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The Effect of Similarities in Skin Texture and Hand Shape on  
Perceived Ownership of a Fake Limb

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Authors' Note

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## Abstract

In the rubber-hand illusion (RHI), people attribute an artificial object to their own body. In the present study, we investigate the extent to which the rubber-hand illusion is affected by visual discrepancies between the artificial object and a human hand. We tested Armel and Ramachandran's (2003) hypothesis that people will experience a stronger RHI when the artificial object is a skin-like textured sheet instead of a tabletop. We did not find support for their hypothesis, but the strength of the RHI diminished when the texture of a hand-shaped object did not resemble the human skin (manipulated by putting a white glove over the cosmetic prosthesis). We provide an alternative explanation for this finding, based on a skill-based sensorimotor account of perceived body ownership. Such an explanation supports Armel and Ramachandran's more general claim that discrepancies in the nature of expected and felt touch diminish the RHI.

Keywords: illusions (perception), body image, visual feedback, sensory integration, kinesthetic perception

The way the body is represented in the brain is not as hard-wired as everyday experience makes us believe. Research on phantom limbs (e.g., Ramachandran & Hirstein, 1998) and experimentally induced bodily illusions (e.g., Lackner, 1988) points toward highly malleable body representations that are shaped through the integration of afferent and efferent information (e.g., Armel & Ramachandran, 2003), modulated by cognitive factors (e.g., Tsakiris & Haggard, 2005) and perhaps by observing other people as well (Brugger et al., 2000; Price, 2006). One paradigm to experimentally investigate how body representations are shaped is the rubber-hand illusion (RHI; Botvinick & Cohen, 1998). In this illusion, a person attributes a fake hand to the body; feeling as if it is actually his or her own. The RHI is induced by having a person watch a fake hand being stroked and tapped in precise synchrony with his or her own concealed hand (see Figure 1A). The RHI illustrates that a few minutes of the right kind of multisensory stimulation can radically alter our sense of bodily boundaries, thereby providing evidence for the malleability of the central nervous system in accommodating perceived bodily alterations. In addition to the subjective experience of body ownership, the RHI also results in a distortion of proprioception. After experiencing the RHI, participants misperceive the location of their concealed hand toward the direction of the fake hand (i.e., proprioceptive drift; Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005).

There is increasing evidence that we distinguish between ourselves and the environment through specific patterns of sensorimotor contingencies (Botvinick, 2004; Lackner, 1988;

Rochat & Striano, 2000; also O'Regan, Myin & Noë, 2005). Every action a person performs (e.g., picking up a cup of coffee) is accompanied by corresponding multisensory impressions (e.g., the visual image of the arm moving toward the cup, or the sensation of warmth and pressure when the fingers touch the cup). These patterns of sensorimotor correlations are exclusively associated with the body and are hence self-specifying: whenever a person senses these sensorimotor correlations, he or she "knows" that the perceived object (e.g., the arm) belongs to the body. In the RHI, people perceive the fake hand as part of their body, because their perception of it matches the body-specific sensorimotor contingencies. If this is no longer the case, for example when participants try to move the fake hand, or when there is a small delay between seen and felt stimulation, the illusion will diminish or break (e.g., Armel & Ramachandran, 2003; Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005).

The strength of the RHI is also considerably diminished when the artificial object is incongruent to the human body, for example when a tabletop (Armel & Ramachandran 2003), a wooden stick (Tsakiris & Haggard, 2005), or a two-dimensional projection of the fake hand is used as the artificial object (IJsselsteijn, de Kort & Haans, 2006), or when the fake hand is in an anatomically incorrect orientation (Ehrsson, Spence & Passingham, 2004; Tsakiris & Haggard, 2005). Relevant in this respect is the finding that neurons in area 5 of the primate parietal lobe, which are thought to be involved in monitoring arm position and movement, respond to an artificial object as well, but only when it resembles a monkey's arm that is

correctly orientated (Graziano, Cooke & Taylor, 2000). These findings suggest that the strength of the RHI depends not only on matching body-specific sensorimotor contingencies, but on the correspondence between the artificial object and a cognitive model of what a human body is like (also de Vignemont, Tsakiris & Haggard, 2006).

In addition, Armel and Ramachandran (2003) argue that discrepancies in the nature of expected and actually felt touch may diminish the RHI. They reported--in an anecdotal fashion--that people experienced a stronger RHI when the tabletop and the real hand were both touched on a band-aid (i.e., a shared texture). They, therefore, conjectured that people will experience a more vivid RHI when the artificial object is a skin-like textured sheet (i.e., resembling the human skin) instead of a tabletop.

