

# I Am There . . . but Not Quite: An Unfaithful Mirror That Reduces Feelings of Ownership and Agency

Perception

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## Abstract

The experience of seeing one’s own face in a mirror is a common experience in daily life. Visual feedback from a mirror is linked to a sense of identity. We developed a procedure that allowed individuals to watch their own face, as in a normal mirror, or with specific distortions (lag) for active movement or passive touch. By distorting visual feedback while the face is being observed on a screen, we document an illusion of *reduced* embodiment. Participants made mouth movements, while their forehead was touched with a pen. Visual feedback was either synchronous (simultaneous) with reality, as in a mirror, or asynchronous (delayed). Asynchronous feedback was exclusive to touch or movement in different conditions and incorporated both in a third condition. Following stimulation, participants rated their perception of the face in the mirror, and perception of their own face, on questions that tapped into agency and ownership. Results showed that perceptions of both agency and ownership were affected by asynchrony. Effects related to agency, in particular, were moderated by individual differences in depersonalisation and auditory hallucination-proneness, variables with theoretical links to embodiment. The illusion presents a new way of investigating the extent to which body representations are malleable.

## Keywords

embodiment, enfacement, defacement, depersonalisation, hallucination-proneness

Our internal representation of the body is necessarily flexible in order to maintain an embodied representation of an entity that changes across time and to coordinate dynamic body movement. The phenomenological experience of existing within an embodied whole gives rise to a sense of ownership over the body, while the capacity to direct the body at will is commonly described as a sense of agency. Here, we focus on the everyday experience of

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seeing one's face in a mirror, and we introduced distortions in the visual feedback. By doing so, we created an experience of *reduced embodiment* and a reduced sense of ownership and agency. Participants reported their experience using Likert scales that measured perceived ownership and agency. In addition, we related variability in perceived ownership and agency to specific individual differences with theoretical links to experiences of reduced embodiment. Illusions of embodiment demonstrate that body representation is malleable and it can be updated to incorporate information about a novel face; this new illusion shows that ownership and agency with respect to one's face can also be reduced after inconsistent visual feedback.

### *Illusions of Embodiment*

Coordinating inputs across the senses is key to maintaining a stable body representation with strong experiences of ownership and agency. The importance of multi-sensory input is demonstrated in effects such as the rubber hand illusion (RHI, Botvinick & Cohen, 1998) where the embodiment of a fake hand is experienced as a result of the manipulation of visual, tactile and proprioceptive inputs. The fake hand, suitably positioned to align with the internal representation of the body, is touched and seen to be touched at the same time as the real hand (hidden from view) is stimulated. The synchrony of vision, touch and proprioception induces illusory feelings of ownership over the fake hand (Botvinick & Cohen, 1998; Costantini & Haggard, 2007; Kammers, de Vignemont, Verhagen, & Dijkerman, 2009; Lewis & Lloyd, 2010; Tsakiris & Haggard, 2005) and affords the fake hand the qualities of an agent (Kammers et al., 2009; Kammers, Mulder, de Vignemont, & Dijkerman, 2010; Newport, Pearce, & Preston, 2010; Zopf, Truong, Finkbeiner, Friedman, & Williams, 2011). Certain individual differences determine the extent of this effect; for example, positive schizotypal traits (lower level hallucinatory-type experiences) have been related to a stronger experience of the illusion (Asai, Mao, Sugimori, & Tanno, 2011).

Manipulation of the correspondence between sensory inputs has been used to create another type of illusion, known as enfacement (Ma, Sellaro, Lippelt, & Hommel, 2016; Sforza, Bufalari, Haggard, & Aglioti, 2010; Tajadura-Jiménez, Grehl, & Tsakiris, 2012; Tajadura-Jiménez, Longo, Coleman, & Tsakiris, 2012; Tsakiris, 2010). Through one procedure that brings about enfacement, participants observe another person's face being touched at the same time as their own face is being touched (Sforza et al., 2010; Tajadura-Jiménez, Grehl, et al., 2012; Tajadura-Jiménez, Longo, et al., 2012; Tsakiris, 2010). Through a second procedure that brings about enfacement, participants control the movement of another's face through virtual reality, in addition to feeling and observing touch (Ma et al., 2016). Unlike the RHI procedure, there is no attempt to disguise the body part (the face) as being that of the participant. The experience is that of watching another person's face, not that of seeing oneself in a mirror. Nevertheless, after a brief stimulation, participants' recognition of their own face is influenced by the characteristics of the other face. The impact of the other face on the recognition of one's own face can be quantified with a self-recognition task, for example, using morphing between an image of self and of the other individual. Participants select an image of their own face that is distorted in the direction of the other face. Other consequences of enfacement include the implicit updating of emotion in line with a smiling other (Ma et al., 2016) and a subsequent tendency to conform to the behaviour of the enfacéd individual (Paladino, Mazzurega, Pavani, & Schubert, 2010). Critically, and consistent with the RHI, the visuotactile and visuomotor stimulation must be synchronised. There are individual differences in the

extent to which the internal representations of the face are updated through this procedure; for example, the enfacement illusion is stronger for those who score higher for perspective taking/empathy (Sforza et al., 2010).

