

Embodying an Invisible Face Shrinks the Cone of Gaze

Mariano D'Angelo

University of Bologna and Birkbeck, University of London

Lara Maister

Birkbeck, University of London and Bangor University

Raffaele Tucciarelli

Birkbeck, University of London

Francesca Frassinetti

University of Bologna and Istituti Clinici Scientifici Maugeri
IRCCS, Pavia, Italy

Matthew R. Longo

Birkbeck, University of London

The possibility of being invisible has long fascinated people. Recent research showed that multisensory illusions can induce experiences of bodily invisibility, allowing the psychological consequences of invisibility to be explored. Here, we demonstrate an illusion of embodying an invisible face. Participants received touches on their face and simultaneously saw a paintbrush moving synchronously in empty space and defining the shape of an invisible face. Using both explicit questionnaire measures (Experiment 1) and implicit physiological measures (Experiment 2), we show that such invisible enfacement induces a sense of ownership. We further demonstrate that embodying an invisible face shrinks the width of the *cone of gaze* (i.e., the range of eye deviations people judge as directed toward themselves; Experiments 3 and 4). These results suggest that the experience of invisibility affects the way in which we process the attention of others toward the self, starting from the perception of gaze direction.

Keywords: bodily illusion, enfacement, body representation, gaze perception, social perception

In Book II of Plato's (1888) *Republic*, Glaucon relates the myth of the ring of Gyges, a golden ring that makes the wearer invisible. Gyges uses the ring to take over the kingdom of Lydia, seducing the queen and killing the king. In the context of Glaucon and Socrates's discussion of justice, the invisibility conferred by the ring is a symbol of ultimate, even godlike, power and freedom from the consequences of one's actions. The conferral of invisibility by objects of great power is common in literature, from Tolkein's (1937) "one ring to rule them all" to the "deathly hallows" in the Harry Potter novels (Rowling, 2007). Invisibility has been used also as a metaphor for social isolation as in Ellison's (1952) *Invisible Man*. It is clear that the idea of invisibility has

captured the imagination of writers and philosophers for millennia for its strong intuitive psychological meaning.

Recent research has started to move invisibility from the realm of fantasy to the laboratory. For example, Guterstam and colleagues (2013) used the logic of the "rubber-hand illusion" (Botvinick & Cohen, 1998) to demonstrate that people can be induced to feel body ownership over an empty region of space, as if their hand had become invisible. Other research has extended this finding to induce the experience of owning an entire invisible body (D'Angelo, di Pellegrino, & Frassinetti, 2017; Guterstam, Abdulkarim, & Ehrsson, 2015; Kondo et al., 2018). To create this illusion, participants wore a head-mounted display (HMD), connected to a camera placed on a tripod and pointing toward the floor (D'Angelo et al., 2017; Guterstam et al., 2015). When participants tilted their heads downward, as if looking at their bodies, they saw in the HMDs the empty space captured by the camera where they expected to see their own body. The experimenter, to induce the illusion, synchronously stroked the participants' real body with a paintbrush, while moving another paintbrush in the empty space in corresponding positions. This setup resulted in the referral of tactile sensations to the empty space and the perception of having an invisible body.

Intriguingly, experiencing one's own body as invisible has been found to have widespread effects on participants' physiological and cognitive processing. Guterstam et al. (2015) showed that the illusion of having an invisible body, as compared with the illusion of owning a mannequin's body, decreased participant's heart rate and subjective level of anxiety in response to standing in front of

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Mariano D'Angelo, Department of Psychology, University of Bologna, and Department of Psychological Sciences, Birkbeck, University of London; Lara Maister, Department of Psychological Sciences, Birkbeck, University of London, and School of Psychology, Bangor University; Raffaele Tucciarelli, Department of Psychological Sciences, Birkbeck, University of London; Francesca Frassinetti, Department of Psychology, University of Bologna, and Istituti Clinici Scientifici Maugeri IRCCS, Pavia, Italy; Matthew R. Longo, Department of Psychological Sciences, Birkbeck, University of London.

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Correspondence concerning this article should be addressed to Mariano D'Angelo, Department of Psychology, University of Bologna, Viale Carlo Berti Pichat, 5, 40127, Bologna, Italy. E-mail: mariano.dangelo2@unibo.it

a crowd of unknown people. These authors argued that representing one's own body as an invisible entity should make participants feel themselves less at the center of other people's attention, reducing the social anxiety produced by a stressful situation. A subsequent study showed that the invisible body illusion reduced the interpersonal distance at which participants felt most comfortable with another person (D'Angelo et al., 2017). The experience of invisibility induced participants to feel themselves more protected and less exposed during another person's approach, allowing the other person to be closer to their body. Thus, knowing whether one is being looked at can be decisive in a social interaction, and experiencing one's own body as invisible may affect the social consequences of being looked at.

Given the importance of gaze in social interactions, it is perhaps not surprising that humans are very accurate in perceiving the gaze directions of others (Anstis, Mayhew, & Morley, 1969; Gale & Monk, 2000; Gibson & Pick, 1963). However, although gaze direction can be perceived accurately in general, observers are prone to assume that they are being looked at when another person is looking even roughly in their direction (Ewbank, Jennings, & Calder, 2009; Gamer, Hecht, Seipp, & Hiller, 2011). For instance, observers assume a mutual gaze when the looker's gaze is directed at their mouth or nose (Lord & Haith, 1974). Several studies have measured the range of gaze directions over which an individual perceives another to be looking at them. Crucially, a relatively wide range of gaze directions have been found to be perceived as being directed at the observer. Indeed, the term *cone of gaze* is used to refer to the range of eye deviations that participants judge as being directed toward themselves (Gamer & Hecht, 2007; Gamer et al., 2011; Mareschal, Calder, & Clifford, 2013). The cone of gaze has been shown to be modulated by several emotional, social, and affective factors. For instance, the cone of gaze is wider for faces that appear angry compared with fearful or neutral faces (Ewbank et al., 2009). Moreover, individuals with social phobia show a larger cone of gaze than control participants (Gamer et al., 2011; Jun, Mareschal, Clifford, & Dadds, 2013). The cone of gaze is also widened by social ostracism (Lyyra, Wirth, & Hietanen, 2017).

In the present study, we investigated the link between the representations of one's own body and the perception of gaze direction. Based on data showing that the invisible body illusion reduces social anxiety (Guterstam et al., 2015) and interpersonal distance (D'Angelo et al., 2017), we speculated that the experience of invisibility affects the way in which participants process the attention of others toward the self, starting from the perception of gaze direction. Thus, we hypothesized that the illusion of having an invisible face would induce participants to feel themselves less observed by others, affecting gaze perception and leading to a reduction of the width of the cone of gaze. One's own face is the body part that most characterizes self-appearance, and recognition of one's face, as distinctive from others', is a fundamental component of self-awareness and self-identity (Tsakiris, 2017). A widely used paradigm to study the plasticity of self-face representation is the enfacement illusion (Paladino, Mazzurega, Pavani, & Schubert, 2010; Tsakiris, 2008). In the enfacement illusion, participants are stroked on their face, while they are looking another face being touched in synchrony and in corresponding positions. When the two touches are synchronous, visuotactile stimulation

elicits illusory feeling of ownership and touch referral over the other face (Sforza et al., 2010; Tsakiris, 2008).

Here, we combined the classical enfacement setup (Tsakiris, 2008) with the logic of the invisible hand illusion (Guterstam et al., 2013) to create the illusion of embodying an invisible face. In our setup, participants were stroked on different parts of their face, while they saw a video in which a hand used a paintbrush to touch a discrete volume of empty space to define the contours and the shape of an invisible face. In Experiment 1, we assessed the illusion through a questionnaire designed to capture the subjective experience during visuotactile stimulation. In Experiment 2, to provide objective evidence of the illusion, we threatened the invisible face with a knife and measured the evoked skin conductance response (SCR) as a physiological measure of anxiety. This test has been used before to provide physiological evidence of body illusions, and there is a direct relationship between the degree of anxiety evoked by threatening the illusory body and the strength of illusory body ownership (Armell & Ramachandran, 2003; Guterstam et al., 2013, 2015; Tajadura-Jiménez et al., 2012). Finally, in Experiment 3 we directly tested the hypothesis that the enfacement for an invisible face affect gaze perception, reducing the cone of gaze. To this end, we used a gaze categorization task, in which several faces looking in various directions were presented and participants are required to judge whether the faces were looking to their left, to their right or directly at them. We speculated that if one's own face representation affects the perception of gaze direction, participants should reduce the range of gaze directions perceived as directed toward them, accordingly to the illusion of having an invisible face.

Experiment 1

Method

Participants. Twenty individuals (10 women) were recruited for this study (age in years: $M = 26.5$, $SD = 5.8$). Participants had normal or correct to normal vision. They all provided written informed consent to participate to the experiment, which was approved by the Department of Psychological Sciences Research Ethics Committee at Birkbeck, University of London. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Stimuli. For the visuotactile multisensory stimulation, we used a video in which a hand uses a paintbrush to stroke different parts of an invisible face. To create such a video, we used the chroma key (or "green screen") technique. *Chroma key* is a post-production video technique by which a color range (often green) in a video can be replaced by an image background or another video (Aksoy, Aydin, Pollefeys, & Smolić, 2016). In particular, the color range in the foreground footage is made transparent, allowing separately filmed background or a static image to be inserted in the scene. In our case, we used a life-sized, 3D model bust with a green mask on the head and a black smock on the shoulders. Behind the bust was a green screen (Figure 1A). In postproduction, all the green was replaced by the static image of an empty room.

Thus, the final video showed the experimenter's hand moving a paintbrush with the deflection of the bristles defining the contours and the shape of an invisible face (see Figure 1B). Four different segments of the head were stroked with long brushstrokes in a

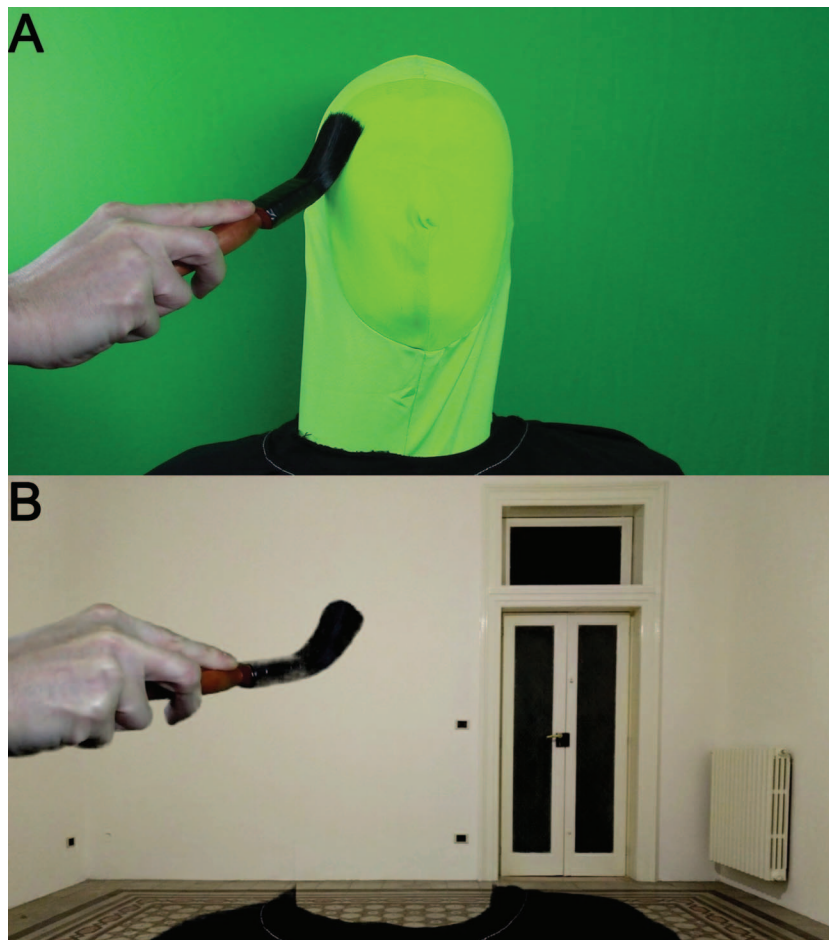


Figure 1. (A) To create the stimulus of an invisible face, we placed a head model with a green hood on it in front of a green screen. A hand stroked different parts of the head model with a paintbrush. (B) In postproduction all the green color was replaced with a static picture of an empty room. Thus, the chroma key technique was used to create realistic visual information about a paintbrush stroking an invisible face. Though the face is not visible, the bristles of the brush were deflected in a way that defined the contours of an invisible face. See the online article for the color version of this figure.

predetermined sequence: two brushstrokes from the right cheek to the chin; two brushstrokes from the middle of the forehead to the right temple; two brushstrokes from the lower part of the forehead to the nose; two brushstrokes from the lips to the end of chin. Each stroke lasted 3 s, and time between the offset of one touch and the onset of the next touch was also 3 s. The entire stroking sequence was repeated three times, thus the video lasted in total 156 s. The pattern of the present visuotactile stimulation is more complex than the simple and linear stroking usually used in the classic enfacement illusion (or in the rubber-hand and full-body illusions). However, we preferred to apply this kind of stimulation because we wanted the paintbrush to clearly define the shape of a head, so that participants could clearly figure out that the paintbrush was stroking a head and not a general object. So, based also on pilot tests, we used brushstrokes that seemed a good compromise between the attempt to shape the figure of a head and the attempt to have more simple and fast stimulation.

Procedure. During the experiment, participants were comfortably seated in front of a table. The induction movie in which a

paintbrush strokes different parts of the invisible face was projected on a monitor placed at ≈ 65 cm from the participant's sternum. Participants were asked to wear the same black smock that appeared in video on the invisible face's shoulders. OpenSesame software (Mathôt et al., 2012) was used to display stimuli and to collect responses. Participants were asked to watch the movie without moving their head, while the experimenter synchronously stroked the participant's face with an identical paintbrush at specularly congruent locations. We compared the illusion condition, with synchronous touches between participant's face and invisible face, to an asynchronous control condition in which the participant's face and the invisible face were touched in alternation. In the asynchronous condition the brushstroke on the participant's face was delivered between the 3 s elapsing between one touch and the other, carefully matching the total number and the length of the stroking. The synchronous and asynchronous condition were each repeated two times with ABBA counterbalancing, with the first condition counterbalanced across participants. Further, the order of presentations was balanced across individuals. At

the end of each visuotactile stimulation period we obtained subjective reports about the experience of the illusion by asking participants to complete a questionnaire containing 14 statements presented in a random order on the PC screen. Statements were adapted from previous studies on enfacement illusions (Sforza, Bufalari, Haggard, & Aglioti, 2010; Tajadura-Jiménez, Grehl, & Tsakiris, 2012). In particular, statements were designed to capture the experience of the illusion in its components of referred sensation ("It seemed like the touch I felt was caused by the paintbrush I saw moving"; "It seemed like I was feeling the touch of the paintbrush at the location where I saw the paintbrush moving"), sense of facial identity ("It seemed like my face was becoming invisible"; "It seemed like face had disappeared; It seemed like I was looking at my own mirror reflection) and sense of self projection ("It seemed like my face was drifting towards the location where I saw the paintbrush moving"; "It seemed like my face was at the location where I saw the paintbrush moving"). Moreover, some statements were designed to control for suggestibility and

task compliance. In particular, control statements include statements that bear several similarities to the illusion-specific statements but do not capture the phenomenological experiences of the enfacement, as described by previous studies. Participants indicated on a PC keyboard the extent of their agreement with the statements using a seven-point Likert scale ranging from -3 (*I completely disagree*) to $+3$ (*I completely agree*).

Results and Discussion

Figure 2 shows the questionnaire results. In line with previous studies of the enfacement illusion (Beck, Cardini, Ládavas, & Bertini, 2015; Cardini, Tajadura-Jiménez, Serino, & Tsakiris, 2013; Maister, Cardini, Zamariola, Serino, & Tsakiris, 2015; Sforza et al., 2010; Tajadura-Jiménez, Grehl, et al., 2012; Tajadura-Jiménez, Longo, et al., 2012), there were clear differences between the synchronous and asynchronous conditions. In particular, Holm-Bonferroni correction revealed a stronger agree-

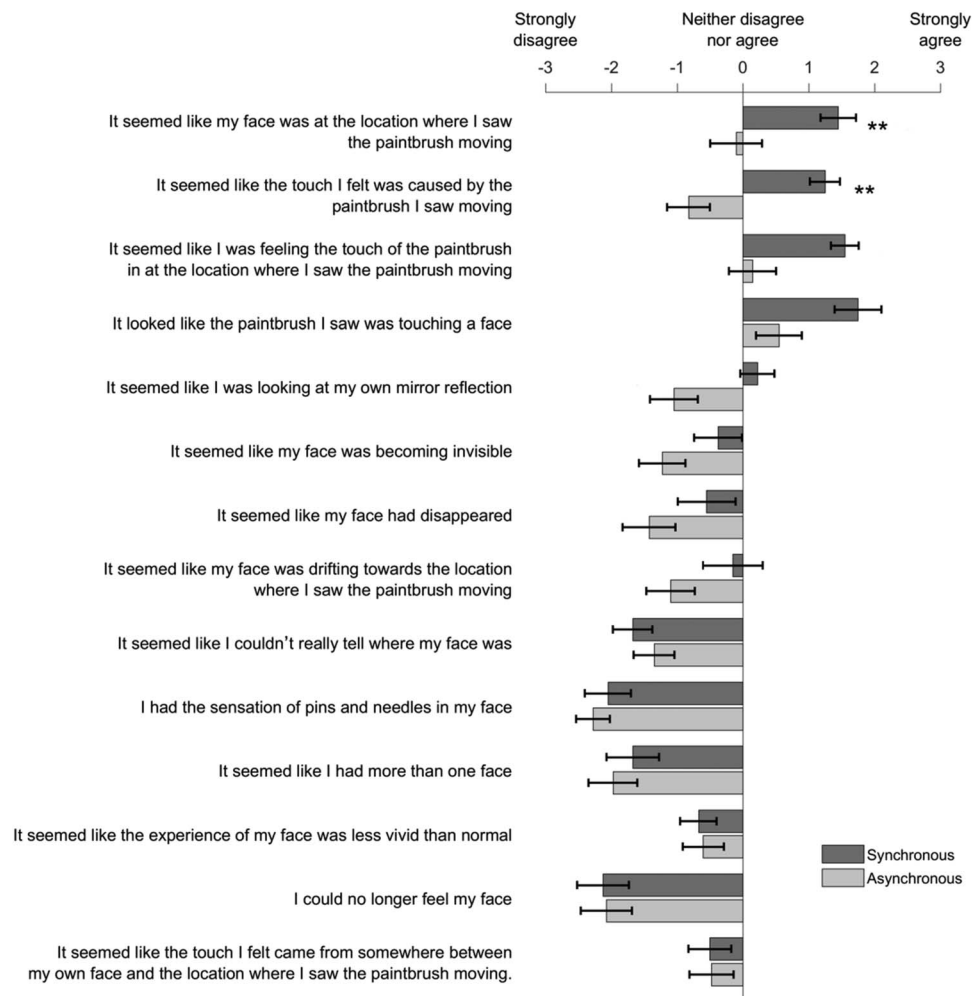


Figure 2. Subjective experience of the enfacement. The graph shows the average ratings for each question as a function of the visuotactile stimulation (synchronous vs. asynchronous). Asterisks mark a significant difference after Holm-Bonferroni correction ($**p < .001$). Error bars represent standard error of mean. Questions are ordered from the more significant to the less significant different.

ment in two statements: "It seemed like my face was at the location where I saw the paintbrush moving," $t(19) = 4.55, p < .05, d_z = 1.017$ and "It seemed like the touch I felt was caused by the paintbrush I saw moving," $t(19) = 4.46, p < .05, d_z = 0.997$. Thus, the phenomenology of the illusion seems to be characterized primarily by a feeling of touch referral over the empty space. Moreover, participants had the sensation that one's own face was projected or transferred in the empty space. This experience is consistent with the illusory experience of other bodily illusion. In the enfacement illusion, for instance, sensations of touch referral over the other face or feeling that one's own facial features are transferred to the other face, are recurrently reported. Thus, our multisensory visuotactile stimulation was effective in manipulating the sense of facial identity. These results suggest that the enfacement illusion can be induced even in the absence of a visible face, thus extending recent research on the invisible hand (Guterstam et al., 2013) and invisible full body (D'Angelo et al., 2017; Guterstam et al., 2015).

Questionnaire scores of many items fall below the scale's midpoint, which represents a "neither agree nor disagree" response. These results are in line with previous data on the enfacement illusion. Unlike the rubber-hand or the full-body illusions in which participants see the fake body in a first person perspective, questionnaire results in the enfacement illusion tend not to fall in the affirmative range of the scale (Beck et al., 2015; Cardini et al., 2013; Sforza et al., 2010; Tajadura-Jiménez et al., 2012). These data can indicate that (1) the sense of identity linked to the face is more stable than that linked to the hand or to the full body and (2) the first person perspective is a key factor for an explicit sense of body ownership (Petkova, Khoshnevis, & Ehrsson, 2011; Porciello, Bufalari, Minio-Paluello, Di Pace, & Aglioti, 2018). Nevertheless, the effects of the enfacement are usually clearly evident with more implicit tasks, such as self-other recognition tasks performed on morphed face (Tsakiris, 2008), SCR (Tajadura-Jiménez et al., 2012), or implicit association tests (Finì, Cardini, Tajadura-Jiménez, Serino, & Tsakiris, 2013). For these reasons, in Experiment 2 and 3, we used more implicit tasks to provide an objective evidence of the illusion.

Experiment 2

The first experiment showed that subjective experiences of enfacement can be elicited over an empty region of space. In this experiment, we investigated the illusion using a more objective test, measuring skin-conductance responses in response to a knife approaching the region of the invisible face. Such autonomic responses have been widely used as an objective measure of body ownership in studies of the enfacement illusion (Tajadura-Jiménez et al., 2012, 2014), the rubber- or virtual-hand illusion (Armell & Ramachandran, 2003; Ehrsson, Wiech, Weiskopf, Dolan, & Passingham, 2007; Tieri, Tidoni, Pavone, & Aglioti, 2015), and the full-body illusion (Ehrsson, 2007; Petkova & Ehrsson, 2008). The rationale behind this paradigm is that bodily threat usually evoked a change in autonomic arousal. Therefore, if participants truly embodied the empty space, SCRs to the knife should be higher after synchronous as compared with the asynchronous stimulation.

Materials and Methods

Participants. Thirty individuals (14 women) were recruited for this study (age in years: $M = 25.6, SD = 6.4$). A statistical power analysis was performed for sample size estimation. We first identified previous studies that used SCRs to objectively measure the effect of a bodily illusion comparing synchronous and asynchronous conditions for which sufficient information was presented to calculate an effect size estimate for this comparison. Four such studies were identified (Armell & Ramachandran, 2003; Guterstam et al., 2013, 2015; Tajadura-Jiménez et al., 2012). Specifically, Armell and Ramachandran (2003), recorded SCRs after injuring a rubber hand over which participants experienced ownership. Tajadura-Jiménez et al. (2012) combined SCRs with the classical enfacement illusion. Finally, Guterstam et al. (2013, 2015), recorded SCRs to a threat after participants experienced the illusion of having an invisible hand or body, respectively. We conducted a random-effects meta-analysis on the effect sizes (Cohen's d_z) to compare synchronous and asynchronous conditions, using ESCI (Cumming, 2013), which resulted in an average effect size of 0.535. We then conducted a power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), with power level of 0.80, which indicated that 30 participants were needed.

Participants had normal or correct to normal vision. They provided written informed consent to participate to the experiment, which was approved by the Department of Psychological Sciences Research Ethics Committee at Birkbeck, University of London. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Stimuli. We used the same video as in Experiment 1, with the only difference that this time at the end of the stroking, a knife appeared on the left side of the screen, moving toward the invisible face making contact with the right side of the face and then disappearing out of the field of view. The entire movement lasted approximately 3 s. As previously mentioned, such stimulation is commonly used to objectively test the degree of embodiment in several bodily illusions. The rationale is that bodily threat usually evokes change in autonomic arousal (Ehrsson et al., 2007). Thus, if an object is qualified as a part of one's own body, a physical threat to it evokes the same anxiety response and autonomic arousal as threat to one's actual body. On the contrary, the asynchronous stimulation serves to exclude a general arousal associated with seeing a knife.

So participants would not be able to anticipate the appearance of the knife, we produced three videos of different lengths (105 s, 156 s, 207 s), which were shown before the knife onset. In the 105-s video, the entire stroking sequence was repeated two times, in the 156-s video the sequence was repeated three times, and in the 207-s video it was repeated four times.

