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7 2 **Selective Distortion of Body Image by Asynchronous**
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10 3 **Visuotactile Stimulation**
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64 1 **Selective Distortion of Body Image by Asynchronous**
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67 2 **Visuotactile Stimulation**
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71
72 4 **Abstract**
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74 In the rubber hand illusion (RHI), a rubber hand is felt as being part of one's body. This
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76 6 illusion is evoked by providing synchronous visuotactile stimulation to the fake and real hands.
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78 7 Asynchronous visuotactile stimulation is known not to produce such an illusion of ownership,
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80 8 being commonly used as the control condition. Here we explored the impact of synchronous and
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82 9 asynchronous visuotactile stimulation on the body image. We combined the induction of the
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84 10 RHI with a quantitative test for the internal representation of body metrics (i.e., the positions of
85
86 11 key fiducial points on the body relative to each other). We found a significant recalibration of
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88 12 the upper/lower arm lengths following asynchronous visuotactile stimulation. In particular, we
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90 13 observed a selective elongation of the lower arm, a distortion typical of deafferentation.
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92 14 Conversely, synchronous visuotactile stimulation did not alter the estimation of the arm
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94 15 segments' length. Our findings are consistent with a dynamic internal representation of body
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96 16 image that is continuously updated based on incoming multisensory information. Furthermore,
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98 17 the use of asynchronous multisensory stimulation as a neutral condition should be reconsidered
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100 18 since it introduces changes in the body image *per se*.

101
102 19 **Keywords:** rubber hand illusion, body image, visuotactile stimulation, multisensory
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104 20 correlations, body ownership, body representation.
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1 Introduction

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

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

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181 1 body part shrinkage (Longo, Kammers, Gomi, Tsakiris, & Haggard, 2009). By means of
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183 2 congruent visuotactile stimulation, a virtual arm could be felt-as-own and then elongated up to
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185 3 three times while the illusion of ownership hardly decayed (Kilteni, Normand, Sanchez-Vives,
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187 4 & Slater, 2012). These studies show that our body image can be easily manipulated by illusory
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189 5 body experiences and that these illusory experiences may prove useful in clinical settings.

191 6 While most RHI experiments use synchronous stimulation of the fake and the real hands,
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193 7 it is not yet known whether and how asynchronous stimulation (often used as the control) of the
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195 8 fake and the real hands may affect body image. A hint that asynchronous stimulation may affect
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197 9 body image comes from a set of rare sensations of “experiencing the hand being less vivid than
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199 10 normal”, probably created by the intersensory conflict in the asynchronous condition and
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201 11 described under the umbrella term “deafference” (Longo, Schüür, Kammers, Tsakiris, &
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203 12 Haggard, 2008). This sensation has been reported in healthy participants during asynchronous
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205 13 visuotactile stimulation (Longo et al., 2008), and that would be similar to that reported in
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207 14 amputees with body image alterations (Gandevia & Phegan, 1999; Paqueron et al., 2003). To
208
209 15 answer the posted question, we carried out two experiments that evaluated whether synchronous
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211 16 or asynchronous visuotactile stimulation of a fake and the real hands results in distortions of the
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213 17 body image. More specifically, we evaluated the differences in the perceived size of different
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215 18 body parts (i.e., body metrics) using the Body Image Task (BIT) (Fuentes et al., 2013) before
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217 19 and after the RHI. We hypothesized that illusory body experiences induced by synchronous and
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219 20 asynchronous visuotactile stimulation would differentially distort the body image. This new
220
221 21 quantitative experimental approach might provide new insights into the mechanisms underlying
222
223 22 illusory body experiences.

23 **2 Methods**

24 **2.1 Participants**

229 25 Twenty healthy participants (10 females, 10 males; mean±SD age: 19.9±2.3 years) were
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231 26 recruited by e-mail advertising on the campus for the first experiment. Another group of 20
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1 healthy participants (10 females, 10 males; age: 22.3 ± 2.1 years) was equally recruited for the
2 second experiment. All participants had normal or corrected-to-normal vision and reported no
3 history of neurological or psychological disorders and were not taking any psychotropic
4 medication at the time of the study. Three subjects from each group were excluded from further
5 analysis because, after outlier exclusion, no trials remained available for at least one of the
6 limbs. Therefore, the final groups contained data from 17 subjects each. All participants were
7 right-handed according to the Edinburgh Handedness Inventory (score >40) (Oldfield, 1971).
8 Upon arrival at the laboratory, they were asked to read and sign a consent form. The experiment
9 was carried out in accordance with the regulations of the Comité Ético de Investigación Clínica
10 de la Corporación Sanitaria Hospital Clínic de Barcelona. All participants were paid 5€ for their
11 participation.