In the present study, we further investigate the extent to which the rubber hand illusion is affected by visual discrepancies between the artificial object and a human hand. In contrast to earlier studies (e.g., Tsakiris & Haggard, 2005), we explore the effects of shape and texture independently by systematically manipulating these qualities of the artificial object. With respect to shape, we expect to corroborate existing research which shows that RHI is stronger when the artificial object resembles a human hand (e.g., Armel & Ramachandran, 2003; Tsakiris & Haggard, 2005). In other words, we expect that a hand-shaped object is more easily attributed to the self than a non-hand-shaped object. The effect of texture has, to our knowledge, not yet been empirically examined. However, a similar effect is to be

expected as for shape: people will develop a stronger RHI when the texture of the artificial object resembles the human skin. We, thus, expect to provide empirical support for Armel and Ramachandran's (2003) hypothesis that a skin-like textured sheet would induce a stronger illusion than a tabletop.

## Method

### *Design*

A two (hand vs. no hand shape) by two (natural vs. non-natural skin texture) repeated measures experiment was conducted. For the hand shape with natural texture condition (abbreviated as ST), a cosmetic prosthesis of a man's left hand was used which was highly realistic in terms of skin texture, color, and shape. For the hand shape with non-natural texture condition (S¬T), a white latex glove was fitted over the prosthesis to modify texture and colour, but not shape. For the no hand shape with natural texture condition (¬ST), a flat sheet (size 24 X 13 cm) of the same material as the prosthesis was used (as suggested by Armel & Ramachandran, 2003). Finally, for the no hand shape with non-natural texture condition (¬S¬T), no object was used, thereby leaving only the white tabletop to be stimulated. The ST condition was always in the first session as this condition was used to select only those participants that were susceptible to the original version of the illusion. The order of the remaining three conditions was balanced across participants.

### *Participants*

Our sample was drawn from students and employees of our university. Twenty-six persons participated in the experiment.

Three out of 26 (i.e., 11.5%) did not experience the illusion in the ST condition. Of the remaining 23 participants, the mean age was 22.3 ( $SD = 2.2$ ; range 18 to 27 years); 14 were male; 18 were right handed. All participants received a compensation of € 7.00.

### *Procedure*

Participants were asked to take a seat and place their left hand on a table. First, the experimenter obtained, for each participant, the base-line (i.e., pre-exposure) difference between actual and felt position of the left hand. For this task, the experimenter asked the participant to close his or her eyes. Subsequently, the experimenter placed a small table (30 by 80 cm with a height of 24 cm) over the participant's left hand (see Figure 1B). Next, the experimenter guided the participant's right hand to the right most edge of the small table (from the participant's point of view), and instructed the participant to slide his or her hand over the table to indicate the *felt* position of the left hand. The differences between actual and felt position were calculated by taking the lateral distance between the middle fingers of the right and the left hand. This distance was coded with a positive sign when the felt position of the left hand was towards the participant's right-hand side. The procedure was repeated two more times, so that three difference measurements were obtained for each participant.

The experimenter removed the table, and instructed the participant to move his or her hands for a while. Next, the rubber-hand illusion was induced in four five minute sessions. At the beginning of each session, the experimenter placed an

artificial object in front of the participants. The participants were asked to place their left hand back on the table (30 cm from the artificial object) and to keep it motionless during the session (see Figure 1A). Next, the experimenter placed a wooden screen between the participant's left hand and the artificial object. Finally, the experimenter used two small brushes to stroke and tap the middle and index finger of the participant's left hand, and, simultaneously, congruent positions on the artificial object. After each session, the experimenter obtained the post-exposure difference between actual and felt position of the left hand, and the participant completed a questionnaire. The post-exposure difference between actual and felt position was obtained by means of the same procedure as for the base-line differences. This time, however, only a single difference was obtained for each participant.

### *Measures*

Similar to previous studies on the RHI (IJsselsteijn et al., 2006; Botvinick & Cohen, 1998), we employed both self-reports and a proprioceptive drift measure. The self-reports consisted of a questionnaire containing both fixed response items and an open-ended question. The open-ended question asked participants to describe their experiences during the session in their own words. Whereas the self-reports tap more or less directly into the participants' experiences, proprioceptive drift is considered to be a more objective corroborative measure of the RHI (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). At the beginning of the experiment, we also informed participants that they were allowed to comment on

their experiences during the sessions. Note that during the actual experiment, we did not further encourage, nor remind, participants to do so. Their remarks were transcribed by an experimenter.

