First person experience of body transfer in virtual reality

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Abstract

Background

Altering the normal association between touch and its visual correlate can result in the illusory incorporation of a fake limb into our body representation. Thus, when touch is seen to be applied to a rubber hand while felt synchronously on the corresponding hidden real hand, an illusion of ownership of the rubber hand usually occurs. The illusion has also been demonstrated using visuomotor correlation between the movements of the hidden real hand and the seen fake hand. This type of paradigm has been used with respect to the whole body generating out-of-the-body and body substitution illusions. However, such studies have only ever manipulated a single factor and although they used a form of virtual reality have not exploited the power of immersive virtual reality (IVR) to produce radical transformations in body ownership.

Principal Findings

Here we show that a first person perspective of a life-sized virtual human female body that appears to substitute the male subjects' own bodies, was sufficient to generate a body transfer illusion. This was demonstrated subjectively by questionnaire and physiologically through heart-rate deceleration in response to a threat to the virtual body. This finding is in contrast to earlier experimental studies that assume visuotactile synchrony to be the critical contributory factor in ownership illusions. Our finding was possible because IVR allowed us to use a novel experimental design for this type of problem with three independent binary factors: (i) perspective position (first or third), (ii) synchronous or asynchronous mirror reflections and (iii) synchrony or asynchrony between felt and seen touch.

Conclusions

The results support the notion that bottom-up perceptual mechanisms can temporarily override top down knowledge resulting in a radical illusion of transfer of body ownership. The research also illustrates virtual reality as a powerful tool in the study of body representation, since it supports experimental manipulations that would otherwise be infeasible, with the technology being mature enough to represent human bodies and their motion.

Introduction

Normally when something strikes our body we feel it at the same place that we see it. When normal correlation between two sensory streams is changed, for example, by seeing a plausibly located rubber hand touched while simultaneously feeling the touch on our out-of-sight real hand, the brain apparently engages in a Bayesian re-evaluation of probabilities and assigns ownership to the visible rubber limb [1, 2]. These methods have also been used to produce illusions of body morphing, adding supernumery limbs to the body [3-6], and out-of-the-body experiences [7-9]. In conjunction with brain-imaging these manipulations can provide insight into the brain areas involved in body representation, for example [10]. While the vast majority of work in this field has shown that it is possible to incorporate physical objects or video images of these into the body representation, it has also recently been shown that the same methods work with entirely virtual objects [11-13].

The examples of out-of-the-body experiences provide indirect evidence that these illusions might apply to the whole body rather than only to body parts. There is also evidence that ownership can be attributed to a manikin that appears visually to substitute the person's real body as seen through head-mounted displays coupled to a video camera oriented down at the manikin body [14]. These out-of-the-body and the manikin experiments employed synchronous visuotactile stimulation – the illusory visual body was seen to be tapped or stroked in the same place as the real body was felt to be stimulated. When there is asynchrony between felt and seen touches changes in ownership do not occur or are less prominent compared to the case of synchrony between both stimuli [13].

The experiment reported here is the first that shows that ownership can be transferred to an entirely virtual body, using an experimental design that separates perspective position from visuotactile stimulation. We found that when perspective position is included as a factor in the experimental design the importance of visual-tactile synchronization diminishes in comparison to what would be expected from the literature.

Results

Overall Design

There were 24 male participants recruited for our study. They were seated, and entered into the virtual reality through a wide field-of-view head-tracked, head-mounted display and stereo headphones. The scene in which they were located is shown in Figure 1. They were asked to visually explore this scene for 2 minutes after which their viewpoint was transported to the other side of the room to where two female virtual characters were located, a seated young girl and a standing woman (Figure 2).

What they experienced then depended on which of the combinations of three binary factors they had been assigned by the experimental design (Table S1). *Perspective* was either first person (1PP, Figure 2A) or third (3PP, Figure 2F) with respect to the seated girl. *Movement* refers to whether the observed head movements of the virtual girl were synchronous with those of the subject (MS, Figure 2D, 2F) or asynchronous (MS'). *Touch* refers to whether the subject felt synchronously (TS) or asynchronously (TS') touched on his shoulder when the standing woman stroked the shoulder of the seated girl (Figure 2C, 2D, 2F).

After almost 7 minutes of this period that included occasional shoulder stroking, the viewpoint of the participant was lifted upwards towards the ceiling, looking down on the scene below (Figure 2G) during which time the shoulder stroking continued but unaccompanied by physical sensations. Suddenly the standing woman was seen to hit the seated girl around the face (Figure 2H). After this the viewpoint translated downwards again, there were some more (felt) shoulder strokes, and then the experimental trial was terminated. The full sequence of events that occurred is shown in Table 1.

Questionnaire Results

Immediately after the experience in the virtual reality, a 13-item questionnaire was answered by the participants (Table S2). Eight of these questions related to the issue of body ownership (Table 2). Perspective gives the clearest set of responses (Figure 3A), where the mean (and median) score for 1PP is always greater than or equal that for 3PP on each of the questions. Movement has no particular effect, and synchronous touch has an effect on some of the variables. From the fitted models estimates of the probabilities of the questionnaire scores for four combinations of the factors were obtained and are shown in Figure 3D. These data show that the most important factors leading to the temporary subjective illusion of ownership of the virtual body are the participant's perspective (i.e. in the girl's body, 1PP) and touch (TS), concordant with a recent account of self-consciousness [15]. Our data also show that apparent head-movement synchrony was least important for the body ownership illusion.

Heart Rate Deceleration

We measured heart rate deceleration (HRD) in response to the woman slapping the girl, a parameter that has been associated with reports of aversive stress in the context of picture viewing [16]. We calculated the negative of the slope of heart rate change during the first 6s after the event in question. The greater this value the greater the initial deceleration and the greater the degree of aversive stress (p588). We consider HRD for two pairs of events (Figure 4). After the *down* transition (Table 2) the participants who perceived from the girl's perspective (1PP) showed a significantly greater HRD than the participants who perceived the scene from the displaced perspective (3PP). The same analysis was carried out for a control period (*across*) and revealed no significant difference between these groups of participants. Similarly, we found that during the slap (*duringS*) the 1PP participants had a significantly greater HRD than the 3PP participants, but for *beforeS* there was no significant difference. Amongst the three factors considered in this experiment only Perspective had a significant influence on the HRD response.

There is, furthermore, consistency between physiological responses (HRD) and the subjective questionnaire responses. During the slap (*duringS*) and after the period of being in the elevated position (*down*) the HRD was significantly positively correlated with a feeling of the participant's own body being attacked (*attack*), the feeling that they might be hurt by the woman (*hurt*) and body ownership (*body*). However, there were no significant correlations between any of the questionnaire responses and HRD for the control periods (*beforeS* and *across*). The full set of correlations and significance levels is in Table S3.

Discussion

The minimal contribution of the specific type of agency that we investigated (MS' compared to MS) seems to be in conflict with previous studies that suggested the importance of motor cues for the sense of self [17, 18]. We note that previous studies have focussed almost entirely on agency manipulations with respect to the upper extremity and have been carried out in isolation from perspective and touch manipulations (see [19] for an exception), making problematic any direct comparison with our results. However, considering our two questions that relate directly to body ownership, (*body* and *mirror* from Table 1) participants in condition MS were more likely to give a higher score to *mirror* than to *body* compared to those in MS'.

