other ps > 0.10.

Manipulation checks

The mixed 2 (social scenario as within-subject factor: inclusion vs. ostracism) × 2 (role as between-subject factor: target vs. observer) ANOVA of the ostracism ratings and ball-received percentage both showed a main effect of scenario only. Participants felt that the target was more excluded in the ostracism condition (M = 5.88, SE = 0.15) than in the inclusion condition (M = 2.22, SE = 0.14), $F(1,58) = 519.76$, $p < 0.001$, $p\eta^2 = 0.90$, BF10 > 1000. No other significant effect was found, ps > 0.18, all BF10 < 0.55. Participants estimated that the target received fewer ball passes in the ostracism condition (M = 66.18, SE = 2.48) than in the inclusion (M = 4.92, SE = 0.48) condition, $F(1,58) = 570.03$, $p < 0.001$, $p\eta^2 = 0.91$, BF10 > 1000. No other significant effect was found, ps > 0.77, all BF10 < 0.27.

Affect grid results

The same mixed 2 × 2 ANOVA of the affect grid results showed main effects of scenario only. Lower valence was found after the ostracism condition (M = 2.63, SE = 0.21)

than after the inclusion condition (M = 7.33, SE = 0.17), F(1,58) = 317.22, $p < 0.001$, $p\eta^2 = 0.85$, BF10 > 1000. No other effect was significant, ps > 0.31, all BF10 < 0.42. Arousal was higher after the ostracism condition (M = 6.53, SE = 0.20) than after the inclusion condition (M = 5.35, SE = 0.28), F(1,58) = 19.58, $p < 0.001$, $p\eta^2 = 0.25$, BF10 > 500. No other effect was significant, ps > 0.09, all BF10 < 0.86.

Explicit agency

The same 2 × 2 ANOVA of the explicit agency questionnaire results showed a scenario main effect: SoA ratings were lower after the ostracism (M = 4.46, SE = 0.14) than after the inclusion condition (M = 6.10, SE = 0.08), F(1,58) = 162.17, $p < 0.001$, $p\eta^2 = 0.74$, BF10 > 1000. The main effect of role just missed significance, F(1,58) = 3.91, $p = 0.053$, $p\eta^2 = 0.06$, BF10 = 1.27: SoA ratings tended to be lower when being the target (M = 5.10, SE = 0.13) than the observer (M = 5.46, SE = 0.13); but the interaction was significant, F(1,58) = 6.36, $p = 0.014$, $p\eta^2 = 0.10$, BF10 = 3.60. See Fig. 2.

A two-tailed paired-samples t-test showed that when participants were target, the SoA was significantly higher after inclusion (mean = 6.09, SE = 0.11) than after exclusion (mean = 4.13, SE = 0.16), t(29) = 10.79, $p < 0.001$, Cohen's d = 2.32. When they were observer, the effect was numerically smaller but SoA was still significantly higher after inclusion (mean = 6.12, SE = 0.11) than after exclusion (mean = 4.80, SE = 0.21), t(29) = 7.22, $p < 0.001$, Cohen's d = 1.55. With respect to role effects, participants did not show any role difference towards the virtual hand under inclusion, $p = 0.91$; but the role effect was significant when ostracism, t(58) = 3.08, $p = 0.005$, Cohen's d = 0.80, due to lower SoA for first-hand experience (mean = 4.13, SE = 0.16) than for vicarious experience (mean = 4.80, SE = 0.21). Hence, being ostracized reduced SoA more than observing ostracism.

Time estimation

In line with previous studies (Dewey & Knoblich 2014), the percentages of estimated time in relation to real time was computed and analyzed. We calculated this value separately for baseline, experience/vicarious ostracism and inclusion, with the formula: temporal interval estimations percentage = [actual interval—estimated interval]/actual interval (Braun et al. 2014), and used the median value across the trials (Dewey & Knoblich 2014) as baseline IB, ostracism IB and inclusion IB value for each participant. According to Haggard et al. (2002), the stronger participants feel that they voluntarily pressed the key and caused the consequent sound, the more compressed the estimated interval between key press and sound should be, and so the higher our time estimation percentage value should be.