Procedure. The procedure was similar to Experiment 1, with the difference that in Experiment 2 we recorded the SCR as a measure of the emotional response when the invisible face was threatened by a knife after a period of visuotactile stimulation. The SCR was collected through a Biosemi ActiveTwo System (Biosemi, Amsterdam, the Netherlands) connected to a dedicated PC through a parallel port. For the skin conductance measures the ActiveTwo uses a 16 Hz SC circuit with a 1 μ A current producing a 16 Hz signal that is synchronized with the ActiveTwo sample rate. The signal was recorded by means of two silver electrodes

placed on the volar surface of the distal phalanges (fingertip region) of the left hand. A saline conductive paste was applied to the electrodes to improve signal to noise ratio. OpenSesame software (Mathôt et al., 2012) sent triggers coding for the stimulus onset to the SCR trace at the moment in which the knife appears on the screen. Participants wore the electrodes for a few minutes before starting the recording at the beginning of the experiment in order to allow a good electrode contact and to allow for the gel to become sufficiently absorbed over the measurement area for high quality data (Dawson, Schell, & Filion, 2007).

The synchronous and asynchronous conditions were repeated three times using ABBAAB counterbalancing, with the first condition counterbalanced across participants. At the end of each visuotactile stimulation period, the invisible face was threatened by the knife appearing on the screen. In addition to the SCRs, at the end of the stimulation period we also asked participants to fill out the same questionnaire used in Experiment 1.

Analysis. We used the EEGLab Toolbox (Delorme & Makeig, 2004) for MATLAB (Mathworks, Natick, MA) to analyze SCRs. The SCR was identified as the peak value on the conductance occurring up to 6 s after the onset of the threat stimuli. The amplitude of the increase in conductance was measured as the difference between the maximal and minimal value of the response identified in this time-window (Armel & Ramachandran, 2003; Guterstam et al., 2013; Petkova & Ehrsson, 2008). We calculated the average of all responses including the trials where no response was apparent, thus, analyzing the magnitude of the SCR (Dawson et al., 2007).

Results

The SCR results are shown in Figure 3. We found a significantly greater threat-evoked SCRs after the synchronous stroking (1,28 μ S) than after asynchronous stroking (0,86 μ S), $t(29) = 2.92$, $p < .007$, $d_z = 0.533$, demonstrating that our synchronous visuotactile stimulation was effective in manipulating the sense of ownership for the empty space.

Figure 4 shows the questionnaire results, which were similar to those of Experiment 1 and confirmed a statistical difference in the synchronous and asynchronous condition in the statements that capture the phenomenology of the illusion. In Experiment 2 more statements were modulated by the synchronous visuotactile stim-

ulation, probably due to the bigger sample size and larger number of blocks. Experiment 3 indeed Holm-Bonferroni correction indeed revealed that participants positively rated illusory touch referral over the empty space, reporting that "It seemed that the touch I felt was caused by the paintbrush moving," $t(29) = 6.18$, $p < .0001$, $d_z = 1.128$, and that "It seemed like I was feeling the touch of the paintbrush in the location where I saw the paintbrush moving," $t(29) = 7.323$, $p < .0001$, $d_z = 1.336$. Moreover, participants were more prone to project their own face into the empty space ("It seemed like my face was at the location where I saw the paintbrush moving," $t[29] = 7.324$, $p < .0001$, $d_z = 1.337$; "It looked like the paintbrush was touching a face," $t[29] = 3.92$, $p < .001$, $d_z = 0.716$), leading to a vague sensation of watching a mirror reflection ("It seemed like I was looking at my mirror reflection," $t[29] = 6.65$, $p < .0001$, $d_z = 1.214$). Crucially, coherently with these sensations, we found also a perceived drift of location of the participant's own face toward the empty space ("It seemed like my face was drifting towards the location where I saw the paintbrush moving," $t[29] = 2.78$, $p < .01$, $d_z = 0.508$). Finally, although participants did not positively affirm that their face was becoming invisible, there was still a significant difference on this item between the synchronous and asynchronous condition ("It seemed like my face had disappeared," $t[29] = 5.04$, $p < .0001$, $d_z = 0.920$; "It seemed like my face was becoming invisible," $t[29] = 5.14$, $p < .0001$, $d_z = 0.938$). Also, in this case, many items tend not to fall in the affirmative range of the scale, in line with previous studies on the enfacement illusion. In summary, results from Experiment 2 provided us a richer phenomenology of the illusion. Sensations of touch referral over the empty space and illusory projection of one's own face in the empty space, led participants to the feeling of looking at their mirror reflection. After visuotactile stimulation, participants were also more willing to feel as if they were invisible. Moreover, the higher SCR after synchronous condition demonstrated that participants embodied the empty space and qualified it as part of their own body.

Experiment 3

Experiment 1 and 2 showed that synchronous visuotactile stimulation between a participant's face and a discrete volume of empty space elicits embodiment of an invisible face, as assessed by questionnaires and SCR. In Experiment 3, we aimed to investigate whether such an illusion is effective in modulating gaze perception. In particular, we hypothesized that if participants truly experienced their own face as invisible, then they should feel themselves as less observed by others, leading to a reduction of the cone of gaze.

Method

Participants. Thirty participants (18 women) were recruited for this study (age in years: $M = 25$, $SD = 3.70$). Participants had normal or correct to normal vision. They all provided written informed consent to participate to the experiment, which was approved by the Department of Psychological Sciences Research Ethics Committee at Birkbeck, University of London. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Stimuli. For this study, we used four faces identities, two males and two females, with a neutral expression, taken from the

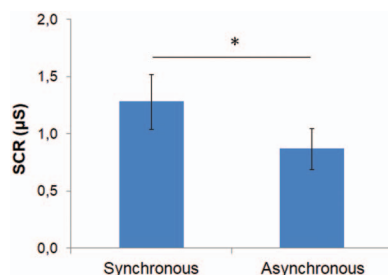


Figure 3. Skin conductance responses time-locked to the appearance of the knife threatening the invisible face. There was an increased reaction in the synchronous condition compared with the asynchronous condition. Error bars are one standard error of the mean. The asterisk indicates a significant difference ($p < .007$). See the online article for the color version of this figure.

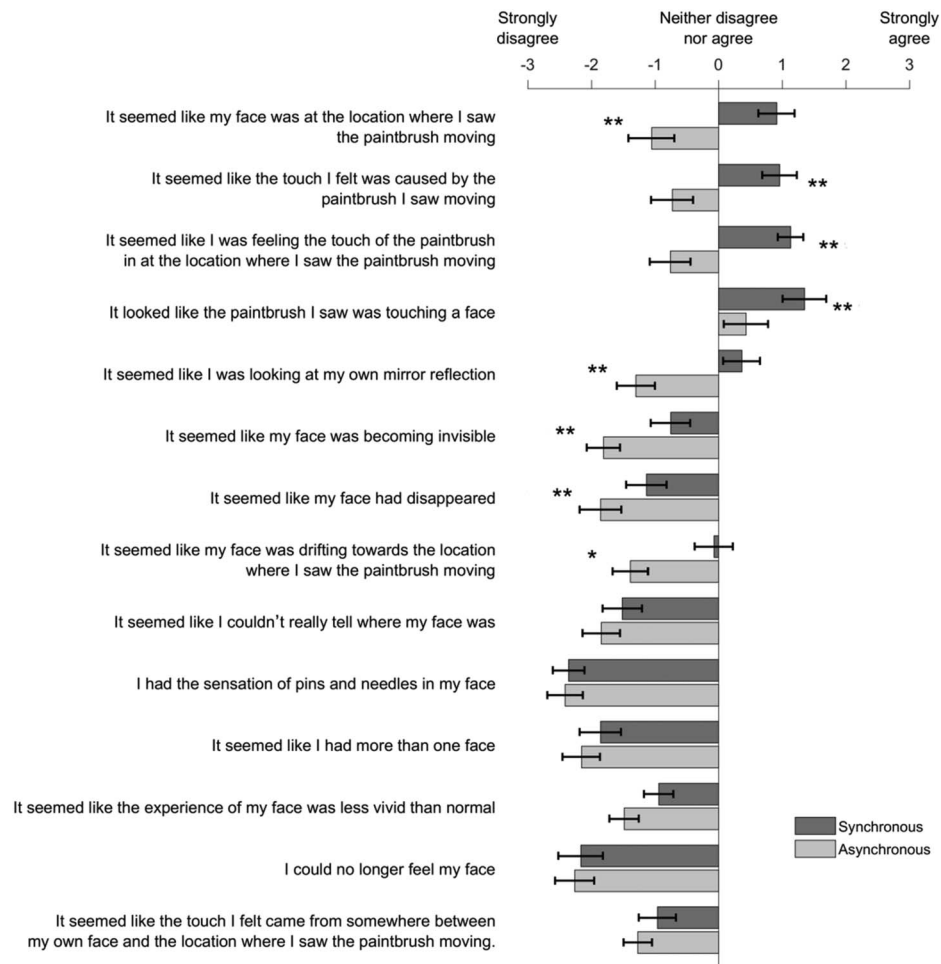


Figure 4. Subjective experience of the enfacement. The graph shows the average ratings for each question as a function of the visuotactile stimulation (synchronous vs. asynchronous). Asterisks mark a significant difference (* $p < .05$; ** $p < .001$) after Holm-Bonferroni correction. Error bars represent standard error of mean.

