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The rubber hand illusion in a mirror

Marco Bertamini *, Nausicaa Berselli, Carole Bode, Rebecca Lawson, Li Ting Wong

School of Psychology, University of Liverpool, United Kingdom

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ABSTRACT

In the rubber hand illusion (RHI) one's hand is hidden, and a fake hand is visible. We explored the situation in which visual information was available indirectly in a mirror. In the mirror condition, compared to the standard condition (fake hand visible directly), we found no reduction of the RHI following synchronised stimulation, as measured by crossmanual pointing and by a questionnaire. We replicated the finding with a smaller mirror that prevented visibility of the face. The RHI was eliminated when a wooden block replaced the fake hand, or when the hand belonged to another person or mannequin. We conclude that awareness of the reflection is the critical variable, despite the distant visual localisation of the hand in a mirror and the third-person perspective. Stimuli seen in a mirror activate the same response as stimuli seen in peripersonal space, through knowledge that they are near one's body.

1. Introduction

1.1. Mirrors and self-recognition

Most people have daily experience of seeing themselves reflected in a mirror. In the modern environment mirrors are familiar objects and people have learned to use them for a number of tasks. In terms of visual information, when we look at ourselves in a mirror what we see is a copy of our own body. Here we limit our discussion to the case of a single plane mirror; by contrast it has been suggested that using two mirrors it is possible to look at the second virtual image and "stand outside oneself" (Altschuler & Ramachandran, 2007). With a single mirror we can see a copy of our body through an aperture, but our conscious experience is not that of a body double (or an out-of-body phenomenon). Instead we immediately relate this visual information back to ourselves. Indeed, many studies have used mirrors as a tool to test for self-recognition (Gallup, 1977). Few other species share with humans this ability to recognise themselves in a mirror and, therefore, relate the information from the mirror to themselves (for a review see Parker, Mitchell, & Boccia, 2006). In humans this self-recognition ability starts in the first few years of life (about 18 months, Anderson, 1984).

Imagine a person sitting at a table with their hands resting on its surface. If a plane mirror were placed in front of the person then they would see their virtual image opposite themselves and mirror reversed. The virtual copy of their left hand, for instance, would be located directly in front of the person's left hand but it would be the right hand of the virtual person and the tips of the fingers of these two hands would face the opposite way. Thus, even though they see the image as belonging to themselves, in terms of visual information they have a third-person perspective of their own body.

People rely on visual information to update an internal model of their own body (for a recent review, see Serino & Haggard, 2010). Given this, we tested whether such adjustments would occur when visual information came exclusively from seeing a reflection in a mirror rather than from seeing one's own body directly.

* Corresponding author. Fax: +44 151 794 2954.
E-mail address: m.bertamini@liv.ac.uk (M. Bertamini).

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1.2. The rubber hand illusion

When a fake hand is stimulated at the same time as one's real but hidden hand, this person may experience a sense of ownership of the fake hand and a sense that the fake hand feels the stimulation. This phenomenon is known as the rubber hand illusion (RHI, Botvinick & Cohen, 1998) and can be used to study how people perceive their own body and how they maintain and update an internal representation of their body. Neuroimaging studies of the sense of body ownership have also harnessed this illusion (e.g. Tsakiris, Longo, & Haggard, 2010).

A necessary condition for the RHI is for the fake and real hands to have a similar orientation. Specifically, Ehrsson, Spence, and Passingham (2004), and Tsakiris and Haggard (2005) found that the illusion was abolished when the fake hand was at 180° and 90° to the subject's own hand. Costantini and Haggard (2007) used smaller rotations (10°, 20° and 30°) and found that the illusion was preserved as long as the stimulation was consistent in a hand-centred frame of reference. More recently, Guterstam, Petkova, and Ehrsson (2011) used a rotation by 180° as a control condition for a new version of the illusion in which participants experience the ownership of a third hand (but not when rotated). In addition to orientation, location and size of the hand are also important. Lloyd (2007) found that the strength of the illusion decayed significantly when the fake hand was over 30 cm from the real hand. Pavani and Zampini (2007) found that size modulated the illusion. The RHI was present for veridical and enlarged images of the hand, but absent when the image of the hand was reduced. However, Bruno and Bertamini (2010) obtained the RHI with realistic fake hands that were either slightly smaller or slightly larger than the hand of the participant. They also found that the size of the fake hand affected the haptic estimation of the size of an object.

Petkova and Ehrsson (2008) have reported an extension of the RHI phenomenon to a whole other body. Participants adopted the visual perspective of a mannequin using a CCTV camera recording from the mannequin's viewpoint. This, in combination with the receipt of correlated multisensory information, triggered the illusion that the mannequin's body was their own. Petkova and Ehrsson concluded that first-person perspective is an important factor in this illusion. Note that this conclusion is consistent with the importance of the orientation of the hand for the RHI because when the fake hand is rotated this is inconsistent with our (usual) first-person perspective of our own hand (we rarely see our own hand rotated 90° or 180°, i.e. with the tip of the fingers towards us). More recently, Petkova, Khoshnevis, and Ehrsson (2011) compared the strength of this full body illusion from the perspective of a first or third person. They concluded that the first-person perspective is essential, and that the multisensory process underlying the sense of self operates in an egocentric reference frame.

We have listed a series of studies showing important constraints on the conditions necessary to induce the RHI. By contrast, Armel and Ramachandran (2003) have suggested that a correlation between vision and touch can induce experiences of ownership of objects completely different from a hand, for instance a table. This view has been criticised because it is incompatible with empirical findings, for instance those reported by Tsakiris and Haggard (2005). Recently, Hohwy and Paton (2010) have suggested a possible resolution. They found that the RHI persists through periods of no tactile stimulation when the real and the fake hand are aligned in personal space. They also reported experiences of touch felt on a cardboard box rather than a fake hand, but only after the basic illusion was established. Without prior onset of the illusion there was no difference between reports of a RHI-like illusion for a cardboard box during synchronous or asynchronous touch. Hohwy and Paton argue that information is treated differently depending on context because of the underlying inferential process. The system is engaged in "explaining away" the incoming evidence.