A mixed 3(social scenario as within-subject factor: baseline, inclusion, ostracism) × 2(role as between-subject factor: target, observer) ANOVA yielded a main effect of social scenario, F(2, 116) = 7.78, $p = 0.001$, $p\eta^2 = 0.12$, BF10 > 100; all other ps > 0.77, all BF10 < 0.37. Post hoc analyses showed that ostracism (mean = 2.76, SE = 0.56) yielded significantly lower interval estimates than the baseline condition (mean = 4.65, SE = 0.72), mean difference = 1.93, SE = 0.56, t(59) = 3.44, $p = 0.002$; and than inclusion (mean = 4.69, SE = 0.59), mean difference = 1.90, SE = 0.56, t(59) = 3.39, p = 0.002. The inclusion condition did not differ from the baseline condition, $p = 0.954$.

We also compared the three IB values against zero with one-sample t test, and results showed that IB values in all three conditions were significantly higher than zero, ts > 4.92, ps < 0.001, ds > 0.63; suggesting that the IB effect occurred in all three conditions.

Explicit ownership

The same 2 × 2 ANOVA of the explicit ownership scores showed a main effect of scenario, showing that SoO ratings were lower after ostracism (M = 3.58, SE = 0.17) than after inclusion (M = 4.58, SE = 0.16), F(1,58) = 119.31, $p < 0.001$,

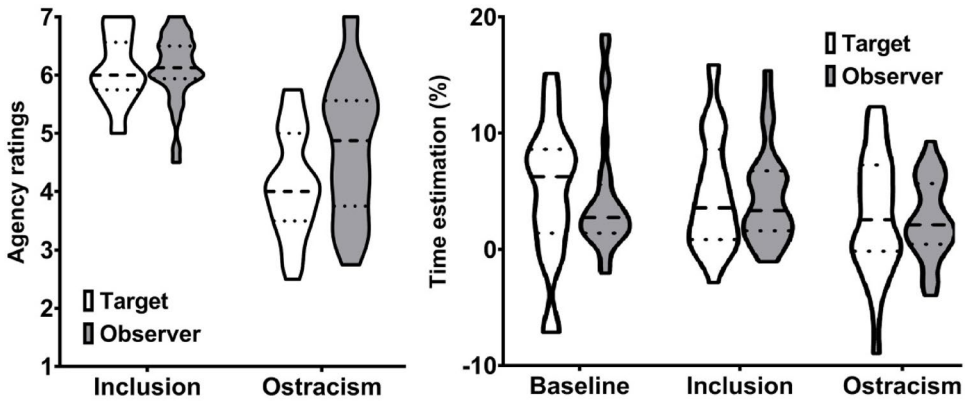

Fig. 2 Explicit SoA ratings and IB results as a function of social scenario condition and role. The middle lines of the violin-plot indicate the median

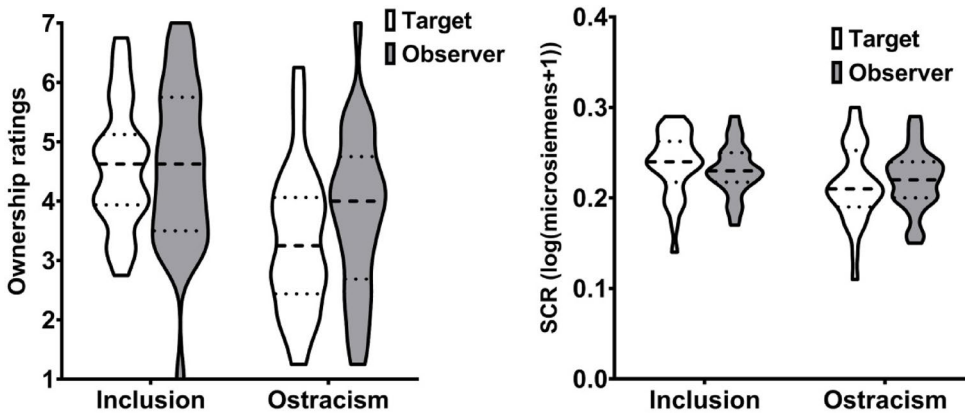

Fig. 3 Explicit SoO ratings and SCR results as a function of social scenario and role. The middle lines of the violin-plot indicate the median

$p\eta^2 = 0.67$, BF10 > 1000. The main effect of role was not significant, $p = 0.48$, BF10 = 0.54; but the interaction was, $F(1,58) = 6.21$, $p = 0.016$, $p\eta^2 = 0.10$, BF10 = 3.09. See Fig. 3.