Karolinska Directed Emotional Faces (KDEF; Lundqvist & Litton, 1998). The hair and nonfacial areas were removed from the photographs so that only the central face area was visible. As in Ewbank et al. (2009), gaze direction was manipulated using Adobe Photoshop (Adobe Photoshop CS6, Adobe Systems, San Jose, CA). The position of the eyes was shifted to the left or to the right of one pixel per images by up to 10 pixels in each direction. Therefore, we had 21 gaze deviations along the horizontal axis for each face (from -10 pixels to 10 pixels), manipulated according to the method of constant stimuli.

Procedure. The experimental setting and the enfacement procedure were the same as Experiment 1. Participants were asked to watch the enfacement induction movie, while the experimenter stroked their face either synchronously or asynchronously with respect to the stroking on the invisible face. Each participant completed six blocks, three in the synchronous condition and three in the asynchronous condition. Counterbalancing of conditions was identical to Experiment 2, that is, the synchronous and asynchronous conditions were repeated for three blocks using AB-BAAB counterbalancing. In each block, participants received 207

s of visuotactile stimulation and then performed the cone of direct gaze task. Gaze deviations were tested using a method of constant stimuli. Each face, randomly selected, was presented for 500 ms in the center of the screen on a gray background using OpenSesame. Participants were required to press one of three buttons according to whether they considered the face was looking to their left, to their right, or directly at them. In each block, 84 faces were presented, such that there were a total of 252 faces presented for each synchronous and asynchronous condition. After every 21 gaze stimuli, we repeated the visuotactile stimulation for 15 s (corresponding to two brushstrokes). These 15-s visuotactile periods served as a top-up to reinforce enfacement effects in the case the illusion could be broken during the task given the possibility for participants to move their head.

Analysis. Our analysis was modeled on that used by Marschal, Calder, Dadds, & Clifford (2013). For each participant, separate analyses were conducted on data from the synchronous and asynchronous conditions. In each case, three curves were fit simultaneously to the data using the *fminsearch* function in MATLAB, implementing the Nelder-Mead simplex algorithm. Data

from the “left” and “right” responses were modeled using logistic curves, and “direc” responses were modeled as a curve defined as one minus the sum of the left and right curves at each point. By definition, therefore, the three curves sum to one, appropriately reflecting the fact that the participant made a three-alternative forced choice judgment. To estimate the width of the cone of direct gaze, we calculated the cross-over points between the curves. The left edge of the cone of gaze was operationalized as the location where the curves for left and direct judgments intersected; the right edge was operationalized as the location where the curves for right and direct judgments intersected. The difference between these two boundaries provides the width of the cone of direct gaze.

Results

Results from gaze perception task are shown in Figure 5. The model showed excellent fit to the data, with mean R^2 values of 0.984 (range = 0.957–0.999) in the synchronous condition and 0.985 (range = 0.950–0.998) in the asynchronous condition.

We compared the mean width of cone across all participants for the synchronous and asynchronous condition through a paired t test. Crucially the cone of gaze in the synchronous condition (5.37 pixels) was significantly thinner than the cone of gaze in the asynchronous (6.12 pixels) control condition, $t(29) = 6.86$, $p < .0001$, $d_z = 1.25$ (see Figure 5).

Experiment 4

Overall, Experiments 1, 2, and 3 showed that the illusion of embodying an invisible face, elicited by synchronous visual and tactile stimuli and assessed by questionnaire and SCR, signifi-

cantly reduced the cone of gaze. Thus, these data suggest that experiencing one’s own face as invisible affects the social perception of gaze direction. However, it is also possible that the shrinkage of the cone of gaze found in Experiment 3 was a result of the embodiment of another face per se, and not to the fact that the face was invisible. The experience of embodying another face may, for example, have produced a general disembodiment effect on the participant’s own face, that is a general effect of owning another face, different from one’s own.

Method

To test this possibility, we ran a fourth experiment in which another group of participants performed the cone of gaze task, but this time after they experienced an enfacement over a visible face. Thus, if the observed change in gaze perception is due to the experience of invisibility, we should find no significant modulation in the width of the cone of gaze after the enfacement toward a real solid face. In contrast, if the shrinkage of the cone gaze is due to a more general disembodiment effect associated with the basic experience of the enfacement illusion, similar modulation of gaze perception should also occur following enfacement of a visible face.

Participants. Another group of 30 participants (18 female; age in years: $M = 25.8$, $SD = 6.1$) were recruited for the study. They all provided written informed consent to participate to the experiment, which was approved by the Department of Psychological Sciences Research Ethics Committee at Birkbeck, University of London. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Procedure. The experimental setting and the enfacement procedure as well as the cone of gaze task were the same as Exper-

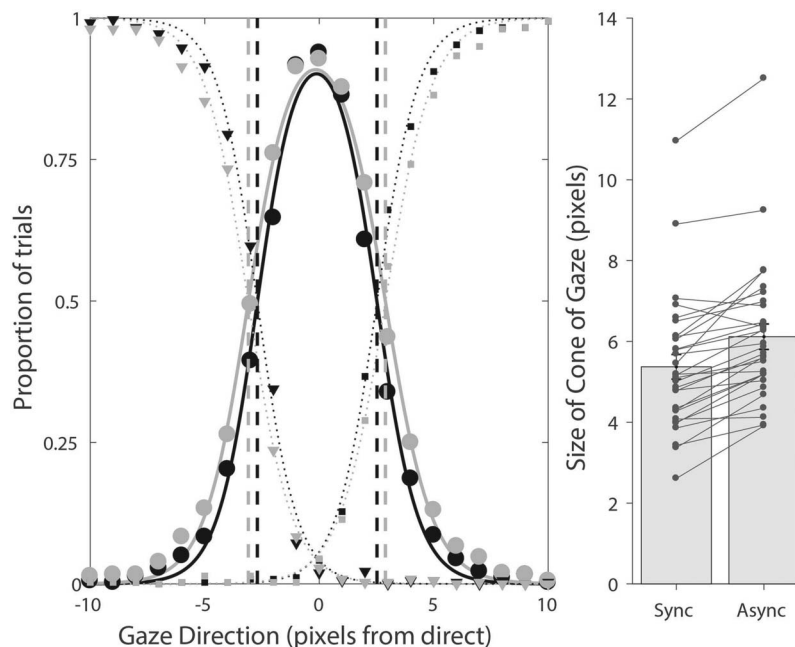


Figure 5. The left panel shows a plot represented mean fitted left, direct, and right responses as a function of gaze direction in the synchronous and asynchronous condition. Vertical lines show cross-over points used to calculate cone of gaze. The right panel shows the mean width of cone across all participants for synchronous (sync) and asynchronous (async) condition. Bars indicate data for each participant.

iment 3, with exception that the induction movie showed a hand which stroked with the paintbrush a real person's face (see Figure 6A). To make the visuotactile stimulation of Experiment 4 as similar as possible to stimuli used in the previous experiments, we again stroked four different segments of the face. In particular, the hand delivered two brushstrokes from the right cheek to the chin; two brushstrokes from the middle of the forehead to the right temple; two brushstrokes from the lower part of the forehead to the nose; two brushstrokes from the lips to the end of chin. Each stroke lasted 3 s and time between the offset of one touch and the onset of the next touch was also 3 s. To match the participants' gender, we created two induction movies: one with a male face and one with a female face. Thus, female participants were presented with

a female face, and male participants were presented with a male face. As in Experiment 3, we had two conditions: synchronous to induce the illusion, in which the experimenter stroked participants' face synchronously with respect to the stroking in the movie, and asynchronous, as a control condition. None of the participants was familiar with the person depicted in the movie. As in Experiment 3, each participant completed six blocks, three in the synchronous condition and three in the asynchronous condition (ABBAAB counterbalancing). In each block, participants received 207 s of visuotactile stimulation and then performed the cone of direct gaze task.