With respect to the key role of alignment of the real and fake arm, Hohwy and Paton's (2010) results are consistent with Petkova and Ehrsson's (2008) results in so far that the alignment in personal space meant that the participant had a first-person perspective of the hand (as well as of the cardboard box).

1.3. Cross-modal congruency data

Maravita, Spence, Sergent, and Driver (2002) have studied a situation in which participants perceived stimuli only indirectly in a mirror placed in front of them. The task was to respond to tactile stimulation; in this paradigm the interference caused by incongruent visual stimuli is called the cross-modal congruency effect. Stronger interference was produced by visual stimuli located near to the stimulated hand, even when these stimuli were only seen indirectly as mirror reflections. This visual-tactile interference for stimuli seen in a mirror implies that the information from the mirror is not treated as belonging to the virtual location, inside the mirror. Instead this information is related to the location where the objects reflected are physically located, near the hand. The study by Maravita et al. (2002) is an example of how visual information gathered directly or indirectly through a mirror may be treated as equivalent.

There have been many studies on the cross-modal congruency effect, and some of them are relevant because, even though they did not involve a mirror, a third-person perspective was used. For instance, Heed, Habets, Sebanz, and Knoblich (2010) found that crossmodal processing in peripersonal space is reduced for perceptual events that another person acts upon. This third person was sitting across a table from the participant and in one condition acted within the visual stimuli present in the participant's peripersonal space. These effects suggest that some congruency modulation does not require a first-person perspective.

A different but related phenomenon has been reported by Pavani, Spence, and Driver (2000). Observers mislocalised a tactile stimulus delivered to an unseen hand if there were lights near a fake hand that flashed in correlation with the tactile stimulus. Pavani et al. (2000) did not find the effect when the hand was rotated by 90°. Austen, Soto-Faraco, Enns, and

Kingstone (2004) found that this effect disappeared when the posture of the fake hand was inconsistent with that of the observer's arms. Despite the importance of orientation and posture, Austin et al. found that specific appearance and texture of the fake hand was not critical.

1.4. The rubber hand illusion in a mirror

Mirrors have been used before to create a situation where the image of the right hand is misperceived as the left hand (or vice versa) (e.g. Holmes, Snijders, & Spence, 2006; Ramachandran, Rogers-Ramachandran, & Cobb, 1995). To achieve this, the mirror was placed in a parasagittal orientation. For example, Holmes et al. (2006) found that reaching movements were affected by exposure to a real hand, partly by exposure to a fake hand, and least of all by exposure to a wooden block. However, this use of a mirror is fundamentally different from the fronto-parallel location that is used for self-recognition.

A plane mirror in front of an observer (fronto-parallel) creates a situation in which the virtual hands, and therefore the visual information about tactile stimulation, are located at a distance from the body of the individual. The distance between virtual and real body is twice the distance between the observer and the mirror (see Fig. 1). Nevertheless, humans as discussed earlier in this introduction, have a sense that the virtual body is their own body. Therefore, we predicted that the rubber hand illusion would occur even when the visual information is coming exclusively from the mirror, despite the dissociation between the location where touch is felt (in peripersonal space) and the location of the virtual image of the hand (inside the mirror), and despite the virtual hand having the opposite orientation to the real hand.

2. Experiment 1

2.1. Participants

Thirty-six right-handed members of the University of Liverpool community took part in the study (mean age 20 years). Half were assigned to the direct view condition and half to the mirror condition. They were unaware of the hypothesis under investigation. We recruited only right-handed participants because the RHI can vary with handedness (Niebauer,

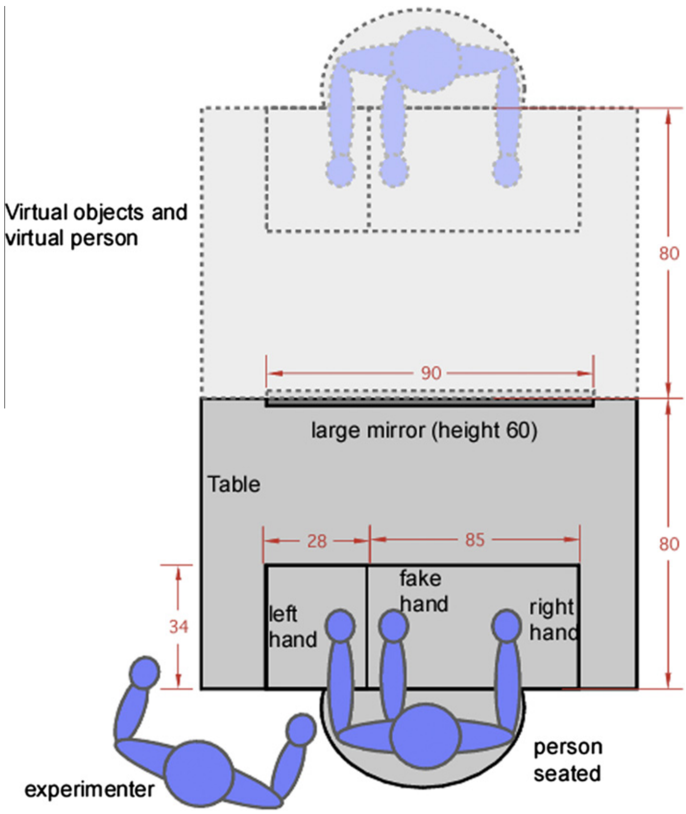

Fig. 1. A diagram of the apparatus in the mirror condition in Experiment 1. All measures are in cm. The upper grey objects are virtual objects visible in the mirror. The rectangle around the hands is the occluder. The same table was used in the direct view condition with the top part of the occluder removed and the mirror covered.

Aselage, & Schutte, 2002) and is stronger when the left hand is tested (Ocklenburg, Rüther, Peterburs, Pinnow, & Güntürkün, 2011).