T-tests confirmed that SoO was significantly more pronounced after inclusion (mean = 4.58, SE = 0.19) than after exclusion (mean = 3.35, SE = 0.22), $t(29) = 9.48$, $p < 0.001$, Cohen's d = 0.98, with first-hand experience; and the same was true with vicarious experience (mean = 4.58, SE = 0.25 vs. mean = 3.80, SE = 0.25), $t(29) = 5.96$, $p < 0.001$, Cohen's d = 0.62. There was no role effect under inclusion, $p = 0.98$, or ostracism, $p = 0.34$. However, t-tests of the differences between inclusion and ostracism indicated a significantly higher effect of the scenario at first-hand than vicarious experience (mean = 1.23, SE = 0.13 vs. mean = 0.78, SE = 0.13), $t(58) = 2.49$, $p = 0.016$, Cohen's d = 0.64, suggesting that being ostracized reduced SoO more than just observing ostracism.

SCR

The same 2 × 2 ANOVA revealed a significant main effect of scenario, $F(1,58) = 8.00$, $p = 0.006$, $p\eta^2 = 0.12$, BF10 = 8.58, indicating that SCR was higher under inclusion (mean = 0.234, SE = 0.004) than under exclusion (mean = 0.217, SE = 0.005). No other effect was significant, ps > 0.27, all BF10 < 0.47.

Discussion

The aim of this study was to compare the effects of first-hand and vicarious ostracism on explicit and implicit measures of SoA and SoO, through a combination of a virtual Cyberball passing game and a VHI paradigm. Manipulation checks suggest that our ostracism manipulation worked, because participants reported that, they felt the target suffered more ostracism and received fewer ball passes in the ostracism condition than in the inclusion condition, no matter the role of the participants were.

Consistent with our hypotheses, and similarly to previous findings of experiencing ostracism first-hand (Malik & Obhi 2019; Sun et al. 2024), and findings from vicarious ostracism (Sun et al. 2023), we found that ostracism reduces both SoA and SoO in both roles and in both explicit and implicit measures. Additionally, the explicit SoA and SoO results showed significant interaction between social scenario and role. Considering these findings and the Bayesian statistics results, we may infer that the subjective strength of the ostracism experience on these explicit measures is reduced for mere observers. In contrast, the implicit results only showed a main effect of ostracism, but no moderation by role. This suggests that, compare to the explicit measures, the implicit measures are more sensitive to the ostracism event as such than to the degree to which the perceiver is involved therein. This is similar to neuroscientific observations that harm targeting another individual can activate the same brain areas that are involved in processing one's own pain (Lamm et al. 2011). With respect to ostracism, this is to our knowledge the first study to demonstrate the relationship between subjective and objective measures in processing vicarious ostracism, and to thoroughly compare the impact of ostracism on both SoA and SoO in both first-hand and vicarious conditions. With respect to the general pattern of the outcomes, two aspects seem noteworthy to us.

First, all explicit and implicit measurements showed main effects of scenario, suggesting that both first-hand and vicarious ostracism affect SoA and SoO. Our findings are consistent with previous claims suggesting that humans are sensitive to violations of social regulations and normative expectations that people have in social life (Rudert et al. 2018); and to social threat caused by social ostracism (Kerr & Levine 2008; Spoor & Williams 2007). People not only respond to social rejection in an automatic, reflexive manner, report pain and feelings of injury after experiencing ostracism (Williams & Zadro 2005); but also are sensitive to the experience of ostracism targeting others (Wesselmann et al. 2009; Giesen & Echterhoff 2018), report negative affect, feel threat of their own basic need of belonging, just

like when experiencing ostracism themselves (Paolini et al. 2017; Wesselmann et al. 2009, 2013).

Our affect grid results were also consistent with previous findings showing that both self-experienced and witnessed ostracism is associated with negative affect and arousal (Wesselmann et al. 2009; 2013; Giesen & Echterhoff 2018). Experiencing ostracism personally and directly as a target triggers negative affect, but observing others being ostracized may also induce the recall of one's own previous ostracism experiences (Giesen & Echterhoff 2018), which in turn may suffice to induce similar feelings than when being a target of ostracism oneself (Masten et al. 2011; Meyer et al. 2013).

Second, SoA and SoO were equally affected by our manipulations, in both explicit and implicit measures separately. This is consistent with previous VHI studies that provided evidence for a strong correlation between explicit SoA and SoO measures (Braun et al. 2018; Ma & Hommel 2015). Of particular interest, the interaction effect was only found for the two questionnaires, but not for the two indirect measures. That is, explicit SoA and SoO decrease more for first-hand than for vicarious experience, whereas implicit measures were not sensitive for people's role. This is similar to previous findings (Qu et al. 2021a, b). However, from the correlational analysis, we may infer that, even similar results patterns of these measures may suggest the convergence; the lack of correlations may support the divergence across these different measurement results.

Especially, the discrepancy between explicit SoA and IB effect is remarkable: explicit SoA judgment often requires congruence between action and effect (e.g., moving one's own hand and seeing the virtual hand move); while IB effect (e.g., the perceived time compression between action and effect) can sometimes be induced with involuntary actions (Kirsch et al. 2019) or even only observation under specific conditions (Schwarz & Weller 2023; Kong et al. 2024), without associated explicit SoA. Also neural mechanisms of implicit and explicit SoA were revealed to be differentiated, Hughes (2018) found that explicit SoA significantly correlates to right TPJ activation, while effect-binding was not affected. Similarly, explicit SoO require more coherent multisensory signal, while some implicit measures (e.g., SCR to threat responses) can be elicited significantly under specific conditions where explicit ownership strength was not much influenced (Ma & Hommel 2013). Also neural mechanisms of implicit and explicit SoO were predicted to be dissociable too, for example, peripersonal space remapping in the premotor cortex is tightly linked to explicit SoO, while remapping in the posterior parietal cortex closely associates to the proprioceptive position sense (Brozzoli et al. 2012). Authors also investigated the relationship of neural correlates between SoA and SoO during voluntary movement, and found that SoO was associated with activity in posterior parietal, premotor, and cerebellar regions, whereas SoA was related to activity in the superior temporal cortex and dorsal premotor cortex, separately. However, it seems that the dorsal premotor cortex and somatosensory cortex show overlapping activity for SoO and SoA (Abdulkarim et al. 2023). Along with the behavioral evidence, the neural findings also suggest the overlapped but distinct relationship between SoO and SoA (Seghezzi et al. 2019).

These findings raise the theoretical possibility that both explicit and implicit SoA and SoO are derived from strongly overlapping informational sources, and that they integrate top-down and bottom-up contributions in not so comparable ways. As in previous studies, explicit measures reflect higher-level cognitive judgments and conscious beliefs, seem to be particularly sensitive to top-down contributions, such as generalized knowledge about expectations and context, and appearance of one's own body, which seems to modulate bottom-up multisensory information from experiencing one's own and the virtual hand (Apps & Tsakiris 2014; Frith et al. 2000; Moore & Fletcher 2012), as suggested by Synofzik et al. (2008). Things are different for implicit and indirect measures, which reflect lower-level sensorimotor integration and predictive processing (Hoerl et al. 2020), such as IB and SCR in the current study. These measures seem to be much more directly driven by bottom-up information (Qu et al. 2021a, b), which is obtained in the current study from participants' current experience with the virtual hand and the Cyberball game. Overall, the divergence between implicit and explicit measures of SoO and SoA is a fundamental reflection of the hierarchical and multi-faceted nature of body representation (Synofzik et al. 2008). Implicit measures may tap into the automatic sensorimotor processes of the body schema, crucial for online action and rooted in predictive multisensory integration. Explicit measures may access the conscious, perceptual, and conceptual body image, shaped by beliefs, emotions, and cognitive interpretations. This dissociation may arise from complex interactions between these types of information, and disruptions at one don't necessarily imply disruption at the other.

