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Selective distortion of body image by asynchronous visuotactile stimulation

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ABSTRACT

In the rubber hand illusion (RHI), a rubber hand is felt as being part of one's body. This illusion is evoked by providing synchronous visuotactile stimulation to the fake and real hands. Asynchronous visuotactile stimulation is known not to produce such an illusion of ownership, being commonly used as the control condition. Here we explored the impact of synchronous and asynchronous visuotactile stimulation on the body image. We combined the induction of the RHI with a quantitative test for the internal representation of body metrics (i.e., the positions of key fiducial points on the body relative to each other). We found a significant recalibration of the upper/lower arm lengths following asynchronous visuotactile stimulation. In particular, we observed a selective elongation of the lower arm, a distortion typical of deafferentation. Conversely, synchronous visuotactile stimulation did not alter the estimation of the arm segments' length. Our findings are consistent with a dynamic internal representation of body image that is continuously updated based on incoming multisensory information. Furthermore, the use of asynchronous multisensory stimulation as a neutral condition should be reconsidered since it introduces changes in the body image.

1. Introduction

The perceptual representation of one's own body (i.e., body image) can be altered by several clinical conditions (Flannery & Faria, 1999) and by experimental manipulations (Botvinick & Cohen, 1998), inducing illusory body experiences. For example, in the case of clinical conditions, the amputation of a limb often leads to the perception of a phantom limb, with the person often feeling pain in the area from which the limb has been amputated. This phantom limb becomes progressively shorter, a phenomenon called "telescoping" (Ramachandran & Hirstein, 1998). In contrast, when a body part is deafferented (deprived of sensory input), for example by local anaesthesia, the feeling of an increased size of that body part often occurs (Gandevia & Phegan, 1999; Paqueron et al., 2003). Such an effect has also been observed in patients with spinal cord injury that perceived their torso and limbs elongated (Fuentes, Longo, & Haggard, 2013).

In the case of experimental manipulations, illusory body experiences can be artificially induced by providing altered multisensory inputs to the brain. In the well-known rubber hand illusion (RHI), both a fake hand and the real hand of the participant receive synchronous tactile stimulation while the real hand is kept out of view. Under these conditions, participants feel on their hand the stimulation that they see on the fake one, leading to an illusion of "owning" the fake hand (ownership), together with a feeling of touch on the fake hand (referral of touch) (Botvinick & Cohen, 1998; Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2008). Such hand illusions can be induced in patients with amputations and can also extend to other body parts. For example, Ehrsson and colleagues artificially reversed the telescoping phenomenon (i.e., the perceived shrinkage of the phantom limb) in upper limb amputees by means of the RHI, with patients feeling the "owned" hand in the original spatial location where the intact hand used to be, and not in the stump (Ehrsson et al., 2008; Schmalzl et al., 2011). The same authors used a full-body illusion to induce the sensation of a telescoped limb in healthy individuals (Schmalzl & Ehrsson, 2011). A similar telescoping effect can be induced by simultaneous vibration of antagonistic muscles, which generates a proprioceptive conflict leading to the perception of body part shrinkage (Longo, Kammers,

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Gomi, Tsakiris, & Haggard, 2009). By means of congruent visuotactile stimulation, a virtual arm could be felt as one's own and then elongated up to three times while the illusion of ownership hardly decayed (Kilteni, Normand, Sanchez-Vives, & Slater, 2012). These studies show that our body image can be easily manipulated by illusory body experiences and that these illusory experiences may prove useful in clinical settings.

While most RHI experiments use synchronous stimulation of the fake and the real hands, it is not yet known whether and how asynchronous stimulation (often used as the control) may affect body image. A hint that asynchronous stimulation may affect body image comes from a set of rare sensations of "experiencing the hand being less vivid than normal", probably created by the intersensory conflict in the asynchronous condition and described under the umbrella term "deafference" (Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008). This sensation has been reported in healthy participants during asynchronous visuotactile stimulation (Longo et al., 2008), and is similar to that reported in amputees with body image alterations (Gandevia & Phegan, 1999; Paqueron et al., 2003). To answer the posted question, we carried out two experiments that evaluated whether synchronous or asynchronous visuotactile stimulation of a fake hand and the hand of the participant results in distortions of the body image. More specifically, we evaluated the differences in the perceived size of different body parts (i.e., body metrics) using the Body Image Task (BIT) (Fuentes et al., 2013) before and after the RHI. We hypothesized that illusory body experiences induced by synchronous and asynchronous visuotactile stimulation would differentially distort the body image. This new quantitative experimental approach might provide new insights into the mechanisms underlying illusory body experiences.