The power of the enfacement illusion is surprising, given the strong familiarity that we have with our own faces, and the fact that recognising our own face is so fundamental to our sense of self. Humans share the ability for self-recognition in a mirror with few other species (Gallup, 1970) – an ability observed from 18 months of age (Anderson, 1984). Self-recognition can be impaired in dementia (Connors & Coltheart, 2011) or after a stroke, particularly to the right hemisphere (Villarejo et al., 2011). Mirror self-recognition has also been found to be impaired in people with schizophrenia and in their first-degree relatives where relationships with social cognitive functioning have also been reported (Irani et al., 2006). Beliefs about mirror reflections include some systematic mistakes (Bertamini & Parks, 2005; Bertamini & Wynne, 2009; Bianchi, Savardi, & Bertamini, 2008). These deficits and errors aside, mirror reflections are a ubiquitous part of everyday life. In fact, identification with the image of our body as reflected in a mirror is so strong and automatic that Bertamini, Berselli, Bode, Lawson, and Wong (2011) found no reduction in the strength of the RHI when visual information was only available indirectly from a mirror. In this study, and similarly to the enfacement procedure, the hand was not seen from a first-person perspective, but rather from a third-person perspective, albeit in the very special case of a mirror reflection.

### *A Theoretical Account*

Behind the surprising power of embodiment illusions is a manipulation of the extent to which self and another person/object are perceived to be similar, be it in terms of physical appearance (Bertamini et al., 2011; Bertamini & O'Sullivan, 2014; Tsakiris, Carpenter, James, & Fotopoulou, 2010; Tsakiris & Haggard, 2005) or in terms of an enacted action (Kammers et al., 2009, 2010; Ma & Hommel, 2015a, 2015b; Newport et al., 2010; Tsakiris, Prabhu, & Haggard, 2006; Zopf et al., 2011). Bringing about similarities between individuals plays a central role in increasing social bonds. Individuals can bond together in social in-groups through adopting the same beliefs (Hogg, Sherman, Dierselhuis, Maitner, & Moffitt, 2007); individuals who coordinate their actions in a social context judge the quality of their social interaction more favourably (interactional synchrony; Lakins & Stel, 2011); individuals who perform similar actions in the same context judge one another's attitudes to be closer to one's own (Cacioppo et al., 2014).

A recent theory that is inclusive in its approach to understanding why similarities across self and other have a strong influence over how both are processed applies Bayesian thinking to sensory processing and action generation (Apps & Tsakiris, 2014; Friston et al., 2013; Moutoussis, Fearon, El-Deredy, Dolan, & Friston, 2014). Within this framework, an information processor develops certainties or beliefs related to the meaning attributable to incoming events, and the meaning that will come from internally generated events. These biases in how the processor operates allow for the generation of priors that are used in monitoring ongoing perception and action. Individual percepts and actions are represented along a posterior distribution of probabilities. Percepts and actions that are consistent with priors reinforce the existence of related beliefs or certainties.

Bayesian reasoning in the context of agency is consistent with the comparator model of agency and supported by clinical and non-clinical evidence emphasising the role of prediction in embodied agentive self-experience (Blakemore & Frith, 2003; Frith, 2005; Miall & Wolpert, 1996; von Holst, 1954; Wegner, 2003). Action outcome predictions that

match actual outcomes are experienced as belonging to self while mismatches (prediction errors) are attributed to external causes. The inability to form appropriate predictions necessary for self-other differentiation of thoughts and actions is argued to constitute one of the core deficits of schizophrenia, most clearly reflected in delusions of control and hallucinations (Jeannerod, 2009; Spence et al., 1997; Woodruff, 2004). Similar processes are at play in body ownership. During the RHI, for example, the prior includes the experience of hands: Somatosensory and visual input favour embodiment of the rubber hand.

It is increasingly acknowledged that the sense of action/body ownership is a multifaceted and hierarchical phenomenon, involving somatosensory signals, body schema and also higher order intentions, goals and belief systems (Gallagher, 2000; Synofzik, Vosgerau, & Newen, 2008). At the upper end of the information processing hierarchy, certainties that influence more global aspects of how the self is – physical aspects might include appearance, gait and typical walking speed; psychological aspects might include personality, beliefs and attitudes – can be described as having more value, given their actual, or perceived, capacity to provide meaning for events in everyday life. Deviations from a prior, or prediction errors, could lead to context-related updating of a prior or even updating of the related belief. The extent to which prediction errors hold such power is, however, contingent on the value attributable to a particular belief. In the case of highly valued beliefs or certainties, the information processor is believed to adapt to the occurrence of a prediction error in order to negate its impact.

Experiencing another individual who is being treated similarly to self and is acting similarly to the self matches the priors that are guiding perception of the self and self-generated action more closely. The degree of match contributes to maintaining certainty in the system. In the enfacement manipulation, the source contributing to maintenance of certainty is the image of the other face being touched in the same way. Attributing higher value to the characteristics of this face in the context of self-recognition updates the posterior distribution towards accepting aspects of the other face. In this way, embodiment comes about when another object or person is perceived as having a value related to an established certainty and is therefore closer to what the self is.

### *An Illusion of Reduced Embodiment*

If the aforementioned theory holds weight, then it should be possible to manipulate sensory input in bringing about a distance from self and the actions that the self is enacting. Bringing about a similarity between one's own face and another face encourages embodiment of that face. Here, we wanted to see whether *dissimilarity* between one's own face, and a reflected image of one's own face, encourages a *reduced* sense of embodiment.

In the *enfacement procedure* described earlier, participants view *another face* that is touched on the cheek in- or out-of-sync with participants' own cheek. In *our procedure*, we used a video camera so that the image on the computer screen was the *face of the participant*. The image was mirror reversed so that it simulated the experience that people have when seeing their own face in a mirror. A chin rest was used to minimise the displacements of the head, but other movements, such as blinks and movements of the mouth, were directly visible and provided visual feedback.