Moreover, we wanted to test also if this version of the enface-ment illusion was effective to manipulate the sense of facial

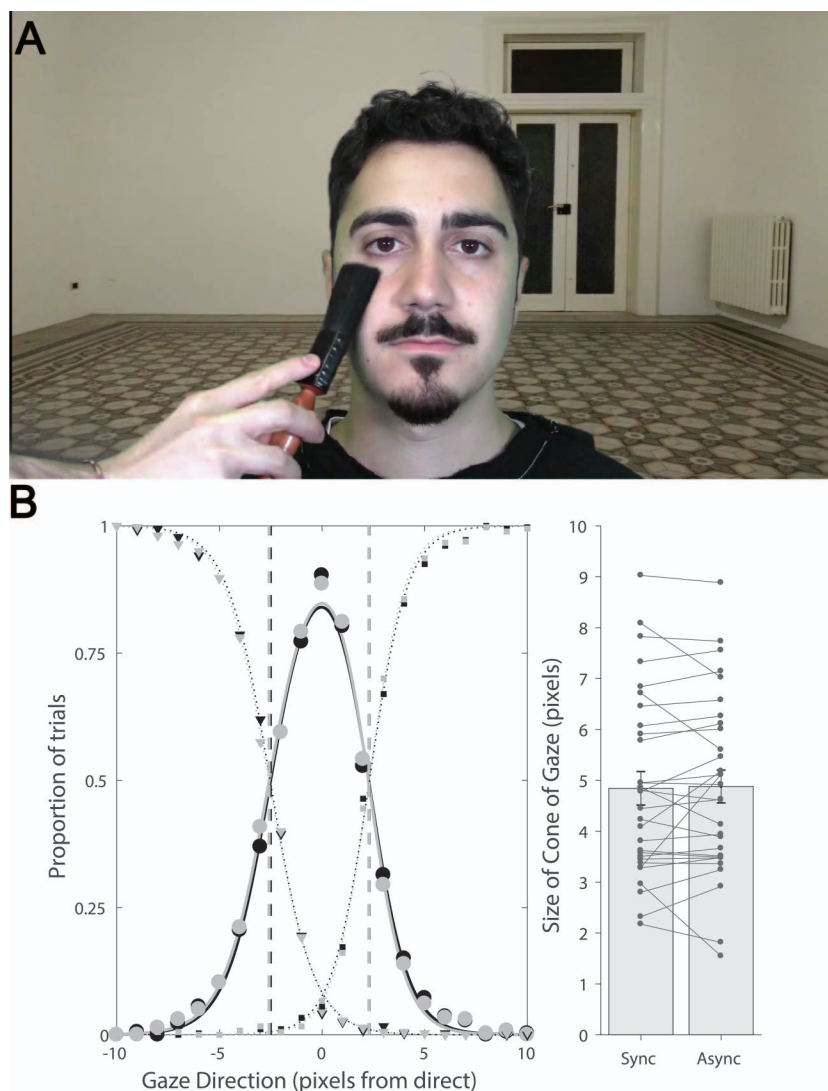


Figure 6. (A) A frame from the video used to induce the enfacement illusion. The subject of the photograph gave his permission for publication. (B) Results of Experiment 4. On the left panel, plot showing mean fitted left, direct, and right responses as a function of gaze direction in the synchronous and asynchronous condition. Vertical lines show cross-over points used to calculate cone of gaze. On the right panel, it was shown the mean width of cone across all participants for synchronous (sync) and asynchronous (async) condition. Bars indicate data for each participant. See the online article for the color version of this figure.

identity. For this aim, when all six blocks with the constant gaze task were terminated, we ran other additional four block (ABBA counterbalancing), but this time at the end of the stimulation period we asked participants to fill out a questionnaire. This questionnaire was only delivered at the end of the experiment, after the cone of gaze task has been completed, to ensure that there were no carry-over effects of the questionnaire on the gaze perception task. The questionnaire items were the same as those in Experiments 1 and 2, except a few items which were modified to refer to the visible face instead of an invisible face.

Results

The results from the gaze perception task in Experiment 4 are shown in Figure 6B. The model showed excellent fit to the data, with mean R^2 values of 0.986 (range = 0.963–0.998) in the synchronous condition and 0.986 (range: 0.928 – 0.999) in the asynchronous condition.

Crucially, unlike in Experiment 3, the size of the cone of gaze was comparable in the synchronous (4.84 pixels) and asynchronous (4.87 pixels) conditions, with no significant difference between them, $t(29) = -0.31$, $p < .75$, $d_z = -0.05$ (see Figure 6). To directly assess the effects of face visibility, we conducted a between-experiments analysis of variance (ANOVA) on the width of cone of gaze with visibility (invisible face vs. visible face) as a between-subjects factor and synchrony (synchronous vs. asynchronous) as a within-subjects factor. There was a main effect of stimulation, $F(1, 58) = 24.70$, $p < .0001$, $\eta_p^2 = 0.29$, and, critically, an interaction between stimulation and visibility, $F(1, 58) = 20.35$, $p < .0001$, $\eta_p^2 = 0.26$, demonstrating that synchronous visuotactile stimulation was effective in manipulating the width of the cone of gaze only in the invisible condition.

Anyway, it is important to notice that when we directly compare the two synchronous conditions, invisible versus visible, they are not significantly different between them, $t(59) = 1.08$; $p = .287$, $d_z = 0.13$. Based on our hypothesis, we should expect a smaller cone of gaze in the synchronous invisible as compared with the cone of gaze measured in the visible enfacement. The double interaction between visibility and synchrony may be therefore driven by the cone of gaze in the asynchronous invisible condition which results to be larger than the cone of gaze in the visible experiment, both in the asynchronous, $t(29) = 2.73$, $p < .05$, $d_z = 0.35$, and synchronous conditions, $t(29) = 2.60$, $p < .015$, $d_z = 0.33$. In other words, the interaction could be an artifact of between-experiment differences, rather than the result of a genuine reduction of the cone of gaze in the synchronous invisible condition. However, it is also possible, in line with our hypothesis, that participants in the invisible experiment reduced their cone of gaze, which however remains not significantly different from the participants' cone of gaze in the visible enfacement, given the high person-to-person variability of this measure. To address this, we conducted a new analysis, eliminating the most extreme values in the cone of gaze and thus matching the average size between the two experiments. We reasoned that if the double interaction was due to an artifact, we should find no significant interaction once we match the two conditions. To do so, we calculated the median size of the cone of gaze collapsed across the two experiments (global $Mdn = 5.075$), and then we selected 20 participants for each experiments: the first 10 participants under the global median and

the first 10 participants over the global median, thereby excluding the most extreme values in both experiments. Then, we ran a new ANOVA with visibility and stimulation as factors. The ANOVA revealed, in line with our hypothesis, that the interaction between stimulation and visibility, was still significant, $F(1, 38) = 11.39$, $p < .003$, $\eta_p^2 = 0.23$. Indeed, only in the invisible enfacement there was a clear difference between synchronous (4.69) and asynchronous conditions (5.53), $t(19) = -7.69$, $p < .0001$, $d_z = -1.72$, although there was no significant difference between synchronous (5.43) and asynchronous (5.53) conditions in the visible enfacement, $t(19) = -0.65$, $p = .51$, $d_z = -0.14$. Most importantly, the cone of gaze measured in the invisible synchronous condition now differ between the cone of gaze measured in the visible experiment, both in the synchronous, $t(38) = -2.18$, $p < .042$, $d_z = -0.34$, and asynchronous conditions, $t(38) = -2.58$, $p < .02$, $d_z = -0.40$. At the same time, the asynchronous invisible condition did not differ now from the visible enfacement conditions, both in the asynchronous, $t(38) = -0.17$, $p = .84$, $d_z = -0.02$, and synchronous conditions, $t(38) = -0.47$, $p = .64$, $d_z = -0.07$. This new result suggests that the interaction found in the main analysis was not due by a mere artifact of the asynchronous invisible condition, but rather it probably depends on a genuine reduction of the size of the cone of gaze in the invisible experiment.