2.2. Materials

The experimental layout is shown in Fig. 1, and Fig. 2 shows photographs of the setup.

We cast a single fake hand created from an alginate mould of a real hand, selected to be of average size (165 mm from the base of the palm to the tip of the middle finger). The hand was painted by an artist with a realistic skin colour. Participants wore a modified shirt on their right arm and torso but placed their left arm and hand behind a screen. The left sleeve was arranged with the fake hand jutting out as shown in Fig. 2. Their left hand was placed parallel to and to the left of the fake hand, behind a screen. The location for the middle fingers of the fake and real hands was marked on the table and the total distance between the two was 22 cm. Two long-handle paintbrushes provided the stimulation. The experimenter provided the stimulation while standing behind the table and therefore the participant's view of the mirror was unoccluded.

To assess the extent to which participants experienced the illusion, we used a nine item questionnaire (Botvinick & Cohen, 1998), see Table 1. For each statement, participants responded by choosing a value on a 7-point Likert scale from "strongly agree" to "strongly disagree". Some statements have been found to elicit strong agreement when the illusion is experienced (e.g., Q1 – re-location of tactile sensation to the fake hand) whilst some do not appear to be influenced by the illusion (e.g., Q7 – my real hand was turning rubbery).

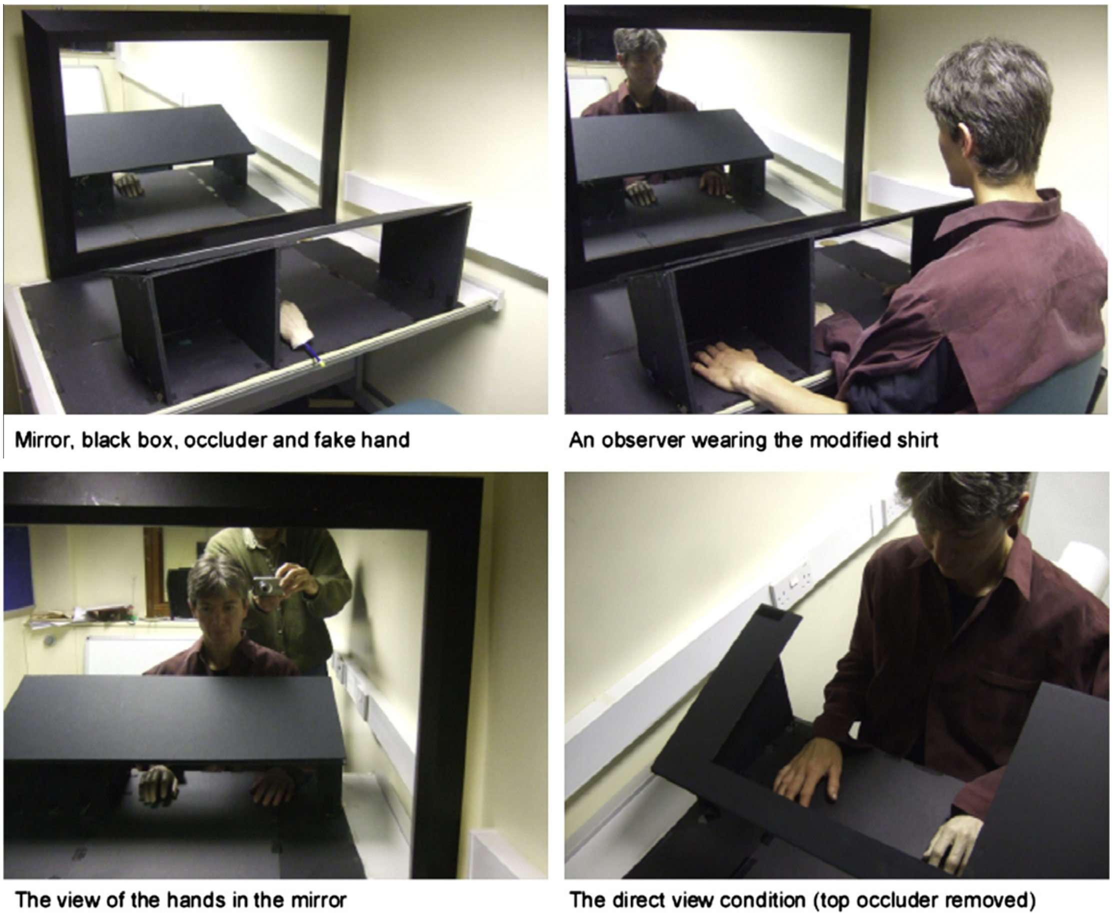

Fig. 2. *Top left*: A photograph of the setup showing the box in which the left hand was hidden, the fake hand, the black occluder and the large mirror. *Top right*: A participant with her hands in position. In the actual procedure she would be sitting nearer the table, these photographs are for illustration only. *Bottom left*: A photograph taken approximately from the viewpoint of the participant. The two hands visible in the mirror reflection are the real right hand of the participant and the fake left hand. *Bottom right*: In the direct view condition part of the horizontal occluder was removed and the participant could see the hands directly.

Table 1
The set of nine questions asked to every participant and taken from Botvinick and Cohen (1998). The order of presentation of questions was random and different for every participant. Responses were on a 7-point Likert scale from "strongly disagree" to "strongly agree".

Q1. It seemed as if I were feeling the touch of the paintbrush in the location where I saw the fake hand.
Q2. It seemed as though the touch I felt was caused by the paintbrush touching the fake hand.
Q3. I felt as if the fake hand were my hand.
Q4. It felt as if my (real) hand was drifting towards the right (towards the real hand).
Q5. It seemed as if I had more than one hand or arm.
Q6. It seemed as if the touch I was feeling came from somewhere between my own hand and the fake hand.
Q7. It felt as if my (real) hand was turning rubbery.
Q8. It appeared (visually) as if the fake hand were drifting towards the left.
Q9. The fake hand began to resemble my own (real) hand, in terms of shape, skin tone, freckles, or some other usual feature.