Dissimilarity between one's own face and the viewed face was introduced in two ways. First, the tactile perception of being touched by the experimenter was out of sync with the visual feedback displayed on the viewed face; that is, while the participant felt that his or her face was being touched, vision failed to confirm the tactile input. Second, the proprioceptive

experience of moving one's lips was out of sync with the visual feedback displayed on the viewed face; that is, while the participant was actively moving his or her lips, vision failed to confirm this proprioceptive output. We hypothesised that dissimilarity between the tactile and proprioceptive experience of the face, on one hand, and visual feedback on the face, on the other, would bring about *defacement* of one's own face.

Hypothesised defacement was measured through questions that assessed the extent to which participants perceived (a) ownership over the face on the screen, (b) themselves to be the agent of the movements of the face on the screen and (c) themselves to be the agent of the movements of their actual face. We hypothesised that asynchronous touch (tactile–vision mismatch) and asynchronous movement (movement–vision mismatch) would reduce the perception of owning the face on the screen (*H1*). With regard to participants' perception of agency over the face of the screen, we hypothesised that asynchronous movement (movement–vision mismatch) would reduce perception of agency to a greater extent than asynchronous touch, or synchrony, given that voluntary movements confer an active sense of being an agent (*H2*). Related, we hypothesised that asynchronous movement might reduce perception of ownership over the viewed face to a greater extent than asynchronous touch, as the voluntary action of moving the mouth might confer a stronger sense of ownership over the face than passive touch (*H3*). The enfacement procedure influences participants' perception of their actual face; here, we hypothesised that the conflict between asynchronous visual, tactile and proprioceptive input might result in reduced perception of agency over the movements of one's own face (*H4*).

Countering the manipulations of visual feedback would be priors seeking similarity in the face on the monitor, with these priors being affected by certainties in the extent to which the face was embodied to begin with. The power of our manipulation to influence the posterior distribution of the extent to which the face on the monitor was felt to be embodied would therefore be a function of these existing priors. In order to test for an impact of pre-existing priors on the effectiveness of our manipulations, and, in so doing, to provide convergent validity, we investigated whether measures of defacement were modulated by individual differences. In particular, we focused on depersonalisation and proneness to auditory hallucinations.

Depersonalisation is a cluster of phenomenological experiences that describe a self that is physically and emotionally disconnected; a self that is embodied to a reduced extent, relative to an average self (Medford, Sierra, Baker, & David, 2005; Sierra, Baker, Medford, & David, 2005; Simeon et al., 2008). Such experiences can be measured through questionnaire; for example, the Cambridge Depersonalisation Scale (CDS; Sierra & Berrios, 2000). Keeping with the theory set out earlier, depersonalisation might be related to priors that anticipate, on average, a reduced sense of embodiment. If our manipulations are successful in bringing about defacement, or reduced embodiment, then increased levels of depersonalisation should relate to reduced perception of ownership and agency over the viewed face with asynchronous visual feedback, in addition to reduced perception of agency over one's actual face (*H5*).

A relationship between hearing voices and depersonalisation/dissociation has been demonstrated on the basis of shared variance in questionnaires (Kilcommons & Morrison, 2005; Perona-Garcelán, Carrascoso-López, et al., 2012; Perona-Garcelán et al., 2008; Perona-Garcelán, García-Montes, et al., 2012; Varese, Barkus, & Bentall, 2012), and hallucination-proneness more generally has been related to a stronger experience of the RHI (Asai et al., 2011). Although largely exploratory, it would be meaningful to see whether an experimentally induced reduction in embodiment has the same effect in relation to hallucination-proneness as depersonalisation (*H6*), in which case it would be

supportive of a clinically oriented hypothesis that reduced levels of embodiment underpin hallucination-proneness (for related proposals in the context of a schizophrenia diagnosis, see de Haan & Fuchs, 2010; Sass, Pienkos, Nelson, & Medford, 2013; Stanghellini, 2009; Stanghellini, Ballerini, Poli, & Cutting, 2012).

## Methods

### Participants

Sixty young adults took part in the study (mean age = 21 years; 47 females and 13 males). The sample was biased towards females, as females are over-represented in the Psychology course from which the sample was selected. They were naïve with respect to the aim of the research and received university course credits for taking part. An internal ethics board approved the study. Informed written consent was obtained from all participants, and the study was conducted in accordance with the Declaration of Helsinki.

### Materials

One computer was used for the visual presentation, and a second for collecting responses. The first computer was a Mac mini connected to a CRT monitor (screen: 37 × 20 cm; resolution: 1280 × 1024) and to a camera positioned above and at the centre of the monitor (Technika; webcam software: Manycam, <http://manycam.com>). A chin rest was used to stabilise the head of the subjects in front of the screen at a distance of 57 cm. We used Pure Data (<http://puredata.info>) to display and manipulate the incoming video stream. The displayed scene was reversed and delay could be introduced either on the full scene or on only the top or bottom parts of the scene. The chin rest was adjusted for each participant to ensure that the line dividing the top and bottom parts of the scene was situated between 2 and 4 cm above their eyebrows. In conditions where no delay was introduced, apart from the slightly lowered direction of gaze (due to the position of the camera) and the device's inherent delay (~60 ms), the setup allowed the participant to view their face as though it were seen through a mirror. The second computer (screen: 34.5 × 19.5 cm; resolution: 1366 × 768) was used to present questions following each condition, and the individual difference questionnaires through a program written in E-Prime (<http://www.pstnet.com>).

### Measures of Agency and Ownership

Immediately after stimulation, participants rated their perception of the viewed face, and their perception of their own face, on questions that tapped into ownership and agency (see Table 1) using a 10-point Likert scale, anchored on the lower end with the statement *not at all* and the upper end with the statement *very much so*. The questions were adapted from those used by Botvinick and Cohen (1998) and Paladino et al. (2010). Control questions were created in order to obtain a measure of affirmative bias and were designed to be less conceptually related to how the manipulations might affect perception.

