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The Supernumerary Rubber Hand Illusion Revisited: Perceived Duplication of Limbs and Visuotactile Events

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A controversial and unresolved issue in cognitive neuroscience is whether humans can experience supernumerary limbs as part of their own body. Some previous experiments have claimed that it is possible to elicit supernumerary hand illusions based on modified versions of the rubber hand illusion. However, other studies have provided conflicting results that suggest that only one rubber hand can be perceived as one's own. To address this issue, we developed a supernumerary hand illusion paradigm that allowed us to disambiguate ownership of individual rubber hands from simultaneous ownership of two fake hands. In our setup, the participant's real right hand was hidden under a platform, while two identical right rubber hands were placed in parallel on top of the platform in direct view of the participant. We applied synchronous strokes to both rubber hands and the real hand (SS), synchronous strokes to one rubber hand and the real hand and asynchronous strokes to the other model hand (AS and SA), or asynchronous strokes to both fake hands in relation to the real hand (AA). Our results demonstrate that a genuine illusion of owning two rubber hands can be elicited and that such a supernumerary hand illusion can be isolated from the sense of ownership of a single rubber hand both in terms of questionnaire ratings and threat-evoked skin conductance responses (SCRs). These findings advance our knowledge about the dynamic flexibility and fundamental constraints of body representation and emphasize the importance of correlated afferent signals for causal inference in body ownership.

Public Significance Statement

We present conclusive evidence for the existence of a three-arm illusion, thereby resolving controversy in psychological science. In our experiments, synchronous visual stimulation applied to two identical right rubber hands, in full view, and the participant's real right hand, which is hidden, elicits the illusion that both rubber hands sense the touches that one sees and that both fake hands are part of one's own body. These results indicate that at the very core of body representation, the brain uses probabilistic approaches to construct the perceptual experience of the body, enabling a single limb to be represented at two locations at the same time and thus giving rise to the feeling of having three arms.

Keywords: bodily self-consciousness, body ownership, embodiment, multisensory integration

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Throughout evolution, the human body plan has remained constant. Human beings have two arms, two legs, a torso, and one head. This fixed body representation with four limbs has helped us successfully interact with the external environment, perform complicated actions, and combine upright locomotion with dexterous manual tasks. Can we challenge this apparently fixed body morphology? Could we have supernumerary limbs? Supernumerary limbs are common in ancient mystical texts and comic books.

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Chenggui Fan and H. Henrik Ehrsson conceived and designed the experiments. Chenggui Fan collected the data and conducted the first statistical analysis. Chenggui Fan and H. Henrik Ehrsson wrote the article, with Chenggui Fan producing the first draft and creating the initial figures. H. Henrik Ehrsson and Sara Coppi revised the article; Sara Coppi reanalyzed all data, performed the correlation analyses, remade the figures and created the supplementary figures; many thanks to Mattias Karlén for help with the illustration of the illusion setup.

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Some Hindu gods (e.g., Brahma, Vishnu, and Shiva) have multiple limbs—sometimes even thousands of them—to demonstrate their undefeatable power and unlimited strength. Even Doctor Octopus, the evil genius in Spider-Man (Amazing Spider-Man #3 Vol. 1, Marvel Comics, 1963), demonstrates the utility of supernumerary limbs to perform several evil tasks at the same time. Interestingly, real individuals are sometimes born with supernumerary fingers or toes, a congenital physical anomaly (Malik, 2014) that is not very rare (with an incidence of .2%; McCarroll, 2000). Such congenital supernumerary digits have been reported in most tetrapod animals (Lange & Muller, 2017), and in rodents supernumerary vibrissae has been described (Welker & Van der Loos, 1986). Interestingly, congenital supernumerary fingers can have substantial functionality and be represented independently at the level of sensorimotor cortical representations (Mehring et al., 2019). More recently, there has been a growing interest in the engineering community in designing supernumerary robotic limbs to augment human physical capabilities in the workplace and rescue operations (Llorens-Bonilla et al., 2012; Parietti & Asada, 2016; Sasaki et al., 2017). These engineering efforts have focused on the technical design of such systems rather than on the fundamental question of extent to which such devices can be incorporated into the body representation (Makin et al., 2017).

Previous studies on people with neurological disorders, including strokes, have demonstrated the possibility of humans experiencing supernumerary phantom limbs. Hari et al. (1998) described a nonamputated individual with frontal lobe lesions involving the presupplementary motor area who perceived a third "ghost arm" in the location where the real left arm had previously been placed (.5 to 1 minute before). This supernumerary phantom limb syndrome indicates the possible simultaneous perception of more than two arms (Khateb et al., 2009). Additionally Giummarra et al. (2011) reported that some upper-limb amputees describe a rubber hand presented in the location where the amputated hand used to be (through a midsagittal placed mirror) as an embodied "third" hand, in addition to the intact contralateral hand and the telescoped phantom hand inside the stump. Although the neural mechanism of supernumerary phantom limbs is unclear, clinical case reports have associated these unusual experiences with lesions in different cortical and subcortical brain areas, including the posterior parietal cortex (Vuilleumier et al., 1997), nonprimary motor areas (Hari et al., 1998; McGonigle et al., 2002), basal ganglia (Halligan et al., 1993), and thalamus (Canavero et al., 1999; Miyazawa et al., 2004). Thus, structural disruptions in central pathways and regions involved in the sensorimotor aspects of body representation can lead to supernumerary phantom limbs, but these reports do not tell us whether healthy individuals can experience extra limbs.

Over the last decade, several experimental studies on healthy participants have been carried out to investigate whether it is possible to elicit supernumerary limb sensation (or "third arm illusion"; Ehrsson, 2009; Folegatti et al., 2012; Giummarra et al., 2011; Guterstam et al., 2011; Newport et al., 2010) based on modified versions of the classical rubber hand illusion (Botvinick & Cohen, 1998). The rubber hand illusion is a well-established model system used to investigate the neurocognitive basis of limb ownership in healthy participants (Ehrsson, 2012, 2020). In the classical rubber hand illusion, participants brushstrokes applied to a visible rubber hand, while synchronous brushstrokes are applied to their real hand, which is hidden from view behind a screen. A period of repeated stroking elicits the illusion that the rubber hand senses the touches that one sees ("referral of touch") and that the model hand is one's own hand ("sense of body ownership"; Blanke et al., 2015; Ehrsson, 2012, 2020; Kilteni et al., 2015; Makin et al., 2008). Asynchronous strokes applied to the rubber hand and the real hand eliminate the illusion and serve as an often-used control condition (Ehrsson, 2012; Riemer et al., 2019; Shimada et al., 2009). In the first supernumerary limb illusion study, Ehrsson (Ehrsson, 2009) placed two right rubber hands next to one another in parallel on the table in view while keeping the participant's real right hand hidden under the table. When synchronous brushing was applied to both rubber hands and the real right hand, skin conductance responses (SCRs) to physical threat applied to either rubber hand, an often-used objective measure of body ownership (Armel & Ramachandran, 2003; Gentile et al., 2013; Guterstam et al., 2013; Petkova & Ehrsson, 2009), were significantly greater than when such threats were applied in a control condition with asynchronous stroking of the hands. Guterstam et al. (2011) took a different approach and demonstrated that even when the real right hand is fully visible and placed next to a right rubber hand, illusory ownership of the rubber hands can still be elicited while ownership of the real hand is maintained, thus eliciting an illusion of owning one extra right (rubber) hand. This latter paradigm has recently been extended to augmented reality with a virtual extra hand instead of a physical hand (Rosa et al., 2019; see also Newport et al. [2016] and Cadete & Longo [2020] for subjective reports of an invisible extra little finger next to the real fingers in view in a mirror illusion). Collectively, the results presented in Ehrsson (2009) and Guterstam et al. (2011) suggest that when the brain is presented with two right hands, both receiving congruent multisensory stimulation, both limbs are incorporated into the body representation and consciously experienced as one's own.

However, the existence of a supernumerary hand illusion has been questioned (Folegatti et al., 2012). By using a setup based on augmented reality where the participants put their hand in a box onto which a computer screen is attached, Newport et al. (2010) presented two digital images of the participant's left hand at equal distances from the real left-hand position. When both artificial hands moved synchronously with the actual hand, ownership was claimed over both artificial hands, but only the artificial hand to the right, that is, the one closest to the body midline, was controlled in a subsequent reaching task and hence was incorporated into the body representation for action (body schema). Folegatti et al. (2012) placed two rubber hands to the left of and adjacent to the participant's real hand and found that only the rubber hand closest to the participant's real hand was fully embodied. Moreover, the relatively modest sample sizes in Ehrsson (2009; N = 20), Newport et al. (2010; N = 12), and Folegatti et al. (2012; max N = 12 in each group) made the subjective and objective measures of ownership in the supernumerary limb illusion prone to both type I and type II errors. In addition to these concerns, the paradigm by Guterstam et al. (2011) could be seen as a special case of the classical rubber hand illusion, in which only one rubber hand is presented and default ownership of the real hand is maintained. Moreover, in the study by Ehrsson (2009), no questionnaire data were collected, so what the participants subjectively perceived during the experiments is unclear. As pointed out by Folegatti et al. (2012), the possibility that the threat-evoked SCRs observed in Ehrsson (2009) could be explained by the participants owning only one of the two rubber hands cannot be fully excluded because it is unclear whether this physiological measure has sufficient spatial resolution to differentiate between threats applied to two model hands placed in close proximity. In sum, the results from previous studies on the ownership of supernumerary rubber hands are mixed and inconclusive. Given the above concerns, a study revisiting supernumerary limb illusion is needed.

To address all the above issues, we developed a modified version of the supernumerary rubber hand illusion paradigm (Ehrsson, 2009). The rationale behind the paradigm was to directly contrast ownership of two rubber hands ("dual-hand ownership") with ownership of individual hands in otherwise equivalent conditions. The participant's real right hand was hidden under a platform, while two identical right rubber hands were placed adjacent to one another and above the hidden hand on the platform in full view. Note that in this setup, both rubber hands were placed at a distance from the real hand that was sufficiently short and within "perihand space" to elicit a robust rubber hand illusion (Kalckert & Ehrsson, 2014b; Kalckert et al., 2019; Lloyd, 2007). The two rubber hands and the real hand were stroked by three paintbrushes in the following four conditions: (a) both rubber hands synchronously with the real hand (SS); (b) the left rubber hand synchronously and right rubber hand asynchronously with the real hand (SA); (c) the left rubber hand asynchronously and the right rubber hand synchronously with the real hand (AS); and (d) both rubber hands asynchronously with the real hand (AA). This design allowed us to isolate the sensation of dual-hand ownership (SS condition) from ownership of each rubber hand individually (AS and SA conditions, with AA serving as a no-illusion control). In total, the study consisted of five separate experiments (labeled Experiment 1, Experiment 2 and Experiments 3A–3C and performed in that order) conducted with five different groups of healthy participants (n = 216 in total). In the first two experiments, we collected questionnaire ratings of various aspects of the subjective illusion experience, and in the latter three experiments, we assessed threat-evoked SCR as indirect objective physiological evidence of limb ownership. In the first experiment (Experiment 1), the real hand was placed below the platform centered precisely between the two rubber hands, as in Ehrsson (Ehrsson, 2009). However, we observed strong (clearly affirmative) ownership ratings in the majority of the participants only for the rubber hand closest to the body midline (see Results). Therefore, in the second experiment (Experiment 2), we shifted the position of the real hand slightly to the right (lateral position) so that it was placed directly under the laterally placed rubber hand. We reasoned that placing the real hand closer to the lateral rubber hand would promote the supernumerary hand illusion by counteracting a general bias in ownership toward the medially placed rubber hand that was closer to the body midline. In the SCR experiments (Experiments 3A–3C), we used an SCR procedure with a highly localized threat stimulus—a stick with a needle at a precise location of a rubber finger—that allowed psychophysiological differentiation of ownership of either one or two rubber hands. Collectively, our results provide conclusive evidence for the existence of the supernumerary rubber hand illusion.

Experiment 1

Method

Participants

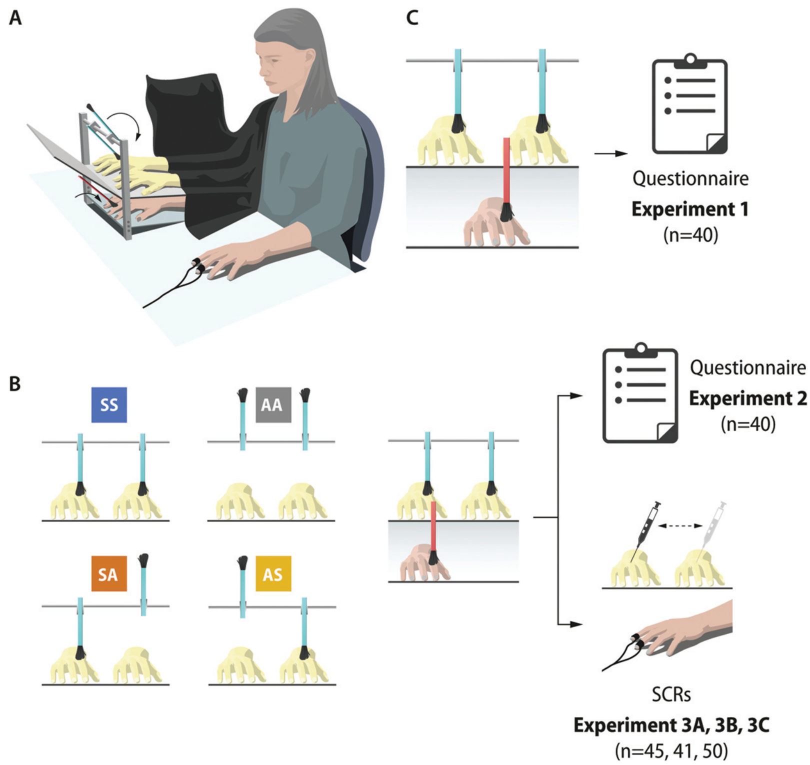
All participants were naïve to the purpose of our experiments. The participants were recruited through advertisements placed on the different university campuses of Stockholm and through social media. They received one cinema ticket as compensation for their participation. In Experiment 1, we tested 40 participants (20 females; age: 27.28 ± 4.27 y, $M \pm SD$). The sample size was based on previous experiments on the rubber hand illusion (Kalckert & Ehrsson, 2014a). All participants had normal or corrected-to-normal vision and were fully healthy. This study, including all individual experiments, was approved by the Regional Ethical Review Board of Stockholm (now renamed the Swedish Ethical Review Authority). The participants signed an informed consent form before the experiment began. We do not have approval from the participants or the Swedish Ethical Review Authority to make the raw data of the study publicly available; but we have permission to release the anonymized source data associated with the figures.