*Self-Report Measure.* The self-report measure was adopted from IJsselsteijn and colleagues (2006) who, in turn, adapted the questionnaire of Botvinick and Cohen (1998). This measure consists of 11 statements describing specific perceptual effects associated with the RHI, such as "It seemed as though the touch I felt was caused by the paintbrush touching the rubber hand". For the purpose of the present experiment several changes were made to the questionnaire. First of all, the statements "The artificial object began to resemble my hand in form" and "The artificial object began to resemble my hand in texture" were excluded as these might potentially be biased in favour of the hand shape and natural texture conditions. Secondly, the statement "It felt as if my hand was turning rubbery" was changed into "It felt as if my hand was turning into the same material as the artificial object". Thirdly, the term "artificial object" in the statements was replaced by the appropriate term for each condition (e.g., "fake hand" or "rubber sheet"). Participants were asked to indicate the extent to which each statement matched their own experiences on a seven-point scale ranging from 0 (not at all) to 6 (completely). The resulting nine items are reported in the Appendix. There were no missing responses.

*Proprioceptive Drift.* Proprioceptive drift is defined as the interval between two differences: the baseline difference between actual and felt hand position (i.e., before exposure

to the rubber-illusion) subtracted from the post-exposure difference between actual and felt position (Tsakiris & Haggard, 2005). Since baseline differences were obtained three times for each participant ( $\alpha = .95$ ), the participant's average baseline difference was used for the calculation of his or her proprioceptive drift. There were no missing responses.

## Results

The results of the present study will be presented in three sections. Results from the self-report measure and the proprioceptive drift measure will be presented separately in the first and second section, respectively. Note that there were few outliers. Since their removal did not affect the results, we report on the analyses with all cases included. In the third section, we will present some of the qualitative data gathered during and after each session.

### *Self-Report Measure*

Scores on the questionnaire items for the four experimental conditions are reported in Figure 2. Similar to previous findings with the same or a comparable sets of items, the first three items showed greatest variance and effects of our manipulations (e.g., Botvinick & Cohen, 1998; IJsselstein et al, 2006; Peled, Ritsner, Hirschmann, Geva & Modai, 2000; for an overview see Holmes & Spence, 2007). Subsequently, we performed a two (hand vs. no hand shape) by two (natural vs. non-natural skin texture) repeated measures Multivariate Analysis of Variance (MANOVA) with the first three items as dependent variables. Using Wilks' criteria, we found that the

combined dependent variables were significantly affected by Shape, with  $F(3, 20) = 28.5$ ,  $p < .01$  and partial  $\eta^2 = 81.0\%$ , indicating that a hand-shaped object induced a stronger RHI than a non-hand-shaped object. In contrast, we did not find a significant main effect of Texture, with  $F(3, 20) = 2.2$ ,  $p = .12$  and partial  $\eta^2 = 24.6\%$ . The Shape by Texture interaction, however, was found to be significant, with  $F(3, 20) = 4.7$ ,  $p = .01$  and partial  $\eta^2 = 41.4\%$ . Additional simple effect analyses on the combined dependent variables showed that a natural skin texture increased the strength of the RHI for a hand-shaped object, with  $F(3, 20) = 7.4$ ,  $p < .01$  and partial  $\eta^2 = 52.7\%$ , but not for a non-hand-shaped object, with  $F(3, 20) < .1$ ,  $p = .98$  and partial  $\eta^2 = 1.0\%$ . Note, however, that the various  $p$ -values should be interpreted with care as the evaluation of assumptions of normality, and homogeneity of variance and covariance matrices was not satisfactory.