12 **2.2 Experimental Design**

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

25 **First (main) experiment.** Visuotactile stimulation consisted of simultaneous tactile
26 stimulation by the experimenter's forefingers of both the real and the rubber hands, tapping and

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1 stroking the hands in a synchronous (“S” condition) or asynchronous (“A” condition) fashion.
2 In the synchronous condition, participants felt the tactile stimulation on their real hand (left or
3 right, depending on the participant) while seeing the tactile stimulation only on the rubber hand
4 of the same side, coincident in location on the hand and in time. In the asynchronous condition,
5 the stimulation on the rubber and the real hands was not coincident in time and location , i.e.,
6 the stimulation site was mismatched on purpose, aiming for example at the little finger of the
7 real hand while aiming at the index finger of the rubber hand. Visuotactile stimulation started
8 either with the synchronous or the asynchronous condition (counterbalanced) on the left or right
9 hand (counterbalanced) for 20 s, time enough to elicit the illusion (Ehrsson, Holmes, &
10 Passingham, 2005; Lloyd, 2007). Then, the stimulation side was changed, and the opposite
11 stimulation (asynchronous or synchronous) continued for 20 s on the other hand. Alternating
12 stimulation has been effectively used by Tsakiris and colleagues (Tsakiris & Haggard, 2005),
13 where they stroked one finger synchronously and the other one asynchronously. In this study,
14 the rationale behind the alternating stimulation pattern was to induce and maintain both
15 conditions (synchronous and asynchronous) simultaneously. Doing the visuotactile stimulation
16 alternatively on both hands had a number of advantages: it allowed the pre-test/post-test to be
17 carried out for both conditions at the same time, enabling the fairest comparison and avoiding
18 possible intra- and inter-session carry-over effects due to the single stimulation of one side of
19 the body. This alternating stimulation procedure was repeated twice in a continuous sequence to
20 reinforce the illusion of ownership (or not), as we feared that the illusion could be reduced over
21 time due to the alternation. Overall, each hand received 40 s of visuotactile stimulation in total.
22 Participants were instructed to pay attention to the rubber hand being stimulated, observing the
23 tactile stimulation performed by the experimenter.

24 **Second (control) experiment.** A previous study suggests that the mere vision of a fake
25 body part from a first-person perspective may induce the feeling of ownership of the fake body
26 part (Maselli & Slater, 2013) and that the proprioceptive effects may gradually rise with

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358 1 stimulation time (Botvinick & Cohen, 1998; Rohde, Di Luca, & Ernst, 2009). Therefore, a
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360 2 control experiment was carried out with a different group of participants in order to rule out the
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362 3 fact that only the vision of the rubber hand *per se*, without any tactile stimulation (Observational
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364 4 condition: “O”), or synchronous visuotactile stimulation for a long time (Long-lasting
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366 5 Synchronous condition: “LS”) may affect body image. In this second experiment, two rubber
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368 6 arms were placed in front of the participant. Following a similar procedure to the one described
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370 7 for the first experiment, this experiment started with one of the two conditions (O or LS,
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372 8 counterbalanced) in the left or right hand (counterbalanced), with the only difference that the
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374 9 stimulation (or just observation) time lasted for 60 s. Then the other condition was applied for
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376 10 60 s to the other hand. This procedure was repeated twice, each hand being stimulated (or just
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378 11 observed) for a total of 120 s.

380 381 **2.3 The Body Image Task (BIT)**

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383 12 Before and immediately after the RHI experiment, participants completed the BIT
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385 14 (Fuentes et al., 2013). The BIT allows for quantification of the perceived size of body parts
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387 15 within one’s body image. Compared to classical behavioural measurements of perceived hand
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389 16 position (such as proprioceptive drift), the BIT tackles different aspects of the body
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391 17 representation and seems to be specially sensitive to changes in the body metrics (Fuentes et al.,
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393 18 2013).

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395 19 Participants sat about 70 cm in front of a PC with a screen resolution of 1024x768 pixels.
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397 20 The experimenter explained the participants that they would see the outline of a head near the
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399 21 top of the screen. They were instructed to imagine that they were looking at a mirrored image of
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401 22 themselves standing with their arms at their sides; the experimenter modelled this position by
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403 23 standing with his legs slightly apart and his arms straight at sides with the palms facing the
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405 24 front. Participants were told to mentally scale the image of their body to the size of the head
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407 25 displayed on the screen. The BIT started with the name of a body part displayed on the screen
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409 26 for 3 s, followed by the head displayed at one of four random positions on the screen.

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417 1 Participants used a mouse to click on the screen where, relative to the displayed head, they
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419 2 thought the specified body part would be located on a corresponding picture of themselves.
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421 3 Participants were given 3 s to respond before the next trial began. They identified the location of
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423 4 12 body parts: left shoulder, right shoulder, left elbow, right elbow, left hand, right hand, left
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425 5 hip, right hip, left knee, right knee, left foot, and right foot. Each body part was repeated four
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427 6 times per test in a pseudo-randomized order, making a total of 48 trials. Participants completed
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429 7 a three-trial practice of the BIT before starting the pre-RHI assessment.

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431 8 During both pre- and post-RHI BIT, participants' arms and hands remained hidden from
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433 9 their view. In the post-RHI test, just after finishing the visuotactile stimulation, the rubber hands
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435 10 remained visible to the participant. During the entire experiment, participants remained seated
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437 11 and performed the BIT with their right hand.