2. Methods

2.1. Participants

Twenty healthy participants (10 females, 10 males; mean ± *SD* age: 19.9 ± 2.3 years) were recruited by e-mail advertising on campus for the first experiment. Another group of 20 healthy participants (10 females, 10 males; age: 22.3 ± 2.1 years) was equally recruited for the second experiment. All participants had normal or corrected-to-normal vision, reported no history of neurological or psychological disorders and were not taking any psychotropic medication at the time of the study. Three subjects from each group were excluded from further analysis because, after outlier exclusion, no trials remained available for at least one of the limbs. Therefore, the final groups contained data from 17 subjects each. All participants were right-handed according to the Edinburgh Handedness Inventory (score > 40) (Oldfield, 1971). Upon arrival at the laboratory, they were asked to read and sign a consent form. The experiment was carried out in accordance with the regulations of the *Comité Ético de Investigación Clínica de la Corporación Sanitaria Hospital Clínic de Barcelona*. All participants were paid 5€ for their participation.

2.2. Experimental design

To determine whether synchronous or asynchronous visuotactile stimulation results in distortions of the body image, we carried out two experiments following the same procedure. In both experiments, participants sat comfortably in front of a desk. The real hands rested palm down on a table, the latter being covered with a black cloth. The real arms and hands were kept out of view, hidden behind a screen. Two rubber arms in white silk gloves were placed face down in front of the participant in place of the real ones (Fig. 1). The gap between the rubber arms and the participant's body was covered, assuring body continuity (Perez-Marcos, Sanchez-Vives, & Slater, 2011). The horizontal distance between the real and the corresponding fake hands was 20 cm (middle finger-to-middle finger distance), with the rubber arms positioned closer to the body midline. Care was taken to place the rubber arms so that they appeared to have the same length as the real arms. The two experiments were carried out in a dim room. The only light came from the ceiling, which illuminated both rubber arms equally and without shadows.

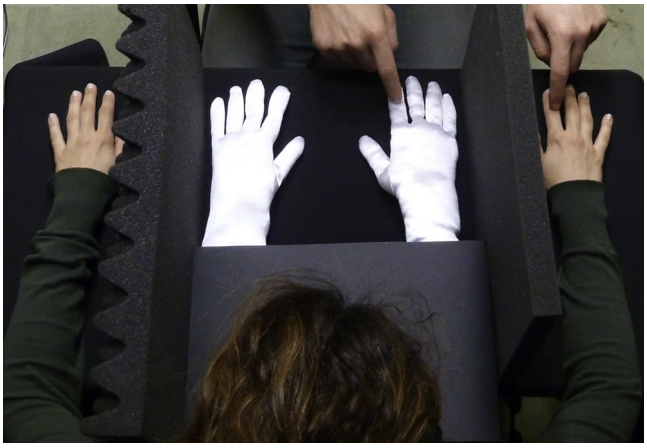

Fig. 1. Experimental rubber hand illusion (RHI) setup: All four arms (two rubber, two real) rested palm down on the table, with the rubber arms positioned closer to the body midline. Two partitions prevented direct view of one's own arms. Participants were asked to concentrate on either the left or right rubber hand where tactile stimulation (synchronous or asynchronous, depending on the condition) was delivered to both real and rubber hands of the same side. After 20 s, the complementary stimulation (asynchronous or synchronous) was delivered to the other hand. In the picture, the experimenter strokes both the real and the rubber right hands synchronously.

2.2.1. First (main) experiment

Visuotactile stimulation consisted in simultaneous tactile stimulation by the experimenter's forefingers of both the real and the rubber hands, tapping and stroking the hands in a synchronous ("S" condition) or asynchronous ("A" condition) fashion. In the synchronous condition, participants felt the tactile stimulation on their real hand (left or right, depending on the participant) while seeing the tactile stimulation only on the rubber hand of the same side, coincident in location on the hand and in time. In the asynchronous condition, the stimulation on the rubber and the real hands was not coincident in time and location, i.e., the stimulation site was mismatched on purpose, aiming for example at the little finger of the real hand while aiming at the index finger of the rubber hand. Visuotactile stimulation started either with the synchronous or the asynchronous condition (counterbalanced) on the left or right hand (counterbalanced) for 20 s, time enough to elicit the illusion (Ehrsson, Holmes, & Passingham, 2005; Lloyd, 2007). Then, the stimulation side was changed, and the opposite stimulation (asynchronous or synchronous) continued for 20 s on the other hand. Alternating stimulation has been effectively used by Tsakiris and colleagues (Tsakiris & Haggard, 2005), where they stroked one finger synchronously and the other one asynchronously. In this study, the rationale behind the alternating stimulation pattern was to induce and maintain both conditions (synchronous and asynchronous) simultaneously. Doing the visuotactile stimulation alternatively on both hands allowed the pre-test/post-test to be carried out for both conditions at the same time, enabling the fairest comparison and avoiding possible intra- and inter-session carryover effects due to the single stimulation of one side of the body. This alternating stimulation procedure was repeated twice in a continuous sequence to reinforce the illusion of ownership (or not), as we feared that the illusion could be reduced over time due to the