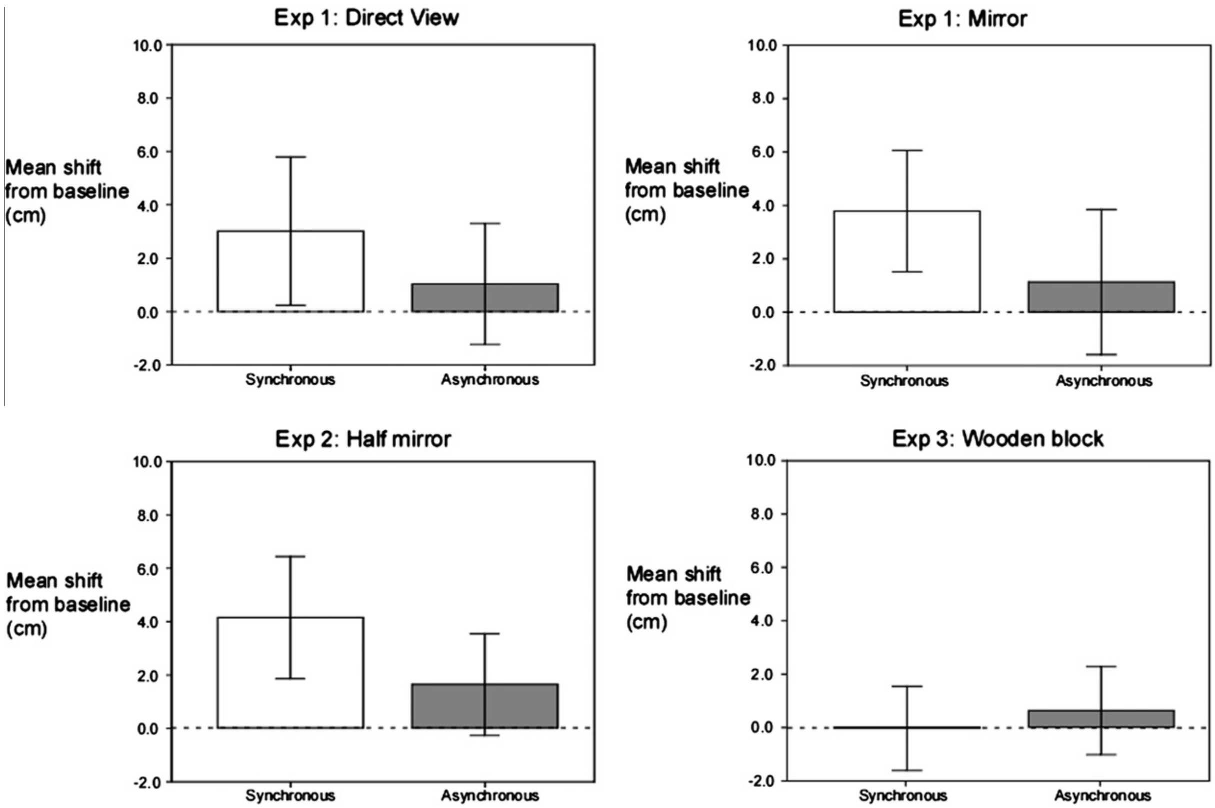

Fig. 3. Crossmanual pointing data from Experiments 1–3. The shift is measured as the difference between the position of the left hand pointed to in the pretest (baseline) condition and in the experimental condition (after stroking the left hand and the fake hand). Positive values are shifts to the right (towards the fake hand). Note that the 95% confidence intervals are appropriate for comparisons against the baseline of zero (no shift), but not for the within-subjects comparison between synchronous and asynchronous conditions. See text for statistical analysis.

2.3. Procedure

Half of the participants were assigned to the direct view condition whereas the other half were assigned to the mirror condition. For each condition half of the participants were tested with synchronous stimulation and then with asynchronous stimulation and the other half were tested with the reverse order of stimulation.

Participants were asked to remove any hand or wrist jewellery before beginning the experiment. Next, the participant's left hand was placed inside a frame, and the left middle finger was placed on a fixed marker for precise localisation. The frame prevented participants from seeing their left hand in both direct view and mirror conditions. In the direct view condition participants could see a fake left hand located farther to the right of their left hand, and they could also see their right hand. In this condition there was no visible mirror reflection. In the mirror condition an occluder covered all three hands, but participants could see the fake left hand and their right hand in the mirror.

A pretest baseline estimate of finger position was obtained prior to stimulation. With eyes closed participants pointed with their right hand to the horizontal position of the left middle finger. The pointing was done on top of the horizontal occluder and the experimenter recorded the horizontal position. Because of this, this occluder was used also in the direct view condition, but only while the participants had their eyes closed. This same procedure was used again after stimulation to obtain the posttest measure.

The experimenter delivered the stimulation with the use of two identical paintbrushes. Frequency was 1 Hz and a visual metronome provided the timing. The experimenter stroked the hand only along the fingers, from the knuckle to the fingertip.

2.4. Results

2.4.1. Crossmanual pointing

We measured the displacement in the pointing task by subtracting the baseline position from the position after the stimulation. Mean values of the difference between pretest and posttest are plotted in Fig. 3. Positive values are displacements toward the right (towards the fake hand). This dependent variable was entered in a $2 * 2 * 2$ mixed ANOVA with viewing condition (direct view vs. mirror) and order (synchronised first or second) as between-subject variables and stroking (synchronised vs. asynchronised) as a within-subject variable. There was an effect of stroking ($F(1, 32) = 5.87$, $p = 0.021$, partial eta squared = 0.15) but there was no effect of viewing condition ($F(1, 32) = 0.09$, n.s.) or order ($F(1, 32) = 0.01$, n.s.) and there were no significant interactions. Therefore the shift in the perceived location of the real left hand towards the location of the fake left hand (to the right) was greater in the synchronous condition but there was no difference if the fake hand was visible directly or in a mirror.