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439 12 For both experiments, perceived body part positions in the BIT were transformed into a
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441 13 common space using a two-point registration procedure, which involved registering sets of
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443 14 coordinates by aligning two of the corresponding landmarks (Bookstein, Colchester, & Hawkes,
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445 15 1991), allowing for comparison of the relative lengths of different body parts. We were
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447 16 interested in the perceived lengths of upper and lower arms and legs before and after the RHI.
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449 17 Therefore, perceived lengths of upper and lower arms and legs were normalized by dividing the
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451 18 perceived length of each part of the arm or leg by the perceived length of the whole arm or leg,
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453 19 separately for each experimental condition and time point (i.e., before and after the RHI). This
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455 20 normalization prevented possible effects due to different drawing scales within subjects.

456 457 21 **2.4 Questionnaire**

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459 22 After completing the post-RHI BIT, participants filled in a 4-item questionnaire to assess
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461 23 the sense of body ownership (Q1 and Q2) and referral of touch (Q3 and Q4; only in those
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463 24 conditions with tactile stimulation) of the rubber hand (Botvinick & Cohen, 1998). Each
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465 25 question was scored according to a 7-point Likert Scale, 1 meaning 'totally disagree' and 7
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467 26 'totally agree'. The questions were displayed in a different random order to each participant.

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476 1 The questions were presented in Spanish but here they have been translated to English (see
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478 2 Supplementary Material for the Spanish version of the questionnaire):
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481 3 Q1. “During the experiment there were times when I felt as if the rubber left hand was my
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483 4 own left hand”.

485 5 Q2. “During the experiment there were times when I felt as if the rubber right hand was
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487 6 my own right hand”.

489 7 Q3. “Regarding the left hand, there were times when it seemed as if I were feeling the
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491 8 touch in the location of the left rubber hand”.

492 9 Q4. “Regarding the right hand, there were times when it seemed as if I were feeling the
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494 10 touch in the location of the right rubber hand”.

499 11 **2.5 Statistical Analysis**

500 12 Analyses were done with Statistica software (version 8.0, Stat-Soft Inc.). Responses in the
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502 13 BIT that were missing or reversed (i.e., left and right sides confounded) were excluded from the
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504 14 analysis (zero missing and 3.7% reversed responses were excluded in the first experiment; zero
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506 15 and 3.5% in the second experiment). Outliers were considered values beyond a participant’s
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508 16 median \pm 2*MAD (median absolute deviation); they were also excluded from the analysis (22.8%
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510 17 excluded in the first experiment; 22.2% in the second experiment).

511 18 Variables from four different body parts (upper and lower arms, and upper and lower
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513 19 legs) were calculated and coded according to the type of stimulation (S vs. A; O vs. LS). For all
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515 20 variables, normality was checked via Kolmogorov-Smirnov test. Then, for each experiment, a
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517 21 2x2 repeated measures ANOVA with factors “Time” (pre-RHI vs. post-RHI) and “Type of
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519 22 Stimulation” (“ToS”: S vs. A in the first experiment; O vs. LS in the second experiment) was
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521 23 carried out for each variable. Newman-Keuls post-hoc test was used for single comparisons.
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535 1 Scores for the questions referring to body ownership and referral of touch were compared
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537 2 separately for the first and the second experiments using a Wilcoxon matched paired-test. The
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539 3 level of significance was set at $p \leq .05$.

542 4 **3 Results**

544 5 **Body ownership and referral of touch**

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546 6 In the first experiment, the RHI was successfully induced by applying synchronous
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548 7 visuotactile stimulation. In the synchronous (S) condition, participants scored significantly
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550 8 higher in body ownership and referral of touch than they did in the asynchronous (A) condition
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552 9 (Figure 2; Body ownership (Q1-Q2): $Z = 3.52, p = .0004$; Referral of touch (Q3-Q4): $Z = 3.41,$
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554 10 $p = .0006$).

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556 11 In the second experiment, participants scored significantly higher in body ownership in
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558 12 the long-lasting synchronous (LS) condition than in the observational (O) condition (Figure 3; Z
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560 13 $= 3.23, p = .0012$). Participants also reported high levels of referral of touch in the LS condition,
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562 14 similar to the S condition of the first experiment. The results from both experiments indicate
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564 15 that synchronous visuotactile stimulation induced a stronger feeling of ownership and referral of
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566 16 touch of the fake hand than the asynchronous visuotactile and the observational conditions did.

569 18 **Body metrics (BIT)**

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571 19 Participants completed the BIT before (pre) and after (post) going through the RHI
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573 20 protocol in both experiments. Tables 1 and 2 show the perceived body part lengths for the first
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575 21 and the second experiment, respectively.

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577 22 In the first experiment, pre-RHI vs. post-RHI analysis of upper and lower arm lengths
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579 23 revealed a differential effect of the type of stimulation over time (Figure 4; “Time” x “ToS”:
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581 24 $F(1, 16) = 4.5, p = .05, \eta_p^2 = .22$). Post-hoc tests disclosed that asynchronous condition altered
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583 25 the perceived lower and upper arm lengths (Post-A vs. Pre-A: $p = .029$), while the synchronous
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585 26 condition did not ($p > .05$). In addition, the perceived lower and upper arm lengths after the

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594 1 asynchronous condition differed from the one measured after the synchronous condition (Post-A
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596 2 vs. Post-S: $p = .034$). In other words, while the synchronous visuotactile stimulation did not
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598 3 affect the successive performance at the BIT, the asynchronous stimulation resulted in a
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600 4 significant modification of the body metrics of the upper limbs. Note that lower and upper arm
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602 5 segments performed equally but in opposite directions in the statistical tests due to the
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604 6 normalization by total limb length. We did not find any significant interactions or main effects
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606 7 in the perceived length of the lower and upper legs (all $ps > .05$).
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609 9 In the second experiment, no interactions or main effects were found for the perceived
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611 10 lower and upper arm lengths (all $ps > .05$). These results suggest that neither the type of
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613 11 stimulation (observational vs. long-lasting synchronous) nor the time of the stimulation (pre vs.
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615 12 post) seem to affect the body metrics. An interaction between the two factors was found for the
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617 13 leg segments lengths (“Time” x “ToS”: $F(1, 16) = 4.6, p = .04, \eta_p^2 = .22$). However, post-hoc
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619 14 comparisons did not reveal any significant changes in body metrics for the lower limbs among
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621 15 conditions ($p > .05$). In other words, just looking at the rubber hand or being subjected to a long
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623 16 (120 s) synchronous visuotactile stimulation did not lead to any difference in body metrics.
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627 18 We also examined whether the distance between the hand and torso in the BIT shifted after the
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629 19 RHI, since a perceived relocation of the hand has been found in various versions of the RHI
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631 20 paradigm (Tsakiris & Haggard, 2005; Abdulkarim & Ehrsson, 2016). Specifically, we
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633 21 calculated the difference between the perceived x position of the hand and the averaged
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635 22 perceived x position of the shoulder and hip on the corresponding side. A value of drift was then
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637 23 calculated by subtracting this “distance between arm and body” after the RHI from the value
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639 24 before RHI. This was done for each participant, separately for the side that received
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641 25 synchronous stimulation and the side that received asynchronous stimulation. Single t-test
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643 26 revealed drifts not being different from zero for the synchronous ($p = .68$) or the asynchronous

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653 1 side ($p = .43$). A paired t-test revealed no difference in drift of the hand between synchronous
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655 2 and asynchronous sides ($p = .88$).
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658 3 **4 Discussion**

659
660 4 In the present study we explored whether synchronous and asynchronous visuotactile
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662 5 stimulation of a fake and the real hands result in distortions of the body image, in particular of
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664 6 the perceived size of the stimulated body parts.

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666 7 We found that synchronous visuotactile stimulation induced a greater sense of body
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668 8 ownership and of referral of touch of the fake hand than asynchronous stimulation did, as
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670 9 expected (Botvinick & Cohen, 1998). Merely observing the same rubber hand from a first-
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672 10 person perspective did not induce a strong illusion of ownership of the fake hand. This
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674 11 modulation is unlike full-body illusions, where the mere observation of a collocated virtual
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676 12 body induces the illusion of ownership, with no need for additional multisensory sensorimotor
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678 13 cues, and even despite asynchronous visuotactile stimulation (Maselli & Slater, 2013).

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680 14 Our measurements of body metrics using BIT showed that the RHI *per se*, i.e., executed
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682 15 in a synchronous fashion, did not influence the body metrics, i.e., the perceived length of the
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684 16 arm segments was not altered. Similarly to the synchronous condition, long-lasting synchronous
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686 17 stimulation periods and mere observation of the rubber hand (i.e., without tactile stimulation)
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688 18 did not distort the body metrics. Interestingly, the body metrics represented by the subjects after
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690 19 asynchronous stimulation included a shift in the elbow position. This shift could be due to a
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692 20 primary shortening of the upper arm and with an elongation of the lower arm. We suggest that
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694 21 the primary change is an elongation of the lower arm since the hand position is visually
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696 22 anchored by the visible position of the fake hand on the table, but the elbow and shoulder are
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698 23 outside the field of view from a first-person point of view in the position of the experiment.

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700 24 Regarding the measure used for quantification of the body metrics, the BIT may be more
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702 25 sensitive to changes in the body image than classical measurements of perceived hand position.
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704 26 Indeed, we did not observe any increase in perceived displacement of the stimulated arm
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712 1 towards the body midline in the synchronous condition compared to the asynchronous
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714 2 condition, unlike some previous studies (Botvinick & Cohen, 1998). This may be in line with
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716 3 previous studies that have found that proprioceptive drift may not be a determinant indicator of
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718 4 ownership of the fake hand after the RHI (Kammers et al., 2009; Rohde, Di Luca, & Ernst,
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720 5 2011; Abdulkarim & Ehrsson, 2016).

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722 6 Forty seconds of asynchronous, but not synchronous, stimulation were sufficient to
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724 7 induce a significant modulation in the representation of one's body size, suggesting that the
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726 8 represented body image is not stable and can be modified in a short time by specific patterns of
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728 9 multisensory stimulation. Further, we found no effect on the estimations of metrics of the legs,
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730 10 suggesting that the distortion of body image is not global, but restricted to the body part
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732 11 receiving asynchronous (incongruent) stimulation.

733 734 735 12 **4.1 Type and Time of Stimulation**

736 13 Our results show that asynchronous stimulation can have important effects on the brain
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738 14 processes underlying body image. Nevertheless, it is often used as a control condition in RHI
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740 15 and in virtual hand illusion studies (Slater et al., 2008). It is known that asynchronous
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742 16 visuotactile stimulation does not induce illusion of ownership and that it easily breaks the
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744 17 illusion of ownership induced by synchronous stimulation (Botvinick & Cohen, 1998; Makin,
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746 18 Holmes, & Ehrsson, 2008). A recent study suggests that longer stimulation time during
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748 19 visuotactile conflict (i.e., asynchronous visuotactile stimulation) may act primarily on
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750 20 proprioception, without necessarily increasing the sense of body ownership (Rohde et al., 2011).
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752 21 Finally, body ownership over fake (real or virtual) bodies can be induced even in the absence of
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754 22 any tactile stimulation (Holmes, Snijders, & Spence, 2006) if a first-person point of view of the
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756 23 body, a highly effective strategy to induce body ownership (Slater, Spanlang, Sanchez-Vives, &
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758 24 Blanke, 2010), is provided. This suggests that multisensory synchrony is not the sole driver of
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760 25 body illusions. In this study, longer synchronous stimulation or observation times did not affect
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762 26 body metrics, ruling out an effect due to long-term illusion of ownership. Our results thus

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771 1 confirm that asynchronous stimulation is not strictly “neutral”, in the sense of being used as
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773 2 “baseline” or control condition, but rather involves a multisensory conflict that has implications
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775 3 for body representation, specifically for body metrics.
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777 778 4 **4.2 The Deafferentation Hypothesis**

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780 5 Previous studies suggest that synchronous and asynchronous conditions involve different
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782 6 components of the body representation. While in the synchronous condition participants
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784 7 experience a feeling of “loss of hand” or disownership of the real hand, a deafferentation
785
786 8 component appears in the asynchronous condition only (Longo et al., 2008; Moseley, 2007).
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788 9 Longo and colleagues related the deafferentation component to the sensation of paraesthesia
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790 10 (tingling sensation, ‘pins and needles’), numbness, and the experience of the hand being less
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792 11 vivid than normal. Similar sensations have been documented when visuomotor conflicts are
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794 12 induced by mirrors (McCabe, Haigh, Halligan, & Blake, 2005). Indeed, actual deafferentation
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796 13 due to local anaesthesia (Gandevia & Phegan, 1999; Paqueron et al., 2003) or after spinal cord
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798 14 injury (Fuentes et al., 2013) produces a selective increase in the perceived size of a body part.
799
800 15 We suggest that the recalibration of the arm segment lengths (i.e., the modulation of the
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802 16 perceived length of the specific body part) induced by asynchronous stimulation may be related
803
804 17 to the deafferentation factor in the RHI. This would imply that the modulation of the body
805
806 18 image comes through an alteration of the internal representation of the body due to incongruent
807
808 19 visuotactile stimulation in the asynchronous condition, which does not occur in the synchronous
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810 20 condition.

811 812 21 **5 Conclusions**

813
814 22 Our results indicate that the internal representation of the body image is a highly dynamic
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816 23 process. Multisensory stimulation is not only critical for our brain to develop a sense of body
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818 24 ownership with respect to the body, but is also necessary for maintaining a stable and correct
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820 25 internal metric representation of the body. Asynchronous (incongruent) multisensory
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822 26 stimulation, often used as a baseline to measure body ownership illusions, is not a neutral

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830 1 stimulus. Here we demonstrated that asynchronous stimulation induces a recalibration of the
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832 2 metrics of the stimulated limb towards elongation. The present study provides further evidence
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834 3 of how complex and malleable the structure of the internal representation of the body is,
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836 4 highlighting the importance of adequately assessing each component individually.
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840
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845 8 the manuscript.
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949 **Tables**
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951
952 **Table 1.** Means and standard errors for the normalized different body part lengths assessed with
953 the BIT prior to (PRE) and after (POST) asynchronous (A) and synchronous (S) stimulation
954 (Experiment 1).
955

	Upper Arm	Lower Arm	Upper Leg	Lower Leg
PRE-A	.669 ± .03	.331 ± .03	.460 ± .03	.540 ± .03
POST-A	.597 ± .04	.403 ± .04	.425 ± .03	.575 ± .03
PRE-S	.671 ± .03	.329 ± .03	.478 ± .03	.522 ± .03
POST-S	.689 ± .03	.311 ± .03	.448 ± .03	.552 ± .03

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964 **p*<.05 compared to POST-A using Newman-Keuls post-hoc test
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Table 2. Means and standard errors for the normalized different body parts lengths assessed with the BIT prior to (PRE) and after (POST) the observational (O) and long-lasting synchronous (LS) conditions (Experiment 2).

	Upper Arm	Lower Arm	Upper Leg	Lower Leg
PRE-O	.665 ± .02	.335 ± .02	.465 ± .04	.535 ± .04
POST-O	.618 ± .04	.382 ± .04	.376 ± .03	.624 ± .03
PRE-LS	.651 ± .03	.349 ± .03	.395 ± .02	.605 ± .02
POST-LS	.644 ± .03	.356 ± .03	.436 ± .04	.564 ± .04

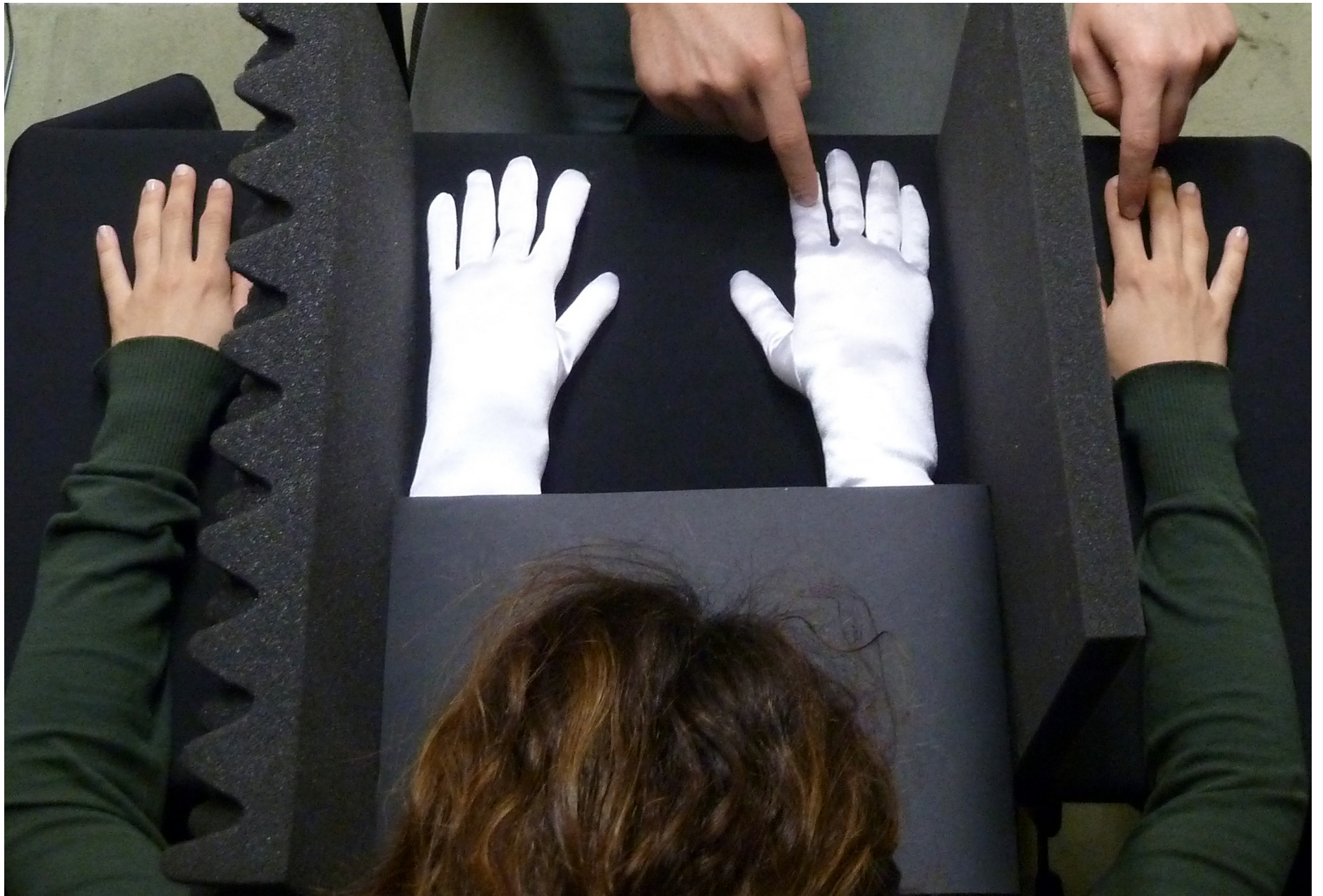
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1067 **1 Figure Legends**
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1072 **4** **Figure 1.** Experimental RHI setup: All four arms (two rubber, two real) rested palm-
1073 **5** down on the desktop, with the rubber arms positioned closer to the body midline. Two partitions
1074 **6** prevented direct view of one's own arms. Participants were asked to concentrate on either the
1075 **7** left or right rubber hand where tactile stimulation (synchronous or asynchronous, depending on
1076 **8** the condition) was delivered to both real and rubber hands of the same side. After 20 s, the
1077 **9** complementary stimulation (asynchronous or synchronous) was delivered to the other hand. In
1080 **10** the picture, one experimenter strokes both the real and the rubber right hands synchronously.