As an alternative, we decided to calculate each person's mean score across all 9 items, and to use those as an aggregated measure of the vividness of the RHI in our analyses (see also IJsselsteijn et al., 2006). The internal consistency of this aggregated vividness measure was .62 in the ST, .72 in the S¬T, .83 in the ¬ST, and .89 in the ¬S¬T condition. With these mean scores as the dependent variable, we performed a repeated measure Analyses of Variance (ANOVA) with Shape and Texture as within-subject factors, and Gender and Handedness as between-subject factors. This time, the evaluation of assumptions of normality, and homogeneity of variance and covariance matrices was satisfactory. As before, we found that the strength of the RHI was significantly affected by Shape, with  $F(1, 20) = 35.8$ ,

$p < .01$  and partial  $\eta^2 = 64.1\%$ , but not by Texture, with  $F(1, 20) = 2.0$ ,  $p = .18$  and partial  $\eta^2 = 8.9\%$ . Again, we found a small, but significant, Shape by Texture interaction, with  $F(1, 20) = 4.7$ ,  $p = .04$  and partial  $\eta^2 = 19.0\%$ . Additional simple effect analyses showed, again, that a natural skin texture increased the strength of the RHI for a hand-shaped object, with  $F(1, 20) = 5.3$ ,  $p = .03$  and partial  $\eta^2 = 20.8\%$ , but not for a non-hand-shaped object, with  $F(1, 20) = .3$ ,  $p = .60$  and partial  $\eta^2 = 1.4\%$ .

Regarding the between-subject effects, we found neither a significant main effect of Gender on the vividness of the RHI, with  $F(1, 20) = .1$ ,  $p = .72$  and partial  $\eta^2 = 0.6\%$ , nor a significant main effect of Handedness, with  $F(1, 20) = 1.3$ ,  $p = .27$  and partial  $\eta^2 = 6.1\%$ . However, we did find a marginally significant Gender by Shape interaction, with  $F(1, 20) = 3.1$ ,  $p = .10$ , and partial  $\eta^2 = 13.3\%$ , indicating that the effect of Shape on the vividness of the RHI was more pronounced for the male sample as compared to the female sample. This, in turn, might result from having used a male sized fake hand. Additionally, we found a marginal three-way interaction between Handedness, Shape, and Texture, with  $F(1, 20) = 4.2$ ,  $p = .05$  and partial  $\eta^2 = 17.5\%$ . Due to the tentative nature of our exploration, we refrained from further investigating this rather complex interaction.

#### *Proprioceptive Drift*

Participants showed, on average, a pre-exposure difference between actual and felt position of the left hand of  $M = 3.5$  cm with  $SE = 0.9$  (i.e., towards the participant's right-hand side). The average post-exposure difference was  $M = 7.1$  cm ( $SE$

= 1.0) after the ST,  $M = 7.2$  cm ( $SE = 1.3$ ) after the S¬T,  $M = 6.5$  cm ( $SE = 0.9$ ) after the ¬ST, and  $M = 7.4$  cm ( $SE = 1.4$ ) after the ¬S¬T condition. We used a series of paired sample  $t$ -tests to compare pre- and post-exposure differences. Post-exposure differences were found to be significantly different from pre-exposure differences for all experimental conditions, with  $t(22) \geq 2.7$  and  $p \leq .02$ .

Secondly, we calculated each person's proprioceptive drift (i.e., post minus pre-exposure difference between actual and felt position of the left hand) and performed a repeated measure ANOVA with Shape and Texture as within-subject factors, and Gender and Handedness as between-subject factors. The evaluation of assumptions of normality, and homogeneity of variance and covariance matrices was satisfactory. None of the effects were found to be significant, with  $F(1, 20) \leq 2.4$ ,  $p \geq .15$  and partial  $\eta^2 \leq 10.3\%$ .

#### *Open-Ended Descriptions*

Our participants' responses to the open-ended question, as well as their remarks during the various sessions, provided rich qualitative data. In this section, we report some of these data. Generally, participants made spontaneous remarks like "this was strange" or "something was not right here". During the sessions, one participant remarked, "Sometimes I was not sure whether my hand was still being stimulated by the brush". In the S¬T condition, this same participant noticed that the stimulation of his own hand and the fake hand were implausibly similar: "There were so many small details (e.g., a couple of hairs on the brush that leaped from one finger to the other) that I both saw and felt, which cannot have

happened synchronously". Interestingly, several participants remarked that the felt stimulation in the S¬T condition did not match their expectations: e.g., "If I would have worn a glove, [then] it would have made more sense, as the stimulation of the glove [on the artificial object] did not match with what I felt".

In the ST condition, one participant remarked, "I was sure that when I would move a finger, I would see the finger of the fake hand move as well". Such feelings of perceived agency were described by several other participants as well. One male participant, for example, remarked, "Sometimes it felt as if the fake hand would respond to my movements". Some of these participants had a similar experience in the S¬T condition.