The mixed ANOVA found a significant within-subjects effect of stroking. The error bars in Fig. 3 instead show a 95% confidence interval around each mean treated as a separate condition. Although not directly linked to the ANOVA, these confidence intervals are informative with respect to the baseline and they confirm that the mean position for the synchronous condition was displaced towards the fake hand. This characteristic of the confidence intervals applies to all our plots.

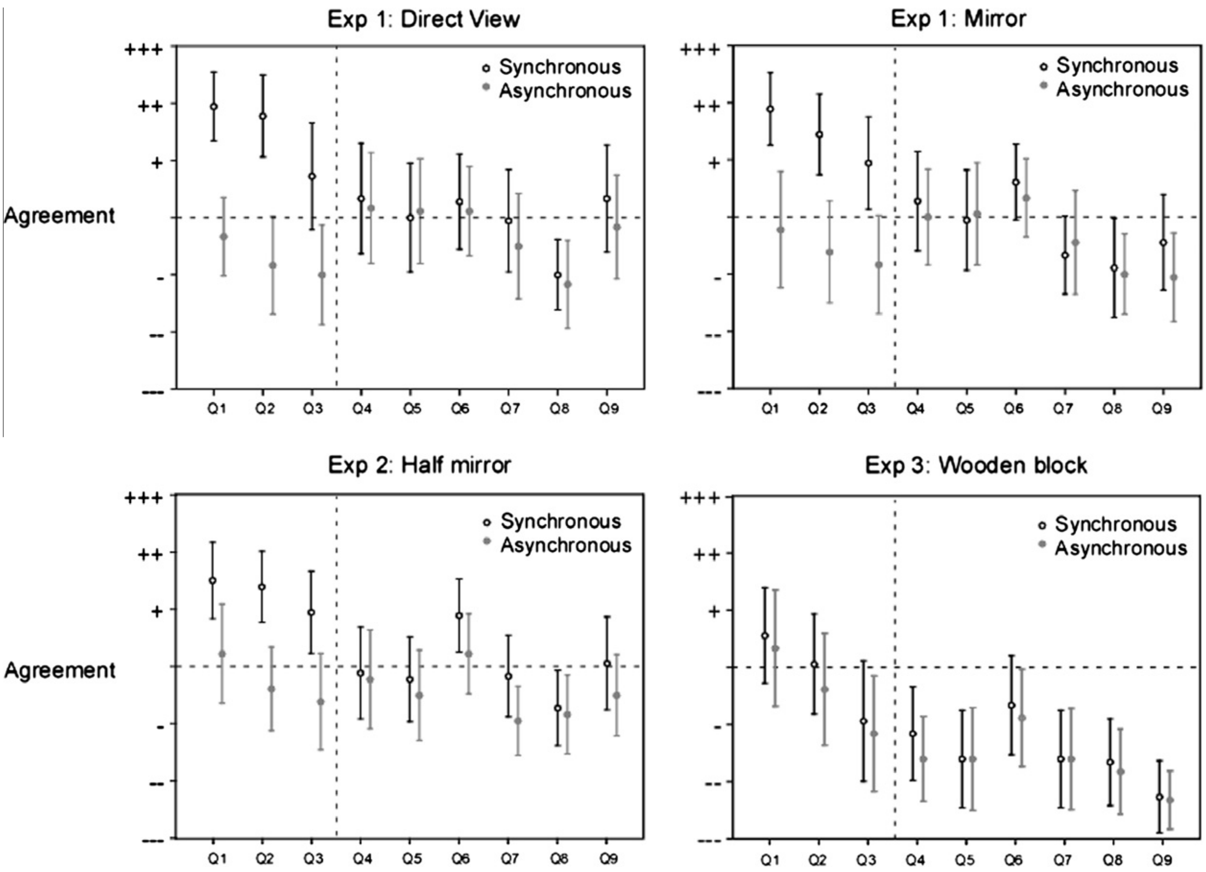

Fig. 4. Questionnaire data from Experiments 1–3. There were nine questions (see Table 1) and a 7-point Likert scale. The dashed line represents lack of either agreement or disagreement. The error bars are the 95% confidence intervals for the means.

2.4.2. Questionnaire data

We plotted mean scores on the nine questions in Fig. 4. The format of the plot is based on the original plot in Botvinick and Cohen (1998). The pattern is consistent with the original findings because the illusion leads to strong agreement on the first three questions after synchronous stimulation. Note that this pattern was not present when the stimulation was asynchronous.

To test the difference between the first three questions and the rest of the questions we grouped them into two sets and tested the average scores. We performed a series of *t*-tests for deviations from the central score, that is, we tested whether the mean score was significantly shifted in the direction of agreement or disagreement. Because we tested both sets separately for synchronous and asynchronous stimulation we used a Bonferroni correction (corrected alpha value 0.0125). In the direct view condition the score on questions 1–3 deviated towards agreement but only for the synchronous stimulation ($t(17) = 1.48$, $p < 0.001$), no such agreement was found on questions 4–9. In the mirror condition we found exactly the same pattern ($t(17) = 1.43$, $p < 0.001$). This is in agreement with the original report of the RHI because only the first three statements were meant to describe the predicted phenomenon (Botvinick & Cohen, 1998).

3. Experiment 2

In Experiment 1 when visual information was available in a mirror the rubber hand illusion was equally strong as when the fake hand was seen directly. This was the case both in terms of the answers to a questionnaire and in terms of displacement in pointing to the felt location of the left hand. This is surprising because the virtual fake hand was visible at a relatively large distance and in a pose that differed from that of both the real left hand and the fake left hand. On the other hand, as discussed in the introduction, humans immediately and effortlessly relate images in mirrors to the objects from which those images originate. The case of seeing our own face reflected is a special case in which this correspondence is particularly strong. The face is often regarded as the primary physical embodiment of the self, and seeing our own face activates a specific right hemisphere network (Cole, 1997; Keenan, Nelson, O'Connor, & Pascual-Leone, 2001; Kircher et al., 2001).

To test the role of seeing one's own face we replicated Experiment 1 using a smaller mirror. Specifically, the only change introduced in Experiment 2 was a reduction in the height of the mirror, from 60 to 30 cm. This meant that the hands and part of the body was visible, but the face was hidden.