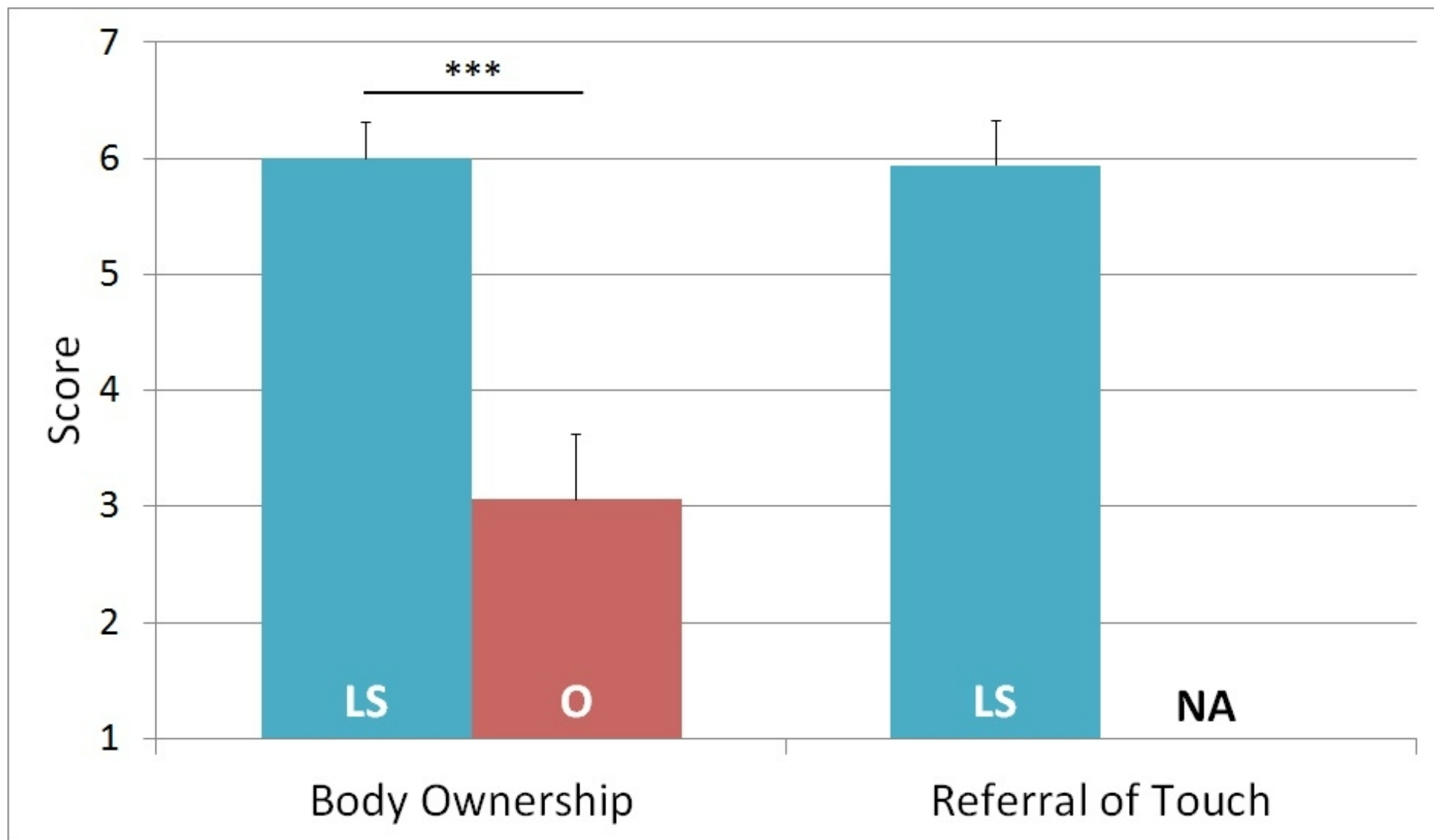
1081 **11** **Figure 2.** Mean scores and standard errors for the body ownership and referral of touch
1082 **12** questions for the synchronous (S) and asynchronous (A) conditions in the first experiment.
1083 **13** *** $p < .005$, Wilcoxon matched paired-test.
1084 **14**