Our participants differed in the location in which they perceived their left hand to be. In the S¬T condition, some participants had the feeling that their hand was inside the glove. After the ¬ST condition, one female participant wrote, "It seemed as if my hand was on top of the rubber sheet". In contrast, another participant experienced her hand to be under the sheet. In the ¬S¬T condition, one participant remarked, "[It seemed] as if I felt my hand to be underneath the table, feeling the stroking that occurred on the surface". In that same condition, another participant remarked, "At one time, I saw a hand shape emerge on the table". Another participant wrote down a similar experience: "I saw my hand appear on the table, but as a transparent ghost hand".

#### Discussion

On the self-report measure, we found that a hand-shaped object induced, as expected, a stronger RHI than a non-hand-

shaped object (cf., Armel & Ramachandran, 2003; Tsakiris & Haggard, 2005). In contrast, we did not find a significant main effect of texture, but there was a significant shape by texture interaction. Further analyses showed that a natural skin texture increased the strength of the RHI for a hand-shaped object, but not for a non-hand-shaped object. These findings corroborate the hypothesis that the RHI diminishes when the artificial object does not resemble the human hand, and thus supports the view that the RHI is affected by top-down cognitive information regarding what a human body is like (e.g., IJsselsteijn et al., 2006; Tsakiris & Haggard, 2005; de Vignemont et al., 2006).

Contrary to our expectations, no differences were found on the proprioceptive drift measure: participants showed the same amount of proprioceptive drift in all experimental conditions. This is surprising, since Tsakiris and Haggard (2005) found that people showed significantly less proprioceptive drift when a wooden stick was used as the artificial object rather than a cosmetic prosthesis. However, there are several noteworthy differences between our method of measuring proprioceptive drift and the method used by Tsakiris and Haggard. Their participants reported on where their left hand was located, whereas our participants reported on where they *felt* their left hand was located. Since some people are aware of the difference between felt and actual (i.e., remembered) location of their left hand (see Gross & Melzack, 1978), the two methods of measuring proprioceptive drift might be difficult to compare. Secondly, the two methods differ in how participants made their reports. Whereas the participants of

Tsakiris and Haggard made their reports verbally, our participants pointed to the felt location with their other hand. However, when directly comparing the two methods of estimation, Gross, Webb and Melzack (1974) did not find a substantial difference between reports made verbally or by pointing with the other hand. Finally, compared to Tsakiris and Haggard, we only partially counterbalanced the experimental conditions (i.e., each participant did the ST condition first), therefore our proprioceptive drift measurements may have been more vulnerable to carry-over effects. Further research will need to demonstrate the conditions under which proprioceptive drift can be assumed to reliably correspond to the RHI.

Interestingly, we did not find support for Armel and Ramachandran's (2003) hypothesis that a skin-like textured sheet induces a stronger RHI than the tabletop: there was no significant difference between the  $\neg$ ST and  $\neg$ S $\neg$ T condition on either the self-report or the proprioceptive drift measure. In the present study, we used a white latex glove to manipulate the colour and texture of the fake hand. By doing so, we not only reduced textural similarity, but inadvertently changed the expected pattern of sensorimotor contingencies as well. During and after the S $\neg$ T session, several participants remarked that their tactile sensations did not match those generally perceived while wearing gloves. It is not unlikely that people know (in a skill-like fashion; cf., O'Regan et al., 2005) how their tactile sensations change when they put on gloves. People, for example, might know the difference in "feel" between being touched directly on the skin and while

wearing gloves (or a band-aid). To experience the gloved fake hand as a part of the body, the perceived sensorimotor contingencies should match those that normally occur while wearing latex gloves. It might, thus, be that the significant difference between the ST and S¬T conditions on the self-report measure is not an effect of visual similarity, but an effect of a change in the admissible pattern of sensorimotor correlations. This would explain why texture had an effect on the hand-shaped objects, but not on the non-hand-shaped objects. Such an explanation supports Armel and Ramachandran's (2003) more general claim that discrepancies in the nature of expected and felt touch diminish the RHI. Unfortunately, the RHI procedure employed in the present study cannot separate the effect of visual similarity from that of knowledge regarding sensorimotor contingencies with respect to tactile sensations. Instead, future studies into this issue might use a somatic version of the RHI (see Ehrsson, Holmes & Passingham, 2005). In this somatic version of the RHI, the experimenter takes hold of the index finger of a person's right hand and strokes that finger over an artificial object. Simultaneously, the experimenter uses his or her own index finger to stroke the person's left hand in a synchronous manner. Since the participant is blindfolded, this setup allows an investigation of the effect of tactile discrepancies in isolation from visual discrepancies.