Finally, the results from the questionnaire showed that we were successful in inducing enfacement over the visible, as demonstrated by clear statistical differences between the synchronous and asynchronous conditions in the items that capture the phenomenology of the illusion (see Figure 7). Like the invisible body illusion, Holm-Bonferroni correction revealed that the bigger difference between synchronous and asynchronous conditions was found in those items regarding touch referral over the other face and the feeling that participant's face was at the location where they see the paintbrush, that is, "It seemed like I was feeling the touch of the paintbrush in the location where I saw the paintbrush moving," $t(29) = 6.67$, $p < .0001$, $d_z = 1.218$, "It seemed that the touch I felt was caused by the paintbrush moving," $t(29) = 5.97$, $p < .00001$, $d_z = 1.090$, and "It seemed like my face was at the location where I saw the paintbrush moving," $t(29) = 5.70$, $p < .00001$, $d_z = 1.040$. Moreover, although also in this case these items do not fall in the affirmative range of the scale, there was still a significant difference in those items regarding the sense of facial identity, that is, "It seemed I was looking at my mirror reflection," $t(29) = 5.54$, $p < .0001$, $d_z = 1.012$, and "It seemed like the other face was my face," $t(29) = 3.63$, $p < .005$, $d_z = 0.663$.

Discussion

In the present study, we presented a novel illusion of embodying an invisible face. Participants received touches on their face and saw a paintbrush moving synchronously in an empty space and defining, through its bristles, the contours and the shape of an invisible face. Crucially, embodying the invisible face has unique effect on social perception, such as it significantly shrinks the cone of gaze. These results have relevant implications for our understanding of the mechanism involved in self face recognition and its interactions with social perception.

Contrary to previous studies on enfacement, in the present study we elicited a manipulation in one's own face representation even

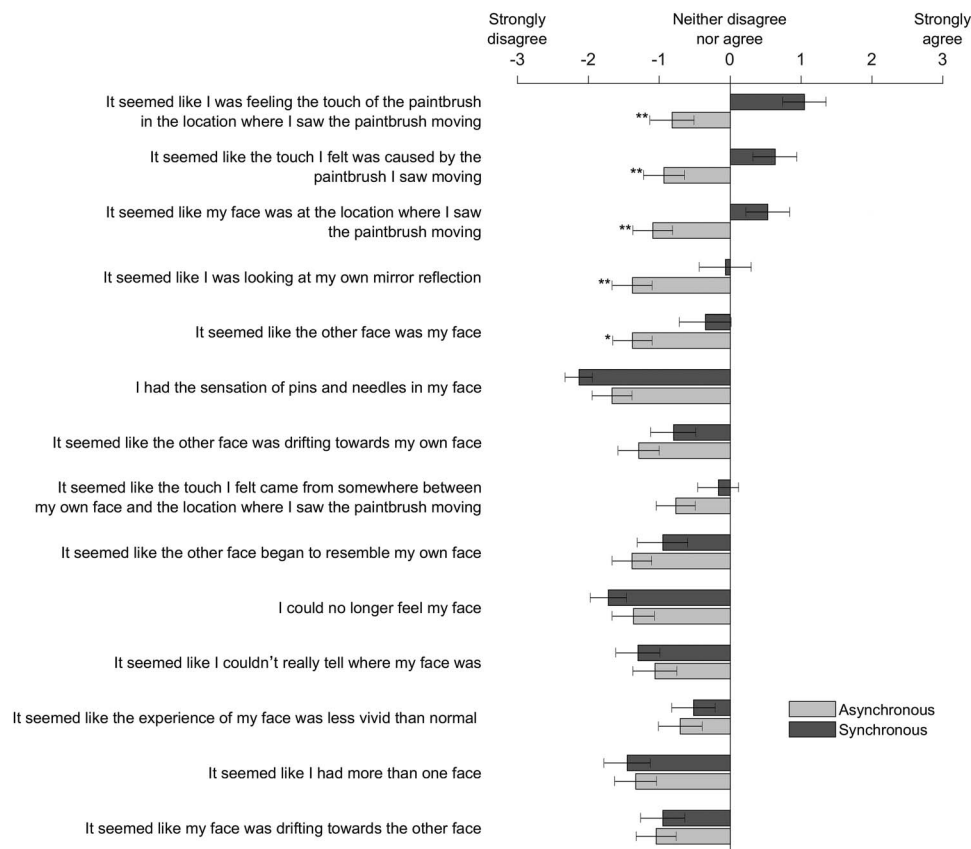


Figure 7. Subjective experience of the enfacement with a real face. The graph shows the average ratings for each question as a function of the visuotactile stimulation (synchronous vs. asynchronous). Asterisks indicate a significant difference (* $p < .005$; ** $p < .001$) after Holm-Bonferroni correction. Error bars represent standard error of mean.

in the absence of visual inputs from a physical face. These data fit with previous results on invisible limb and body (Guterstam et al., 2013, 2015), showing that the illusion of invisibility can be extended also to one's own face. In Experiment 1 and 2, we used explicit questionnaire ratings to capture the phenomenology of the illusion. Results suggest that synchronous visuotactile stimulation on the participant's face and on the empty space, was effective in modulating the perception of facial identity and inducing a sense of ownership for an invisible face. Participants perceived one's own face in the empty space and referred tactile sensations on the empty space. Moreover, participants had also the sensation of looking at their mirror reflection, as if their own face was projected in the empty space. This phenomenology was in line with previous studies on enfacement, in which participants often reported feeling the touch to the other face on one's own face or to perceive the other face more similar to one's own, as if their facial characteristics are transferred onto the mirrored face (Paladino et al., 2010; Porciello et al., 2018; Sforza et al., 2010; Tajadura-Jiménez et al., 2012). Unlike the invisible hand or invisible full-body illusions, questionnaire scores for many items tended not to fall in the affirmative range of the scale. As recalled previously, these results are in line with previous data on enfacement illusion and indicate that, being at the core of sense of self identity, facial representa-

tions are less amenable to changes. Nevertheless, the effects of the enfacement are usually clearly evident with more implicit task. In the same vein, in our study, the evidence of a clear and more implicit enfacement effect, found in Experiments 2 and 3, is even more surprising and interesting. Thus, in this respect, despite their limitations, questionnaire's results constitute a meaningful data point about their relationship with other, more implicit measure of embodiment.

Physiological evidence for the illusion was obtained in Experiment 2 by demonstrating that physical threats to the invisible face increased SCRs after the synchronous visuotactile stimulation as compared with the asynchronous control condition. The significant difference in skin conductance between synchronous and asynchronous condition, indicates that the empty space is embodied by participants and qualified as part of their body (Guterstam et al., 2013, 2015). Previous data on enfacement illusion showed that participant's skin conductance in response to a threat approaching the other face is higher following synchronous visuotactile stimulation (Tajadura-Jiménez et al., 2012, 2014). Thus, it seems that the multisensory mechanisms involved in the invisible enfacement illusion are similar to the mechanisms involved in generating the classical enfacement illusion or other bodily illusion.

The enfacement illusion was found to elicit activity in unimodal visual (inferior occipital gyrus) and multimodal visuo-tactile areas, such as the intraparietal sulcus (IPS) and temporoparietal junction (TPJ; Apps, Tajadura-Jiménez, Sereno, Blanke, & Tsakiris, 2015). It has been proposed (Bufalari, Lenggenhager, Porciello, Serra Holmes, & Aglioti, 2014; Porciello et al., 2018) that TPJ detects a conflict between self-touch and other visual signals and then informs IPS that serves to maintain a coherent body representation. Indeed, IPS contains peripersonal space neurons that are multisensory neurons, anchored to the surface of specific body parts (e.g., the face) and responding both to tactile stimuli on body parts and to visual stimuli presented near the same body part (Colby, Duhamel, & Goldberg, 1993; Graziano & Gross, 1995). IPS remaps the visual information about the touch applied to the other face on one's own face and the space around the other face as seen in a mirror, thus resolving the conflict (Bufalari et al., 2014; Cardini et al., 2011; Porciello et al., 2018). The result of the visuospatial remapping is the updating of the representation of one's own face (stored in memory) to include the facial features of the other's face. Our data extend this model suggesting that the visuospatial remapping responsible for the plasticity of self-face representation occurs also in absence of visual information from a physical face. However, it is important to note that although the face was not visible, the bristles of the paintbrush used for the visuotactile stimulation deflected in a way that defined the contours of an invisible head. Thus, it is possible to imagine that the visual information created by the bristles' deflection was a necessary cue to manipulate the sense of facial identity, although this question is not directly explored in our study.