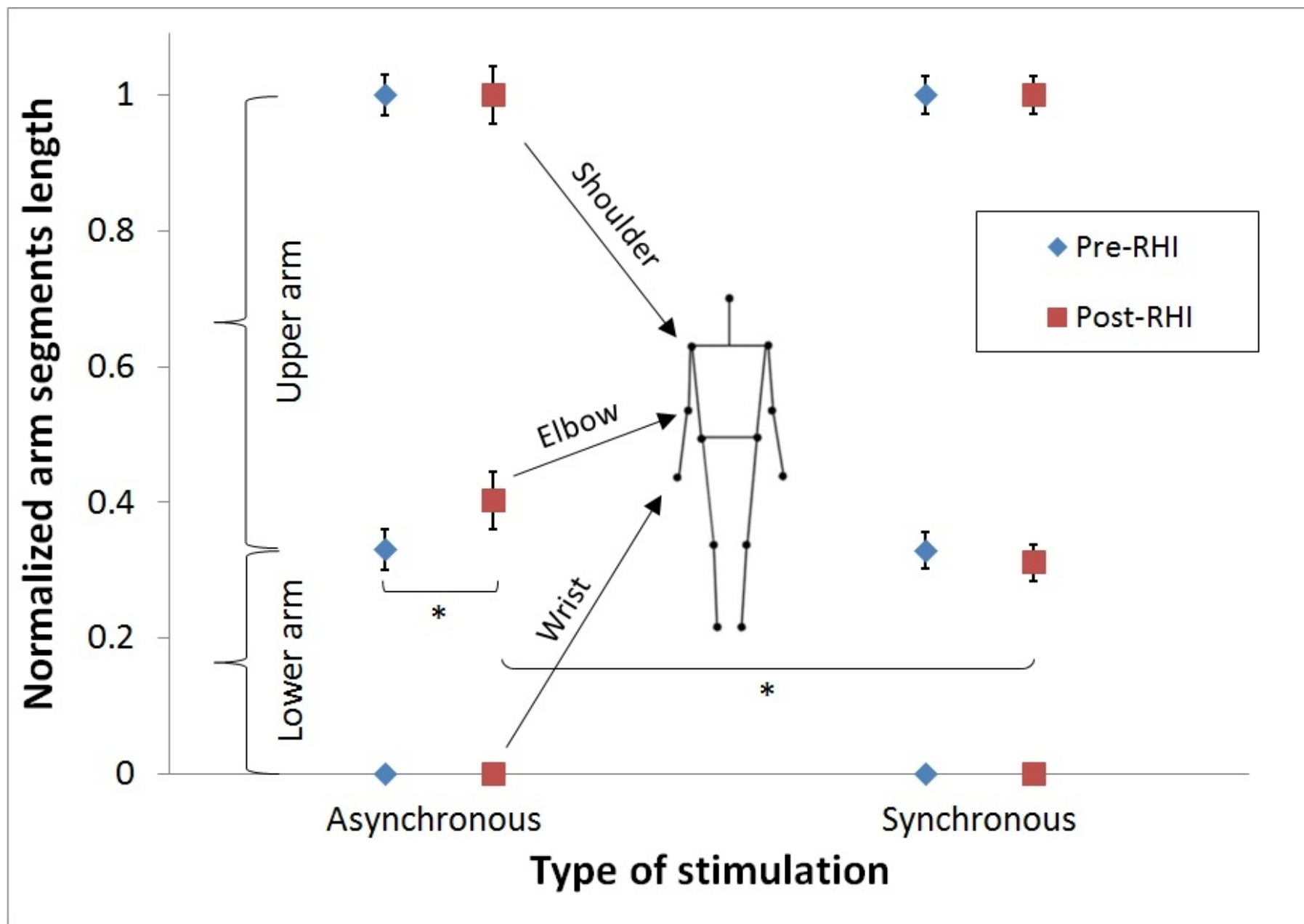
1085 **15** **Figure 3.** Mean scores and standard errors obtained for the body ownership for the long-
1086 **16** lasting synchronous (LS) and observational (O) conditions, and for the referral of touch
1087 **17** questions (only LS) in the second experiment. *** $p < .005$, Wilcoxon matched paired-test.
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1089 **19** **Figure 4.** Stacked representation of pre-RHI and post-RHI normalized lower and upper
1090 **20** arm lengths using the BIT for the synchronous (S) and asynchronous (A) conditions in the first
1091 **21** experiment. For each data column, data points represent the relative positions (i.e., normalized
1092 **22** with respect to whole arm length) of the hand, the elbow and the shoulder (from bottom to top).
1093 **23** * $p < .05$, Newman-Keuls post-hoc test.
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Supplementary Material

Questionnaire items (Spanish version)

Q1. *“Durante el experimento hubo momentos en los que sentía como si la mano de goma izquierda fuera mi propia mano izquierda”.*

Q2. *“Durante el experimento hubo momentos en los que sentía como si la mano de goma derecha fuera mi propia mano derecha”.*

Q3. *“Respecto a la mano izquierda hubo momentos en los que tuve la sensación de estar recibiendo los golpecitos en el lugar en el que se encontraba la mano de goma izquierda”.*

Q4. *“Respecto a la mano derecha hubo momentos en los que tuve la sensación de estar recibiendo los golpecitos en el lugar en el que se encontraba la mano de goma derecha”.*