The qualitative data, gathered during and after each session, show substantial individual differences in the vividness with which people develop the RHI. Whereas some participants' RHI is limited to experiencing something strange, others reported

feeling as if they could even move the artificial object. To date, only a few studies have investigated these individual differences in the RHI (MacLachlan, Desmond & Horgan, 2003; Mussap & Salton, 2006; for similar studies regarding other experimentally induced body illusions, see Burrack & Brugger, 2005; Juhel & Neiger, 1993). Further research is needed to understand the physiological mechanisms behind, and personality correlates of, these individual differences in people's susceptibility to experimentally induced body illusions.

In sum, we have corroborated that a hand-shaped artificial object can be more easily attributed to the self than a non-hand-shaped object (e.g., Armel & Ramachandran, 2003; Tsakiris and Haggard, 2005). Our results, thus, support the view that the RHI is affected by top-down cognitive information regarding what a human body is like (also IJsselsteijn et al., 2006; de Vignemont et al., 2006). In contrast, we did not find support for Armel and Ramachandran's (2003) hypothesis that a skin-like textured sheet would allow for a more vivid illusion than a tabletop. Instead, we found that texture did have an effect on a hand-shaped object: the RHI was significantly decreased when the texture of the fake hand did not resemble the human skin. This finding seems to support Armel and Ramachandran's more general claim that discrepancies in the nature of expected and felt touch diminish the RHI.

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## Appendix

## Self-Report Measure

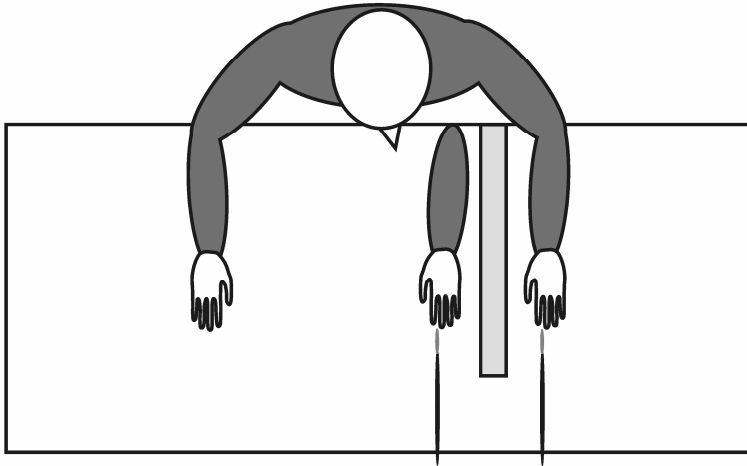
1. It seemed as if I were feeling the touch in the location where I saw the artificial object being touched.
2. It seemed as though the touch I felt was caused by the paintbrush touching the artificial object.
3. I felt as if the artificial object were my hand.
4. It felt as if my hand were drifting towards the artificial object.
5. It seemed as if I had more than one left hand.
6. It seemed as if the touch I was feeling came from somewhere between my own hand and the artificial object.
7. It felt as if my hand was turning into the same material as the artificial object.
8. It appeared as if the artificial object was drifting towards my hand.
9. It felt as if my hand was inside the artificial object.

Note that the term "artificial object" was replaced by the appropriate term for each experimental condition (e.g., "fake hand" or "rubber sheet").

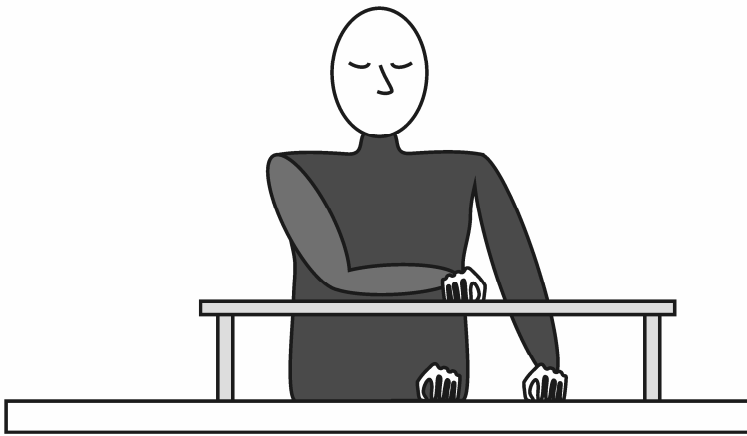
## Figures

Figure 1: The experimental setup during (A) the induction of the rubber-hand illusion and (B) the measurement of proprioceptive drift.