Experimental Setup

All experiments took place in a soundproof behavioral testing room (40-dB noise reduction). The participants were seated comfortably in front of a table and placed their right hand, palm down, on the lower level of a tilted two-level platform. On the upper level of the platform, 12.5 cm above their real hand, two identical cosmetic male prosthetic hands ("rubber hands"; Natural Definition Glove, Color Y02, Fillauer LLC, Chattanooga), TN filled with gypsum were placed in parallel, palm down, at a distance of 11 cm between the two rubber index fingers (Figure 1A). The rubber hands were very lifelike and had a light skin tone. The platform was tilted approximately 30° vertically to allow a good view of both model hands. A piece of black cloth blocked the vision of participants' right upper arm so that the real right arm and hand were completely occluded; thus, only the two right rubber hands placed on the upper platform could be seen by the participants (Figure 1A). The participants were asked to keep their right hand relaxed at all times during all experimental trials (see below) and not to make any movements of the arm, wrist, thumb, or fingers. They were further instructed to look at and attend to both of the rubber hands.

We carefully applied two minutes of repeated paintbrush strokes to the index (Experiments 1 and 2) or middle (Experiments 3A–3C) finger of the two rubber hands and real hand in the following conditions: (a) both synchronous (SS)—we applied synchronous strokes to both rubber hands and the real hand; (b) left synchronous and right asynchronous (SA)—we synchronously stroked the rubber hand on the left and the real hand while asynchronously stroking the rubber hand on the right; (c) left asynchronous and right synchronous (AS)—we synchronously stroked the right rubber hand and the real hand while asynchronously stroking the left rubber hand; and (4) both asynchronous (AA)—we applied asynchronous strokes to the two rubber hands and the real hand. Synchronous visuotactile stimulation elicits the rubber hand illusion, and asynchronous stimulation eliminates it, in otherwise equivalent conditions (Botvinick & Cohen, 1998; Chancel & Ehrsson, 2020; Ehrsson, 2020; Ehrsson et al., 2004; Shimada et al., 2009; Tsakiris & Haggard, 2005); therefore, with this experimental design, we

Figure 1
Illustration of the Experimental Setup, Procedures, and Conditions



Note. (A) The participant's real right hand (skin color) was hidden under a platform, while two identical right rubber hands (light yellow for illustrative purposes) were placed adjacent to one another on the platform in full view of the participant. The brushstrokes to the rubber hands (turquoise paint brushes) were applied with a "brushstroke apparatus" that allowed for the delivery of well-controlled stimulation (see Method section). The brushstrokes to the real hand (red paintbrush) were applied by the experimenter. Skin conductance responses (SCRs) were recorded with the participant's real left hand (through surface electrodes attached to the middle finger and index finger). (B) Main conditions used in the study. The two rubber hands and the hidden real hand were stroked at 0.5 Hz at the index (Experiments 1 and 2) or middle finger (Experiments 3A–3C) by three small paintbrushes in the following conditions: both rubber hands synchronously (SS) with the real hand; both asynchronously (AA) with the real hand; left synchronously and right asynchronously (SA) with the real hand; left asynchronously and right synchronously (AS) with the real hand. (C) In Experiment 1, the participant's right hand was placed precisely between the two rubber hands. In Experiments 2 and 3, the participant's real right hand was placed directly under the right rubber hand. The illustration was made by Mattias Karlén.

expected to be able to independently manipulate illusory ownership for each of the two rubber hands and elicit the supernumerary limb illusion only in the SS condition. To apply brushstrokes in a well-controlled manner, we used a 'brushstroke apparatus' (Figure 1A) that we developed in our laboratory. Two small paintbrushes (length: 12.9 cm, width: 1.30 cm; Penselset Hobby 7070; Habo Penslar AB, Bankeryd, Sweden) were attached to one rotating rod placed 10 cm above the index digits of the two rubber hands. This rod was rotated by the experimenter's left hand, which held the lateral end of the rod and continuously rotated the handle in a circular (360-degree) movement. The handle and the experimenter's hand were out of sight of the participant; thus, the participant could see only the two rotating paintbrushes repeatedly stroking the two rubber hands. At the same time, the experimenter's right hand applied strokes with a paintbrush (identical to the brushes touching the rubber hands) to the corresponding section of the participant's matching real right finger as synchronously as possible with the strokes applied to the rubber hands (SS) or one of the rubber hands (AS, SA). In the AA condition, these strokes were applied with a one-second delay (see Figure 1B). The procedure of stroking the real hand took place under the platform and was thus out of the participant's view. Paintbrush strokes were applied to the finger from the metacarpophalangeal joint to the distal interphalangeal joint at a frequency of .5 Hz. During the entire experiment, the experimenter maintained this frequency and a steady velocity of the paintbrush strokes by rotating the handle that generated the rotation of the brushes at a regular speed so that an entire 360-degree rotation of the handle was completed every 2 seconds (the experimenter listened to an auditory metronome as a rotation cue) and matched this frequency and velocity for the strokes manually applied to the real right hand. For all asynchronous conditions, we adjusted the alignment of one (AS and SA) or both (AA) of the paintbrushes seen by the participants by 180° in relation to the hidden paintbrush touching the real hand to achieve a one-second delay between the seen and felt touches. In Experiment 1, the real right hand was placed directly under the vertical midline of the two rubber hands (Figure 1C, top left panel) so that the distance between the real hand and each of the two rubber hands was identical (as in Ehrsson, 2009).

Before each experimental trial commenced, we reminded the participant to keep looking at both rubber hands and to attend to them equally. The participants were explicitly instructed not to fixate on only one of the rubber hands. The experimenter regularly checked the participants' gaze throughout the experiment to ensure that the participant followed these instructions. We wanted to avoid participants looking at and attending to only one rubber hand owing to the concern that such behavior might bias the questionnaire ratings (or SCR responses in Experiments 3A–3C) toward a particular rubber hand.

Procedure

Experiment 1 focused on the quantification of the subjective experience of the illusion by using a questionnaire. Each of the four conditions was repeated once in separate trials. Each trial took two minutes, during which sixty individual paintbrush strokes were applied to each hand. The orders of the four conditions across participants were pseudorandomized. All participants were asked to complete a questionnaire after each trial. In this questionnaire, the participants were asked to rate on a Likert scale how much they agreed or disagreed with ten statements that referred to possible feelings that they may have experienced during the preceding trial. The rating scales consisted of 7 points from −3 to +3, where −3 means *completely disagree*, 0 means *neither agree nor disagree, that is, not sure* and +3 means *totally agree*.

We constructed the questionnaire based on statements adopted from previous rubber hand illusion studies (Botvinick & Cohen, 1998; Folegatti et al., 2012; Guterstam et al., 2011; Newport et al., 2010; see Table 1). In this questionnaire, two statements were used to describe the illusion for the rubber hand on the left (medial position; S1 and S2); two statements were related to the illusion for the rubber hand on the right (lateral position; S3 and S4); and two statements specifically described the rubber hand illusion for both rubber hands at the same time (S5 and S6). These illusion-related questions included separate statements regarding sensing touch on the rubber hand(s) where they were being stroked ("referral of touch"; S1, S3, and S5) and explicit feelings of ownership of the hand(s; S2, S4, S6), which are the two most prominent perceptual features of the rubber hand illusion (Ehrsson, 2012). Statements S5 and S6 are the most important in this study because they directly assess the explicit senses of duplicated referral of touch (S5) and dual-rubber hand ownership (S6). The last four questions were control statements (S7–S10) that were included to control for possible effects related to suggestibility and task compliance.

Statistical Analysis

We set the significance threshold to $p < .05$ for the statistical analysis, and all tests were two-sided unless otherwise specified. All comparisons were planned based on our hypotheses and were in line with the experimental design of the study, if not clearly identified as a post hoc test. Hence, we corrected for the number of critical illusion-related questionnaire items in Experiment 1 (S1–S6) only when contrasting the conditions of interest, resulting in a significance level of $p = .05/6 = .0083$ for these results (all reported p values are "uncorrected" values). The questionnaire results in Experiment 1 were not normally distributed (Shapiro-Wilks test p values always $< .05$). We therefore applied nonparametric tests, that is, the Friedman test and Wilcoxon signed-ranks test (two-tailed, Bonferroni correction, significance level $p = .05/6 = .0083$), to the critical questionnaire statements (S1–S6). The statistical analyses were conducted using the software RStudio 3.6.1 (R Core Team, 2019).

Results

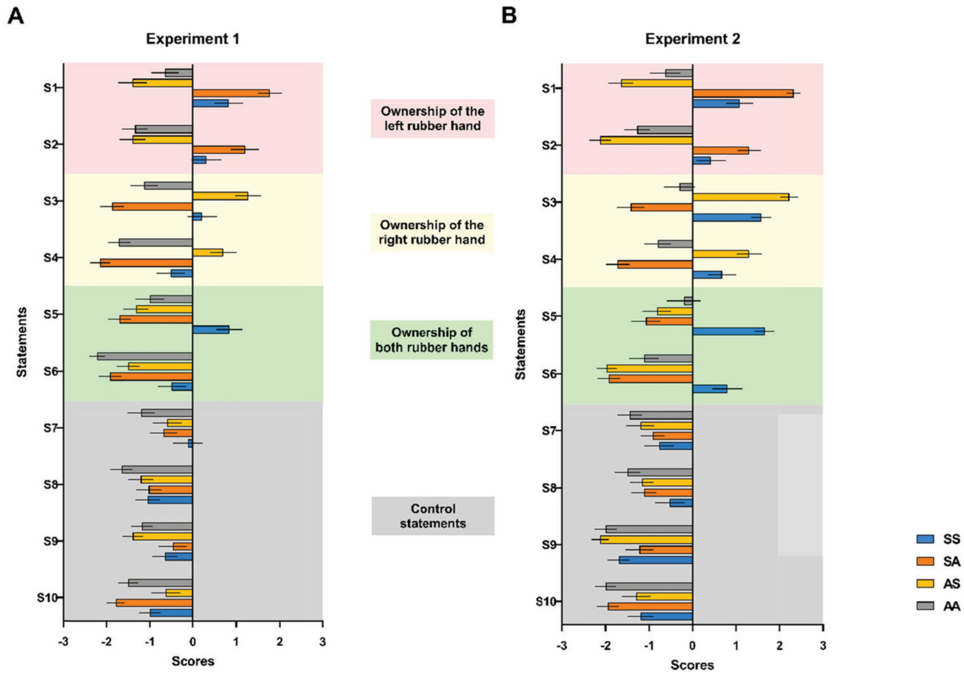
Questionnaire

An overview of the questionnaire results from the first experiment ($N = 40$), including all statements, is provided in Figure 2A and Table 2 (see also Figure 1 in the online supplemental materials). As expected, the participants gave higher ratings of hand ownership and referral of touch for the rubber hand(s) that received synchronous visuotactile stimulation than for those that received asynchronous stimulation. Furthermore, they provided negative ratings for the four control statements, meaning that they rejected these statements and that their overall questionnaire

Table 1
The Statements From the Questionnaire Used in Experiments 1 and 2

Statement number	Statements
S1	It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand furthest to the left touched.
S2	I felt as if the rubber hand furthest to the left were my hand.
S3	It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand furthest to the right touched.
S4	I felt as if the rubber hand furthest to the right were my hand.
S5	It seemed as if I were feeling the touches of the paintbrushes in the locations where I saw both rubber hands touched.
S6	I felt as if both rubber hands were my hands.
S7	It felt as if my (real) hand was turning "rubbery."
S8	It no longer felt like my (real) hand belonged to my body.
S9	It appeared (visually) as if the rubber hands were drifting towards the left.
S10	It appeared (visually) as if the rubber hands were drifting towards the right.

Figure 2
Overview of Questionnaire Results From Experiments 1 and 2



Note. (A) Questionnaire results from Experiment 1. (B) Questionnaire results from Experiment 2. The rating scales consist of 7 points from −3 to +3, where −3 means *completely disagree*, 0 means *neither agree nor disagree (i.e., not sure)*, and +3 means *totally agree*. For display purposes and for consistency with previous studies, mean values are presented; the error bars represent standard errors. For individual data points and the distribution of the data, see Figures 1 and 2 in the online supplemental materials. SS = both rubber hands synchronously; AA = both rubber hands asynchronously; SA = left synchronously and right asynchronously; AS = left asynchronously and right synchronously.

responses should therefore be reliable. Notably, the participants also gave higher ratings for the statements (S5 and S6) related specifically to the supernumerary hand illusion in the SS condition than in the other conditions, although the ratings for dual-hand ownership (S6) were not clearly affirmative, as we had expected (see further below). In the statistical analysis, we separately analyzed the rating scores for the illusion-related statements (S1–S6) and present the results in the following paragraphs and in Figure 3.

Illusion for the Medial (Left) Rubber Hand

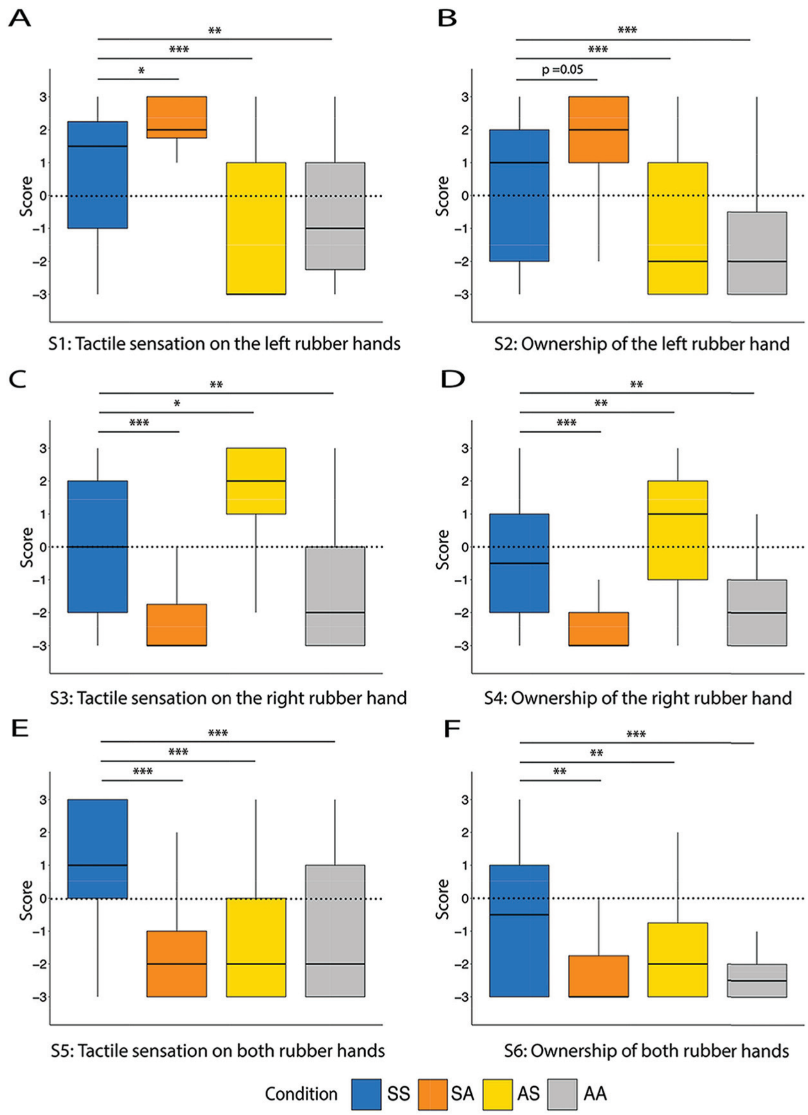
Regarding the referral of touch and ownership over the rubber hand on the left (S1 and S2), there was a statistically significant difference in the rating scores of agreement among the four conditions

Table 2
Median Values and Interquartile Ranges of Questionnaire Statements in Experiment 1

	Experiment 1 rating median (Interquartile ranges)			
Statement	SS	SA	AS	AA
S1	1.5 (−1 ∼ 2.25)	2 (1.75 ∼ 3)	−3 (−3 ∼ 1)	−1 (−2.25 ∼ 1)
S2	1 (−2 ∼ 2)	2 (1 ∼ 3)	−2 (−3 ∼ 1)	−2 (−3 ∼ −0.5)
S3	0 (−2 ∼ 2)	−3 (−3 ∼ −1.75)	2 (1 ∼ 3)	−2 (−3 ∼ 0)
S4	−0.5 (−2 ∼ 1)	−3 (−3 ∼ −2)	1 (−1 ∼ 2)	−2 (−3 ∼ −1)
S5	1 (0 ∼ 3)	−2 (−3 ∼ −1)	−2 (−3 ∼ 0)	−2 (−3 ∼ 1)
S6	−0.5 (−3 ∼ 1)	−3 (−3 ∼ −1.75)	−2 (−3 ∼ −0.75)	−2.5 (−3 ∼ −2)
S7	1 (−3 ∼ 2)	−1 (−3 ∼ 1)	−0.5 (−3 ∼ 1)	−2 (−3 ∼ 0)
S8	−1.5 (−3 ∼ 1)	−1.5 (−3 ∼ 1)	−1.5 (−3 ∼ 0.25)	−2.5 (−3 ∼ −1)
S9	0 (−2.25 ∼ 1)	0 (−3 ∼ 1)	−2 (−3 ∼ 0)	−1.5 (−3 ∼ 0)
S10	−1 (−3 ∼ 0)	−2 (−3 ∼ −1)	−0.5 (−3 ∼ 1.25)	−2 (−3 ∼ −1)

Note. SS = both rubber hands synchronously; AA = both rubber hands asynchronously; SA = left synchronously and right asynchronously; AS = left asynchronously and right synchronously.

Figure 3
Boxplots of Questionnaire Results From Experiment 1



Note. (A) Questionnaire results regarding sensing touch on the left rubber hand (S1). The rating scores in both the two rubber hands synchronously (SS) and left synchronously and right asynchronously (SA) conditions confirmed referral of touch to the left rubber hand in these conditions, whereas the left asynchronously and right synchronously (AS) and both hands asynchronously (AA) conditions were associated with a denial of such illusory tactile experiences. (B) Questionnaire results regarding the feeling of ownership of the left rubber hand (S2). The rating score in the SS condition was significantly higher than those in the AS and AA conditions; moreover, a statistical trend for a difference between SA and SS was also observed. (C) Questionnaire results regarding the tactile feeling on the right rubber hand (S3). Only the rating scores in the AS condition confirmed that the participants sensed touch on the right rubber hand, whereas in the SA and AA conditions, the subjects rejected this statement, and in the SS condition, the participants' median score indicated uncertainty. (D) Questionnaire results regarding body ownership of the right rubber hand (S4). Only the rating scores in the AS condition confirmed the ownership of the right rubber hand, whereas in the SA and AA conditions, the participants rejected this statement, and in the SS condition, the participants were uncertain. (E) Questionnaire results regarding sensing touches on both rubber hands at the same time (S5). Only the scores in the SS condition positively confirmed the touch feeling of the two rubber hands. (F) Questionnaire results regarding body

(Continued on next page)

(SS, SA, AS and AA; S1: $\chi^2(3) = 53.173$, $p < .001$, $W = .443$; S2: $\chi^2(3) = 40.916$, $p < .001$, $W = .341$). As expected, the participants rated significantly stronger referral of touch (S1) and ownership (S2) for the left rubber hand in the SS condition than in the AS condition (S1: $Z = -3.937$, $p < .001$, $r = -.44$; S2: $Z = -3.954$, $p < .001$, $r = -.442$) and in the SS condition than in the AA condition (S1: $Z = -3.110$, $p = .002$, $r = -.348$; S2: $Z = -3.813$, $p < .001$, $r = -.426$; see Figure 3A and 3B). The median rating scores indicated that the participants felt the rubber hand on the left much like their own hand when the two rubber hands were synchronously stroked (SS condition; S1: median = 1.5; S2: median = 1) and rejected these statements when the two hands were asynchronously stroked (AA condition; S1: median = −1; S2: median = −2) or just the rubber hand on the left was stroked (AS condition; S1: median = −3; S2: median = −2). We further noted (post hoc) that the ratings for the illusion of the left model hand were somewhat higher in the SA condition (S1: median = 2; S2: median = 2) than in the SS condition (S1: median = 1.5; S2: median = 1; S1: $Z = -2.469$, $p = .014$, $r = -.276$; S2: $Z = -1.96$, $p = .05$, $r = -.219$), although this difference did not reach statistical significance after Bonferroni correction for multiple comparisons ($p < .0083$).

Illusion for the Lateral (Right) Rubber Hand

Regarding the illusion of the rubber hand on the right (S3 and S4), there was a statistically significant difference in the rating scores of agreement among the four conditions (SS, SA, AS and AA; S3: $\chi^2(3) = 51.372$, $p < .001$, $W = .428$; S4: $\chi^2(3) = 49.234$, $p < .001$, $W = .410$; see Figure 3C and 3D). In line with our hypothesis, the ratings for referral of touch and right hand ownership were significantly greater in the SS condition than in the SA condition (S3: $Z = -3.748$, $p < .001$, $r = -.419$; S4: $Z = -3.696$, $p < .001$, $r = -.413$) and in the SS condition than in the AA condition (S3: $Z = -3.031$, $p = .002$, $r = -.340$; S4: $Z = -2.867$, $p = .004$, $r = -.321$). In terms of absolute rating scores, the participants were uncertain whether they felt the illusion for the right rubber hand when both artificial hands received synchronous strokes (SS condition; S3: median = 0; S4: median = −.5), but they firmly denied both ownership and referral of touch sensations when asynchronous strokes were applied to the rubber hand on the right (SA condition: S3: median = −3; S4: median = −3; AA condition: S3: median = −2; S4: median = −2). We further noted (post hoc) that the feeling of touches on the right rubber hand (S3) was stronger in the AS condition (S3: median = 2) than in the SS condition (S3: median = 0; S3: $Z = -2.468$, $p = .014$, $r = -.276$), although this effect did not survive the Bonferroni correction ($p = .0083$). Similarly, the ratings of right rubber hand ownership were significantly stronger in the AS condition (S4: median = 1) than in the SS condition (S4: median = −.5; S4: $Z = -2.935$, $p = .003$, $r = -.328$).

Supernumerary Rubber Hand Illusion

Regarding the referral of touch and ownership of both rubber hands (S5 and S6), there was a statistically significant difference among the four conditions (SS, SA, AS and AA; S5: $\chi^2(3) = 37.471$, $p < .001$, $W = .312$; S6: $\chi^2(3) = 23.751$, $p < .001$, $W = .198$; see Figure 3E and 3F). In support of our hypothesis, the ratings of duplicated referral of touch (S5) and dual-rubber hand ownership (S6) were significantly higher in the SS condition (S5: median = 1; S6: median = −.5) than in the SA condition (S5: median = −2; S6: median = −3; S5: $Z = -4.414$, $p < .001$, $r = -.493$; S6: $Z = -3.183$, $p = .001$, $r = -.356$), the AS condition (S5: median = −2; S6: median = −2; S5: $Z = -4.199$, $p < .001$, $r = -.469$; S6: $Z = -2.621$, $p = .009$, $r = -.293$), and the AA condition (S5: median = −2; S6: median = −2.5; S5: $Z = -3.514$, $p < .001$, $r = -.393$; S6: $Z = -3.665$, $p < .001$, $r = -.409$). On the basis of the median scores, we can conclude that the participants affirmed feeling the touches on both rubber hands (S5: median = 1), while they were uncertain about the ownership of the two artificial hands (S6: median = −.5) when both rubber hands were synchronously stroked (SS). Importantly, although the supernumerary hand illusion was associated with clearly affirmative ratings only for referral of touch to both rubber hands, the dual-hand ownership ratings were still statistically significantly stronger in the SS condition than in all other conditions in our design (SA, AS and AA; see above), which provides evidence for a significant perceptual effect in line with our hypothesis.

Summary

The questionnaire results from the first experiment provided support for the hypothesis that the rubber hand illusion can be elicited simultaneously for two fake hands, that is, that a supernumerary rubber hand illusion can be induced. The participants reported experiencing significantly stronger duplication of touch (S5) and significantly stronger dual-hand ownership (S6) in the critical SS condition than in each of the three other conditions (AS, SA and AA; all $p < .05$). We noted, however, that although the rating scores for referral of touch to both rubber hands were affirmed (median = 1), the ratings for dual-hand ownership were somewhat lower that we had expected and indicated uncertainty rather than being affirmative (median = −.5). This latter observation could indicate that the supernumerary hand illusion is subjectively less

Figure 3 ***(Continued)***
ownership of both rubber hands (S6). The SS condition was not associated with a clear positive confirmation of the dual-hand ownership statement, although the participants expressed a degree of uncertainty. Importantly, however, the rating scores on both S5 and S6 were significantly higher in the SS condition than in the other three conditions (AS, SA and AA), which provides evidence for a significant supernumerary hand effect even if the illusion of dual-hand ownership was not vivid for the majority of the participants. The boxplots depict the data based on their median (thick black line) and quartiles (upper and lower ends of boxes). The vertical lines (i.e., the whiskers indicate the minimum or maximum and illustrate variability outside the upper and lower quartiles. For individual data points and the distribution of the data, see Figure 1 in the online supplemental materials; for individual pairwise comparison lines, see Figure 3 in the online supplemental materials.
* $p < .05$. ** $p < .01$. *** $p < .001$ (two-tailed, uncorrected *p-values*).

vivid than the classic rubber hand illusion (the latter which is typically associated with affirmative median ratings; Botvinick & Cohen, 1998; Kalckert & Ehrsson, 2014b), or it could suggest that for some reason, our paradigm was not optimal in eliciting a maximally strong supernumerary limb experience. We theorized that the latter seemed more likely because when looking at the ratings for single-hand ownership and referral of touch, one can see that these were stronger with the left rubber hand (S2: median = 1; S1: median = 1.5) than with the right rubber hand (S4: median = .5; S3: median = 0) in the SS condition (Figure 3A–3D), as if the basic illusion was not perfectly "balanced" between the two model hands in this condition (although these differences were not statistically significant in a post hoc Wilcoxon-rank test; S2 vs. S4: $Z = -1.90$, $p = .05729$, $r = -.21$; S1 vs. S3: $Z = -1.27$, $p = .2037$; $r = -.14$). We theorized that this unbalancing and bias toward the medially placed rubber hand could explain the somewhat low dual-hand ownership sensations because the supernumerary rubber hand illusion probably depends on there being equally strong sensory evidence in favor of ownership of both model hands (Ehrsson, 2009). To counteract this bias and thereby produce a stronger supernumerary rubber hand illusion, we placed the hidden real hand closer to the right rubber hand in Experiment 2.

Experiment 2

Method

Unless otherwise stated, all methods were identical to Experiment 1.

Participants

In Experiment 2, we tested 40 naïve participants (26 females; age: 27.92 ± 7.29 y, $M \pm SD$). The sample size was based on previous experiments on the rubber hand illusion (Kalckert & Ehrsson, 2014a).

Procedure

The aim of Experiment 2 was the same as for Experiment 1—to provide questionnaire evidence for the hypothesized supernumerary rubber hand illusion—but with the added goal to boost the subjective experience of dual-hand ownership by making a small adjustment to the setup whereby the participant's real right hand was directly under the more laterally placed right rubber hand (Figure 1C, lower left panel). We reasoned that the combined effect of reducing the distance between the hidden real hand and right rubber hand and increasing the distance between the real hand and the left rubber hand would lead to more matched illusion strength across the two model hands and hence stronger dual-hand ownership. Informal pilot experiments carried out on the authors and other members of the Brain, Body, and Self laboratory using the adjusted setup seemed to provide support for this hypothesis. Apart from this change in position of the real hand, all other experimental procedures remained identical to Experiment 1.

Statistical Analysis

The questionnaire results for Experiment 2 were not normally distributed (Shapiro-Wilks test p values always $< .05$). We therefore applied nonparametric tests, that is, the Friedman test and Wilcoxon signed-ranks test (two-tailed, Bonferroni correction, significance level $p = .05/6 = .0083$), to the critical questionnaire statements (S1–S6) in line with our planned comparisons. To test the differences in the questionnaire responses between Experiments 1 and 2, we used a two-tailed Mann–Whitney U test.

Results

Questionnaire

A summary of the questionnaire results for all statements is provided in Figure 2B and Table 3 (see also Figure 2 in the online supplemental materials). The most notable differences in comparison to the first experiment was that the participants now gave affirmative ratings for sensing ownership of both rubber hands (S6) in the SS condition and that the single-hand illusion strength was more balanced between the left and the right rubber hands. As expected, and highly consistent with the results from the first experiment, the participants provided higher ratings of ownership and referral of touch for the synchronously stroked rubber hand(s) than for the asynchronously stroked ones; furthermore, they gave negative ratings for the control statements. The statistical results for the illusion-related statements (S1–S6) are presented below and in Figure 4.

Illusion for the Medial (Left) Rubber Hand

Regarding the illusion of the left rubber hand (S1 and S2), there was a statistically significant difference in the rating scores for ownership and referral of touch statements in the four main conditions (SS, SA, AS and AA; S1: $\chi^2(3) = 61.7$, $p < .001$, $W = .514$; S2: $\chi^2(3) = 56.116$, $p < .001$, $W = .468$; see Figure 4A and 4B). For both illusory sensations—in line with our predictions—the ratings were significantly higher in the SS condition than in the AS condition (S1: $Z = -4.232$, $p < .001$, $r = .473$; S2: $Z = -4.371$, $p < .001$, $r = .489$) and the AA condition (S1: $Z = -3.039$, $p = .002$, $r = .340$; S2: $Z = -3.45$, $p = .001$, $r = .386$). In terms of the magnitude of ratings, the participants affirmed feeling that the rubber hand on the left was their own when the left rubber hand was synchronously stroked in the SS condition (S1: median = 2; S2: median = 1) and the SA condition (S1: median = 3; S2: median = 2); conversely, they denied this illusory experience when the left hand was asynchronously stroked in the AS (S1: median = −2.5, S2: median = −3) and AA conditions (S1: median = −1.5; S2: median = −2). In addition, we found that the affirmative ratings of left-hand ownership and referral of touch were higher in the SA condition than in the SS condition (S1: $Z = -3.493$, $p < .001$, $r = .390$; S2: $Z = -2.418$, $p = .016$, $r = .270$), although the left rubber hand received synchronous strokes in both of these conditions.

Illusion for the Lateral (Right) Rubber Hand

Regarding the referral of touch and ownership of the right rubber hand (S3 and S4), there was a statistically significant difference in the rating scores of agreement among the four conditions (SS, SA, AS and AA; S3: $\chi^2(3) = 49.718$, $p < .001$, $W = .414$; S4: $\chi^2(3) = 51.216$, $p < .001$, $W = .427$; see Figure 4C and D). Importantly, these ratings were significantly higher in the SS condition than in the SA condition (S3: $Z = -4.824$, $p < .001$, $r = .539$; S4: $Z = -4.090$, $p < .001$, $r = .457$) and the AA condition (S3: $Z = -3.591$, $p < .001$, $r = .401$; S4: $Z = -3.087$, $p = .002$, $r = .345$).

Table 3
Median Values and Interquartile Ranges of Questionnaire Statements for Experiment 2

Statement	Experiment 2 rating median (Interquartile ranges)			
	SS	SA	AS	AA
S1	2 (0 ∼ 3)	3 (2 ∼ 3)	−2.5 (−3 ∼ −0.75)	−1.5 (−3 ∼ 1)
S2	1 (−1.25 ∼ 2)	2 (1 ∼ 3)	−3 (−3 ∼ −2)	−2 (−3 ∼ 0.25)
S3	2 (1 ∼ 3)	−2.5 (−3 ∼ 0)	3 (2 ∼ 3)	0 (−2 ∼ 2)
S4	1 (−0.25 ∼ 2.25)	−3 (−3 ∼ −1)	2 (1 ∼ 3)	−1 (−3 ∼ 1)
S5	2 (1 ∼ 3)	−2 (−3 ∼ 1)	−0.5 (−3 ∼ 1)	−0.5 (−2.25 ∼ 2)
S6	2 (−1 ∼ 3)	−3 (−3 ∼ −1)	−3 (−3 ∼ −1)	−2 (−3 ∼ 1)
S7	−2 (−3 ∼ 1)	−1 (−3 ∼ 1)	−2 (−3 ∼ 1)	−2 (−3 ∼ 0)
S8	0 (−3 ∼ 1)	−2 (−3 ∼ 0)	−2 (−3 ∼ 0)	−2 (−3 ∼ 0)
S9	−3 (−3 ∼ 0)	−2.5 (−3 ∼ 1)	−3 (−3 ∼ −1.75)	−3 (−3 ∼ −1.75)
S10	−2 (−3 ∼ 0)	−3 (−3 ∼ −1)	−2 (−3 ∼ 0.25)	−3 (−3 ∼ −1.75)

Note. SS = both rubber hands synchronously; AA = both rubber hands asynchronously; SA = left synchronously and right asynchronously; AS = left asynchronously and right synchronously.

The participants felt the rubber hand on the right much like their own hand when both rubber hands were synchronously stroked in the SS condition (S3: median = 2; S4: median = 1) and denied this feeling when the right rubber hand was asynchronously stroked in the SA (S3: median = −2.5; S4: median = −3) and AA conditions (S3: median = 0; S4: median = −1). The relatively small differences in ratings between the SS (S3: median = 2; S4: median = 1) and AS conditions (S3: median = 3; S4: median = 2) on referral of touch (S3: $Z = -2.269$, $p = .023$, $r = .254$) or ownership of the right rubber hand (S4: $Z = -1.674$, $p = .094$, $r = .187$) did not survive Bonferroni correction ($p = .0083$).

Supernumerary Rubber Hand Illusion

Regarding the supernumerary rubber hand illusion involving both rubber hands (S5 and S6), there was a statistically significant difference among the four conditions (SS, SA, AS and AA; S5: $\chi^2(3) = 43.629$, $p < .001$, $W = .364$; S6: $\chi^2(3) = 56.867$, $p < .001$, $W = .474$; see Figure 4E and F and Figure 4 in the online supplemental materials). Importantly, for both sensing touch on both rubber hands and dual-hand ownership, there were significantly higher ratings in SS (S5: median = 2; S6: median = 2) than in SA (S5: median = −2; S6: median = −3; S5: $Z = -5.028$, $p < .001$, $r = .562$; S6: $Z = -4.661$, $p < .001$, $r = .521$) conditions, in SS than in AS conditions (S5: median = −.5; S6: median = −3; S5: $Z = -4.598$, $p < .001$, $r = .514$; S6: $Z = -4.951$, $p < .001$, $r = .554$), and in SS than in AA conditions (S5: median = −.5; S6: median = −2; S5: $Z = -3.737$, $p < .001$, $r = .418$; S6: $Z = -4.217$, $p < .001$, $r = .471$). Furthermore, the participants affirmed both dual-hand ownership (S6) and referral of touch to both artificial hands (S5) in the SS condition (S5: median = 2; S6: median = 2) and provided negative median rating scores for these statements in the other conditions. Collectively, these questionnaire results suggested that the participants experienced a vivid supernumerary hand illusion in the SS condition in Experiment 2.

Midline Bias Index: Comparing the Questionnaire Ratings Across Experiments 1 and 2

We theorized that the change in real hand position between the experiments, from a more medial position in Experiment 1 to further from the body midline in Experiment 2, would have significant effects on the supernumerary hand illusion by better balancing the single-hand illusions across the two rubber hands. To test for a significant effect of the hand position manipulation with respect to the bias in illusion strength for the fake hand placed closest to the body midline, we computed a "midline bias index" (MBI) based on our questionnaire data [(S1 + S2) − (S3 + S4)]. S1 + S2 equals the general illusion feeling (tactile feeling + ownership feeling) on the left rubber hand, whereas S3 + S4 refers to the feeling on the right rubber hand. A positive MBI value suggested that participants had a stronger illusion for the left rubber hand than for the right rubber hand, and a negative MBI value indicated the opposite, that is, a relatively stronger illusion for the right rubber hand.

In this post hoc analysis, we directly compared the MBI between Experiments 1 and 2 for the four main conditions (see Figure 5). We applied the Mann–Whitney U test to the MBI ($N = 80$). We found a significantly greater MBI in Experiment 1 than in Experiment 2 in our main SS condition ($N = 80$, $W = 1.006$; $p = .043$, $r = .227$) as well as in the AS condition ($N = 80$, $W = 1.018$; $p = .036$, $r = .235$) and the AA condition ($N = 80$, $W = 995$, $p = .044$, $r = .228$). No significant difference was found in MBI between the two experiments in the SA condition ($N = 80$, $W = 865$, $p = .532$, $r = .070$). Collectively, these results suggested that our manipulation of hand position with regard to the midline in Experiment 2 successfully reduced the midline bias in Experiment 1, which was evident in the data from the SS, AS and AA conditions.

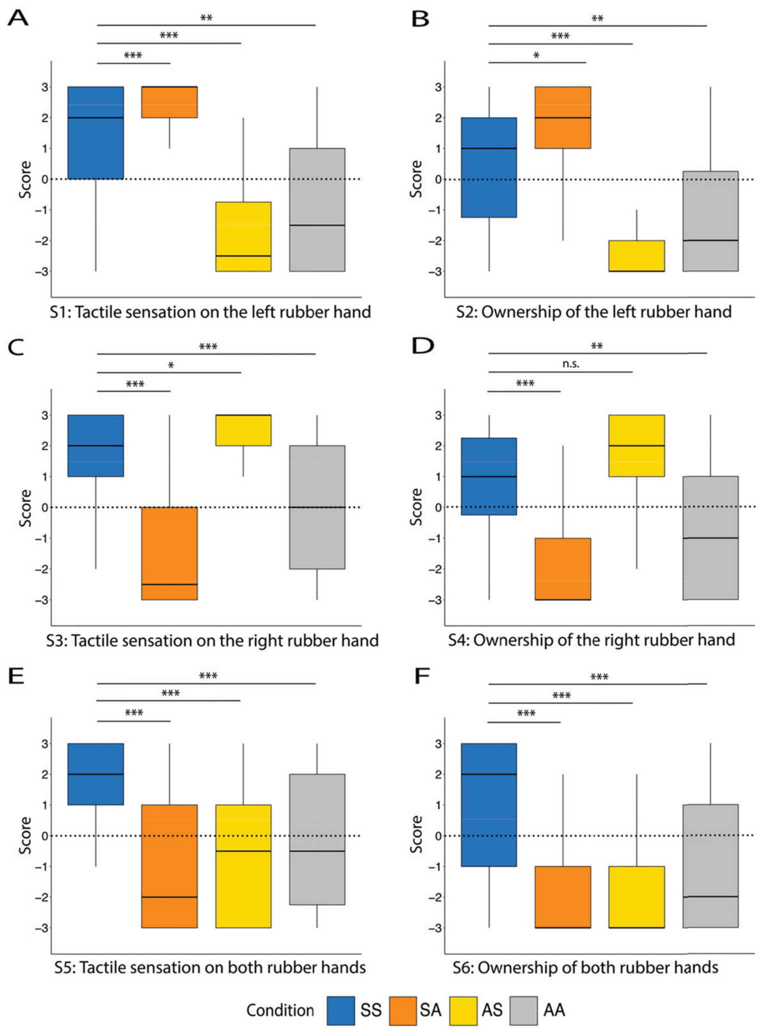
Next, we examined whether the supernumerary hand illusion was statistically significantly stronger in Experiment 2 than in Experiment 1. Contrasting the ratings for touch sensations on both rubber hands (S5) and dual-hand ownership (S6) ratings in a descriptive post hoc approach across experiments, using a Mann–Whitney (two-sided) test, revealed significantly stronger S6 ratings ($Z = 2.7149$; $p = .006$, $r = .304$) and a trend for stronger S5 ratings ($Z = 1.945$, $p = .052$, $r = .217$) in Experiment 2.

Summary

The questionnaire results from Experiment 2 showed that participants experienced the supernumerary hand illusion in the SS condition. The ratings of dual-hand ownership (S6) and duplicated touch sensations on the two model hands (S5) were both

Figure 4

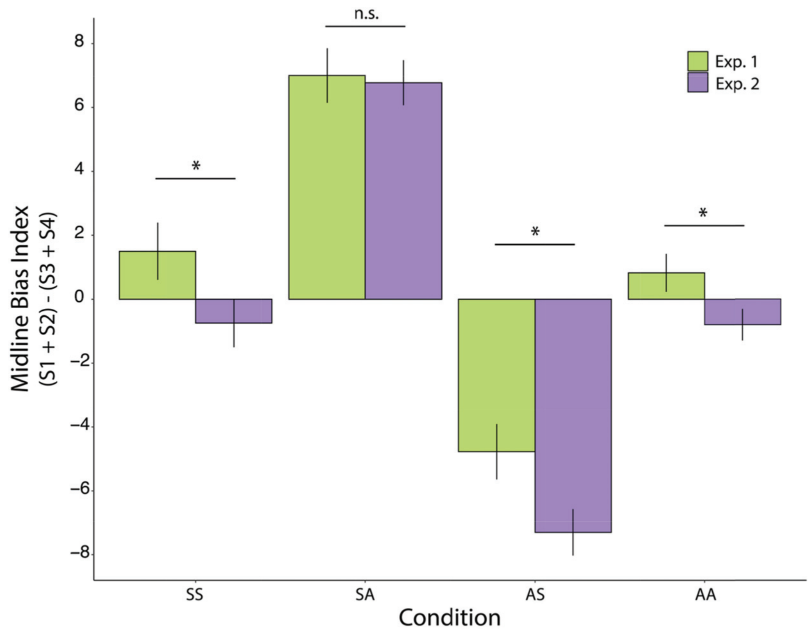
Boxplots of Questionnaire Results From Experiment 2



Note. (A) Questionnaire results regarding referral of touch to the left rubber hand (S1). The rating scores in both the two rubber hands synchronously (SS) and left synchronously and right asynchronously (SA) conditions confirmed the tactile sensations on the left rubber hand, while in the left asynchronously and right synchronously (AS) and both hands asynchronously (AA) conditions, the participants denied this experience. (B) Questionnaire results regarding ownership of the left rubber hand (S2). Affirmative rating scores were higher in both the SS and SA conditions than in the AS and AA conditions, which were both negative. (C) Questionnaire results regarding referral of touch to the right rubber hand (S3). The rating scores in both the SS and AS conditions confirmed the participants' referral of touch to the right rubber hand. (D) Questionnaire results regarding the feeling of ownership of the right rubber hand (S4). (E) Questionnaire results regarding referral of touch to both rubber hands at the same time. Only in the SS condition did the rating scores positively confirm that the participants sensed touches located on both rubber hands. (F) Questionnaire results regarding body ownership of both rubber hands. Only the scores in the SS condition positively confirmed that the volunteers experienced ownership of both rubber hands. The rating scores for referral of touch and ownership were both significantly higher in the SS condition than in the other three conditions. The boxplots depict the data based on their median (thick black line), the upper and lower quartiles (upper and lower ends of boxes) and the whiskers that indicate the minimum or maximum (thus illustrating variability outside the quartiles). For individual data points and the distribution of the data, see Figure 2 in the online supplemental materials; for individual pairwise comparison lines, see Figure 4 in the online supplemental materials. n.s. = not significant.

* $p < .05$. ** $p < .01$. *** $p < .001$ (two-tailed, uncorrected *p-values*).

Figure 5
Comparisons of the Midline Bias Index in Experiments 1 and 2



Note. Body midline bias index based on the questionnaire data [(S1 + S2) – (S3 + S4)] displayed per condition ($M \pm SE$) in Experiments 1 and 2. We observed significant differences in the midline bias index between experiments in the both rubber hands synchronously (SS), left asynchronously and right synchronously (AS), and both hands asynchronously (AA) conditions but not in the left synchronously and right asynchronously (SA) condition. Asterisks indicate a significant difference between conditions. n.s. = not significant.
* $p < .05$.

affirmative in this condition, and these ratings were significantly higher in the SS condition than in the other conditions involving the rubber hand illusion with a single hand (SA and AS) or no illusion (AA). The illusion for single-hand ownership (S2 and S4) and touch sensations (S1 and S3) were more balanced in the SS condition in Experiment 1, with a significant reduction in the bias toward the medially placed left rubber hand that had been observed in Experiment 1. Furthermore, illusory dual-hand ownership (S6) was significantly stronger in Experiment 2 than in Experiment 1. Thus, although the questionnaire results from Experiments 1 and 2 are generally consistent, it seems as if the spatial arrangement of rubber hands and real hand used in the second experiment was more effective in inducing a vivid supernumerary rubber hand illusion.

Experiment 3

Method

Unless otherwise stated, all methods were identical to Experiment 2.

Participants

All participants were naïve to the purpose of our experiments. In Experiment 3A, we tested 45 participants (25 females; age: 28.73 ± 7.77 y, $M \pm SD$; nine participants were excluded from the SCR data analysis as "nonresponders" due to reasons and criteria described in the Procedures section below); Experiment 3B involved 41 participants (24 females; age: 28.83 ± 6.66 y, $M \pm SD$; five participants were excluded from the SCR data analysis); and Experiment 3C tested 50 participants (27 females; age: 29.3 ± 6.58 y, $M \pm SD$; 14 participants were excluded from the data analysis). For the SCR experiments, data were collected until we had reached the predetermined target of 36 "responders," a number that was chosen because it is the number closest to 40 (Kalckert & Ehrsson, 2014a) that allows for perfect matching of the order of the conditions across participants (see below).

Procedure

Experiment 3 (A–C) concerned the objective physiological measure of the illusion by registering SCRs evoked by physical "threats" toward the rubber hands. The SCR reflects increased sweating attributable to the activation of the autonomic nervous system (Dawson et al., 2007). When the body is physically threatened, the threat triggers feelings of fear and pain anticipation and the associated autonomic arousal that can be registered as an SCR some seconds after the threat event. The difference in "threat-evoked SCR" between two well-matched conditions has been shown to be a reliable index of body ownership in the rubber hand illusion paradigm (Gentile et al., 2013; Guterstam et al., 2013; Petkova & Ehrsson, 2009). In the current experiments, the threat stimuli consisted of the prick of a needle ('needle sting'; based on Ehrsson et al., 2008) to the middle finger of one of the rubber hands (right rubber hand in Experiment 3A and left in Experiments 3B and 3C). For the needle sting, the experimenter makes a small movement of a needle attached to a syringe (diameter of needle: .8 mm; length of syringe: 160 mm) directly toward the middle finger of one of the two rubber hands so that the needle slightly touches the rubber skin and stings it gently. This procedure provided a threat that was spatially restricted and precise and targeted the central area of each rubber hand. In line with this, we also applied the brushstrokes to the middle fingers of the rubber hands and the participant's real right hand (instead of the index fingers, as in Experiments 1 and 2). The total number of trials in each SCR experiment was nine, and we included the three most important conditions in each experiment (SS, SA and AA conditions in Experiments 3A and 3C and SS, AS and AA conditions in Experiment 3B). SCRs are subject to attenuation effects over repeated threats, so minimizing the number of conditions in each experiment was important to ensure the quality of the data. The needle sting was delivered immediately at the end of each one-minute trial in the three experimental conditions. The needle sting procedure took approximately 4 seconds in total (presentation of the syringe, stinging the middle finger and retracting the syringe). All three conditions were repeated three times. The order of the conditions was counterbalanced among the participants. From an ethics perspective, it should be pointed out that the threat procedure was completely risk-free. Moreover, we informed the participants that we would never threaten their real hands, and they were familiarized with the needle and the needle-sting procedure before the actual experiment commenced.

Registration of SCR

SCRs were recorded with a Biopac System MP150 (Goleta, U.S.A.). Two electrodes were attached to the index and middle fingers of the participant's left hand. We collected the data at a sample rate of 100 Hz. The experimenter flagged the exact timing of the "needle-sting" event in the recording data file by pressing a foot pedal. The participants who did not display detectable SCRs (i.e., there was a $< .1$ μS peak amplitude change from the preceding baseline in the 10-s time window from the onset of syringe presentation) in more than two thirds of the threat trials were excluded from the SCR data analysis (Petkova & Ehrsson, 2009). Considering the large variability in SCR amplitudes across individuals, each SCR amplitude value was divided by the maximum SCR amplitude detected for that individual during the experiment (Dawson et al., 2007; Lykken et al., 1966). The average of all responses for each participant, including those in which no increase in amplitude could be identified, was separately calculated for each condition, and this value was taken as the SCR magnitude (Dawson et al., 2007). This normalized SCR magnitude was then statistically compared across the different conditions.

Data Analysis

We set the significance threshold to $p < .05$ for the statistical analysis. The SCR results from Experiments 3A, 3B and 3C were normally distributed and passed the Shapiro-Wilk normality test (p values $>$ .05). We used the paired sample t test (two-tailed) to analyze the SCR results in accordance with our a priori planned comparisons in Experiment 3A–C. Specifically, in Experiment 3A, these comparisons were SS versus SA and SS versus AA; in Experiment 3B, SS versus AS and SS versus AA; and in Experiment 3C, SS versus AA and SA versus AA. Additional comparisons were conducted post hoc and reported for descriptive purposes. We used RStudio 3.6.1 for the statistical analyses (R Core Team, 2019).

Results

Skin Conductance Responses

In Experiment 3A (N = 36), we applied the needle sticks to the right rubber hand (Figure 6A; Figure 5 in the online supplemental materials, top row), and in line with our hypothesis, we observed significantly greater SCRs in the SS condition than in the SA condition, $t(35) = 2.5584$, $p = .015$, Cohen's $d = .506$, 95% CI [.02, .179], and in the SS condition than in the AA condition, $t(35) = 3.1686$; $p = .003$, Cohen's $d = .7$, 95% CI [.045, .207]. These results provided objective physiological evidence for the supernumerary hand illusion and indicated that this effect can be differentiated from single-hand ownership with the current threat-evoked SCR approach.

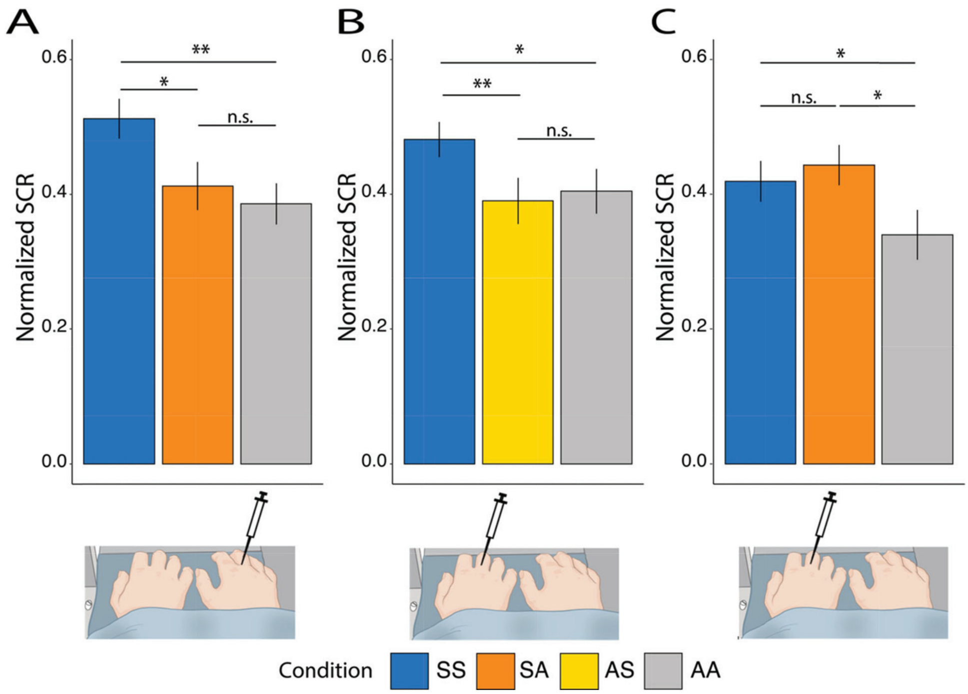
In Experiment 3B ($N = 36$), we changed the target of the needle threat to the left rubber hand and tested the SS, AS, and AA conditions (Figure 6B; Figure 5 in the online supplemental materials, middle row). As hypothesized, we observed significantly greater SCRs in the SS condition than in the AS condition, $t(35) = 2.0821$, $p = .008$, Cohen's $d = .5$, 95% CI [.02, .15], and significantly greater SCRs in the SS condition than in the AA condition, $t(35) = 2.508$, $p = .017$, Cohen's $d = .43$, 95% CI [.01, .13]. These results were consistent with the findings from Experiment 3A and thus corroborated the psychophysiological evidence for the supernumerary hand illusion.

In Experiment 3C ($N = 36$), we used the same three conditions as in Experiment 3A (SS, SA, and AA conditions) but threatened the left rubber hand (Figure 6C; Figure 5 in the online supplemental materials, lower row). Consistent with our hypothesis and the above results, we observed significantly greater SCRs in the SS condition than in the AA condition, $t(35) = 2.28$, $p = .028$, Cohen's $d = .4$, 95% CI [.008, .149], and significantly greater SCRs in the SA condition than in the AA condition, $t(35) = 2.690$, $p = .01$, Cohen's $d = .511$, 95% CI [.025, .181]. These results provided further support for our main conclusion and additionally confirmed the effectiveness of the single-hand ownership manipulation in the current paradigm (AS vs. AA).

Summary

The SCR data from Experiments 3A–3C provided objective physiological evidence that each of the two rubber hands was being represented as part of the participant's own body in the SS condition. Critically, we observed significantly stronger SCRs when stinging the *right* rubber hand in the SS condition than when stinging this hand in the SA and AA conditions (Experiment 3A) and significantly stronger SCR when stinging the *left* rubber hand in the SS condition than when stinging this hand in the AS or AA conditions (Experiment 3B). Moreover, the results confirmed that when applying synchronous visuotactile stimulation to one of the rubber hands and asynchronous stimulation to the other, the synchronously stimulated rubber hand was associated with significant increases in threat-evoked SCR, confirming successful indication of the classic rubber hand illusion with one hand in the current

Figure 6
Skin Conductance Response (SCR) Results From Experiments 3A–3C



Note. The normalized SCR magnitude ($M \pm SE$) is displayed for each of the three conditions that was included in each of the three experiments. (A) SCR results from Experiment 3A. The middle finger of the right rubber hand was stung by a needle after a period of synchronous brushing eliciting the supernumerary hand ownership illusion (both rubber hands synchronously [SS] condition) or asynchronous brushing when experiencing ownership only of the left hand (left synchronously and right asynchronously [SA] condition) or no illusion for either rubber hand (both hands asynchronously [AA] condition). (B) SCR results from Experiment 3B. The middle finger of the left rubber hand was stung by the needle after the SS, left asynchronously and right synchronously (AS), or AA condition. In these two experiments, we observed a significantly stronger SCR magnitudes in the SS condition than in the two other conditions for needle threats applied to either model hand, which provides physiological evidence in support of our main hypothesis regarding the existence of the supernumerary rubber hand illusion. (C) SCR results from Experiment 3C. The left rubber hand was stung by the needle after the SS, SA and AA conditions. As expected, we observed significantly greater SCR magnitudes in the two conditions with synchronous stimulation applied to the left hand (SS and SA) than in the AA condition. Asterisks indicate a significant difference between conditions. For individual data points pairwise comparison lines, see Figure 5 in the online supplemental materials. n.s. = not significant.
* $p < .05$. ** $p < .01$.

paradigm (Experiment 3C). Collectively, these physiological results were consistent with the questionnaire results reported in Experiments 1 and 2 and thus provided an important objective validation of the supernumerary illusion phenomenon.

General Discussion

In the current study, we revisited the question of whether it is possible to elicit a supernumerary rubber hand illusion. To this end, we developed a modified version of the original setup with two right rubber hands (Ehrsson, 2009) and used an experimental design that allowed us to isolate supernumerary hand ownership from single-hand ownership. Both the questionnaire results and the threat-evoked SCR results demonstrated that the application of synchronous strokes to both rubber hands (SS) induced ownership over *both* artificial hands compared with the conditions in which we applied asynchronous strokes to one rubber hand and the real hand (SA and AS) or asynchronous strokes to both fake hands (AA). These results are important because they resolve a discussion in the literature about whether the rubber hand illusion is restricted to one model hand by establishing that the supernumerary rubber hand illusion is a genuine body illusion. Conceptually, this finding is significant because first, it shows that the dynamic flexibility of body representation goes beyond the constraints of the human body plan in terms of number of limbs; second, it indicates that the everyday experience of having four limbs that most people have is not an automatic "default" but the result of active integrative processes in the brain that are binding visual, tactile, proprioceptive signals into a coherent multisensory bodily experience that is most consistent with current sensory inputs; and third, it suggests that the process of causal inference in multisensory own-body perception (Ehrsson & Chancel, 2019; Fang et al., 2019;

Kilteni et al., 2015; Samad et al., 2015) is highly influenced by the spatiotemporal pattern of bottom-up sensory information and allows for highly unusual causal structures that apparently violate prior experience of the human body. From an applied perspective, our results are relevant for emerging technologies and applied research into embodiment of supernumerary prostheses and wearable robotic extra arms by providing a proof-of-principle that it might be possible for users to experience such devices as part of their own body.

Evidence Supporting the Existence of the Supernumerary Rubber Hand Illusion

The current experiments were designed to address the critical points raised by Folegatti, Farne, Salemme & de Vignemont (Folegatti et al., 2012) and to overcome the inherent limitations of the Ehrsson (Ehrsson, 2009) study. In the latter, Ehrsson revealed a significant difference in threat-evoked SCRs between a condition where synchronous strokes were applied to the two rubber hands and the real hand (SS) and a condition with asynchronous strokes (AA) delivered to the two model hands. However, no control condition with ownership of one of the two rubber hands was included, and no questionnaire data were collected, which left open the possibility that only one of the two rubber hands was perceived as owned and that the "spatial resolution" of the SCRs was too low to differentiate between threats applied to each of the two rubber hands (Folegatti et al., 2012). This latter concern is not unreasonable given that both model hands are presented within a perihand space from the real hand, which is a "safety zone" around the body in which threatening stimuli elicit augmented emotional defense reactions (Brozzoli et al., 2014; Ehrsson et al., 2007; Graziano & Cooke, 2006). Importantly, the questionnaire results—especially those from Experiment 2—together with the SCR results from Experiment 3A–3C refute these previous concerns. The latter experiments showed that the threat-evoked SCR approach has sufficient spatial resolution to differentiate between the illusion for two adjacently placed rubber hands, as is evident from the significant differences in SCRs for the AS versus AA conditions and SA versus AA conditions. More importantly, by threatening the asynchronously stimulated rubber hand in the SA and AS conditions in Experiments 3A (right) and 3B (left), respectively, and comparing these SCRs with those evoked when the corresponding rubber hand was threatened in the SS condition, we could eliminate any possible "spreading effect" of the SCRs between the two rubber hands and thus reveal SCR increases that are specific to ownership of each of the two right rubber hands. Our questionnaire results from Experiment 2 were also very important in this respect because they demonstrated significantly greater affirmative ratings for the statements we designed to directly describe dual-hand ownership (S6) and dual referral of touch (S5) in the SS condition compared with the conditions in which only one rubber hand was synchronously stroked (AS, SA). Finally, our study had a larger sample size than previous studies, which reduced the risk of false positive and false negative findings. Based on the sample size calculation, the valid number of participants would be 34 (effect size = .5, two-tailed, significance level = .05, power = .8). Our sample size was 36 in Experiments 3A, 3B, and 3C, which suggests that our statistical results should be reliable. Thus, based on the considerations discussed above, we conclude that a genuine supernumerary rubber hand illusion can be identified.

Multisensory Processes That Mediate the Supernumerary Hand Illusion

The classical rubber hand illusion is often explained within a theoretical framework of multisensory integration in which a coherent multisensory representation of one's own arm is dynamically formed based on the available visual, tactile, proprioceptive and other sensory signals (Ehrsson, 2012, 2020; Ehrsson & Chancel, 2019; Ehrsson et al., 2004; Fang et al., 2019; Kilteni et al., 2015; Samad et al., 2015). According to such theories, multisensory perception involves determining which sensory signals to combine and which to not combine, that is, solving the multisensory binding problem by inferring the causal structure responsible for generating the multisensory signals (causal inference; Dokka et al., 2019; Ehrsson & Chancel, 2019; Fang et al., 2019; Kayser & Shams, 2015; Kording et al., 2007; Litwin, 2019) and then combining the relevant sensory signals according to relative reliability (optimal integration; Ernst & Banks, 2002; van Beers et al., 1999). These processes are dynamic and influenced both by prior information (previous experience and innate factors) and information derived from the afferent sensory signals in terms of temporal and spatial correlations and other forms of multisensory congruence patterns. From this perspective, the rubber hand illusion thus occurs as a consequence of the brain inferring that the rubber hand is the most likely cause of the tactile, visual, proprioceptive and other sensory impressions one is experiencing, which leads to the fusion of the unisensory signals into a coherent multisensory perception of a single own hand (Ehrsson, 2012, 2020; Ehrsson & Chancel, 2019). However, how does the supernumerary rubber hand illusion fit in this multisensory framework of body ownership? We argue that supernumerary limb illusions can be elicited due to striking flexibility in the causal inference process that allows for causal structures that involve "duplicated" limbs. Thus, tactile and proprioceptive (or other somatic) sensations from the hidden real hand are perceptually fused with the visual impressions of the two rubber hands being stroked, which leads to the multisensory sensation of both model hands as one's own and duplication of the visuotactile stroking events. Critically, we theorize that this illusory supernumerary experience depends on the equal probability of each rubber hand being one's own given the pattern of afferent sensory information and prior experiences of the body. Each right rubber hand—when considered in isolation—did not violate prior knowledge about the shape and human-like appearance of the right upper limb (Guterstam et al., 2013; Tsakiris et al., 2010). In addition, the degree of spatiotemporal congruence of the afferent visual, tactile and proprioceptive signals from the real hand and the two rubber hands were equally consistent with the scenario for ownership of each of the two fake hands in the SS condition. These equal probabilities of top-down and bottom-up factors contributing to illusion induction for the two model hands lead to the causal inference that the pair of rubber hands were both one's own, and multisensory combination consequently occurred for both fake hands. Notably, the current illusion does not violate the humanoid rule that only objects that resemble human body parts can be experienced as own body parts (Ehrsson 2012, 2020; Kalckert et al., 2019; Litwin, 2019; Petkova &

Ehrsson, 2009; Tsakiris & Haggard, 2005; Tsakiris et al., 2010) but provides a special case where two right human-like hands can be experienced as part of one's body at the same time. Arguably, this supernumerary limb experience violates prior knowledge about the human body plan at a whole-body level and the assumption that a specific body part can only be located at a single place at any given moment, but evidently such top-down factors do not constitute strong constraints for the rubber hand illusion. Conceptually, our findings underscore the importance of the pattern analysis of afferent multisensory signals and the relative balancing of different casual scenarios in body ownership, a conclusion that has a bearing on theoretical work regarding the importance of prior information and top-down constraints in the process of causal inference in own-body perception (Ehrsson & Chancel, 2019; Fang et al., 2019; Kilteni et al., 2015; Samad et al., 2015) and multisensory causal inference more generally (Cao et al., 2019; Dokka et al., 2019; Rohe et al., 2019).

The importance of somatosensory signals in the current supernumerary rubber hand illusion should be underscored. Somatic sensations play a critical role in body ownership (Ehrsson et al., 2005; Makin et al., 2008; Scandola et al., 2014; Tsakiris, 2010; Walsh et al., 2011) because the fusion of somatosensory signals with signals from other sensory modalities gives the multisensory representations of limbs and body parts a special phenomenological quality of being part of one's physical self (Ehrsson, 2020; Gallagher, 2000; Tsakiris, 2010). In the present supernumerary rubber hand illusion, participants experienced touch and body ownership from two separate right rubber hands in direct view. Thus, they experienced an unusual multisensory perceptual bodily illusion involving somatic sensations originating from two right upper limbs that both felt like parts of their body. Such a supernumerary limb illusion involves changes in immediate bodily awareness inconsistent with the actual state of the physical body. Therefore, this sensation does not merely correspond to two visual representations of a single limb, as is the case, for example, when one observes two reflections of one's own right upper limb in a pair of mirrors placed at different angles (like in a fitting room). (In mirrors, the visual impressions are reflected back to the person in front of the mirror [Bertamini et al., 2011; Gregory, 1996; Preston et al., 2015], but this normally does not trigger bodily illusions. When observing mirror reflections of one's own right hand in multiple mirrors, it feels as if a single hand is in front of the mirrors, and this feeling is different from the sensation experienced when two spatially and physically distinct artificial right hands feel as if they are as one's own hands, as in the current illusion).

Illusory duplication of touch has been described before in various paradigms (Blankenburg et al., 2006; Geldard & Sherrick, 1972; Petkova & Ehrsson, 2009; Wozny et al., 2008), but a key difference in the current study is that the double referral of touch sensations occurred together with a duplicated ownership experience of a whole hand. The findings of illusory "arm and touch duplication" are somewhat similar to the famous cross-modal illusion often referred to as the "sound-induced flash illusion" (or "double flash illusion"; but occurring in space rather than time), in which participants mistakenly perceive one flash accompanied by multiple auditory beeps as multiple flashes (Shams et al., 2000, 2005; for cross-modal versions of this illusion involving touch, see Wozny et al., 2008). In this audiovisual illusion, participants experience an illusory duplication of visual flashes, presumably attributable to a causal inference process in which two audiovisual events are inferred by the brain (Rohe et al., 2019). In the present study, the participants similarly perceived duplication of their somatically experienced right hand and of visuotactile stroke events on these hands, which might indicate that the same probabilistic principles determine multisensory perception of the external world and one's bodily self.

Not all people experience the rubber hand illusion, and this was the case for the current supernumerary limb illusion; therefore, individual differences are briefly addressed. The supernumerary rubber hand illusion was experienced by 63% of the participants in Experiment 2 who affirmed ($\geq +1$) experiencing ownership of the two rubber hands (S6) in SS (25/40 participants). This proportion of illusion responders is similar to that reported for the rubber hand illusion (Kalckert & Ehrsson, 2014a) and similar also to the number of participants in Experiment 2 that affirmed single-hand ownership for the left artificial hand (S2) in SA and the right artificial hand (S4) in AS (28/40 participants; 70%). Additionally, the stronger the participants felt the single rubber hand illusion for the right ($r_s = .54$, $p < .001$) or the left artificial hand ($r_s = .44$, $p = .005$), the stronger they experienced the supernumerary rubber hand illusion (see Figure 6 in the online supplemental materials). These relationships suggest that similar factors mediate illusion susceptibility in the supernumerary and classic versions of the rubber hand illusion. Individual differences in the rubber hand illusion are likely related to how different brains integrate visual, tactile and proprioceptive signals (Ehrsson, 2020; Horváth et al., 2020) with respect to the spatial and temporal windows of integration (Costantini et al., 2016; Shimada et al., 2014), the binding process (causal inference; Ehrsson & Chancel, 2019; Fang et al., 2019; Samad et al., 2015), and the relative weights assigned to different sensory channels (Chancel & Ehrsson, 2020; Kilteni et al., 2015; Litwin, 2019). Cognitive, postperceptual, factors can also influence how an individual thinks about and consciously interprets the bodily experience, but across individuals, the variability related to these high-level cognitive factors tends to be relatively small and have been observed across conditions and different types of questionnaire statements, including control statements (David et al., 2014; Louzolo et al., 2015; Marotta et al., 2016; Walsh et al., 2015). Notably, trait hypnotic suggestibility explains only between 7 and 9% of the variance in illusion statements and control statements in rubber hand illusion questionnaires (Lush et al., 2020). However, *no* relationship between hypnotic suggestibility and the rubber hand illusion is observed when one considers the *differences* in the illusion statement ratings between synchronous and asynchronous conditions (and a Bayesian analysis supports this null finding; Lush et al., 2020). Because the present conclusions regarding the supernumerary rubber hand illusion are critically based on significant differences in illusion ratings between synchronous and asynchronous conditions, the current findings cannot be explained by hypnotic suggestion, a conclusion that is further corroborated by the SCR results.

Possible Neural Mechanisms

What could be the neuronal mechanisms of the supernumerary hand illusion? In the rubber hand illusion and similar paradigms, the sense of ownership of a single hand has been associated with increases in BOLD activation (Brozzoli et al., 2012; Ehrsson et al., 2004; Gentile et al., 2013; Guterstam et al., 2013; Limanowski & Blankenburg, 2016) and high gamma activity (Guterstam, Collins, et al., 2019) in the premotor cortex and the cortices lining the intraparietal sulcus (IPS). Moreover, in the brains of macaque monkeys, these regions contain neurons that integrate visual and somatosensory information from the upper arm (Fang et al., 2019; Graziano, 1999; Graziano et al., 2000) and activity in the premotor cortex seems to reflect visuoproprioceptive causal inference in hand ownership (Ehrsson & Chancel, 2019; Fang et al., 2019). Therefore, we theorize that the supernumerary rubber hands illusion can also be implemented by active neuronal populations within these premotor-parietal areas. Anatomical connections between these areas (Gentile et al., 2013; Guterstam et al., 2013; Limanowski & Blankenburg, 2015) could also play an important role because stroke that damages white fiber matter tracts and associated subcortical gray matter can lead to disturbances in the sense of body ownership (Gandola et al., 2012; Jenkinson et al., 2018; Moro et al., 2016). We theorize that single-cell recordings in nonhuman primates and human fMRI studies employing multivariate pattern analysis should be able to identify the specific neural signatures of the supernumerary rubber hand illusion in the premotor cortex and (perhaps) the intraparietal cortex, and future neuroimaging investigations should examine this hypothesis.

Possible Midline Bias and Placement of Rubber Hands

One of the key ideas behind the paradigms developed in both Ehrsson (Ehrsson, 2009) and Newport, Pearce & Preston (Newport et al., 2010) was that each of the two rubber hands should be equally effective in inducing an ownership illusion (from Ehrsson [2009]; "two equally probable locations of the right arm," and from Newport et al. [2010]; "were equidistant from the location of the real hand"). These authors assumed that the best way to achieve this illusion was to place the two artificial hands at an equal distance from the real hand, which was the setup we used in Experiment 1 (the distance between the two rubber hands was 10 cm in Ehrsson [2009]; 12 cm in Newport et al. [2010] and 11 cm in our manipulation). However, in Experiment 1, we observed that the rubber hand closest to the midline received significantly ($p < .05$) stronger ownership ratings than the more laterally placed rubber hand when stroked synchronously and that the median ratings for the lateral (right) rubber hand ownership (S4) and dual-hand ownership (S6) in the SS condition were not clearly affirmative, although they were still significantly higher than the median ratings in the asynchronous condition (AA; see Results and Figure 3D and 3F). Based on this observation and earlier reports that the classical rubber hand illusion is stronger for hands placed closer to the body midline than for more lateral locations (Newport et al., 2010; Preston, 2013; Zopf et al., 2010); we made changes in the spatial arrangement of the hands in Experiment 2 to counteract this bias. Specifically, we changed the position of the real right hand so that it was placed more laterally, directly under the right rubber hand. This spatial manipulation worked well, as in Experiment 2, the median questionnaire ratings for the supernumerary rubber hand illusion (S6) and ownership of the most laterally placed rubber hand (S4) were affirmative (positive scores > 1). Moreover, the difference in general illusion strength between the left and right rubber hands (midline bias index: [S1 + S2] – [S3 + S4]) was significantly ($p < .05$) smaller in Experiment 2 than in Experiment 1, providing evidence that our experimental manipulation was effective in reducing the effect of midline bias and achieving a better balance in probabilities of ownership between the two fake limbs (see Figure 5).

The mechanism behind the "midline bias" is still unclear and could relate to several factors. One factor could be prior experience that one's hand is more often in front of the trunk and head than in more lateral locations. This prior knowledge could bias the multisensory integration process of hand ownership in the former part of space. Indeed, we know that the relative weightings of vision and proprioception in visuoproprioceptive integration for hand location differ in different parts of space (van Beers et al., 2002), and similarly, the strength of the rubber hand illusion varies in different parts of space (Kalckert et al., 2019; Preston, 2013). The midline bias could also reflect potential influence by head-centered (Duhamel et al., 1998) and trunk-centered (Hyvarinen, 1981) reference frames in addition to multisensory integration in arm-centered coordinates (Brozzoli et al., 2012; Graziano et al., 1997). Finally, it is also relevant to consider the degree of anatomical-postural congruence between the rubber hand and the participant's real arm and shoulder: the relative postural congruence between the real shoulder and upper arm and the "extrapolated" position of the unseen illusory upper arm that is connected to the seen rubber hand changed between Experiments 1 and 2. When the real hand was placed directly under the laterally placed rubber hand in Experiment 2, greater postural congruence was achieved in terms of shoulder and upper-arm postures for the lateral rubber hand than in Experiment 1. Our data cannot differentiate between these different explanations for the spatial "midline" bias, and further studies are needed to reveal the factors that contribute to variations in rubber hand illusion strength in different parts of space. Finally, we should clarify that it is unlikely that the participants' real *left* hand played any role in the current supernumerary hand illusion or in the "midline bias" effects discussed above. We know that the rubber hand illusion only works when the laterality of the rubber hand matches the laterality of the real hand, so in experiments with right rubber hands, as the current illusion, the rubber hand illusion can only be elicited for the right hand (Guterstam et al., 2011; Petkova & Ehrsson, 2009). Moreover, the participant's real left hand was placed too far away from the rubber hands to elicit the illusion (Kalckert & Ehrsson, 2014b; Lloyd, 2007), and this hand did not receive any synchronized visuotactile stroking that is necessary to elicit the rubber hand illusion (Guterstam, Larsson, et al., 2019). In addition, multisensory neurons in the parietal cortex that integrate visual and proprioceptive signals from the upper limb are sensitive to the matching laterality between the seen and felt arms (Graziano et al., 2000). Thus, given the considerations above, we think that it is highly implausible that the representation of the left hand contributed to the current right supernumerary rubber hand illusion.

Conclusion

In summary, the present study presents conclusive evidence that the supernumerary rubber hand illusion does exist and provides new information about the optimal setup for its successful induction. Importantly, our results disambiguate ownership of two right rubber hands from ownership of a single right rubber hand and demonstrate that a subjectively experienced supernumerary limb illusion can arise beyond the perceptual experiences associated with the classical rubber hand illusion. This finding is important because it solves the ongoing debate in the literature and has important theoretical implications for body representation research and work on causal inference in multisensory perception. Additionally, the results bear on current studies of supernumerary robotic limbs and advanced prostheses for amputees and paralyzed individuals because they reveal the conditions under which it could be possible to design such a system with ownership of the extra artificial limb.