### Individual Differences

At the end of the procedure, participants completed questionnaires exploring depersonalisation and hallucination-proneness. The CDS was used to investigate the sense of depersonalisation (Sierra & Berrios, 2000). The CDS has 29 items, and participants report



**Table 1.** List of Questions to Test Sense of Agency and Ownership – Category Labels Determined Through Factor Analysis (see Factor Analysis section).

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Agency Questions-viewed face

- I felt as if I was causing the movement I saw
- I felt as if I was controlling the movements of the face I was seeing
- The face in the monitor moved just like I wanted it to, as if it was obeying my will
- Whenever I moved my mouth, I expected the mouth I saw to move in the same way

Ownership Questions-viewed face

- I felt as if I was looking at my own face
- I felt as if the face on the monitor was my face
- I felt as if the face on the monitor was part of my body
- It seemed as if I were sensing the movement of my face in the location where the other face moved<sup>a</sup>

Agency Questions-own face

- I could sense the movement from somewhere between my real face and the other face
- I felt as if the face in the monitor was controlling my will
- I felt as if the face on the monitor was controlling my movements
- It seemed as if the face I saw had a will of its own
- It seemed as if I had more than one face

Affirmative bias

- I felt as if my real face was turning rubbery
  - It appeared as if the other face was drifting towards my real face<sup>a</sup>
  - It felt as if I had no longer a face, as if my face had disappeared
  - I felt as if my real face was changing gender
  - I felt as if my real face was changing size
  - I felt as if my real face was turning metallic
  - I felt as if my real nose was growing
- 

<sup>a</sup>Questions were removed the following factor analysis.

the frequency and the duration of various sensations using a scale between 0 and 4 in measuring frequency, and between 1 and 6 in measuring duration. We focused on one of the five factors, *Unreality-of-self*, as it picks up on the core aspects of 'physical disconnectedness' experienced through depersonalisation. The six questions tapping this factor ask about experiences such as feeling like a detached observer of oneself, not quite inside one's own body and mechanical when moving. The widely used Launey–Slade Hallucination Scale – Revised (LSHS-R; Bentall & Slade, 1985) was used to measure proneness to auditory hallucinations. The questionnaire has 12 items describing hallucinatory-type experiences. Participants report the degree to which these experiences apply to them on a scale from 0 (*certainly does not apply*) to 4 (*certainly applies*).

## Procedure

Participants were told that the aim of the study was to investigate perception of their own face while they watched their face on a computer screen. They were asked to place their head on a chin rest positioned in front of the screen, see Figure 1. To produce the touch stimulation, the examiner touched the forehead 3 times in three different locations with a pen, whilst saying the words 'one, two, three' aloud at a frequency of 1.0Hz. After a 1-second gap (allowing the pattern to fit within four beats), the participant repeated 'one, two, three' in a similar manner also followed by a 1-second gap, watching the visual feedback





were analysed using analysis of variance and analysis of covariance (see Supplementary Material for analysis of the individual questions). Ratings on 24 trials were missing due to participants having pressed the enter key before inputted a response. The missing data points were replaced with imputed values based on each relevant variable involved (4 agency responses, 6 ownership and 14 control; assumed to be completely missing at random) and calculated through taking an average from five imputed points for each individual missing data point. No participant missed more than two questions.

## Results

### Factor Analysis

The aim of the factor analysis was to test whether agency, ownership and affirmative bias questions could be discriminated from one another, independently of the particular manipulation at hand. Ratings on individual questions were collapsed across conditions, and the 20 questions were added to a factor analysis using maximum likelihood extraction, and an oblimin rotation with Kaiser Normalisation. The analysis generated a Kaiser–Meyer–Olkin value of .832, consistent with good factorability of the data, and Bartlett's Test of Sphericity was significant,  $\chi^2(190) = 927.58, p < .001$ .

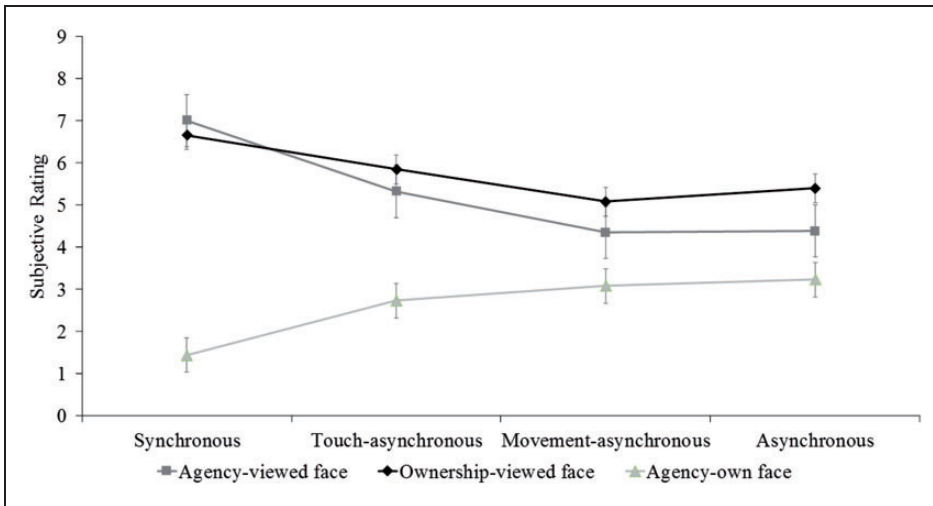
Four factors were extracted from the data on the basis of having eigenvalues over 1 (see Figure S1 for scree plot), with a goodness-of-fit of  $\chi^2(116) = 162.75, p = .003$ . An *agency factor* that tapped in perceived agency over the *viewed face* accounted for 39.13% of the variance in the data. An *ownership factor* that contained three of the expected questions that tapped into perceived ownership over the *viewed face* accounted for 11.20% of the variance. The remaining questions fell into two factors. The first contained six questions that we would argue tap into an affirmative response bias and accounted for 9.99% of variance. The second contained five questions that measured the impact of the viewed face on the perception of one's *own face*, with a particular focus on the *perceived agency* of one's own face. One of the affirmative bias questions was removed due to also loading on the agency factor-own face. The ownership question that was removed loaded on both agency factors.

### Experimental Effects

Data on three of the four factors were sufficiently normally distributed, specifically Agency-viewed face (skewness =  $-.391 [SE = .31]$ ; kurtosis =  $1.75 [SE = .61]$ ), Ownership-viewed face (skewness =  $-.333 [SE = .31]$ ; kurtosis =  $0.06 [SE = .61]$ ), Agency-own face (skewness =  $.47 [SE = .31]$ ; kurtosis =  $-0.23 [SE = .61]$ ) and not affirmative bias (skewness =  $1.35 [SE = .31]$ ; kurtosis =  $1.24 [SE = .61]$ ).

A  $3 \times 4$  analysis of variance of Question-Type  $\times$  Condition explored the Agency-viewed face, Ownership-viewed face and Agency-own face, as a function of the experimental manipulations, see Figure 2. All effects were significant: Question-Type,  $F(2, 118) = 73.83, p < .001$  ( $\eta_p^2 = .56$ ), Condition,  $F(3, 177) = 9.59, p < .001$  ( $\eta_p^2 = .14$ ), Question-Type  $\times$  Condition,  $F(6, 354) = 26.46, p < .001$  ( $\eta_p^2 = .31$ ).

For the Agency-viewed face questions, an effect of Condition was significant,  $F(3, 177) = 25.82, p < .001$  ( $\eta_p^2 = .30$ ). Perceived agency of the viewed face did not differ between A and MA ( $p = .910$ ; A:  $M = 4.39, SD = 2.21$ ; MA:  $M = 4.35, SD = 2.18$ ). Asynchronous movement (A and MA) significantly reduced perceived agency relative to S,  $t(59) = 7.94, p < .001$ ;  $M = 7.01, SD = 2.20$ , and TA,  $t(59) = 2.83, p = .006$ ;  $M = 5.33, SD = 2.20$ . However, asynchronous touch (TA) itself reduced perceived agency relative to synchronous touch



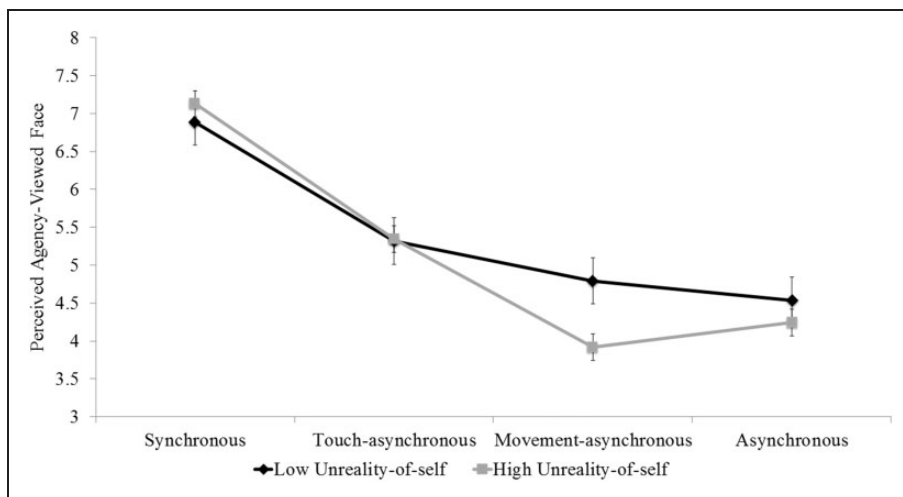
**Figure 2.** Responses to the questions across all four conditions. S = Synchronous, TA = Touch Asynchronous, MA = Movement Asynchronous, A = Asynchronous. Error bars are  $\pm 1$  SEM.

and synchronous movement, S,  $t(59) = 5.37$ ,  $p < .001$ . Comparisons are significant at a corrected  $p$  value of .013.

For the Ownership-viewed face questions, an effect of Condition was significant,  $F(3, 177) = 10.40$ ,  $p < .001$  ( $\eta_p^2 = .15$ ). Perceived ownership over the viewed face did not differ between A and MA ( $p = .178$ ; A:  $M = 5.41$ ,  $SD = 2.25$ ; MA:  $M = 5.09$ ,  $SD = 2.54$ ). Asynchronous movement (A and MA) significantly reduced perceived ownership relative to S ( $M = 6.66$ ,  $SD = 2.10$ ),  $t(59) = 4.31$ ,  $p < .001$ . The drop in perceived ownership between asynchronous movement (A and MA) and Asynchronous Touch (TA) did not reach significance at the corrected threshold,  $t(59) = 2.29$ ,  $p = .025$ . Asynchronous touch (TA) itself ( $M = 5.85$ ,  $SD = 2.08$ ) reduced perceived ownership relative to synchronous touch and synchronous movement (S),  $t(59) = 3.01$ ,  $p = .004$ . Comparisons are significant at a corrected  $p$  value of .013.

For the Agency-own face questions, an effect of Condition was significant,  $F(3, 177) = 26.55$ ,  $p < .001$  ( $\eta_p^2 = .31$ ). Perceived agency of one's own face did not differ between A and MA ( $p = .528$ ; A:  $M = 3.23$ ,  $SD = 2.18$ ; MA:  $M = 3.09$ ,  $SD = 2.10$ ). Asynchronous movement (A and MA) significantly reduced perceived agency relative to S,  $t(59) = 8.09$ ,  $p < .001$ ;  $M = 1.45$ ,  $SD = 1.57$ . The drop in perceived agency between asynchronous movement (A and MA) and Asynchronous Touch (TA) did not reach significance at the corrected threshold,  $M = 2.73$ ,  $SD = 1.98$ ;  $t(59) = 2.33$ ,  $p = .023$ . Asynchronous touch (TA) also reduced perceived agency relative to synchronous touch and synchronous movement, S,  $t(59) = 5.37$ ,  $p < .001$ . Comparisons are significant at a corrected  $p$  value of .013.

Data for the affirmative bias questions were not normally distributed (skewness = 1.35 [ $SE = .31$ ]; kurtosis = 1.24 [ $SE = .61$ ]), calling for non-parametric tests. Wilcoxon signed-rank tests revealed that scoring in conditions that introduced asynchrony contributed to an affirmative response bias over scoring in the Synchronous condition (TA [ $Mdn = .67$ ,  $IQR = 2.29$ ] vs. S [ $Mdn = .42$ ,  $IQR = 1.50$ ];  $Z = 734.50$ ,  $p = .002$ ; MA [ $Mdn = .50$ ,  $IQR = 2.17$ ] vs. S;  $Z = 551.00$ ,  $p = .009$ ; A [ $Mdn = .33$ ,  $IQR = 1.83$ ] vs. S;  $Z = 520.50$ ,  $p = .029$ ).



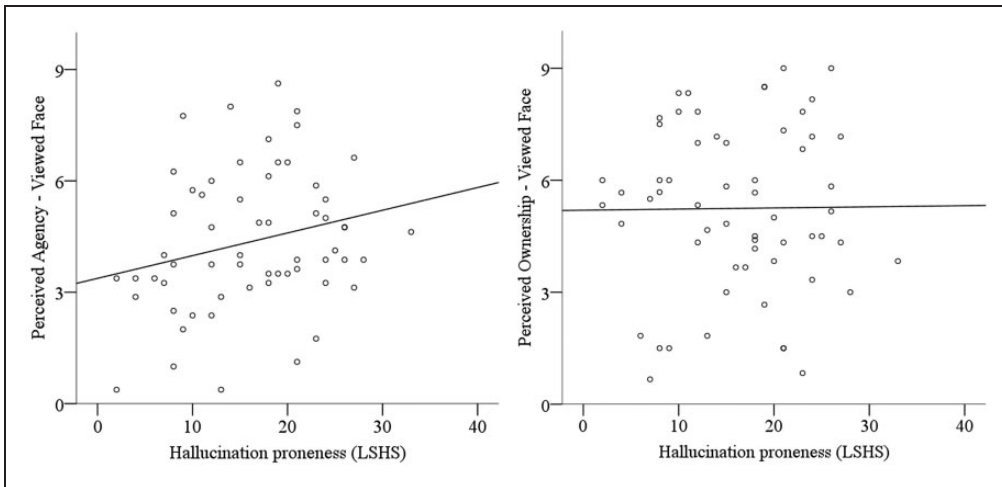
**Figure 3.** Responses to the questions across the four conditions for both the high and low Unreality-of-self (depersonalisation) groups. Error bars are *SEM* for each group across conditions.

### Individual Difference Effects

Unreality-of-self from the CDS scale was related to LSHS,  $r_s(59) = .386$ ,  $p = .002$ . LSHS scores were normally distributed (skewness =  $-.056$  [ $SE = .31$ ]; kurtosis =  $-.816$  [ $SE = .61$ ]), allowing for hallucination-proneness to be included in subsequent analyses as a continuous variable. Skewness and kurtosis of the Unreality-of-self variable were problematic (skewness =  $1.17$  [ $SE = .31$ ]; kurtosis =  $1.45$  [ $SE = .61$ ]); therefore, the ratings were split at the median to generate groups: those scoring above the median on Unreality-of-self and those scoring below.

In the Agency-viewed face data, both Unreality-of-self and LSHS interacted with Condition,  $F(3, 171) = 3.17$ ,  $p = .026$  ( $\eta_p^2 = .05$ ) and  $F(3, 171) = 4.50$ ,  $p = .005$  ( $\eta_p^2 = .07$ ), respectively. When the movement alone was asynchronous (MA), the high Unreality-of-self group ( $M = 3.92$ ,  $SD = 1.54$ ) scored significantly lower on perceived agency relative to the low Unreality-of-self group ( $M = 4.79$ ,  $SD = 2.63$ ),  $F(1, 57) = 8.48$ ,  $p = .005$  ( $\eta_p^2 = .13$ ), see Figure 3. LSHS was also related to perceived agency when the movement alone was asynchronous (MA); however, the direction of the effect was in the opposite direction, with increasing LSHS scores being related to an *increased* perception of agency,  $r(57) = .380$ ,  $p = .003$ , see Figure 4. Neither Unreality-of-self nor LSHS were related to perceived agency in the remaining conditions (Unreality-of-self, S,  $p = .515$ , TA,  $p = .771$ , A,  $p = .322$ ; LSHS, S,  $p = .784$ , TA,  $p = .629$ , A,  $p = .243$ ).

In the Ownership-viewed face data, Condition failed to interact with Unreality-of-self and hallucination-proneness ( $ps > .2$ ). There was a main effect of Unreality-of-self, with the high group generally rating ownership over the viewed face lower than the low group,  $F(1, 57) = 4.33$ ,  $p = .042$  ( $\eta_p^2 = .07$ ; high,  $M = 6.23$ ,  $SD = 1.93$ ; low,  $M = 5.28$ ,  $SD = 1.41$ ). Likewise, in the Agency-own face data, condition failed to interact with Unreality-of-self and hallucination-proneness ( $ps > .3$ ). The high Unreality-of-self group tended to rate questions more highly than the low group, although this was not significant,  $F(1, 57) = 3.80$ ,  $p = .056$  ( $\eta_p^2 = .06$ ; high,  $M = 3.06$ ,  $SD = 1.75$ ; low,  $M = 2.20$ ,  $SD = 1.47$ ).



**Figure 4.** Movement Asynchronous only condition (MA), the relationship between hallucination-proneness (LSHS) and perceived agency over the viewed face is on the left; the relationship between hallucination-proneness and perceived ownership over the viewed face is on the right, with least square lines of the best fit.

Independent-samples median tests contrasting high and low Unreality-of-self groups on the affirmation bias questions in each condition revealed no differences ( $ps > .07$ ). Partial correlations (controlling for Unreality-of-self) found no relationship between LSHS and scoring on these questions ( $ps \geq .16$ ).

The opposing relationships between LSHS, Unreality-of-self, and perceived agency over the viewed face with asynchronous movement was unexpected, and meant that, in the relationship to perceived agency in this paradigm, LSHS was acting as a suppressor of the reduction of perceived agency over the viewed face when the movement was asynchronous. As a more concrete demonstration of this, the relationship between Unreality-of-self and perceived agency over the viewed face when the movement was asynchronous was significantly lower when variance shared with LSHS was not removed,  $r_s(59) = -.219$ ,  $p = .093$ , relative to when it was removed,  $r_s(59) = -.373$ ,  $p = .003$ ;  $Z = 3.14$ ,  $p = .001$ .

## Discussion

The principal aim here was to test whether it would be possible to bring about reduced levels of embodiment through introducing a temporal discrepancy in the multi-sensory alignment of sensed touch, movement and vision. Participants observed their face on a monitor being touched while they mouthed a sequence of digits. In one condition, visual feedback was synchronous with tactile input and proprioceptive output, whilst in another, visual feedback was asynchronous with both tactile input and proprioceptive output. In two remaining conditions, asynchrony was limited to either a visual–tactile mismatch or a visual–proprioceptive mismatch. The procedure was successful in bringing about reduced feelings of embodiment, as measured in questions that tapped perceptions of agency and ownership over the face on the screen and agency over one's own face. Individual differences moderated the resultant effects, providing convergent validity.

## Experimental Effects

When visual feedback from the face was asynchronous with either, or both, tactile input and proprioceptive output, participants perceived a reduced sense of ownership over the face on the screen (*H1*). The face on the monitor *was* still the face of the individual participant; yet, the introduction of visual prediction errors through the mismatch between visual feedback on the face, on one hand, and tactile or proprioceptive experience of one's actual face, on the other, distanced the face on the monitor, making it feel less owned. Likewise, asynchrony between visual feedback and proprioceptive experience, in particular, reduced participants' perception of being the agent of the movements enacted by the face on the screen (*H2*). The movements of the mouth on the monitor *did* match those of individual participants; however, the temporal separation of proprioceptive experience of making the movements, and visual feedback on the movements taking place, reduced participants' feeling that they were in control of the movements on the screen.

In addition to bringing about a reduced sense of embodying the face on the screen, the manipulations also affected participants' experience of being an agent over their actual face (*H4*). This finding makes sense from the perspective that participants had embodied the face on the monitor to some extent. The visual prediction errors must have been forcing an update, bottom-up driven, to proprioceptive control, which conflicted with participants' top-down control over mouth movement, bringing about the reduced sense of being an agent over one's own movements.

It is unclear from this study the extent to which reducing multi-sensory alignment affects one's *actual* capacity to act. For example, could defacement affect speech quality? Could de-armment affect the precision with which an action is being completed? Could de-footment interfere with one's capacity to walk? Likewise, it is unclear whether reducing multi-sensory alignment affects one's *actual* ownership of a body part. For example, could defacement make one feel that speech output which is actually theirs belongs to someone else? Could de-armment or -footment make one feel that someone else is controlling the arm or foot's actions? Further manipulations of the procedure introduced here would allow such questions to be addressed, in addition to the use of more objective measures, such as Electromyography (EMG).

As they stand, the findings are consistent with a Bayesian view of information processing. Our perception of self is stabilised by distributions of probabilities, defined by entropies/beliefs, that can be shifted through prediction error; however, in relation to beliefs of stronger value, such as the extent to which I feel ownership over my own face or the extent to which I feel an agent of face moment, prediction error can be negated. The extent to which prediction error can be negated is dependent on the priors, as confirmed in the individual difference data given later.

## Individual Differences

Mapping on to the phenomenological content of the Unreality-of-self questions, we expected that asynchrony across vision, touch and proprioception would have a larger impact on individuals with higher Unreality-of-self scores (*H5*). The results showed that, specifically, when there was a mismatch between visual feedback on the face and proprioceptive output, higher Unreality-of-self scores were related to an increased perception of having lost agency over the face on the screen. Individuals prone to depersonalisation may have priors of reduced certainty/entropy corresponding to the representation of body parts/the body whole. Such a distribution would be more likely to update following prediction error, which, in the context of the manipulation, led to a more noticeable difference in the perceived agency over the face on the screen with increasing Unreality-of-self scores. Perhaps consistent with less stable priors,

Unreality-of-self was related to a general reduction in the extent to which the face on the monitor felt owned, indicative of reductions in the baseline embodiment.