If the visuospatial remapping in the invisible enfacement truly update participants' face representation, they should share the characteristic of being invisible. Indeed, previous studies on the enfacement illusion placed particular emphasis on the changes in the perceived physical similarity between the self and the other, suggesting that the participant's visual representation of their own and another's face become partially blurred (Paladino et al., 2010; Tajadura-Jiménez et al., 2014). In other words, a key component of the enfacement illusion is that participants assimilate features of the other's face in the mental representation of their own face. Experiment 3 suggest that this is true also for the invisible enfacement illusion. Indeed Experiment 3 showed that participants reduced the range of eye deviations perceived as directed toward them, that is, the cone of gaze. This result demonstrates that participants truly experienced the invisibility and represented their own face as invisible to outside observers as well. This in turn induced participants to feel themselves less observed by others. Crucially, in a control experiment (Experiment 4), in which we induced the enfacement illusion over a visible face, we did not find any significant differences in the cone of gaze between the synchronous and asynchronous conditions, suggesting therefore that the reduction of the cone of gaze was not due to a general disembodiment effect. However, when we compared the two experiments' results, although there was a clear evidence for an interaction, the size of the cone of gaze in the invisible synchronous enfacement was not significantly different from the size of the cone of gaze in the visible enfacement. We think that this is due to the different sizes of the cone of gaze in the two different populations of participants, given the person-to-person variability in the size of the cone of gaze. This claim is supported by a further

analysis excluding the extreme values in the cone gaze's size in both experiments. Crucially, this new comparison still revealed a double interaction and now the cone of gaze size in the invisible synchronous condition was significantly different from the cone of gaze in the visible enfacement.

We used the metaphor of cone of gaze to refer to the range of gaze directions that are perceived as directed at the participant (Gamer et al., 2007). In previous studies the cone of gaze has been shown to be modulated mainly by high-order cognitive factors concerning personality traits (Gamer et al., 2011; Jun et al., 2013), emotion perception (Ewbank et al., 2009) and perception of social contexts (Lyyra et al., 2017). Here, instead, we showed that also a mere change in one's own face representation can affect the perception of gaze direction, demonstrating a close relationship between the perception of gaze directions and one's own face representation. These data fit nicely with recent studies on embodied cognition showing the existence of a causal link between body representations and social cognition or interpersonal attitudes, revealing a relationship between bodily external appearance and our everyday social interaction (Maister et al., 2015). The type of body, over which participants experience illusory ownership, induces temporary changes in perception and attitudes that are appropriate for that type of body (Banakou, Groten, & Slater, 2013; Yee & Bailenson, 2007). Therefore, changing one's own body visual appearance can change aspects of our self-identity and the way in which the self is conceptualized (Banakou et al., 2013). This in turn may change our interpersonal attitudes and the way in which we interact with other people, to conform to the new body representation (Maister et al., 2013; Peck, Seinfeld, Aglioti, & Slater, 2013; Yee & Bailenson, 2007).

In particular, investigations on enfacement have not only found evidence of changes in perceived physical similarity between self and other, but also a blurring of self-other conceptual boundaries. Ma and coworkers (2016, 2019) called this effect "features migration", referring to the fact that increasing self-other similarity allows also affective and conceptual features to "migrate" from the representation of the other to the representation of oneself. Ma et al. (2016), for instance, demonstrated that after enfacing a smiling face, participants showed a better mood as explicitly assessed by questionnaires, and also a better performance in a mood-sensitive creativity task. A subsequent study from the same research team, showed that enfacing an ape face reduced the performance in a fluid intelligent task and increased the willingness to attribute emotions to apes (Ma et al., 2019). Thus, the enfacement illusion paradigm showed that increasing the overlap between the self and another face representation promotes illusory conjunctions, in which features of the other become features of oneself. In our case, enfacing an invisible face may lead participants to share the characteristic of being invisible, that is, the impossibility of being gaze upon, thus reducing the range of gaze deviations perceived as directed toward the self.

When people notice that they are being looked at, they become aware that the attention or intentionality of another person is directed at them. This awareness is fundamental during social interactions and is obviously distinct from the awareness of one's own physical body because it requires the existence of another person (Sugiura, 2013). Thus, our results suggest that the experience of invisibility may affect the manner in which we process the attention of others toward the self. These data are strongly in

agreement with previous research by Guterstam et al. (2015), showing that the illusory ownership for an invisible body illusion reduces the level of subjective stress and decreases heart rate in response to standing in front of a crowd of unknown people. In particular, these authors argued that when participants experienced the invisible body illusion, their body was represented as invisible to outside observers as well, which in turn should reduce social anxiety related to being the center of other people attention. This conclusion is particularly interesting for the present study, because research on the cone of gaze has demonstrated that it is wider in people suffering from social anxiety (Gamer et al., 2011; Jun et al., 2013). People with social anxiety show a hyper vigilance-avoidance pattern of attention to threat stimuli (Onnis, Dadds, & Bryant, 2011). Therefore, in the case of socially anxious individuals, hyper-vigilance may exacerbate the normal tendency to assume other's people gaze as directed toward the self, producing a wider cone of gaze and leading to an exaggerated feeling of being looked at (Jun et al., 2013). Thus, it is possible to speculate that perceiving one's own body as invisible reduces the attention to others' eye region, inducing a weaker judgment of those eyes being directed at the observer.

As previously recalled, indeed, humans have an expectation that the gaze is directed toward themselves (Mareschal, Calder, Dadds, et al., 2013). In a notable study, Mareschal, Calder, Dadds, et al. (2013), by applying Bayesian framework, demonstrated that this expectation dominates perception when there is high uncertainty. In this study authors, by adding visual noise to the eyes, found that participants systematically perceived the noisy gaze as being directed more toward them. In accordance with previous evidence, it is possible to assume that participants, representing one's own face as invisible after synchronous multisensory stimulation, may update also their prior expectation that the gaze is directed toward the self, accordingly with the new body representation. However, it is not our intention to claim that the illusion of having an invisible face is the only body change effective in modulating gaze perception. The cone of gaze is extremely plastic depending on several emotional or affective contexts, thus it is possible to imagine that also other bodily illusions may affect the cone of gaze. For instance, embodying a scared face may lead participants to be hyper-vigilant, thus enlarging their cone of gaze in a similar manner to people with social phobia.

It is possible that the dynamic interaction between one's own face representation and the perception of gaze direction could happen also at the neural level. Perception of direct eye gaze is associated with activation in amodal association cortices in the medial frontal and lateral posterior cortices (Sugiura, 2013). In particular, activation has been identified in the medio prefrontal cortex encompassing the anterior cingulate cortex (Kampe, Frith, & Frith, 2003; Schilbach et al., 2006; Steuwe et al., 2014), the TPJ/pSTS (Pelphrey, Viola, & McCarthy, 2004; Schilbach et al., 2006; Steuwe et al., 2014), the anterior temporo parietal cortex. These regions have often been recognized as a cortical network supporting the inference of another's mental state, namely mentalizing or theory of mind (Amodio & Frith, 2006). We can therefore hypothesize that the observed effects on the cone of gaze, is reflected in the neural interplay between multisensory representations of one's own face in intraparietal areas and the cortical neural network supporting mentalizing and theory of mind. This is an intriguing hypothesis that future studies could test.

In conclusion, we have described an illusion of embodying an invisible face created through a synchronous visuo-tactile stimulation on the participants' face and a discrete volume of empty space. Participants referred touch on the empty space, and they could easily imagine their own face projected in the empty space, as if the empty space mirrored their own face. After synchronous visuotactile stimulation, participants qualified the empty space as part of their own body, as demonstrated by higher SCR to a threat moving toward the invisible face. Finally, we showed that participants truly experience a feeling of being invisible because they reduced the range of eyes deviation judge as directed toward them (i.e., the cone of gaze). Thus, these results show that indivisibility may affect the way in which we process the attention of others toward the self, starting from the perception of eye gaze direction.

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