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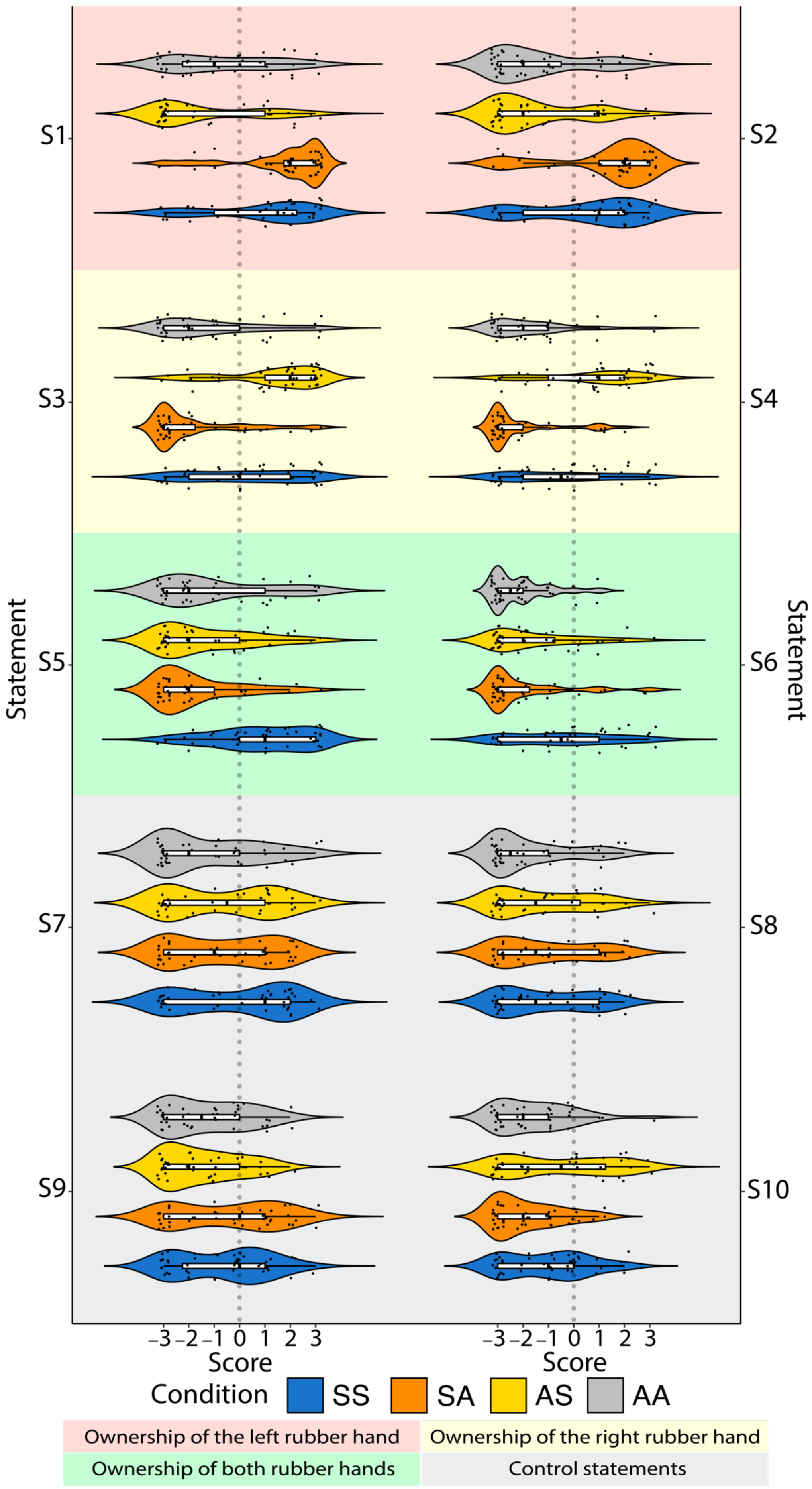
Supplementary Material:

Fan et al. "The supernumerary rubber hand illusion revisited: perceived duplication of limbs and visuotactile events"

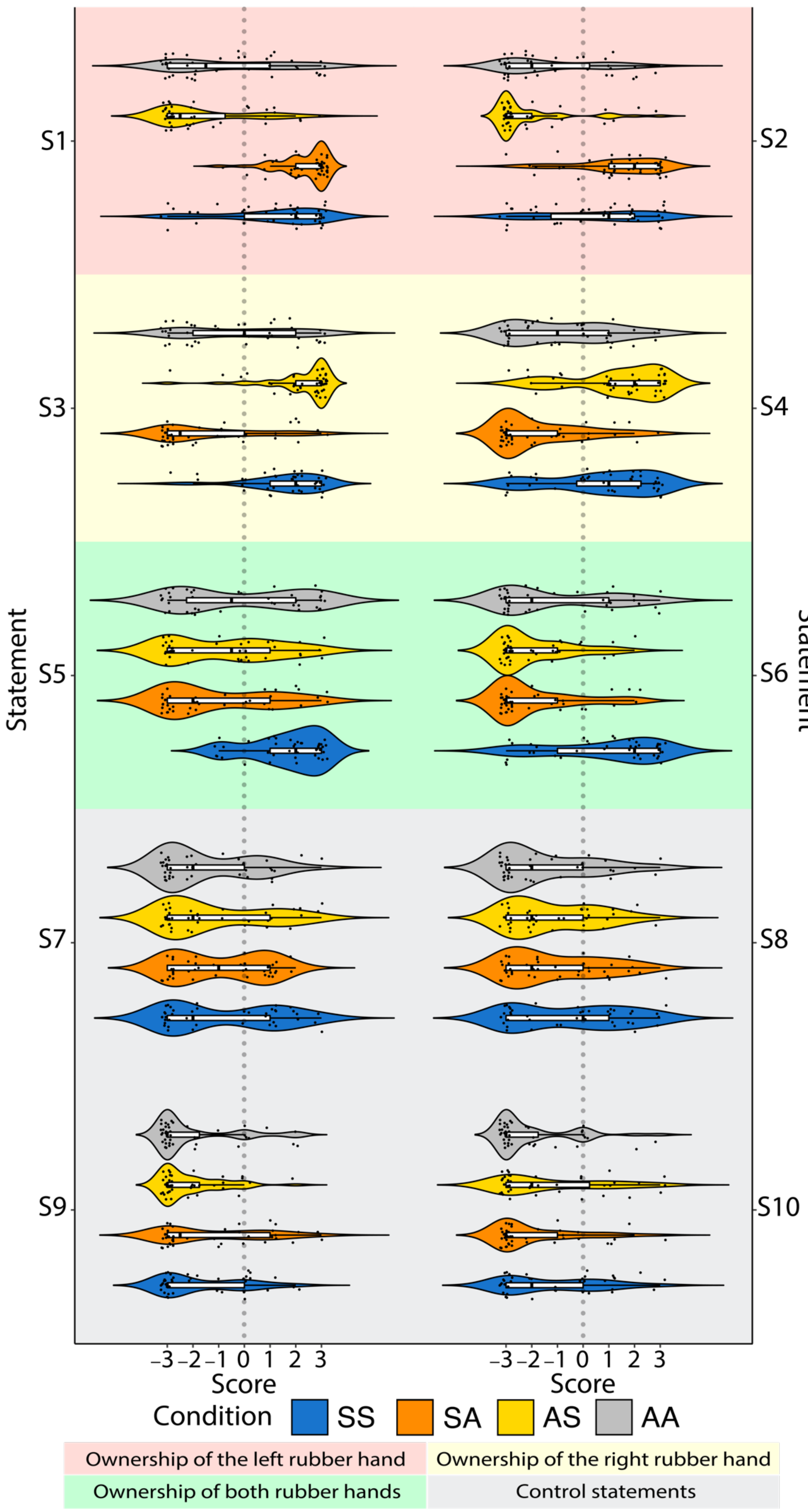
Journal of Experimental Psychology: Human Perception and Performance.

Supplementary Figures 1 to 6.



S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
Statement
Statement
–3 –2 –1 0 1 2 3
Score
–3 –2 –1 0 1 2 3
Score
Condition
SS
SA
AS
AA
Ownership of the left rubber hand
Ownership of the right rubber hand
Ownership of both rubber hands
Control statements

Supplementary Figure 1. Questionnaire results from experiment 1. Individual data points, the distribution of the data (violin plots), and interquartile ranges (box plots) are shown for all statements (S1-S10). The filled "violins" are kernel density estimations that represent the probability that a member of the group will take on the given value; the wider the shape, the higher the probability.


S1
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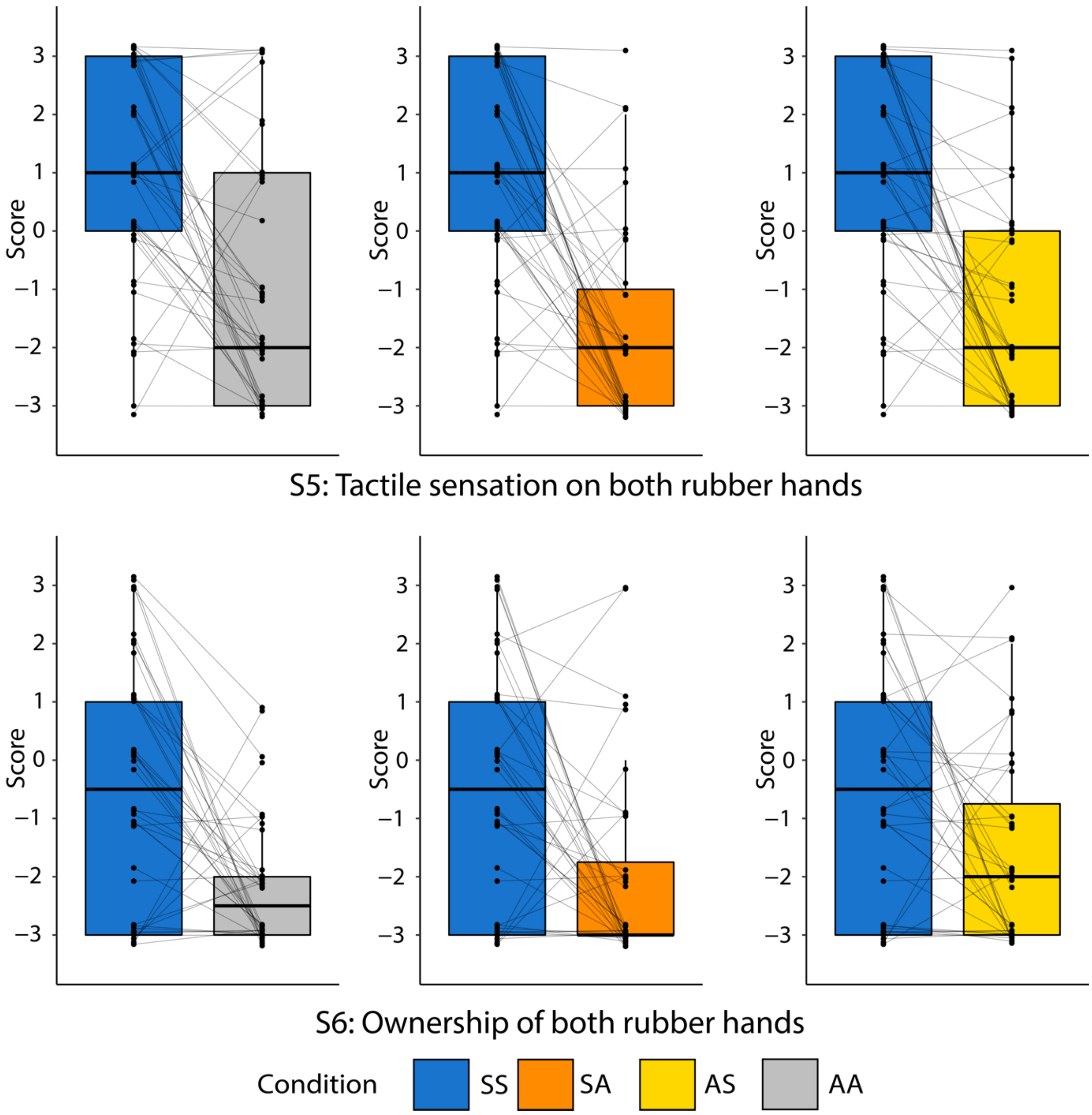
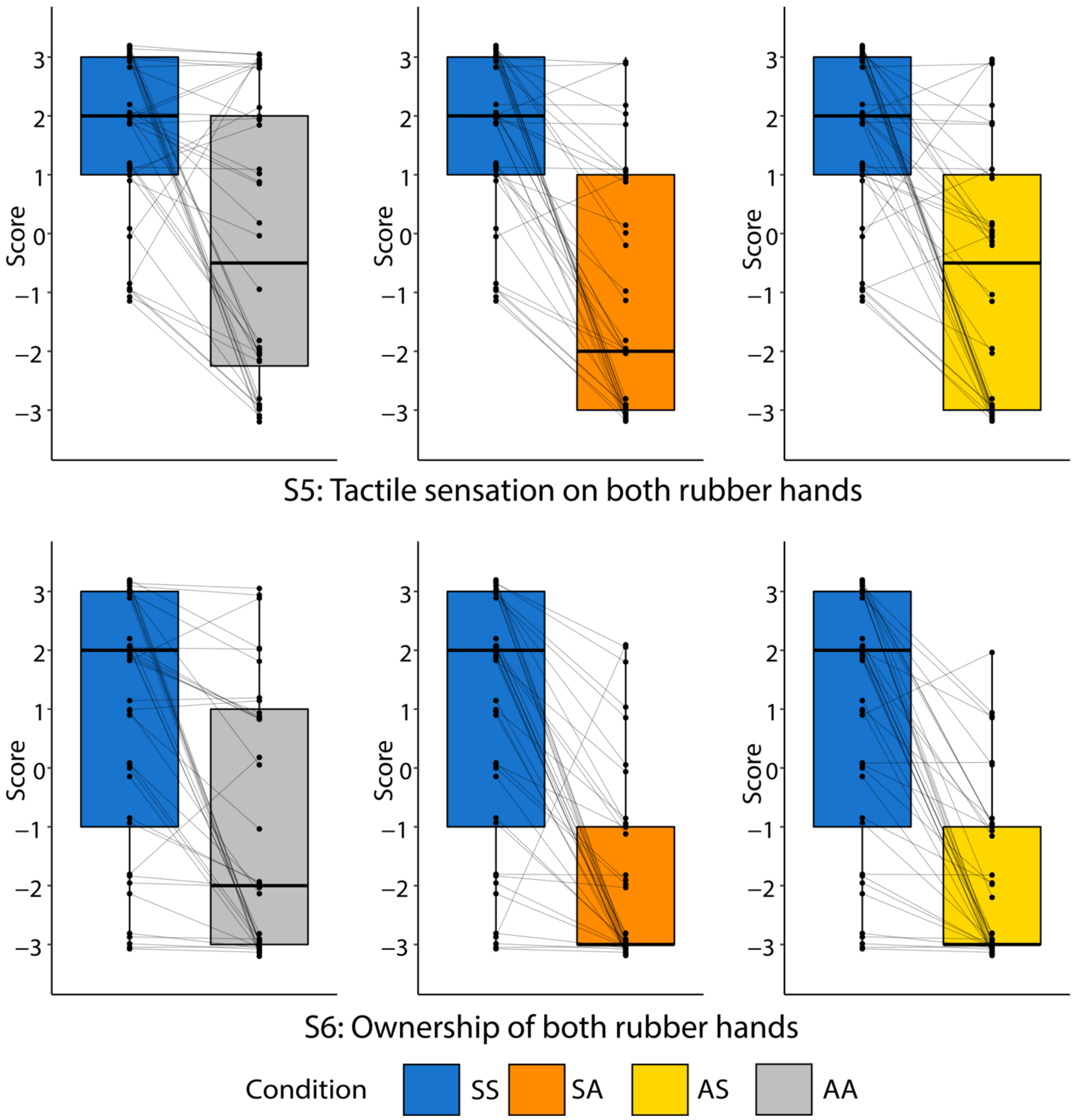
Statement
Statement
−3 −2 −1 0 1 2 3
Score
−3 −2 −1 0 1 2 3
Score
Condition
SS
SA
AS
AA
Ownership of the left rubber hand
Ownership of the right rubber hand
Ownership of both rubber hands
Control statements

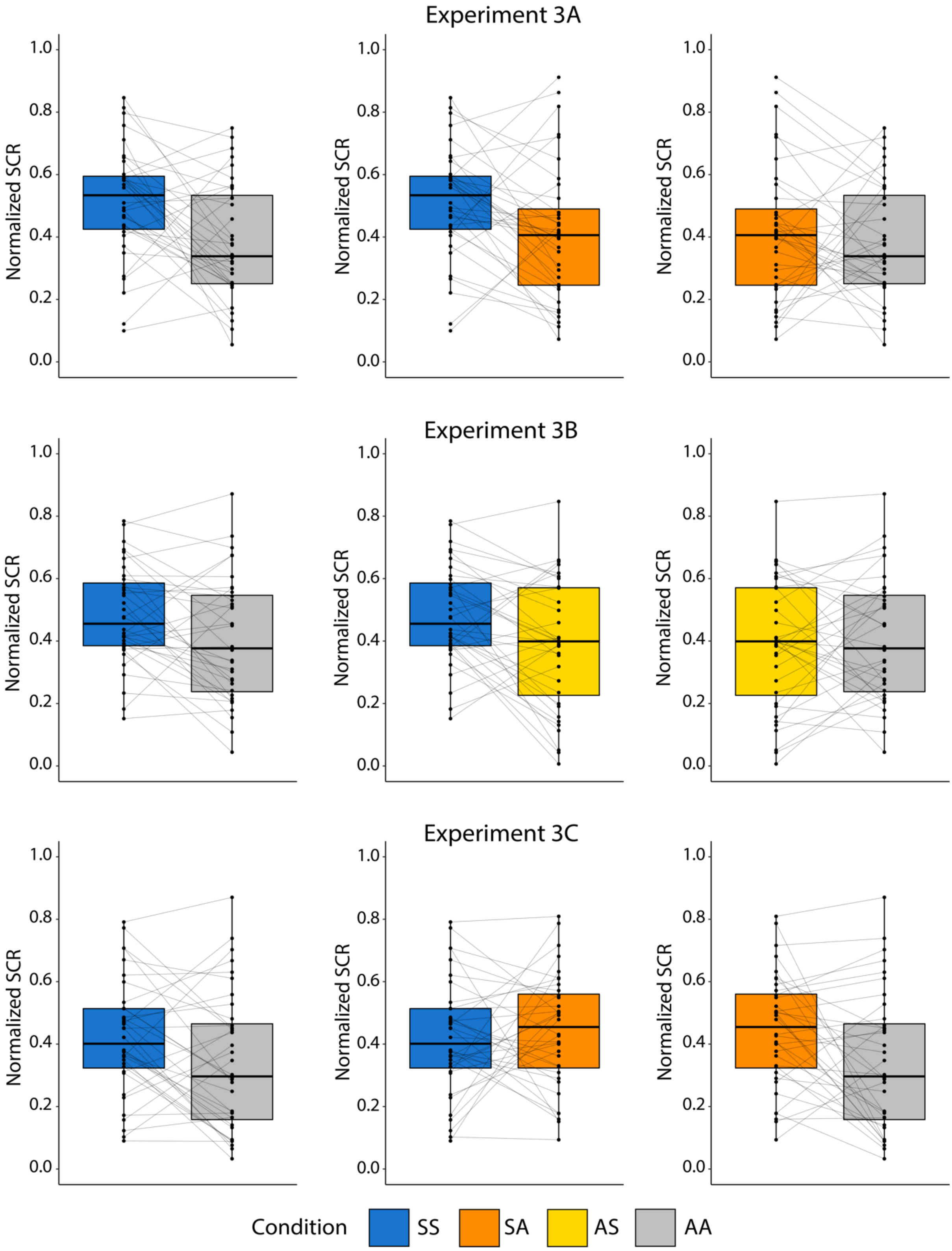
Supplementary Figure 2. Questionnaire results from experiment 2. Individual data points, the distribution of the data (violin plots), and interquartile ranges (box plots) are shown for all statements (S1-S10). The filled “violins” are kernel density estimations that represent the probability that a member of the group will take on the given value; the wider the shape, the higher the probability.



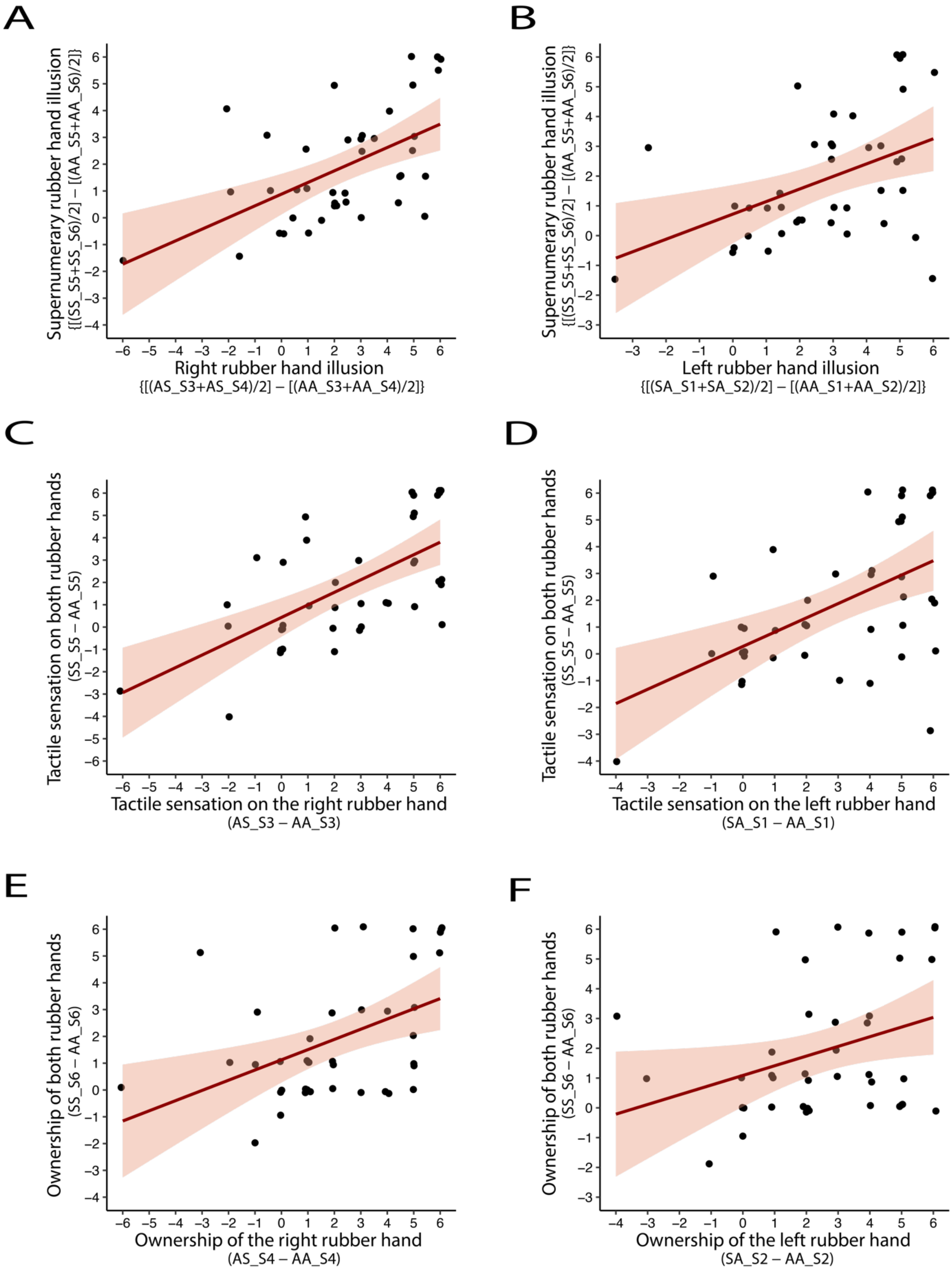
Supplementary Figure 3. Individual pairwise comparison lines for the planned comparisons of questionnaire statements S5 and S6 across conditions in experiment 1. Box plots are also shown (medians and interquartile ranges).



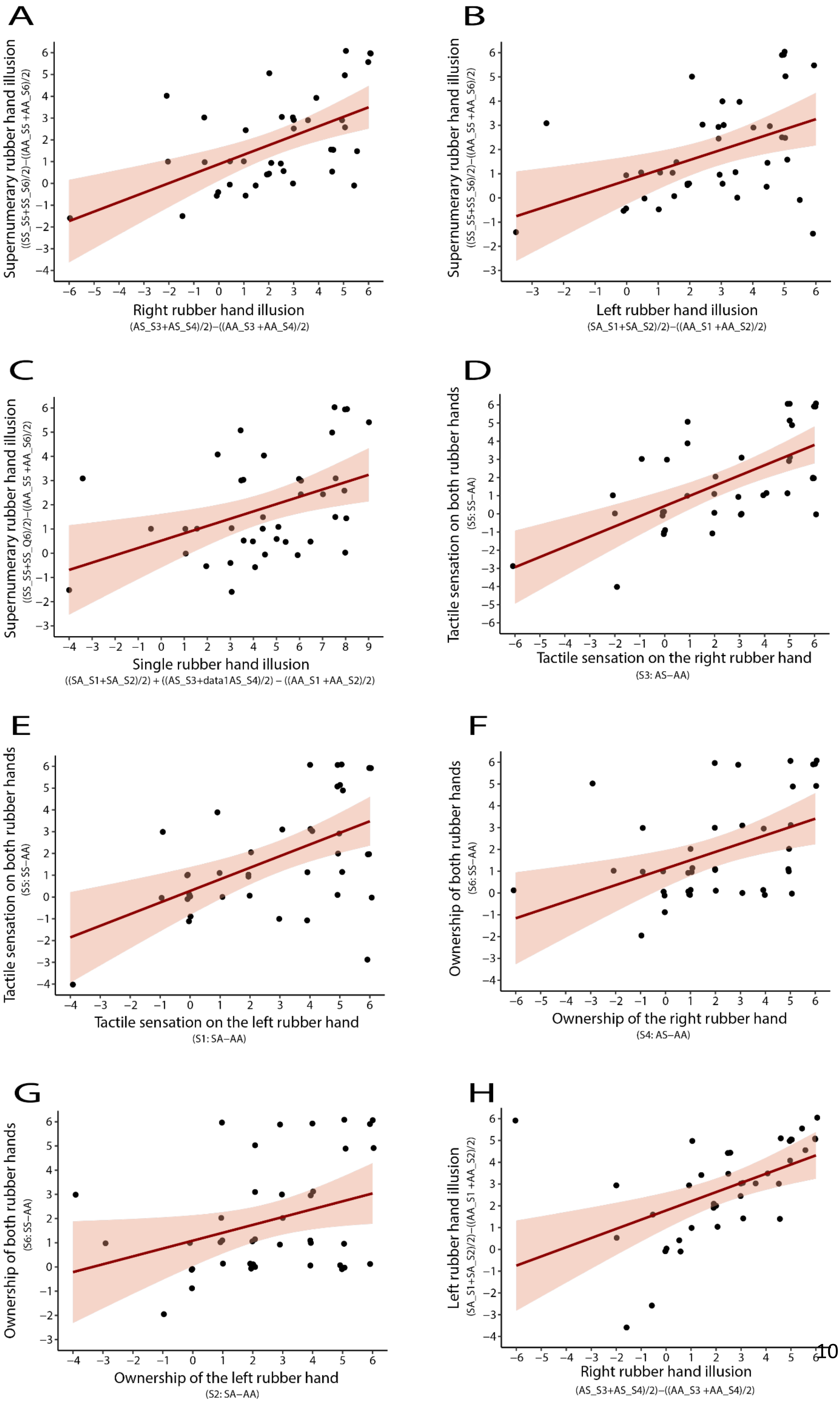
Supplementary Figure 4. Individual pairwise comparison lines for the planned comparisons of questionnaire statements S5 and S6 across conditions in experiment 2 Individual data points and box plots are also shown (medians and interquartile ranges).



Supplementary Figure 5. Individual pairwise comparison lines for the critical statistical tests of the normalized skin conductance response (SCR) data in experiments 3a, 3b, and 3c are displayed. The box plots illustrate medians and interquartile ranges, and these are included for descriptive purposes.



Supplementary Figure 6. The results of the post-hoc Spearman correlation analysis showed a significant positive association between the supernumerary rubber hand illusion and the right rubber hand illusion (r_s= 0.54, p < 0.001; A), and the left rubber hand illusion (r_s= 0.44, p= 0.005; B). Tactile sensations originating from both rubber hands was significantly positively correlated with tactile sensation from the right rubber hand (r_s= 0.61, p < 0.001; C) and with tactile sensation from the left rubber hand (r_s= 0.49, p= 0.002; D). Additionally, the analysis revealed significant positive associations between ownership of both rubber hands and ownership of the right rubber hand (r_s= 0.48, p= 0.002, E). The correlation between the ownership of both rubber hands and the left rubber hand did not reach a level of significance (borderline significance) but showed a clear positive trend in the expected direction (r_s= 0.31, p= 0.05091, F).


A
Supernumerary rubber hand illusion
((SS_S5+SS_S6)/2)−((AA_S5 +AA_S6)/2)
Right rubber hand illusion
(AS_S3+AS_S4)/2)−((AA_S3 +AA_S4)/2)
B
Supernumerary rubber hand illusion
((SS_S5+SS_S6)/2)−((AA_S5 +AA_S6)/2)
Left rubber hand illusion
(SA_S1+SA_S2)/2)−((AA_S1 +AA_S2)/2)
C
Supernumerary rubber hand illusion
((SS_S5+SS_Q6)/2)−((AA_S5 +AA_S6)/2)
Single rubber hand illusion
((SA_S1+SA_S2)/2) + ((AS_S3+data1AS_S4)/2) − ((AA_S1 +AA_S2)/2)
D
Tactile sensation on both rubber hands
(S5: SS−AA)
Tactile sensation on the right rubber hand
(S3: AS−AA)
E
Tactile sensation on both rubber hands
(S5: SS−AA)
Tactile sensation on the left rubber hand
(S1: SA−AA)
F
Ownership of both rubber hands
(S6: SS−AA)
Ownership of the right rubber hand
(S4: AS−AA)
G
Ownership of both rubber hands
(S6: SS−AA)
Ownership of the left rubber hand
(S2: SA−AA)
H
Left rubber hand illusion
(SA_S1+SA_S2)/2)−((AA_S1 +AA_S2)/2)
Right rubber hand illusion
(AS_S3+AS_S4)/2)−((AA_S3 +AA_S4)/2)