Figure 2: Means and standard errors of each item for the four experimental conditions (see Appendix for items).



A



B

Figure 1:

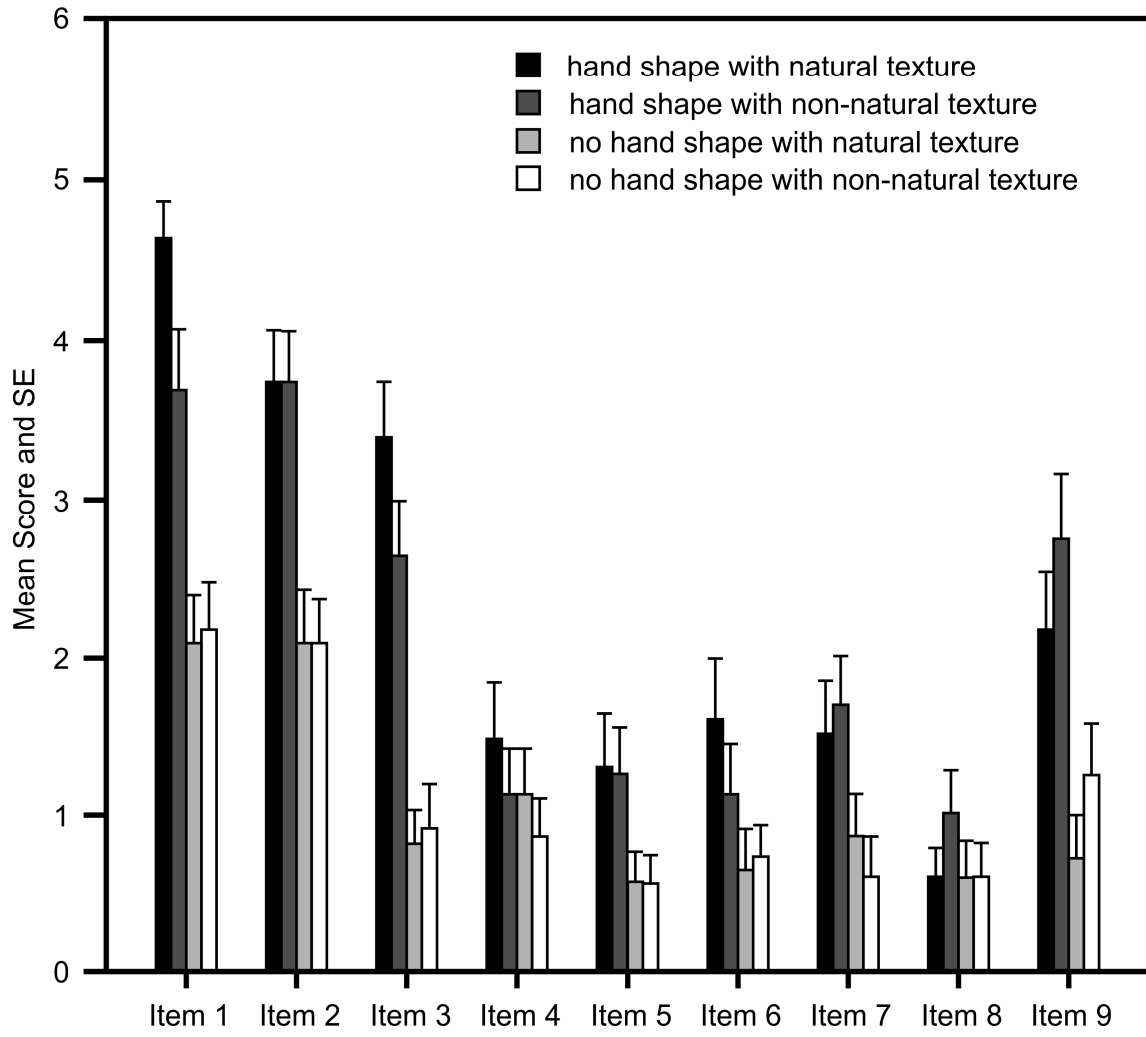


Figure 2: