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Video Ergo Sum: Manipulating Bodily Self-Consciousness

Bigna Lenggenhager *et al.*

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A fraction of dynamic loci (178 loci, table S2) show species-specific differences, whereat the conserved gene pair was interrupted in the three strains of one species by genes absent from the three strains of the other species. These loci would include sites whereat differences arose while the *Escherichia* and *Salmonella* lineages were diverging. Other dynamic loci (e.g., those where only a single strain shows a difference) would have arisen only after recombination had effectively ceased between the two lineages. Genes adjacent to species-specific loci are 6.2% older than genes adjacent to other dynamic loci ($P < 10^{-2}$ by randomization; gray bars in Fig. 3); thus, species-specific genes are not randomly distributed but are found preferentially in the older regions, indicating that the incipient *Escherichia* and *Salmonella* lineages continued to participate in recombination at loci unlinked to lineage-specific genes.

In contrast to the rapid formation of eukaryotic species boundaries, the ~70-My time frame over which genetic isolation evolved between *Escherichia* and *Salmonella* represents a temporal fragmentation of speciation. Because separate lineages arise within populations that continue to recombine at some loci for tens of millions of years, relationships among species inferred from few loci may underestimate their underlying complexity. Taxa may show different relationships depending on the genes compared. Long periods of partial genetic isolation allow extant, named species (such as *E. coli*) to contain multiple nascent species. Although one can observe recombination at some genes within *E. coli* as a whole, strains also have niche-specific loci that may act as genetic progenitors for the creation of new species. That is, it may not possible to make a clear distinction between intraspecific and interspecific variability (*26*), and clearly defined species cannot represent newly formed lineages. Therefore, the species concept proposed by Dykhuizen and Green [in which gene phylogenies are congruent among representatives of different species but are incongruent among members of the same species (*5*)] works to delineate long-established species but fails to recognize incipient species.

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Video Ergo Sum: Manipulating Bodily Self-Consciousness

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Humans normally experience the conscious self as localized within their bodily borders. This spatial unity may break down in certain neurological conditions such as out-of-body experiences, leading to a striking disturbance of bodily self-consciousness. On the basis of these clinical data, we designed an experiment that uses conflicting visual-somatosensory input in virtual reality to disrupt the spatial unity between the self and the body. We found that during multisensory conflict, participants felt as if a virtual body seen in front of them was their own body and mislocalized themselves toward the virtual body, to a position outside their bodily borders. Our results indicate that spatial unity and bodily self-consciousness can be studied experimentally and are based on multisensory and cognitive processing of bodily information.

Ever since William James categorized different aspects of self-consciousness at the end of the 19th century, these aspects have been continuously refined and expanded, including many different sensory, emotional, or cognitive layers. This has led to an excess of definitions, in the absence of a widely accepted model of self-consciousness that is based on empirical neurobiological data (*1*). More recent philosophical and neurological theories converge on the relevance of bodily self-consciousness (i.e., the nonconceptual and prereflective processing and representation of body-related information) as one promising approach for the development of a comprehensive neurobiological model of self-consciousness (*1*–*4*).

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We investigated bodily self-consciousness experimentally, and we now describe an illusion during which healthy participants experienced a virtual body as if it were their own and localized their "selves" outside of their body borders at a different position in space. We modified the so-called "rubber-hand illusion" (RHI), during which synchronous stroking of a seen fake hand and one's own unseen hand causes the fake hand to be attributed to one's body (to "feel like it is my hand"; misattribution). Under such conditions of multisensory conflict, vision typically dominates over proprioception and touch (*5*). Several studies have demonstrated that the RHI also induces a mislocalization of one's hand toward the fake hand, which is often referred to as "proprioceptive drift" (*6*–*8*). Brain-imaging studies associated the RHI mainly with the activation of the multisensory premotor cortex, posterior parietal areas (*7*), and right posterior insula (*9*); these areas have also been implicated in the integration of visual and somatosensory signals in nonhuman primates (*10*). These experimental findings corroborate anecdotal clinical data in neurological patients with right temporo-parietal damage leading to somatoparaphrenia, during which patients misattribute their own hand or foot as belonging to another person (*11*). The data on the RHI shows that important subglobal aspects of bodily experience, such as self-attribution and self-localization of body parts, can be manipulated experimentally (*12*).

Yet, the fundamental sense of selfhood (*2*, *13*, *14*) that is associated with bodily self-consciousness (but not with cognitive or emotional layers of self-consciousness) is experienced as the transparent content of a single, coherent whole-body representation, rather than as multiple representations of separate body parts. Accordingly, the latter have been referred to as the sense of body-part ownership, whereas whole-body representations or global ownership are directly associated with the sense of selfhood (*2*). Studies on the RHI and somatoparaphrenia thus investigated only body-part ownership or the attribution and localization of a body part with respect to the global bodily self; i.e., a part-to-whole relationship. Thus, these studies did not experimentally manipulate selfhood per se.

To manipulate attribution and localization of the entire body and to study selfhood, we designed an experiment based on clinical data in neurological patients with out-of-body experiences. These data suggest that the spatial unity between self and body may be disrupted (*15*–*17*), leading in some cases to the striking experience that the global self is localized at an extracorporeal position (*15*, *17*). The aim of the present experiments was to induce out-of-body experiences in healthy participants to investigate selfhood. We hypothesized that, under adequate experimental conditions, participants would experience a visually presented body as if it were their own, inducing a drift of the subjectively experienced bodily self to a position outside one's bodily borders. Evidence for this conjecture stems not just from out-of-body experiences, but also from early anecdotal mirror-induced whole-body illusions (*18*) and the phenomenon of "presence" in virtual-reality environments (*19*, *20*).

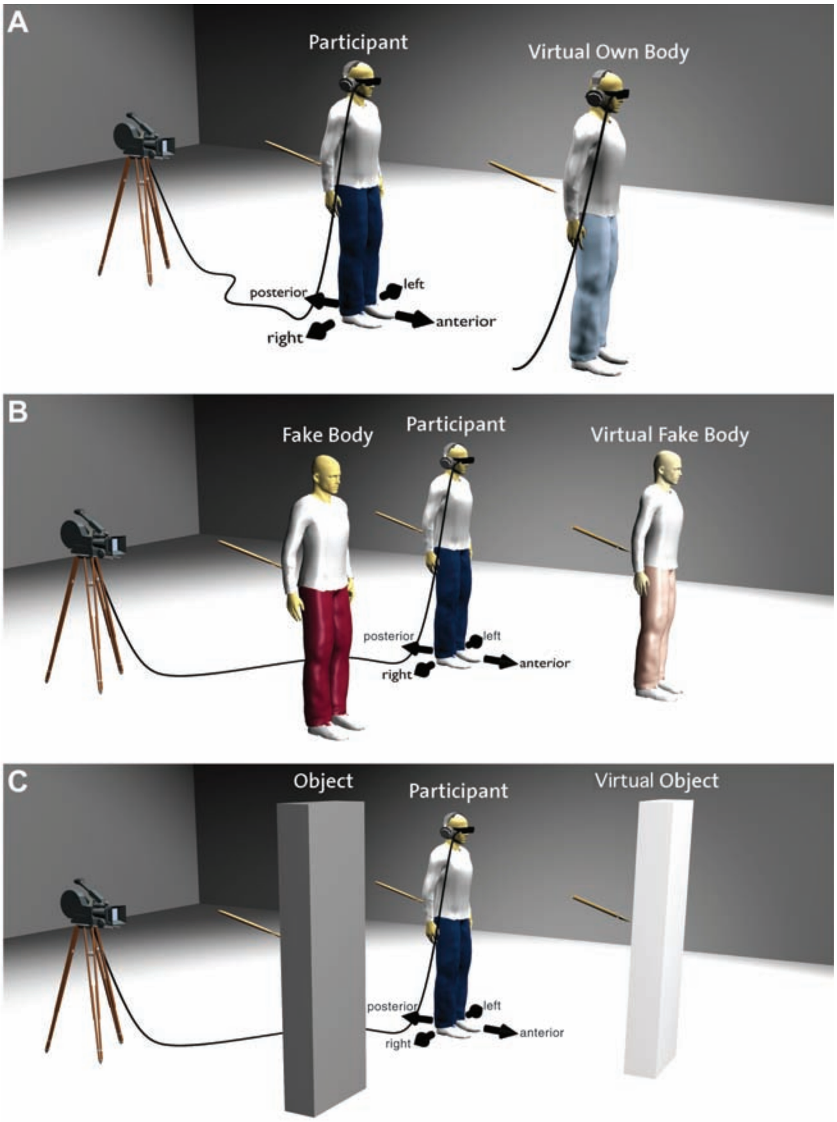

Fig. 1. (**A**) Participant (dark blue trousers) sees through a HMD his own virtual body (light blue trousers) in 3D, standing 2 m in front of him and being stroked synchronously or asynchronously at the participant's back. In other conditions (study II), the participant sees either (**B**) a virtual fake body (light red trousers) or (**C**) a virtual noncorporeal object (light gray) being stroked synchronously or asynchronously at the back. Dark colors indicate the actual location of the physical body or object, whereas light colors represent the virtual body or object seen on the HMD. [Illustration by M. Boyer]

We applied virtual reality to examine the possible induction of out-of-body experiences by using multisensory conflict. In the first experiment, participants viewed the backs of their bodies filmed from a distance of 2 m and projected onto a three-dimensional (3D)–video head-mounted display (HMD) (Fig. 1A). The participants' backs were stroked for 1 min, either synchronously or asynchronously with respect to the virtually seen body. Global self-attribution of the virtual character was measured by a questionnaire that was adapted from the RHI (*6*). Global self-localization was measured by passively displacing the blind-folded participants immediately after the stroking and asking them to return to their initial position (*21*).

As predicted, participants showed a drift toward the virtual body (anterior-posterior axis) in the synchronous condition [24.1 ± 9.0 cm (mean ± SEM)]. This position differed significantly from the initial position (P = 0.02, Student's t test = 2.67) (*21*). In the asynchronous condition, the drift was smaller (12. ± 8.5 cm) and no longer significant (P = 0.17, t = 1.45) (Fig. 2A). No significant drift was measured along the left-to-right axis (fig. S1). Global illusory self-localization was corroborated by high–self-attribution scores on the three relevant questionnaire items (Q1 to Q3) (*21*) also showing significant differences between synchronous and asynchronous conditions (all P values < 0.001) (Fig. 2B). Participants reported varied feelings of "weirdness" or "strangeness," and some found the experiment irritating. None of the participants reported sensations of overt disembodiment or a change in visuospatial perspective.

In a second study, we examined whether this illusion depends on cognitive knowledge about bodies and whether the drift toward the virtual body was not due to a general motor bias to overshoot the target position. With the use of a constant time delay in asynchronous conditions, we either presented the participant's own body (as in study I) (Fig. 1A), a fake body (Fig. 1B), or an object (Fig. 1C) being stroked synchronously or not. Compared to a motor-control condition [no visual scene was shown (*21*)], we found a significant drift toward the virtual own body (P = 0.02, t = 2.78) and the fake body (P = 0.01, t = 3.02) (*21*). This drift was weaker and no longer significant in the case with a noncorporeal object (P = 0.07, t = 1.95) and absent when the stroking was asynchronous (all P values > 0.11) (Fig. 3). There was no drift in further control conditions or for the left-to-right axis (*21*). Yet, self-attribution differed between the bodily conditions and the object condition. The first two questions of the questionnaire (Q1 and Q2) were answered positively in all of the synchronous conditions (own body, fake body, and object) and were significantly different and answered negatively in the asynchronous conditions ($P < 0.01$, $t > 2.56$). However, the third question (Q3: "It felt as if the virtual character was my body") led to different results. Whereas in both bodily conditions (own body and fake body) the result was the same as in Q1 and Q2 ($P < 0.05$, $t > 2.40$), this was not the case in the object condition where participants gave negative scores in the synchronous condition, revealing no significant difference between synchronous and asynchronous stroking ($P > 0.05$, $t = 1.55$) (fig. S2). This suggests that Q3 is important to evaluate self-identification with virtual bodily and nonbodily characters, whereas the first two questions seem more related to the feeling and location of touch.

With the use of virtual reality and multisensory conflict, we induced an illusion that makes it possible to quantify selfhood by manipulating attribution and localization of the entire body. Our results show that humans systematically experience a virtual body as if it were their own when visually presented in their anterior extrapersonal space and stroked synchronously. This finding was corroborated by the participants' mislocalization of their own bodies to a position outside their bodies, showing that self-attribution and localization of the entire body rely, at least partly, on similar visual-somatosensory integrative mechanisms to those of body parts (*6*–*8*). Although research of visual-somatosensory integration has mostly investigated directly visible body parts, comparable interactions have also been found for body parts that humans cannot see directly, such as the back (*22*). The overall pattern of the data from studies I and II suggests that, under appropriate conditions of multisensory conflict between visual signals conveying information about a virtual body (on a HMD) and tactile, proprioceptive, and vestibular signals conveying information from the participant's body, visual capture is still present. There were also differences between both studies. Asynchrony in study II was more predictable (*21*), and the relation between felt and seen events might have been perceived as stronger, leading to larger drifts in the asynchronous conditions in study II. This might have led to the diminished effect of synchrony on the drift in the own-body condition, which is compatible with higher questionnaire scores for the asynchronous conditions from study II as compared with those from study I (Q1 to Q3) (Fig. 2C and fig. S2A) (*21*).

By manipulating visual input in the RHI, controversial data have been reported concerning the influence of cognitive constraints on multisensory integration, self-localization, and self-attribution. Whereas some authors argue that multisensory correlation is a sufficient condition for self-attribution (*23*), others argue for additional cognitive constraints in terms of higher-level knowledge about the body (*8*). We found evidence for higher-level knowledge by revealing in study II a weaker drift toward the object as compared with the fake-body condition, as well as a selective effect of synchrony in the fake-body condition. Because the fake-body and object conditions are completely comparable concerning the experimental setup (*21*), and given the pattern of results, we suggest that in order to investigate the influence of cognitive knowledge on self-localization, the comparison between the fake-body and object conditions is more relevant than that between the own-body and object conditions. These effects on illusory self-localization were corroborated by illusory self-attribution. When asked whether it felt as if the virtual character or object was their body (Q3), participants self-identified with both bodily stimuli but not with the object during synchronous stroking. Collectively, these findings speak in favor of bottom-up mechanisms as well as cognitive constraint (*8*), rejecting a pure Bayesian account (*23*) for self-attribution and self-localization of the entire body.

Illusory self-localization to a position outside one's body shows that bodily self-consciousness and selfhood can be dissociated from one's physical body position. This finding differs from the RHI, in which this aspect of selfhood remained constant and only the attribution and localization of the stimulated hand was manipulated. Does illusory self-localization to a position outside one's body mean that we have experimentally induced full-blown out-of-body experiences? Out-of-body experiences are characterized by a disembodiment of the self to an extracorporeal location, an extracorporeal visuospatial perspective, and the sight of one's own body from this self-location. Because the present illusion was neither associated with overt disembodiment nor with a change in visuospatial perspective, we argue that we have induced only some aspects of out-of-body experiences or rather the closely related experience of heautoscopy that has also been observed in neurological patients (*15*–*17*). During heautoscopy, patients either constantly or intermittently experience as if they were seeing from and were localized at the position of an illusory body, their physical body, or at an intermediate position (*15*, *24*). Such patients may also see themselves from behind (*17*) and often identify with the illusory body and partly transfer selfhood to the illusory body, even if visual bodily detail is lacking (*17*). Yet, they never report the overt disembodiment that is the most characteristic feature of out-of-body experiences (*25*, *26*). Because our healthy participants did not report feelings of overt disembodiment, the present data suggest that other mechanisms in addition to conflicting visual-somatosensory information, such as visual-vestibular disintegration, are involved in generating full-blown out-of-body experiences and a more complete transfer of selfhood to an illusory body. These findings are compatible with clinical data (*15*, *17*). Damage to or electrical stimulation of the temporo-parietal junction may lead to out-of-body experiences and heautoscopy (*15*, *27*), and healthy participants activate the same region when employing extracorporeal self-locations in mental imagery (*28*, *29*). Although other important aspects of self-consciousness are likely to involve additional brain areas such as the amygdala and the right frontal cortex (*3*) as well as multisensory areas in premotor and parietal cortices [representing both

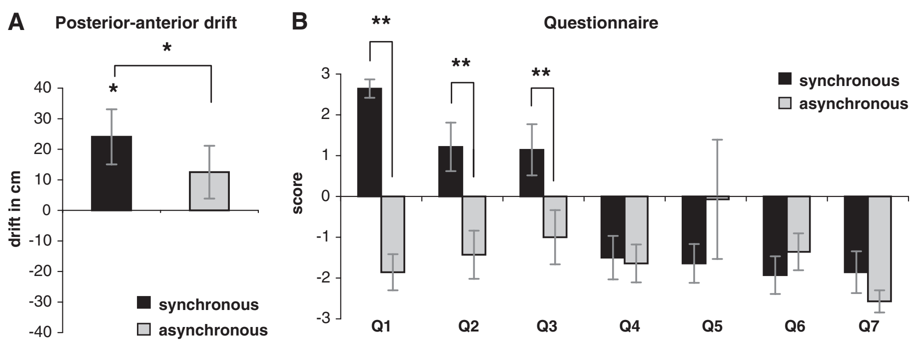

Fig. 2. (**A**) Drift measured in centimeters [mean ± SEM (error bars)] in the synchronous (black) and asynchronous stroking conditions (gray) on the posterior-anterior axis. Participants showed a significantly stronger drift in the direction of the virtual body in the synchronous condition. *$P < 0.05$. (**B**) Score (mean ± SEM) on the "self-attribution questionnaire" as adapted from (*6*). **$P < 0.01$.

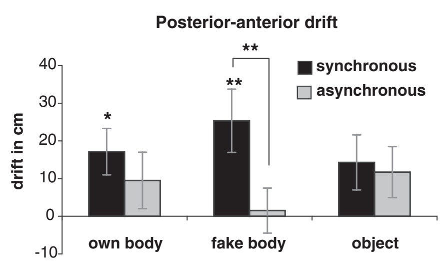

Fig. 3. Drift measured in centimeters, relative to the pure motor-control condition [mean ± SEM (error bars)] in the synchronous (black) and asynchronous stroking conditions (gray) for the different experiments: own body, object, and fake body. Only posterior-anterior drift is shown. *$P < 0.05$, **$P < 0.01$.

the seen and felt positions of one's arm (*10*) and correlating with the RHI (*7*)], we speculate that humans' daily experience of an embodied self and selfhood, as well as the illusion reported here, relies on brain mechanisms at the temporo-parietal junction. Experimentally creating illusions of the globalized, multisensory awareness of selfhood in a controlled manner with virtual-reality technology opens a new avenue for the investigation of the neurobiological, functional, and representational aspects of embodied self-consciousness. Further research should include the entire spectrum of disturbed global own-body perceptions, ranging from autoscopic hallucinations and heautoscopy to full-blown disembodied states such as out-of-body experiences.

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Supporting Online Material

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Material and methods

Fourteen participants (mean age 23.1 years ± 4.4SEM, 9 women) participated in Study I. An independent group of 14 participants (mean age 24.8years ± 5.1SEM, 7 women) took part in Study II. All participants were right-handed and had no history of neurological or psychiatric disorders. Participants were naïve to the purpose of the study and gave written informed consent. The study protocol was approved by the local ethics research committee at the University of Lausanne, Switzerland and has been performed in accordance with the ethical standards laid down in the Declaration of Helsinki.

Experimental set-up and procedure

Study I

Participants were wearing a white t-shirt and standing upright with their back facing a video camera (JVC 5 Mega Pixel Digital Media Video Camera). A Virtual FX 3D converter (I-O Display Systems) converted the standard 2D video image into a true, holographic-like 3D projection. The camera was placed on a tripod stand, two meters behind the participants. The back of the participants was filmed while it was irregularly stroked with a large orange pen. The video was projected real time onto a head mounted display (HMD; i-glasses Video 3D Pro; Resolution 800x600, horizontal field of view 25.6°, vertical field of view 17.1°) which enabled the participants to view the interlaced 3D video in stereoscopic 3D. The HMD was covered by black tissue occluding all surrounding visual input. Participants listened to white noise presented through headphones to exclude surrounding auditory input that could have given additional cues about the location of the stroking or the own body in space.

Accordingly, participants felt the stroking during 60 seconds on their back while seeing their own virtual back being stroked at a distance of 2m in front of them (virtual own body; Fig.1A). After the stroking the video was turned off and subjects were instructed to do small-size steps as if they were walking on a treadmill. Simultaneously they were guided slowly backwards by the experimenter (resulting step-size ~20cm). Then the subjects were asked to walk with normal-sized steps back to the initial position.

After completion of a training session to familiarize participants with the exact procedure and the displacement, participants carried out two different experimental conditions: in the synchronous condition the video signal was projected in real time to the HMD so that visual and the somatosensory signals were perfectly synchronised. In the asynchronous condition the video signal that had been recorded in the training session was re-played to the HMD while the participant was stroked such that visual and somatosensory input were not synchronized.

Two measures that have previously been used to quantify the degree of the rubber hand illusion (RHI) were adapted. After each condition we measured the distance between the actual position during the stroking and the position indicated by the participant (drift in cm; self-localization). We also used a 7-item questionnaire (score between -3 and 3) modified from the "RHI questionnaire" (*S1*) to measure the degree of self-attribution of the virtual character. The questionnaire contained the following questions:

During the experiment there were times when…

Q1 It seemed as if I were feeling the touch of the highlighter in the location where I saw the virtual body/ mannequin/ object touched.

Q2 It seemed as though the touch I felt was caused by the highlighter touching the virtual body/ mannequin/ object.

Q3 It felt as if the virtual body/ mannequin/ object was my body.

Q4 It felt as if my (real) body was drifting towards the front (towards the virtual body/ mannequin/ object).

Q5 It seemed as if I might have had more than one body.

Q6 It seemed as if the touch I was feeling came from somewhere between my own body and the virtual body/ mannequin/ object.

Q7 It appeared (visually) as if the virtual body/ mannequin/ object were drifting backwards (towards the real body).

Study II

As in Study I participants were placed in front of the camera and saw their body being stroked either synchronously or asynchronously in the HMD ("own body" condition; Fig.1A). In the other conditions participants were again placed 2m in front of the camera, but shifted ~1.5m to the left (outside the visual field of the camera). Instead of their own back, we projected either a video of the back of a human-size fake body (mannequin) wearing a white t-shirt ("fake body" condition, Fig.1B) or the back of a white human-size rectangular object ("object" condition, Fig.1C), stroked synchronously or asynchronously, to the HMD. All conditions were randomized between participants. For asynchronous stimulation we now used a delaying device (Delay Line Time, Ovation Systems, UK) to induce a systematic time lag of 200ms to the video signal before projecting it onto the HMD. The time-lag was chosen according to the results of Franck and colleagues (*S2*) who showed that with a delay of 200ms healthy participants can clearly discriminate between their movement and the visual feedback. The use of a delay allowed a randomised presentation of the conditions without the need for a pre-recorded session. We also measured data in an additional "empty room" condition where participants felt the stroking on their back while seeing the same visual scene but without any body or object in it. In a further condition ("motor control" condition) the drift was measured after having displaced the participants with eyes closed without any prior visual input or stroking.

Data acquisition and processing

The scores on the modified RHI-questionnaire as well as the drift were analysed using repeated-measures analyses of variance (ANOVAs) and t-tests. In Study I the drift was calculated relative to the initial position (=0) while in Study II it was measured relative to the motor control condition by subtracting it for each condition and participant separately. One-sample t-tests were made to compare the drifts to the corresponding baseline (Study I: initial position during stroking, Study II: motor control condition). Results were considered statistically significant for $p<0.05$.
Additionally ANOVAs were done for results of both the drift and the questionnaires (see supporting online text). For the drift we used the within-factors Synchrony (synchronous / asynchronous), the within-factor Axis (anterior-posterior / left-right) and the within-factor Condition (own body/fake body/object). For the results of the questionnaire we added the within-factor Question (Q1-Q7). Paired and two-tailed t-tests were used to further analyse the significant effects on the ANOVAs.

Supporting Text

Supplementary results Study I

Self-localization
In the synchronous condition participants showed on the anterior-posterior axis a mean drift of 24.1cm (±9.0SEM) towards the virtual body. This position differed significantly from the initial position ($p=0.02$ $t=2.67$; one sample t-test). As predicted, the drift to the front was smaller in the asynchronous condition (12.5cm ±8.5) and did not deviate significantly from the participants' initial position ($p=0.17$, $t=1.45$; one sample t-test). Also, no significant drift (synchronous $p=0.59$, $t= 0.55$; asynchronous $p=0.69$, $t= 0.41$; one sample t-tests) was observed along the left-right axis (synchronous 3.5cm ± 6.2; asynchronous 2.2cm ±5.7).

A 2x2 repeated measures ANOVA with the within factors Synchrony (synchronous, asynchronous) and Direction (anterior-posterior, left-right) revealed a significant main effect of Synchrony ($p=0.02$, $F=6.67$). With respect to the anterior-posterior axis, paired t-tests revealed a significantly stronger drift towards the virtual body in the synchronous condition compared to the asynchronous condition ($p=0.01$, $t =2.92$; Fig. 2A). No such difference was found on the lateral axis ($p=0.75$, $t=0.52$; fig. S1A).

Self-attribution
In the synchronous condition, participants scored positively (on a scale from -3 to 3) in the first three questions: Q1: 2.6 ±0.8SEM; Q2: 2.2 ±0.6SEM; Q3: 2.1 ±0.6SEM. All other questions and all questions after asynchronous stroking were answered negatively (Fig. 2B).
A 2x2 repeated measures ANOVA with the within factors Synchrony (synchronous, asynchronous) and Question (Q1-Q7) revealed a significant main effect of Synchrony

(p=0.003, F=12.83), a significant main effect of Questions (p=0.001, F=4.31) and a significant interaction (p=0.0001, F=8.64). Paired t-test showed in the positively answered questions (Q1-Q3) a significantly higher rating in the synchronous condition than in the asynchronous condition (p<0.01, t<3.24).

Supplementary results Study II

Self-localization

Compared to the motor control condition we found a mean drift towards the virtual own body of 17.1cm (±6.1SEM) and towards the virtual fake body of 25.4cm (±8.4SEM) in the posterior-anterior axis when participants were stroked synchronously. Using one sample t-tests both drifts differed significantly from the motor control condition (own body: p=0.02 t=2.78; fake body: p=0.01, t=3.02). The drift was weaker (14.3cm ±7.3SEM) and no longer significant (p=0.07, t=1.95) when a non-corporeal object was used (Fig.3A). When using a room without any object in it, no drift was found (1.12cm±5.7SEM, p=0.83 t=0.21). Asynchronous stroking did not lead to any significant anterior drift in any of the conditions (drift between 1.5cm and 11.7cm, p>0.10; Fig.3A,). In the left-right axis the measured drifts varied between 0.1 and 8.5cm and we did not find any significant drift compared to the control condition (fig. S1B).

In the posterior-anterior axis the 2x3 ANOVA with the within-factors Synchrony and Condition revealed a significant interaction effect (p=0.04, F=3.70). Further, paired t-tests revealed that only the fake body condition showed a significant difference between synchronous and asynchronous conditions (p=0.0004, t=4.70, Fig. 3A) and that in the synchronous conditions only the fake body and the object differed significantly (p=0.04, t=2.26) whereas the asynchronous conditions did not differ between own body, fake body and object (p>0.05, t<1.41). In the left-right axis no such interaction was found (fig. S1B). As fake body and object condition are completely comparable concerning the experimental set-up (filming of the own body may lead to visual feedback of small bodily movements that are absent in fake body and object conditions) we suggest that the comparison between object and fake body conditions is most relevant for studying the influence of cognitive knowledge about bodies in illusory self location. In addition, similar conditions to the fake body and object condition have also been tested in the RHI (Tsakiris and Haggard, 2005).

Self-attribution

Results on the modified RHI-questionnaire were similar to those of to study I. The first (virtual body: 2.5 ±0.3SEM, mannequin: 2.2 ±0.3SEM, object: 2.6 ±0.2SEM) and the second questions (virtual body 1.4 ±0.4SEM, mannequin 1.6 ±0.5SEM, object 1.9 ±0.4SEM) were answered positively in all synchronous conditions and negatively in the asynchronous condition. Yet, the third question (Q3; "I felt as if the virtual body/object/mannequin was my real body") lead to different results. Whereas in both conditions with bodily characters (own body: 2.1 ±0.5SEM; fake body: 0.6 ±0.6SEM) the result was the same as in Q1 and Q2, this was not the case in the object condition where subjects gave negative scores even in the synchronous condition (-0.4 ±0.6SEM) revealing no significant difference between synchronous and asynchronous stroking. In the asynchronous condition all questions were rated negatively (fig. S2). These data suggest that the first two questions seem more related to the feeling and location of touch, whereas the third question asks about identification with the virtual character. We suggest that when an object is shown, subjects feel the touch outside their body, but do not experience the virtual character as if it were their own.

A 2x3 ANOVA showed a significant main effect of Synchrony ($p<0.01$, $F>43.46$), Question ($p<0.001$, $F>25.25$) and interaction of Synchrony and Question ($p<0.001$, $F>7.65$). Paired t-tests revealed significant differences between synchronous and asynchronous conditions for the bodily characters in the first three questions (fig. S2, table S 1).

Corroborating results from Study I participants showed stronger errors in self-localization and self-attribution in the synchronous conditions, particularly when a bodily object was used. Although the direct comparison between the synchronous and the asynchronous conditions revealed a significant difference only for the fake but not the own body condition, both synchronous conditions using a bodily character led to significantly larger drifts with respect to the motor control condition. This was supported by higher self-attribution scores when asked whether "it felt as if the virtual character/mannequin was my body" (Q3) in both conditions employing a bodily stimulus. Furthermore, we could extend our findings from Study I by showing that illusory self-localization to a position outside the physical body is stronger when bodily character is stroked than when a non-corporeal character is stroked. The empty room condition and the motor control condition also allowed us to exclude that these effects on self-localization are due to a motor bias characterized by a general tendency to overshoot the target position. Indeed in these conditions the drift was negative. The differences between the synchronous and asynchronous conditions were smaller in Study II compared to Study I. A potential reason could be the different method of achieving asynchronous stimulation in the two studies. In Study I stimulation was completely random, whereas in Study II we used a constant time lag leading to a situation with more predictable visual input. The asynchronous condition of Study II was for the subjects thus more predictable and the relation between the felt and the seen event might have been perceived as stronger leading to larger drifts. This is also suggested by the questionnaire scores in Study I and II: Comparing Fig 2C with Fig. S2A subjects indicated higher self-attribution Q 3) and a stronger feeling of the touch on the virtual body (Q2, Q3) in the asynchronous condition of Study II than of Study I.

Supporting figures

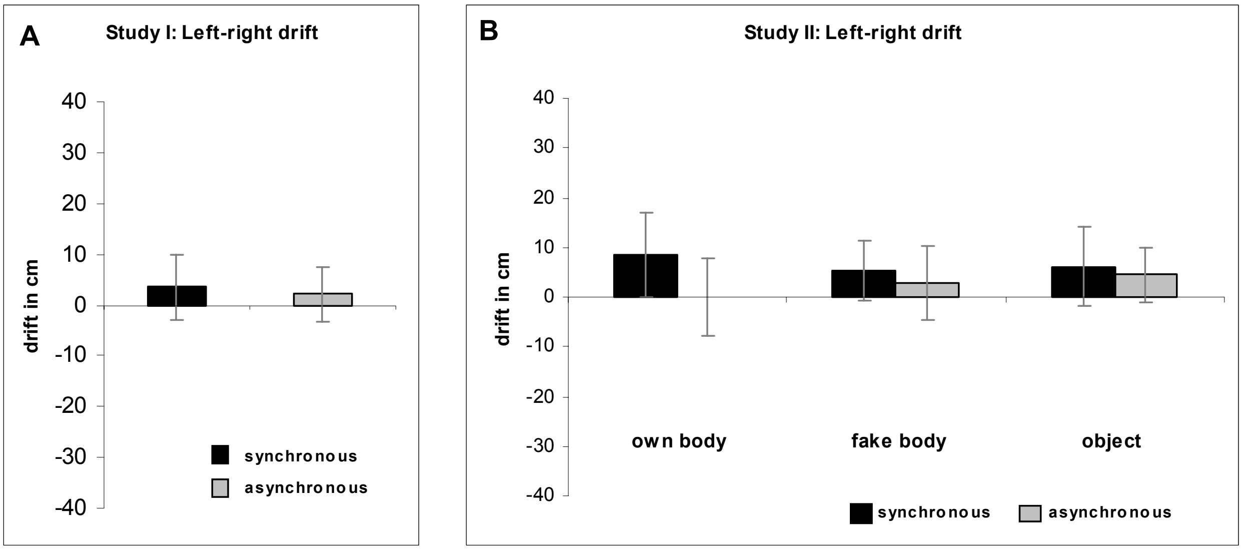

Figure S1: Data from Study I (A) and II (B). Drift on the left-right axis measured in cm [mean ±SEM] in the synchronous (black) and in the asynchronous stroking condition (gray): no significant effects were found. Positive values correspond to rightward deviations, negative values to leftward deviation.

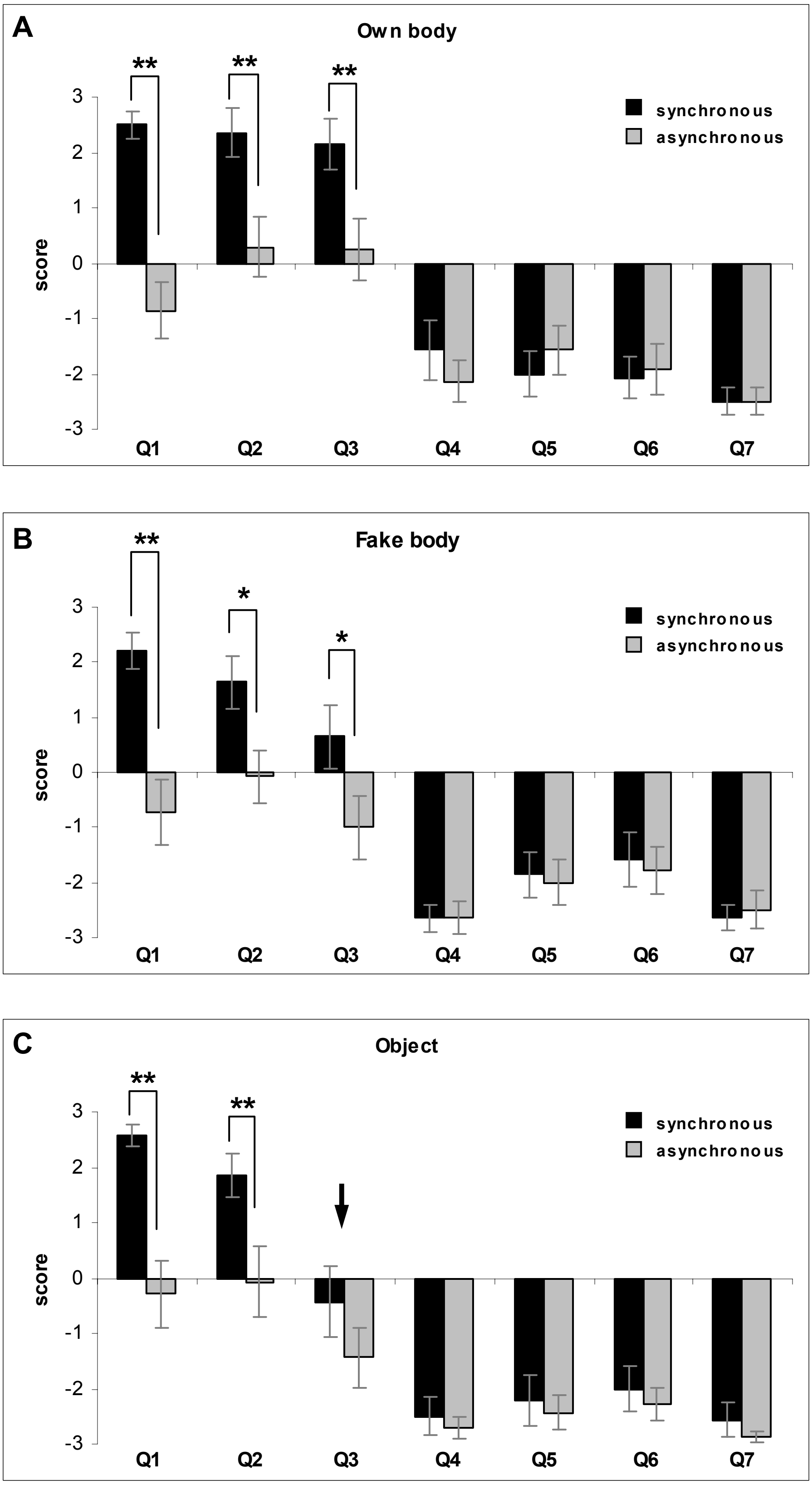

Figure S2: Data from Study II. Mean scores [±SEM] of self-attribution measured by questionnaire in the different conditions: (A) own body, (B) fake body, and (C) object. Self-identification (Q3; indicated by arrow) is stronger for bodily characters than for an object. Q1-Q7 refer to the different questions, compare text).

Supporting Table

	Own body		Fake body		Object	
	p-value	t-value	p-value	t-value	p-value	t-value
Question 1	0.0001	5.5	0.001	4.01	0.006	4.49
Question 2	0.01	2.56	0.017	2.70	0.009	3.09
Question 3	0.001	4.16	0.032	2.56	n.s.	1.55

Table S 1: T-tests for the interaction effect between Question and Synchrony. P- and t-values for the paired t-test between the score in the first three questions for the synchronous and the asynchronous conditions in the own body, the fake body and the object condition.

Supporting references

1. M. Botvinick, J. Cohen, *Nature* **391**, 756 (1998).
2. N. Franck *et al.*, *Am. J. Psychiatry* **158**, 454 (2001).
3. M. Tsakiris, P. Haggard, *J. Exp. Psychol. Hum. Percept. Perform.* **31**, 80 (2005).