A plot of the scores is shown in Figure S1. There are only 2 out of 12 cases for those in condition MS where *mirror* < *body*, and only 1 out of 12 cases for those in condition MS' where *mirror* > *body*. The correlation between these two sets of scores for those in condition MS ($r = 0.91$, $p < 3.5\times10^{-5}$) is greater than for those in MS' ($r = 0.71$, $p < 0.01$). Analysis of covariance of *mirror* on condition M with *body* as a covariate suggests that the regression line of *mirror* on *body* has greater slope in condition MS than in condition MS' ($p = 0.06$). The same analysis has stronger support for there being two positively sloped parallel lines with the one for MS having a greater intercept than for MS' ($p = 0.0093$). This suggests that the synchronised head movement did make a difference – resulting in those participants in condition MS giving higher scores to the question *mirror* than to the question *body*.

Our experiment includes that of Lenggenhager et al. [7] as a special case. The essence of their setup was to manipulate ownership by a 3PP self-representation, that was touched asynchronously or synchronously, comparable to our 3PP and TS' compared with 3PP and TS. Figure 3D shows that with respect to the questionnaire responses the estimated probability of the response being in the Very Low category was much greater in the asynchronous touch than in the synchronous touch condition. Figure S2 gives the equivalent graph for the questions *touch* and *woman*, which have greater probability estimates for the Medium to High questionnaire response in the synchronous compared to the asynchronous condition. There are no significant effects for T in the case of the HRD.

Our experiment also includes that of Petkova and Ehrsson [14] as a special case. Their main setup was to also manipulate ownership by a 1PP self-representation (a manikin) that was touched either asynchronously or synchronously – similar to our 1PP and TS' (girl’s perspective and asynchronous stroking) and 1PP and TS (girl’s perspective but synchronous stroking), respectively. Figure 3D shows that the responses to the question *body* supports the idea that synchronous stroking enhances ownership of the 1PP perceived virtual body. The same is true for the other questionnaire responses (Figure S2). However, HRD is not affected by T.

Yet, there is a critical difference between our experiment and that of Petkova and Ehrsson [14] where cameras on the manikin's head were in a fixed position, looking down at the manikin's body, and therefore the experimental subjects had to have their head fixed in the same orientation. In our setup the real-time head-tracking ensured that the act of looking down involved motor acts and corresponding perceptual changes comparable to physical reality. This may be why in Petkova's and Ehrsson's setup synchronized touch was a critical factor to achieve changes in ownership but it was less important in our experiment. This also ties in with a recent observation that the strong illusion of being in the place depicted by the virtual reality [20] occurs when sensorimotor contingencies for perception [21, 22] are similar to those of physical reality, that is, when a participant can use their body for perception in much the same way as normally [23]. Sensorimotor contingencies endow 'place-ness' to virtual space and the objects within it, and a unique and highly special object is one's own body. When the virtual body is perceived to be in the same place as where the real body should be, perhaps this provides overwhelming evidence for the brain to generate the illusion that the virtual body is one's own. This finding was unexpected in comparison with previous results that have emphasized the importance of visuotactile synchronization.

Through an IVR a person can see through the eyes and hear through the ears of a virtual body that can be seen to substitute for their own body, and our data show that people have some subjective and physiological responses as if it were their own body. This virtual body may be seen when looking directly at oneself from a first-person perspective (or in a virtual mirror) and the multisensory and sensorimotor contingencies involved in the active process of looking down and seeing a virtual body where one's own body would be provides an important tool not just for presence and virtual reality research [20], but also to understand – eventually in combination with neurophysiology and neuroimaging techniques - the neurobiology of self-consciousness.

Materials and Methods

Introduction

24 male subjects were recruited who were naïve to the purposes of the experiment. The experiment was approved by the Comité Ético de Investigación del IDIBAPS (Hospital Clínic, University of Barcelona). A balanced between-groups design was used with the three binary factors being Perspective, Movement and Touch as discussed above (Table S1). Subjects were fitted with a wide field-of-view light-weight (less than 1Kg) head-mounted display (HMD) which was head tracked. This was a Fakespace Labs Wide5 HMD, which has field of view 150º × 88º with an estimated 1600 × 1200 resolution displayed at 60Hz, and the head-tracking was with an Intersense 900. They were also fitted with a Nexus 4 physiological recording device. Electrodes attached to this device were placed on their left and right collar bones and the lowest left rib in order to record the ECG (sampling rate 1024Hz).