Thus, it is important to consider the type of information needed to generate explicit and implicit measures in order to make sense of the outcome pattern. In our design, participants can always freely control the virtual hand whenever they want to move, no matter whether they are the target or observer of ostracism, and no matter whether they need to pass a ball or not. Thus, the available bottom-up information is likely to be the same for different measures. Accordingly, the observed differences between measures are likely reflecting the experience of the participant with respect to the social scenario and the first-hand versus vicarious nature

of the experience. Even though ostracism affects one's experience under both first-hand and vicarious conditions (Giesen & Echterhoff 2018), participants were likely to be able to nevertheless differentiate between different sources of social pain, possibly based on differences between the neural networks associated with directly experienced vs. empathically experienced pain (Lamm et al. 2011). Like other social sources that otherwise contextual scenario (Lafleur et al. 2020), these differences in experience had a stronger impact on explicit than on implicit measures, which like in previous studies seemed to be mainly driven by top-down information.

We note that our study did have certain limitations that may inspire possible future work. On the one hand, future research may expand the sample to explore changes in the SoA and SoO of males when experiencing and observing social ostracism or inclusion. And on the other hand, in our time estimation task we only included the effect-binding effect, without the action-binding effect. Even we have strong arguments for this method; it is still possible that action-binding effect differs from the effect-binding effect. As previous studies showed, with specific experimental design, some factors may influence the magnitude of the two effects differently (Ruess et al. 2018a, b). Also one study showed that the two sub-components of temporal binding, that is, the action and effect binding, are not inter-individual correlated, and suggesting possible independent cognitive processes for them (Tonn et al. 2021). Thus it would be interesting to see whether the first-hand/vicarious ostracism may influence the action binding effect; and whether this impact is similar or correlate to current findings on effect binding.

Conclusion

In this study, we compared the impact of first-hand and vicarious social inclusion and ostracism on sense of agency and ownership, using both explicit and implicit measures, through a combination of a virtual Cyberball passing game and a VHI paradigm. As a target or observer of ostracism, participants showed reduced sense of agency and ownership in both explicit and implicit measures. Specifically, while the implicit measures were affected by first-hand and vicarious experience equally, the explicit measures showed a stronger decrease of sense of agency and ownership for ostracism target than observer.

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Author contributions All authors contributed to the study design. Participants testing and data collection were performed by Y. S. Data analysis and manuscript drafting was performed by K. M., and B. H. provided critical revisions. All authors approved the final version of the manuscript for submission.

Data availability Open practices statement: Raw data of the study are available on the Open Science Framework (https://osf.io/jt2cn/); the Experiment was not preregistered.

Declarations

Conflict of interests The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article. All procedures performed in this study were in accordance with the ethical standards of the ethics committee of Southwest University and with the 1964 Helsinki declaration and its later amendments. Informed consents were obtained from all participants included in this study.

References

Abdulkarim Z, Guterstam A, Hayatou Z, Ehrsson HH (2023) Neural substrates of body ownership and agency during voluntary movement. J Neurosci 43(13):2362–2380

Apps MAJ, Tsakiris M (2014) The free-energy self: a predictive coding account of self recognition. Neurosci Biobehav Rev 41:85–97

Ataria Y (2015) Sense of ownership and sense of agency during trauma. Phenomenol Cogn Sci 14:199–212

Baumeister RF, Leary MR (1995) The need to belong: desire for interpersonal attachments as a fundamental human motivation. Psychol Bull 117(3):497–529

Baumeister RF, Brewer LE, Tice DM, Twenge JM (2007) Thwarting the need to belong: Understanding the interpersonal and inner effects of socialexclusion. Soc Personal Psychol 1(1):506–520

Beeney JE, Franklin RG, Levy KN, Adams RB (2011) I feel your pain: Emotional closeness modulates neural responses to empathically experienced rejection. Soc Neurosci 6(4):369–376

Benenson JF, Markovits H, Hultgren B, Nguyen T, Bullock G, Wrangham R, Sinigaglia C (2013) Social exclusion: more important to human females than males. PLoS ONE 8(2):e55851

Botvinick M, Cohen J (1998) Rubber hands 'feel' touch that eyes see. Nature 391(6669):756

Braun N, Thorne JD, Hildebrandt H, Debener S (2014) Interplay of agency and ownership: the intentional binding and rubber hand illusion paradigm combined. PLoS ONE 9(11):e111967

Braun N, Debener S, Spychala N, Bongartz E, Soros P, Muller HHO, Philipsen A (2018) The senses of agency and ownership: a review. Front Psychol 9:535

Brozzoli C, Gentile G, Ehrsson HH (2012) That's near my hand! Parietal and premotor coding of hand-centered space contributes to localization and self-attribution of the hand. J Neurosci 32(42):14573–14582

Caspar EA, Cleeremans A, Haggard P (2015) The relationship between human agency and embodiment. Conscious Cogn 33:226–236

Dewey JA, Knoblich G (2014) Do implicit and explicit measures of the sense of agency measure the same thing? PLoS ONE 9(10):e110118

Ebert JP, Wegner DM (2010) Time warp: authorship shapes the perceived timing of actions and events. Conscious Cogn 19(1):481–489

Ehrsson HH, Spence C, Passingham RE (2004) That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. Science 305(5685):875–877

Ehrsson HH, Wiech K, Weiskopf N, Dolan RJ, Passingham RE (2007) Threatening a rubber hand that you feel is yours elicits a cortical anxiety response. Proc Natl Acad Sci U S A 104(23):9828–9833
Faul F, Erdfelder E, Lang AG, Buchner A (2007) G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39(2):175–191
Figner B, Murphy R (2011) Using skin conductance in judgment and decision making research. In: Schulte-Mecklenbeck M, Kühberger A, Ranyard R (eds) A handbook of process tracing methods for decision research: A critical review and user's guide. Psychology Press, pp 163–184
Finotti G, Garofalo S, Costantini M, Proffitt DR (2023) Temporal dynamics of the rubber hand illusion. Sci Rep 13(1):7526
Frith CD, Blakemore SJ, Wolpert DM (2000) Abnormalities in the awareness and control of action. Philos Trans R Soc Lond B Biol Sci 355(1404):1771–1788
Gallagher S (2000) Philosophical conceptions of the self: implications for cognitive science. Trends Cogn Sci 4(1):14–21
Giesen A, Echterhoff G (2018) Do i really feel your pain? Comparing the effects of observed and personal ostracism. Pers Soc Psychol Bull 44(4):550–561
Gutzeit J, Weller L, Kürten J, Huestegge L (2023) Intentional binding: merely a procedural confound? J Exp Psychol Hum Percept Perform 49(6):759
Haggard P (2017) Sense of agency in the human brain. Nat Rev Neurosci 18(4):196–207
Haggard P, Clark S, Kalogeras J (2002) Voluntary action and conscious awareness. Nat Neurosci 5(4):382–385
Hoerl C, Lorimer S, McCormack T, Lagnado DA, Blakey E, Tecwyn EC, Buehner MJ (2020) Temporal binding, causation, and agency: developing a new theoretical framework. Cogn Sci 44(5):e12843
Hommel B (2018) Representing oneself and others: an event-coding approach. Exp Psychol 65:323–331
Hommel B (2019) Theory of event coding (TEC) v2. 0: representing and controlling perception and action. Atten Percept Psychophys 81(7):2139–2154
Hommel B, Müsseler J, Aschersleben G, Prinz W (2001) The theory of event coding (TEC): a framework for perception and action planning. Behav Brain Sci 24:849–878
Hughes G (2018) The role of the temporoparietal junction in implicit and explicit sense of agency. Neuropsychologia 113:1–5
Imaizumi S, Tanno Y (2019) Intentional binding coincides with explicit sense of agency. Conscious Cogn 67:1–15
Kalckert A, Ehrsson HH (2012) Moving a rubber hand that feels like your own: a dissociation of ownership and agency. Front Hum Neurosci 6:40
Kassner MP, Wesselmann ED, Law AT, Williams KD (2012) Virtually ostracized: studying ostracism in immersive virtual environments. Cyberpsychol Behav Soc Netw 15(8):399–403
Kerr NL, Levine JM (2008) The detection of social exclusion: evolution and beyond. Group Dyn Theory Res Pract 12(1):39–52
Kim D, Hommel B (2019) Social cognition 2.0: towards mechanistic theorizing. Front Psychol 10:2643
Kirsch W, Kunde W, Herbort O (2019) Intentional binding is unrelated to action intention. J Exp Psychol Hum Percept Perform 45(3):378
Klaffehn AL, Sellmann FB, Kirsch W, Kunde W, Pfister R (2021) Temporal binding as multisensory integration: manipulating perceptual certainty of actions and their effects. Atten Percept Psychophys 83(8):3135–3145
Kong G, Aberkane C, Desoche C, Farnè A, Vernet M (2024) No evidence in favor of the existence of "intentional" binding. J Exp Psychol Hum Percept Perform 50(6):626
Lafleur A, Soulières I, d'Arc BF (2020) Sense of agency: sensorimotor signals and social context are differentially weighed at implicit and explicit levels. Conscious Cogn 84:103004
Lamm C, Decety J, Singer T (2011) Meta-analytic evidence for common and distinct neural networks associated with directly experienced pain and empathy for pain. Neuroimage 54(3):2492–2502
Liepelt R, Dolk T, Hommel B (2017) Self-perception beyond the body: the role of past agency. Psychol Res 81:549–559
Loftus EF, Pickrell JE (1995) The formation of false memories. Psychiatr Ann 25(12):720–725
Ma K, Hommel B (2013) The virtual-hand illusion: effects of impact and threat on perceived ownership and affective resonance. Front Psychol 4:604
Ma K, Hommel B (2015) The role of agency for perceived ownership in the virtual hand illusion. Conscious Cogn 36:277–288
Ma K, Hommel B, Chen H (2019) Context-induced contrast and assimilation effects in explicit and implicit measures of agency. Sci Rep 9(1):3883
Ma K, Qu J, Yang L, Zhao W, Hommel B (2021) Explicit and implicit measures of body ownership and agency: affected by the same manipulations and yet independent. Exp Brain Res 239:2159–2170
Malik RA, Obhi SS (2019) Social exclusion reduces the sense of agency: evidence from intentional binding. Conscious Cogn 71:30–38
Masten CL, Eisenberger NI, Pfeifer JH, Dapretto M (2010) Witnessing peer rejection during early adolescence: neural correlates of empathy for experiences of social exclusion. Soc Neurosci 5(5–6):496–507
Masten CL, Morelli SA, Eisenberger NI (2011) An fMRI Investigation of Empathy for "Social Pain" and Subsequent Prosocial Behavior. Neuroimage 55:381–388
McEneaney JE (2013) Agency effects in human–computer interaction. Int J Human-Comput Interact 29(12):798–813
Meyer ML, Masten CL, Ma Y, Wang C, Shi Z, Eisenberger NI, Han S (2013) Empathy for the social suffering of friends and strangers recruits distinct patterns of brain activation. Soc Cogn Affect Neurosci 8(4):446–454
Moore JW, Fletcher PC (2012) Sense of agency in health and disease: a review of cue integration approaches. Conscious Cogn 21(1):59–68
Moore JW, Obhi SS (2012) Intentional binding and the sense of agency: a review. Conscious Cogn 21(1):546–561
Paolini D, Pagliaro S, Alparone FR, Marotta F, van Beest I (2017) On vicarious ostracism. Examining the mediators of observers' reactions towards the target and the sources of ostracism. Soc Influ 12(4):117–127
Paul S, Simon D, Kniesche R, Kathmann N, Endrass T (2013) Timing effects of antecedent- and response-focused emotion regulation strategies. Biol Psychol 94(1):136–142
Pfister R, Klaffehn AL, Kalckert A, Kunde W, Dignath D (2021) How to lose a hand: sensory updating drives disembodiment. Psychon Bull Rev 28(3):827–833
Pyasik M, Burin D, Pia L (2018) On the relation between body ownership and sense of agency: a link at the level of sensory-related signals. Acta Psychol 185:219–228
Qu J, Ma K, Hommel B (2021a) Cognitive load dissociates explicit and implicit measures of body ownership and agency. Psychon Bull Rev 28(5):1567–1578
Qu J, Sun Y, Yang L, Hommel B, Ma K (2021b) Physical load reduces synchrony effects on agency and ownership in the virtual hand illusion. Conscious Cogn 96:103227
Rudert SC, Sutter D, Corrodi VC, Greifeneder R (2018) Who's to blame? Dissimilarity as a cue in moral judgments of observed ostracism episodes. J Pers Soc Psychol 115(1):31–53
Ruess M, Thomaschke R, Kiesel A (2018a) Intentional binding of visual effects. Atten Percept Psychophys 80(3):713–722