A relationship between Unreality-of-self scores and reduced perception of agency failed to reach significance when visual feedback on tactile input, in addition to proprioceptive output, was asynchronous. Perhaps the temporal alignment between visual feedback on touch and proprioception, when there were visual–touch and visual–proprioceptive mismatches, maintained a sense of agency over the face, even if delayed, as opposed to when there was temporal misalignment between visual feedback on touch and proprioception.

We had considered a simplistic hypothesis that a state of reduced embodiment connected with depersonalisation causes hallucinatory experiences (*H6*). However, the surprising finding was that auditory hallucination-proneness did not match depersonalisation (Unreality-of-self) in its relationship to perception of agency. Instead, those scoring higher on hallucination-proneness were *less* likely than average to report reduced agency with visually asynchronous mouth movement. A reduced tendency to report that one's sense of agency is being affected by asynchronous multi-sensory input could stem from two, although perhaps not mutually exclusive, sources.

We have made a theoretical connection between a trait tendency towards reduced embodiment (depersonalisation) and a tendency to be affected by asynchronous multi-sensory input. *Increased* or hyper-embodiment may be related to a reduced tendency to be affected by asynchronous multi-sensory input: Any temporal discrepancy might be compensated for more rapidly, reducing the impact of asynchronous input on perception and awareness. Hallucination-proneness may differ from depersonalisation in being related to priors of increased certainty, being more likely to negate prediction errors requiring an update to the distribution. Consistent with this argument, hallucination-proneness is related to a tendency to attribute the outcomes of actions carried out under uncertainty to another agent, as opposed to being self-generated (de Bezenac, Sluming, O'Sullivan, & Corcoran, 2015).

Alternatively, as argued more globally in the schizophrenia literature (e.g. Sass & Parnas, 2003), hallucination-proneness might be related to hyper-reflexivity: In this case, hyper-reflexivity towards tracking conscious movement. Such hyper-reflexivity might, in subjective measures at least, compensate for reduced embodiment, negating an awareness of asynchrony in multi-sensory input. This latter account is consistent with the argument that subconscious attempts to restore multi-sensory integration in the face of perceptual mechanisms that fail to generate multi-sensory integration play a causative role in producing hallucinated content (Postmes et al., 2014). Such restorative efforts might generate hyper-embodied representations that are less affected by perceptual errors in multi-sensory input (see also Fuchs, 2010). And so, reduced embodiment, in combination with hyper-reflexivity, might account for the decreased tendency to feel affected by asynchronous multi-sensory input observed here. Postulating aside, there does seem to be some relationship between embodiment, and both depersonalisation and hallucination-proneness, worthy of further investigation. In the context of the current study, suffice it to say that the modulatory effects of individual differences on specific conditions are consistent with the manipulations impacting on perception of agency.

### *Limitations and Further Research*

Participants tended to score higher on the affirmative bias/control questions in the Asynchronous conditions. It is possible that this arose either because participants found it difficult to label accurately the altered experience brought about by these manipulations or because of a bias towards higher responding generally following asynchronous stimulation. Nevertheless, the factor analysis was able to separate variance on the bias questions from



variance in the remaining questions, consistent with the ownership and agency questions measuring true perceptions of ownership and agency.

Participants rated their perceived agency over the viewed face, in addition to their own face, lower with asynchronous touch alone, as opposed to when the actual and viewed faces were in synchrony. We had not predicted that perception of agency would be affected by asynchronous touch (*H2* and *H4*). However, proprioceptive representations are themselves influenced by inputs from other senses; thus it is feasible for a mismatch between vision and touch to affect proprioception and consequently perceived agency.

Finally, we had reasoned that a mismatch between vision and proprioception would have a stronger impact on perception of ownership than a mismatch between vision and touch. Perceptions of owning the viewed face *were* more reduced following the asynchronous movement, as opposed to asynchronous touch; however, the difference did not survive correction for multiple comparisons. This is a limitation in the study. Participants' experiences of reduced embodiment were measured subjectively. The predictable differences on ownership and agency found across conditions, as well as the predicted individual difference effect with depersonalisation, provide credibility in the illusion; however, an objective measure would substantiate the procedure's capacity to bring about reduced embodiment, and would test the source of the underlying mechanisms behind individual differences in performance. Another follow-up to the procedure could involve replacing one's own face with another face, investigating to what extent asynchrony across faces reduces embodiment of characteristics of the other; for example, characteristics of their face, which would be the reverse of the enfacement procedure. Future studies could also manipulate the characteristics of spoken output, taking advantage of its rich source of information for self-recognition (Zheng, MacDonald, Munhall, & Johnsrude, 2011).

Illusions of embodiment measure the extent to which external objects become integrated in internal representations of the body. This is conceptually different to what is measured during an illusion of reduced embodiment. In such an illusion, variance relates to the extent to which individuals become disconnected from their body. Intuitively one would predict an increased tendency to disconnect from the body would be related to flexible body representations that are easily updateable. Likewise the converse: A reduced tendency to disconnect from the body would be related to less flexible body representations that are less easily updateable. Synchronous sensory input offers a route through which the flexibility of body representations can be measured; asynchrony offers a route through which disconnection from the body can be measured. Both types of illusion provide avenues to study clinically related, often distressing, experiences that are currently poorly understood.

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### **Supplemental Material**

Supplementary material is available for this article online.

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