3.1. Participants

Eighteen right-handed members of the University of Liverpool community took part in the study (mean age 20 years). They were unaware of the hypothesis under investigation.

3.2. Materials and procedure

The experimental layout was identical to the mirror condition of Experiment 1, but the mirror surface was 30 cm instead of 60 cm in height. As a consequence participants could not see their own face reflected in the mirror. The procedure was identical to that in the mirror condition of Experiment 1.

3.3. Results

3.3.1. Crossmanual pointing

We measured the displacement in the pointing task by subtracting the baseline position from the position after the illusion (see Fig. 4). We entered these data in a mixed ANOVA to test the effect of stroking (synchronised vs. asynchronised) and order. The shift to the right was greater in the synchronous condition ($F(1, 16) = 7.90$, $p = 0.013$, partial eta squared = 0.33) even when the participants could not see their own face. There was no effect of order and no interaction.

3.3.2. Questionnaire data

Fig. 4 shows mean scores on the nine questions. The pattern is consistent with the Botvinick and Cohen (1998) findings because the illusion leads to strong agreement on the first three questions. We tested whether the mean score for questions 1–3 and for questions 4–9 deviated significantly in the direction of agreement or disagreement. Because we also tested both sets (1–3 and 4–9) separately for synchronous and asynchronous stimulation we used a Bonferroni correction (corrected alpha value 0.0125). The score on questions 1–3 deviated towards agreement but only for the synchronous stimulation ($t(17) = 1.27$, $p < 0.001$), no such agreement was found on questions 4–9. This is in agreement with the results from Experiment 1.

4. Experiment 3

The asynchronous condition is an important control for the synchronous condition in that it demonstrates that the effect is not driven by vision alone. Nevertheless, the visual information is necessary and the shape and position of the fake hand play an important role as demonstrated in many studies (e.g. Lloyd, 2007; Tsakiris & Haggard, 2005). Recently, Hohwy and Paton (2010) have shown that even an object that does not resemble a hand can elicit the rubber hand illusion, but only when the illusion has already been experienced by that individual. Therefore, based on the published data we would not expect a naive participant to experience the RHI with a wooden block that does not resemble a hand, even when stimulation is synchronous.

We tested a situation in which a wooden block was visible in a mirror at the end of the left sleeve. This condition has never been tested before and there are two possible outcomes. The first is that the RHI will occur for a wooden block because the mirror provides clear visual information about the relationship of the object to the body. That is, seeing a reflection of our upper body with a wooden block at the end of one arm is more vivid than a first-person perspective of a wooden block. In other words this experiment tests how far we can change the visual information provided by a mirror and still retain the RHI. The second possibility is that the third-person perspective of our body in a mirror is equivalent to the first-person perspective because of how observers use the information from a mirror. If so, the RHI will not occur when a wooden block replaces a fake hand.

4.1. Participants

Eighteen right-handed members of the University of Liverpool community took part in the study (mean age 21 years). They were unaware of the hypothesis under investigation.

4.2. Materials and procedure

The experimental layout was identical to the mirror condition of Experiment 1, except that the fake hand was replaced by a wooden block. The dimensions of the block approximately matched in length and height the dimensions of the fake hand (17 cm by 8 cm). The procedure was identical to that in the mirror condition of Experiment 1.

4.3. Results

4.3.1. Crossmanual pointing

We measured the displacement in the pointing task by subtracting the baseline position from the position after the illusion (see Fig. 3). We entered these data in a mixed ANOVA to test the effect of stroking (synchronised vs. asynchronised) and order. There was no evidence of a difference between the stroking conditions ($F(1, 16) = 1.00$, n.s.), no effect of order ($F(1, 16) = 0.01$, n.s.) and no interaction. Therefore, based on a measure of the perceived position of the left hand we found no evidence for the RHI with a wooden block instead of a fake hand.

4.3.2. Questionnaire data

We plotted mean scores on the nine questions in Fig. 4. Unlike in Experiments 1 and 2 there was no clear agreement with any of the first three statements. Similarly to the analysis of Experiment 1, we tested whether the mean score for questions 1–3 and for questions 4–9 deviated significantly in the direction of agreement or disagreement. Because we also tested both sets separately for synchronous and asynchronous stimulation we also used a Bonferroni correction (corrected alpha value 0.0125). The score on questions 4–9 deviated towards disagreement but this was true for both synchronous and asynchronous stimulation ($t(17) = -1.50$, and $t(17) = -1.64$, both $p < 0.001$), no such agreement was found on questions 1–3. Given the lack of an effect for questions 1–3, and more importantly the lack of an effect of stroking, these low scores are of relatively little consequence with respect to the RHI. Overall the questionnaire data were consistent with the cross-manual data and confirmed that there was no evidence for the RHI in Experiment 3.

5. Experiment 4

In the RHI literature the change in position and orientation of the hand causes a reduction or elimination of the effect (Ehrsson et al., 2004; Guterstam et al., 2011; Tsakiris & Haggard, 2005). However, placing a disembodied hand in front of a participant may not be equivalent to having a person sitting in front of the participant, matching the third-person perspective that is produced by a frontoparallel mirror. Therefore in Experiment 4 we collected data using the same fake hand used in the mirror studies but placing this in such a way as to appear to belong to another person. To be precise the fake hand was a right hand in this case, to match the reflected left hand in Experiment 1. In terms of layout, we replaced the mirror with a second table of identical size to the one at which the participant was sitting. The location and posture of the new person was similar to the location and posture of the virtual body visible in a mirror (see Fig. 5). In terms of the appearance of the new person we conducted two versions of this new study; in one we used a full-scale mannequin, and in the other we used a confederate. The mannequin had the advantage that it provided full control over location and posture, which was fixed for all participants. The confederate had the advantage of using a real person. However, based on the literature we predict that a RHI will be weak or absent in both versions of this study.