Ruess M, Thomaschke R, Kiesel A (2018b) The time course of intentional binding for late effects. Timing & Time Perception 6(1):54–70
Russell JA, Weiss A, Mendelsohn GA (1989) Affect grid: a single-item scale of pleasure and arousal. J Pers Soc Psychol 57(3):493–502
Saito N, Takahata K, Murai T, Takahashi H (2015) Discrepancy between explicit judgement of agency and implicit feeling of agency: implications for sense of agency and its disorders. Conscious Cogn 37:1–7
Sanchez-Vives MV, Spanlang B, Frisoli A, Bergamasco M, Slater M (2010) Virtual hand illusion induced by visuomotor correlations. PLoS ONE 5:e10381
Schwarz KA, Weller L (2023) Distracted to a fault: attention, actions, and time perception. Atten Percept Psychophys 85(2):301–314
Seghezzi S, Giannini G, Zapparoli L (2019) Neurofunctional correlates of body-ownership and sense of agency: a meta-analytical account of self-consciousness. Cortex 121:169–178
Slater M, Perez-Marcos D, Ehrsson HH, Sanchez-Vives MV. (2008). Towards a digital body: The virtual arm illusion. Front Hum Neurosci 2:6
Spoor JR, Williams KD (2007) The evolution of an ostracism detection system. In: Forgas JP, Haselton MG, von Hippel W (eds) Evolution and the social mind: Evolutionary psychology and social cognition. Routledge/Taylor & Francis Group, pp 279–292
Sun Y, Hommel B, Ma K (2023) Vicarious ostracism reduces observers' sense of agency. Conscious Cogn 110:103492
Sun Y, Zhu R, Hommel B, Ma K (2024) Social exclusion in a virtual cyberball game reduces the virtual hand illusion. Psychon Bull Rev. https://doi.org/10.3758/s13423-024-02456-w
Suzuki K, Lush P, Seth AK, Roseboom W (2019) Intentional binding without intentional action. Psychol Sci 30(6):842–853
Synofzik M, Vosgerau G, Newen A (2008) Beyond the comparator model: a multifactorial two-step account of agency. Conscious Cogn 17:219–239
Tanaka T, Matsumoto T, Hayashi S, Takagi S, Kawabata H (2019) What makes action and outcome temporally close to each other. A systematic review and meta-analysis of temporal binding. Timing & Time Perception 7(3):189–218. https://doi.org/10.1163/22134468-20191150
Tonn S, Pfister R, Klaffehn AL, Weller L, Schwarz KA (2021) Two faces of temporal binding: action-and effect-binding are not correlated. Conscious Cogn 96:103219
Tsakiris M, Prabhu G, Haggard P (2006) Having a body versus moving your body: how agency structures body ownership. Conscious Cogn 15(2):423–432
Wesselmann ED, Bagg D, Williams KD (2009) "I Feel Your Pain": The effects of observing ostracism on the ostracism detection system. J Exp Soc Psychol 45(6):1308–1311
Wesselmann ED, Williams KD, Hales AH (2013) Vicarious ostracism. Front Hum Neurosci 7:153
Wiesing M, Zimmermann E (2024) Intentional binding–is it just causal binding? A replication study of Suzuki et al. (2019). Conscious Cogn 119:103665
Williams KD, Zadro L (2005) Ostracism: The indiscriminate early detection system. In: Williams KD, Forgas JP, von Hippel W (eds) The social outcast: Ostracism, social exclusion, rejection, and bullying. Psychology Press, pp 19–34
Williams KD (2001) *Ostracism: The power of silence.* Guilford Press
Williams KD (2009) Ostracism: A temporal need-threat model. In M. P. Zanna (Ed.), *Advances in Experimental social psychology,* 41:275–314). Elsevier Academic Press