Once they had entered the virtual environment they were asked to look around the environment and report what they saw, for purposes of acclimatization to the HMD and familiarization with the environment, and especially to see the standing woman and seated girl on the other side of the room. Then the experiment started signaled by the virtual TV screen showing a music video, and there was no further communication with the experimenters until the completion of the trial. At the end of the experiment the participants completed a questionnaire, and the critical questions relating to the issue of body ownership are shown in Table 1.

Subject Recruitment

Male participants were recruited by advertisement around the campus. Recruitment continued until we had error free physiological data for the target 24 participants. The mean age of the retained 24 participants was 27.6 ± 4.3 years, almost all were students, researchers or employees of the University, who had no prior knowledge of the experiment. Most of them had no prior experience of virtual reality, and none of them had any experience of our virtual reality system or laboratory. They were paid 10€ for their participation.

Procedures

After being fitted with the physiological recording equipment and the HMD the subjects were instructed to look around the virtual environment and report what they could see. This was in order for them to become used to wearing the HMD and also to become familiar with the scene, and especially to notice the two female virtual characters on the other side. After this period of acclimatization headphones were put on and the virtual TV screen on the left hand side of the room now started playing a recorded music video. The subjects had been instructed to continue to look around the room, remembering also to look downwards.

After 2 minutes the first viewpoint transition occurred after which the subject was on the other side of the virtual room. How they experienced subsequent events depended on which combination of the experimental factors they had been assigned.

Experimental Factors

The experimental factors were:

Perspective: In the 1PP (first person) condition the participant saw through the eyes of the body of the virtual girl (Figure 2A) and in the 3PP condition (third person) the participant's position was 1m to the left of the girl's body (Figure 2F).

Movement: in the synchronous condition (MS) the head movements of the girl were displayed to be synchronous with those of the participant (Figs 2D, 2F); in the asynchronous condition (MS') the head movements of the girl were displayed to move asynchronously with respect to the participant, and were based on pre-recorded head movements. Although the movements of the virtual girl's head were synchronous or asynchronous with respect to the head movements of the participant, this was independent of the visual field seen by the participant. This was always correct based on his head position and orientation with respect to the virtual scene, and determined wholly by the head-tracking.

Touch: in the synchronous condition (TS) when the woman stroked the shoulder of the virtual girl the participant would feel synchronous stroking on his shoulder (visuotactile correlation) (Figure 2C, D,F, G); in the asynchronous condition (TS') the stroking felt on his shoulder would occur during the same time interval as the stroking seen on the girl but the felt strokes themselves would be asynchronous with respect to the visual strokes.

Sequence of Events

Various events were programmed to occur during the course of the 10 minutes after the viewpoint transition (Table 2). Almost immediately after ‘arriving’ in the location of the girl (white shirt), the virtual woman (brown sweater) raised her left arm and stroked the right shoulder of the girl. There were 28 stroking periods during the course of the subsequent 10 minute experience, each consisting of between 2 and 5 strokes. A critical event was that 415s after the first viewpoint transformation there was a second transformation, where the participant’s viewpoint was elevated to near the top of the ceiling and oriented to be looking down on the scene below (Figure 2G). The spatial coordinates of this viewpoint transformation were chosen based such transformations in neurological patients with out-of-body experiences [24, 25]. As reported by many of these patients this elevated location is not represented as embodied in a person’s body and patients report not perceiving or having reduced perception of somatosensory cues from their body. Accordingly, although the visual arm strokes continued during this period they were not accompanied by any actual stroking of the participant’s arm. Then 45s into this elevated position the woman suddenly slapped the girl around the face three times, and the girl’s body swayed (Figure 2H) and there were corresponding sounds. We rendered our animation in this way because previous work on ownership has shown that threat-like behavior is often associated with physiological changes [2, 9, 14, 26]. After this, the situation returned to as it had been before the slapping, with the occasional arm stroking, and after a further 50s the perspective shifted down again to the same situation as it had been before the upward translation (location of the girl).

Questionnaire

The questionnaire administered afterwards is shown in Table S2. The questionnaire scores (between 0 and 10) were recoded into ranges as Very Low (0), Low (1-3), Medium (4-6), High (7-9) and Very High (10), based on the layout of the questionnaire.

Statistical Methods

For the questionnaire responses we have chosen the proportional odds cumulative logit model [27] since this appropriately treats the responses as ordinal data. In order to use this we needed to group scores together, since the responses are too sparsely distributed over the original range of scores from 0 to 10.

However, for comparison we have also analysed the questionnaire responses using traditional analysis of variance. Three-way analyses of variance with all two-way interactions were carried out on the questionnaire responses. This is strictly not an appropriate form of analysis since it assumes that the responses are at least on an interval scale, and clearly this is not the case. Nevertheless this approach is common, and it is presented for the sake of completeness, but the results are not different from the previous analysis. The significant results are presented in Table S4. The residual errors of all models were compatible with normality, based on Jarque-Bera tests.

A requirement of ANOVA is that the residual errors of the model fit should follow a normal distribution. In most of the analyses we carried out this was the case, as judged by a Jarque-Bera test [28]. When this is not the case the standard solution is to try to find a monotonic transformation of the response variable so that the residual errors become normal. This was accomplished systematically using the Box-Cox family of transformations [29] y^{λ}, and finding the maximum likelihood estimator for λ.

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Figure 1. The scene. The scene that the participants entered was a room approximately the same size as the real room in which they were located. (A) There were two female characters at the other end of the room, a standing woman who could be seen stroking the shoulder of a seated girl, and a fireplace behind. (B) Looking down at himself a participant would see an empty chair. (C) To the participant's left was a TV showing a real-time music video. (D) To the right were a mirror frame and a door opening to a field.

Figure 2. Participants were transferred to the other side of the room. (A) In the 1PP condition their body was substituted by that of the girl's (white shirt), and when looking down at themselves they would see her body. (B) Looking up they would now see that the woman (brown sweater) was standing by them. (C) The woman stroked their shoulder. (D) Looking left they would see the reflection of the girl and the woman in a mirror. (E) They were seeing the room and hearing the sounds from the TV from the perspective of the opposite side than in the first two minutes. (F) In the 3PP condition they would be located to the right of the girl, and so see her and her reflection in the mirror – in the case shown with her head moves synchronized with their own head moves. (G) Later the viewpoint shifted near to the ceiling and the woman continued to stroke the shoulder of the girl, but the participant did not feel this. (H) Suddenly the woman struck the girl three times around the face - the wide-field-of-view in this image corresponds more precisely to what the subject would have seen.

Figure 3. Questionnaire responses for the main effects. (A-C) show the means and standard errors of the questionnaire responses by each of P, M and T. Using proportional-odds cumulative logit models the notable significance levels are for P (*body*, p = 0.031; *touch*,

0.023; *woman*, 0.033; *cloth*, 0.003; *hurt*, 0.046), and T (*body*, p = 0.095; *touch*, 0.085; *woman*, 0.024). The model fits were good, with the highest deviance being 29.8 on 25 d.f. Panel (D) shows the estimated probabilities for the questionnaire responses for *body*, for four cases: for third person (P3, disembodiment) and for asynchronous (TS') and with synchronous touch (TS), and for first person (P1, embodiment) again comparing TS' with TS. In each case M=MS (the graph is almost identical for M =MS'). There were no scores of 10 in these responses which accounts for the low estimated probability of ‘Very High’.

Figure 4. Means and standard errors of the Heart Rate Deceleration data. The figure shows the means and standard errors for HRD after four events: *across*: 0.5s after initially arriving at the other side of the room; *down*: 0.5s after descending from above; *beforeS*: 7s before the slap; *duringS*: 2s into the slap sequence. 1PP was significantly greater than 3PP on *down* (0.028) and *duringS* (0.034). The ANOVA fits satisfied the requirement of normally distributed residual errors using the Jarque-Bera test [28], except for 1PP on *down*, where a variable transformation was found to obtain normality.

Table 1 Sequence of the Events During the Experiment

Variable Name	Event Description	Time to next event (s)	Cummulative time (s)
	Baseline: Experiment Starts with participant seeing the girl and woman across the other side of the room	120	120
across	Move across the room to enter the girl's perspective (1PP) or to the right of the girl's perspective (3PP)	5	125
stroke_1	First stroke by the woman on the girl's shoulder	415	540
	Perspective Shifts to the ceiling – girl and woman seen below	5	545
	First arm stroke seen from ceiling position	45	590
duringS	The woman slaps the girl*	50	640
down	The perspective shifts back down to the girl	20	660
stroke_n	The final arm stroke	31	691
	The view moves back to the original perspective, and this continues for a final 30s.	30	-

* The event *beforeS* (before slap) was taken as 7s before the actual slap.

Table 2 Questions relating to body ownership and their labels used in the text and figures

body	How much did you feel that the seated girl's body was your body?
touch	How strong was the feeling that the woman you saw was directly touching you on the shoulder?
woman	How strong was the feeling that the touch you felt was caused by the woman that you saw?
cloth	How strong was the feeling that you were wearing different clothing, from when you started the experiment, while you were in the part of the room where the standing woman was located?
mirror	How strong was the feeling that the body of the girl in the mirror was your body?
cnct	When you were looking down from above how much did you feel a strong connection with the seated girl as if you were looking down at yourself?
attack	When the standing woman hit the seated woman, how much did you feel this as if this was an attack on your body?
hurt	After you returned from looking down from above how much did you feel that the standing woman might hurt you?

SUPPORTING INFORMATION

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Supporting Methods

General Procedures

When participants first entered the laboratory they were given an information sheet to read about the experiment, and if they agreed to continue (all did) they signed a consent form. They then completed a short questionnaire that provided basic demographic information (age, status, medicine prescriptions, the extent of game playing, and past experience with virtual reality).

There were two experimenters in the lab throughout. One helped the participant put on the ECG recording equipment. They were then invited to sit in a comfortable position with their hands resting on their knees. This was to roughly match the posture of the virtual girl. They then entered into a virtual reality by donning a Fakespace Labs Wide5 head-mounted display (HMD), which has field of view $150^o \times 88^o$ with an estimated 1600×1200 resolution displayed at 60Hz. The lights in the lab were then turned off.

Participants were asked to open their eyes and to look around and to describe all the features of the virtual room. They were told to look around only by moving their head, not by turning their whole upper body. This was because only their head was tracked, and therefore only the head movements of the virtual girl could match their own movements. While looking around they would be able to see to their left a TV, a window, and a bookcase. Directly in front of them was a table with a small Pinocchio figure on it, and in front at the other side of the room was a seated girl facing towards the subject, and facing away from the subject but towards the girl was a standing woman who could be seen to be occasionally stroking the right shoulder of the girl. Nearby could be seen the frame of a body sized mirror facing towards the girl. Behind the girl was a fireplace with a burning fire. To the right was a sofa and on the wall was a painting. As the participants continued looking round to their right they would see a frame for a large mirror, but not the mirror itself, and then an open door to the outside, and some grass could be seen through the door. Participants were instructed to look down at themselves and they would see an empty chair. They were told that once the scenario started they should continue to look around, remembering occasionally to look down at themselves, and that this was their only task.

An experimenter then put some headphones (Sennheiser HD215 stereo) on the participants and initiated the actual start of the experiment. The participants would then see in the virtual reality a video playing on the virtual TV, and would hear associated sounds and music that were directional. This continued for 2 minutes after which the image that they saw distorted giving the impression of movement and when the image reformed their visual ego centre was on the other side of the room where the virtual females had been seen to be located. What happened next was the same for all participants, except that they would perceive the events differently, depending on the combination of factors to which they had been assigned.

Throughout the whole experiment an experimenter stood behind where the participant was sitting, and paid attention to a PC screen displaying what the participant was seeing. The experimenter was responsible for stroking the arm of the participant whenever the virtual woman stroked the arm of the girl, and these arm strokes could always be seen on the monitor. In the case of the synchronous (T) condition the experimenter would carefully match the touch of the woman, stroke for stroke, and in asynchronous (T') condition would deliver strokes during the same period as the woman, but being careful not to match the woman's strokes.

Finally the participant's viewpoint was moved back to the original starting position on the original side of the room, and the experiment was complete. The lab lights were switched on.

Participants were asked for their immediate impressions of their experience while they were taking off the various equipment, and then asked to complete the questionnaire (available in Spanish and English) (Table S3).

Physiological Measures

The ECG was acquired with the Nexus 4 device (sampling frequency: 1024 Hz)**,** and the analysis was performed with the g.BSanalyze biosignal analysis software package (g.tec – Guger Technologies OEG, Graz, Austria). The first step in ECG analysis was to detect QRS (ventricular contraction) complexes in the ECG time series. The QRS complexes determine the distance in time from one heart contraction to the next one (RR interval). The QRS complexes in the ECG data were detected automatically based on a modified Pan-Tompkins algorithm [1]. Then a visual inspection of the detected QRS complexes was performed to correct any missed or wrongly assigned points.

Supporting Video Material

The video shows some extracts from the scenario, mainly from the first person perspective position of the virtual girl, and also from the 3PP condition. There is no sound on the video although the subjects would have heard the music from the virtual TV (spatialised). The sound is not included for copyright reasons.

Supporting References

1. Pan, J. and W.J. Tompkins, *A Real-Time Qrs Detection Algorithm.* Ieee Transactions on Biomedical Engineering, 1985. **32**(3): p. 230-236.

Supporting Figures

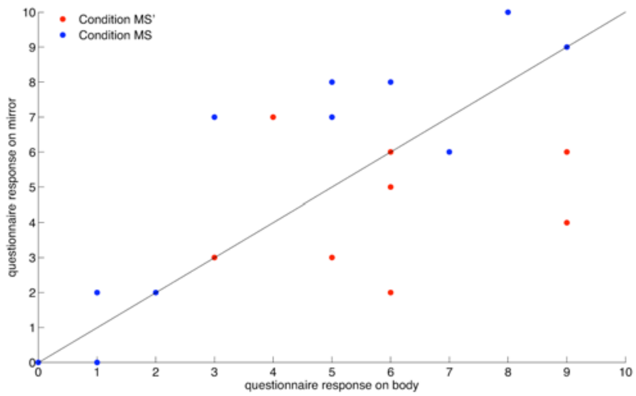

Figure S1: Scatter diagram of the questionnaire responses of *mirror* by *body*, classified by M. Some of the coordinates occur more than once so that the plotted points overlay one another. Points above the diagonal line have *mirror* > *body*.

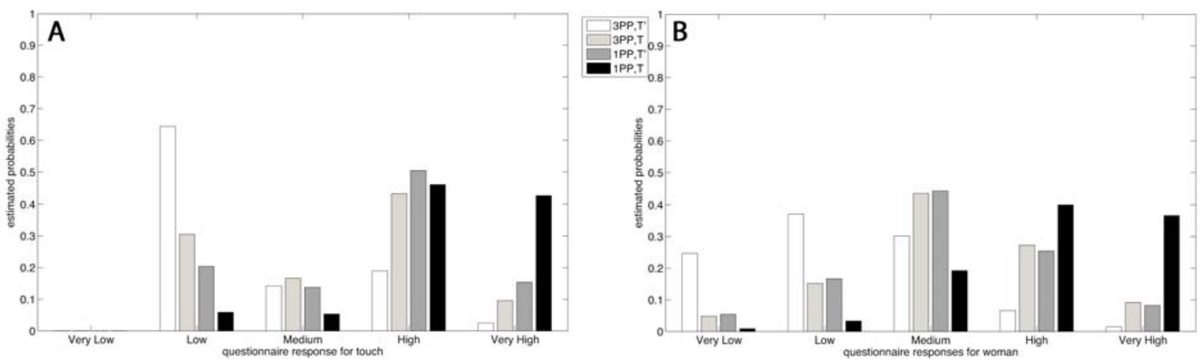

Figure S2: Estimated probabilities for the questionnaire responses on the touch related questions. These are shown for four combinations of the factors, each with M = MS. The results are almost identical for MS'. The left panel shows the results for *touch* (Q5), and the right *woman* (Q10). There are no 0 scores for touch.

Supporting Tables

Table S1 Allocation of Participants to the Experimental Factors.

Subject number:

Factor:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
P	0	1	0	1	1	0	1	0	0	1	0	1	1	1	0	0	1	0	0	1	1	0	1	0
M	1	1	1	0	1	0	0	0	1	0	0	1	0	0	1	0	1	0	0	0	1	1	1	1
T	0	0	1	0	0	1	1	1	1	0	0	1	0	1	0	0	1	1	0	1	1	1	0	0

For example subject 1 was allocated to the condition P', M, T'; subject 9 to the condition P', M, T.

Table S2 Post Experiment Questionnaire

1. When you were looking down from above how much did you feel a strong connection with the seated girl as if you were looking down at yourself?
2. When the standing woman hit the seated woman, how much did you feel this as if this was an attack on your body?
3. After you returned from looking down from above how much did you feel that the standing woman might hurt you?
4. How much did you feel that the seated girl's body was your body?
5. How strong was the feeling that the woman you saw was directly touching you on the shoulder?
6. How strong was the feeling that your body had shifted location when you moved to the other side of the virtual room?
7. How much was this more like watching a scene from the outside compared to really being part of the scene?
8. How much did you feel heat from the fire that you saw?
9. How strong was the feeling that the body of the girl in the mirror was your body?
10. How strong was the feeling that the touch you felt was caused by the woman that you saw?
11. When you were above the scene how strong was the feeling that you were dissociated from your body (as if your self and your body were in different locations)?
12. After you returned from looking down from above how much did you feel that the standing woman appeared to be different compared to before?
13. How strong was the feeling that you were wearing different clothing, from when you started the experiment, while you were in the part of the room where the standing woman was located?

For each question except for Q7, 0 = 'Not at all' and 10 = 'Very Much'.
For Q7, 0 = 'From outside', 10 = 'Part of the scene'.
These were set in the following panel underneath each question:

NOT AT ALL 0	1 2 3 4 5 6 7 8 9	10 VERY MUCH

Table S3 Correlations Between Questionnaire Responses and Heart Rate Deceleration

Event	cnct	attack	hurt	body	touch	mirr	woman	clothing
across	-0.02	0.06	-0.35	-0.35	-0.33	-0.38	-0.35	-0.36
beforeS	0.03	0.21	0.15	0.11	0.06	-0.06	-0.09	0.10
duringS	**0.43** (0.038)	**0.43** (0.038)	**0.58** (0.003)	**0.39** (0.058)	0.25	0.04	0.10	**0.55** (0.005)
down	0.20	**0.40** (0.051)	**0.49** (0.016)	**0.61** (0.002)	**0.43** (0.036)	0.25	0.35	0.31

Significance levels are shown in brackets.

Table S4 Significance Levels of Analysis of Variance of Questionnaire Responses

Questionnaire Variable	P	T
Hurt	0.041	
Body	0.033	0.100
Touch	0.031	
Cloth	0.0003	