5.1. Participants

Thirty-six right-handed members of the University of Liverpool community took part in the study (mean age 21 years). Eighteen were tested in the mannequin condition and eighteen in the confederate condition. Order (synchronised

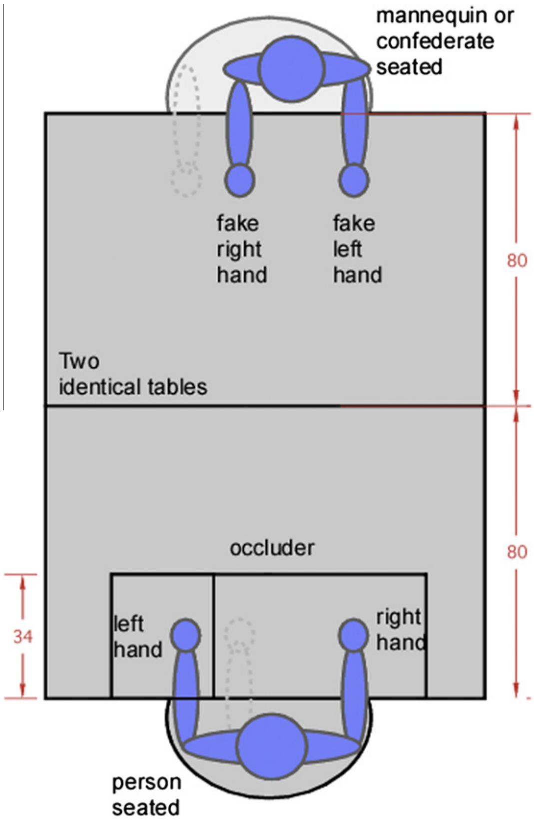

Fig. 5. A diagram of the apparatus used in Experiment 4. The rectangle around the hands is the occluder. The location of the mannequin/confederate matched the location of the virtual person in Experiment 1 (mirror condition) as shown in Fig. 1, and was wearing the same shirt.

stimulation first or second) was balanced across participants (nine for each order, for each version). Participants were unaware of the hypothesis under investigation.

5.2. Materials and procedure

The experimental layout and the procedure were similar to the mirror condition of Experiment 1, but instead of a mirror a second table was placed in front of the first table, as illustrated in Fig. 5. The mannequin was a full-size (total height 178 cm) female, but she was sitting at a table and her arms were removed. She wore the same loose shirt that was used in the previous studies, and a pair of fake hands were placed on the table, coming out of the sleeves. The left hand was the one used in Experiment 1, and the right hand was the cast from the same model. Despite the fact that the mannequin was female the lack of hair (she wore a hat) and the loose shirt meant that the gender was ambiguous. For a separate set of participants the mannequin was replaced by a male confederate (height 178 cm, age 20). He wore the same shirt as the mannequin and the same set of fake hands were used jutting out of the sleeves. In both cases the participant wore a shirt identical to that worn by the mannequin or the confederate.

As in Experiment 1, an occluder was used to prevent direct view of the participants' hands. The experimenter, standing to the side of the table, could reach in both directions and provide the stimulation to the real hand and the fake hand. Participants could see and were asked to focus attention only on the hands on the mannequin/person located across the table from them.

5.3. Results

5.3.1. Crossmanual pointing

We measured the displacement in the pointing task by subtracting the baseline position from the position after the illusion. Mean values are plotted in Fig. 6. We entered these data in a mixed ANOVA to test the effect of stroking (synchronised vs. asynchronised) order and model (mannequin vs. person). There were no significant effects or interactions. Therefore, based on a measure of the perceived position of the left hand we found no evidence for the RHI with a third-person perspective.

5.3.2. Questionnaire data

Fig. 6 shows mean scores on the nine questions and 95% confidence intervals. We followed the same approach as in the previous analyses and tested whether the score for questions 1–3 and for questions 4–9 deviated in the direction of agreement or disagreement. Because we tested both sets separately for synchronous and asynchronous stimulation we used a Bonferroni correction (corrected alpha value 0.0125). The score on questions 1–3 deviated towards disagreement in the synchronous stimulation condition ($t(35) = -0.61$, $p = 0.006$), and the score on questions 4–9 deviated towards disagreement for the both synchronous and asynchronous stimulation ($t(35) = -1.17$, and $t(35) = -1.41$, both $p < 0.001$).

One could argue that this pattern of answers is not in line with the crossmanual pointing data, and therefore it suggests a degree of dissociation between the two measures. However, the evidence is mainly suggesting a stronger tendency to reject any of the statements in the asynchronous condition, whether they belonged to the first or the second set of questions. As such this is not evidence in support of the RHI. Fig. 6 also suggests that within the first three questions there was relatively high agreement to question 1. This question is about feeling the touch of the paintbrush at the location of the fake hand. It is possible that demand characteristics played a larger role for this question compared to the others, because participants could understand that the procedure was devised to match stimulation on the real and the fake hands.

6. Conclusions

After exposure to multisensory stimulation participants reported (in a questionnaire) a sense of ownership of a fake hand. The illusion also led to a mislocalisation of the left middle finger, presumably because of an update of an internal model of hand position. A key aspect of this multisensory illusion is that stimulation of the two hands (real and fake) has to be synchronous (Botvinick & Cohen, 1998). The analyses confirmed a significant difference between synchronous and asynchronous stimulation (see Figs. 3 and 4).

Experiments 1 compared a direct view condition and a condition in which visual information was presented only in a large mirror. The RHI remained equally compelling when there was no direct first-person visual information about the location of the fake hand and the stimulation. In Experiment 1 we used a mirror that was 60 cm in height in which participants could see their hands, upper body and face. In Experiment 2 we reduced the height so that the face was no longer visible but the hands and some of the body remained visible. The illusion was confirmed in Experiment 2, thus showing that there was no critical role for face self-recognition.

In the crossmanual pointing task the shift away from baseline was about 4 cm, which is broadly consistent with the original report (Botvinick & Cohen, 1998). Some studies have excluded participants on the basis of a pilot test that showed if they were sensitive to the rubber hand illusion, i.e. whether they reported experiencing the illusion (Ijsselsteijn, de Kort, & Haans, 2006). As expected, this procedure reduced variability in the data. We chose not to exclude any participants because we wanted to test the role of mirrors in the general population rather than in a subset.

In Experiment 3 participants saw their own reflection in a mirror but a wooden block replaced the fake hand. This is an interesting condition because observers could see and recognise themselves in the mirror, but they observed an extraneous object coming out of the sleeve where their hand should have been. The rubber hand illusion was abolished, suggesting that visual information from a mirror has to match expectations about our body to be effective. This agrees with the conclusion of Tsakiris and Haggard (2005) but not with the idea that temporal correlation is sufficient (Armel & Ramachandran, 2003).

The use of mirrors has important theoretical implications in relation to egocentric and exocentric frames of reference. Because a plane mirror generates a virtual copy of the body of the participant, from the participant's viewpoint, and based on visual information alone, this object is located on the other side of the mirror at a distance that matches the distance of the person from the mirror. In our setup the table was 80 cm in width and therefore, in terms of visual information, the virtual person was 160 cm away from the participant, and outside peripersonal space. Despite this visual information of a distant object, humans do not experience seeing another body in a mirror because they immediately relate the visual information back to their own body.

We suggest that this strong sense of identity is the reason why, in the case of the rubber hand illusion, the information gathered from a mirror had the equivalent effect of the information gathered from a direct view of a hand. Therefore, strictly speaking the physical location of the fake hand in peripersonal space and the first-person perspective of the hand are not necessary conditions for establishing the rubber hand illusion. However, the results from Experiment 4 show that a mirror reflection of ourselves is different from a third-person perspective with another person sitting in front of us.

A phenomenon related to the rubber hand illusion has been reported for synchronous stroking of the cheek of a participant and of a second person (Paladino, Mazzurega, Pavani, & Schubert, 2010; Tsakiris, 2008). Following synchronous stimulation, recognition of one's own face was biased in the direction of the other person's face (Tsakiris, 2008). Paladino et al. (2010) also reported effects on judgment of the inner state of the other, closeness felt toward the other, and conformity behaviour. It is particularly interesting that the stimulation was applied to the congruent cheek; meaning that when the right cheek of the participant was touched the left cheek of the other person was touched. They did this to simulate what happens in a mirror (Tsakiris, 2008). The implicit assumption was that a weaker effect would follow stimulation of the anatomically matched part of the body (i.e., the right cheek for both persons) although to the best of our knowledge no direct comparison has been yet performed.

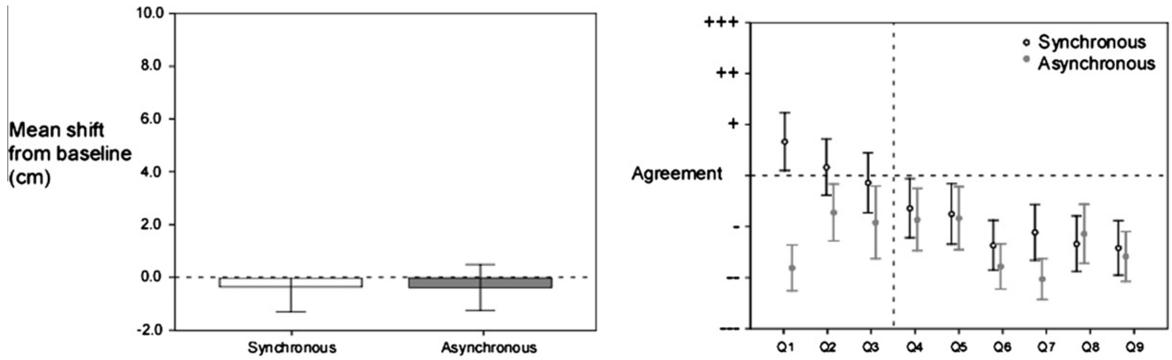

Fig. 6. *On left*: Crossmanual pointing data from Experiment 4. The shift is measured as the difference between the position of the left hand pointed to in the pretest (baseline) condition and in the experimental condition (after stroking the left hand and the fake right hand). *On right*: Questionnaire data from Experiment 4. The dashed line represents lack of either agreement or disagreement.

The ability of humans to recognise their own image in a mirror has been extensively studied as an important cognitive landmark (Gallup, 1977; Parker et al., 2006). Understanding and predicting the behaviour of a mirror image is, by contrast, not something that people find easy, and systematic mistakes have been documented (Bertamini, Lawson, Jones, & Winters, 2010; Bertamini, Spooner, & Hecht, 2003). However, these mistakes are consistent with the fact that mirrors are never treated as pictures. Observers are good at judging the objects visible inside the mirror, for instance their size, because these objects are perceived as distal objects whether they are real or virtual (Lawson, Bertamini, & Liu, 2007). In other words some of these mistakes can be seen as the result of the compelling nature of the visual information available in mirrors.

In our experiments we compared a direct view of the fake hand and a reflected view of the fake hand. In Experiment 4 we tested a situation where a person was sitting at a table across from the participant. This position matched the location of the virtual person seen in the mirror. This allowed us to compare a reflected view of the fake hand with a view of another person's hand in a position that matched the view in the mirror. The rubber hand illusion as measured by crossmanual pointing was completely abolished in Experiment 4. This is consistent with the evidence in the literature about a rotated hand (Costantini & Haggard, 2007; Ehrsson, Holmes, & Passingham, 2005; Tsakiris & Haggard, 2005).

In the case of the cross-modal congruency effect, Maravita et al. (2002) compared a condition in which the hand was virtual (in a mirror) or real. In their Experiment 3 a person sat opposite the participant, completely hidden except for his or her hands. They found a significant difference in the congruency effect between this third person condition and the mirror condition. It is, therefore, reasonable to conclude that mirrors are special and that caution should be taken not to generalise results obtained with mirrors to other situations in which visual information is only obtained indirectly.

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