BRILL Multisensory Research 28 (2015) 101–110 brill.com/msr

# Two-Dimensional Rubber-Hand Illusion: The Dorian Gray Hand Illusion

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Received 19 August 2014; accepted 24 December 2014

**Abstract**
The rubber-hand illusion provides a window into body representation and consciousness. It has been found that body-ownership extended to numerous hand-like objects. Interestingly, the vast majority of these objects were three-dimensional. We adopted this paradigm by using hand drawings to investigate whether rubber-hand illusion could be extended to two-dimensional hand samples, and we measured skin conductance responses and behavioural variables. The fact that this illusion extended to two-dimensional stimuli reveals the dominant role of top–down information on visual perception for body representation and consciousness.

**Keywords**
Rubber-hand illusion, body representation, body ownership, skin conductance, consciousness

## 1. Introduction

Perceptual (Gregory, 1968; Leibowitz *et al.*, 1969) and cognitive (Kahneman and Tversky, 1996) illusions provide unique opportunities to unveil mental representations and brain functioning. Illusions can involve more than one sensory modality and in this case they can provide a means to discover how the senses are combined (Choe *et al.*, 1975; Geldard and Sherrick, 1972; Jousmäki and Hari, 1998; McGurk and MacDonald, 1976; Shams *et al.*, 2000). In particular, the rubber-hand illusion (RHI, Botvinick and Cohen, 1998) combines visual and tactile perception to produce illusory ownership of an alien limb. Thus, studies of this illusion provide knowledge of how body representation

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DOI:10.1163/22134808-00002473

and body ownership are established and maintained. Initially, it was believed that external bottom–up cues provided by vision and touch (i.e., multisensory) were at the core of RHI (Botvinick and Cohen, 1998; Brozzoli *et al.*, 2012; Graziano *et al.*, 2000; Makin *et al.*, 2008), thus suggesting that this information plays a pivotal role in body representation and sense-of-ownership. Later top–down projections (e.g., self-attributions, Tsakiris and Haggard, 2005) were taken into account, while only very recently interoceptive information has also been found to influence the RHI (e.g., heartbeat, Tsakiris *et al.*, 2011).

The first aim of our work was to further investigate the visual cues used to trigger the RHI. Crucially, Armel and Ramachandran (2003) reported that 'non-hand' objects can be incorporated into body representation; nevertheless this result was not replicated by subsequent studies (Haans *et al.*, 2008; Tsakiris and Haggard, 2005). Therefore, there is an implicit consensus that only 'hand-like' objects can be incorporated into one's own body representation. Crucially, these studies focused on three-dimensional hand samples or objects, while it is still unknown whether an impoverished, two-dimensional hand representation can trigger the rubber hand illusion. As a matter of fact, three- *versus* two-dimensional rendering affects visual perception (Bennett and Vuong, 2006; Lee and Saunders, 2011; Pasqualotto and Hayward, 2009), and object recognition (Tarr *et al.*, 1998). Here we will explore the use of a two-dimensional object, that is, a white sheet with the two-dimensional drawing of the participant's own hand. This stimulus allowed us to examine whether a two-dimensional and degraded representation of a human hand can still elicit the rubber hand illusion. Extension of body ownership to the hand drawing will be tested by cutting the drawing while measuring palmar skin conductance (see Lader, 1967). A significant increment in skin conductance (Ehrsson *et al.*, 2007) would indicate that body ownership extended to the drawn hand, thus cutting the paper hand would be like hurting oneself — similar to what occurred to the fictional character 'Dorian Gray' (Wilde, 1890). Aside skin conductance, we added a behavioural measure of proprioceptive drift (Tsakiris and Haggard, 2005), and a subjective report of the illusion on a Likert scale (Armel and Ramachandran, 2003). Finding that even two-dimensional objects, which are a mere depiction, can be incorporated into one's own body would suggest that top–down projections, for example from the prefrontal cortex (Tomita *et al.*, 1999), are even more relevant than it was supposed before.

## 2. Material and Methods

### *2.1. Participants*

We tested 15 right-handed participants (eight females). Their ages ranged from 18 to 30, with a mean age of 23.33 (SD = 3.18). All of them were students at Queen Mary University of London who gave their consent to take part in the investigation. The study was approved by the Queen Mary Research Ethics Committee and the Bath Department of Psychology Ethics Committee.

### *2.2. Apparatus*

The experiment involved two synthetic paintbrushes (2 cm wide) which were used to stroke both the participants' real hand and the drawn hand. A customised black cardboard box was used to occlude the participant's real hand; it was open-ended on the side facing the experimenter, and had a hand-sized hole for participants to insert their hand. Skin conductance was recorded by using a PsychLab™ Contact Precision Instruments skin conductance recorder. Two 8 mm silver-plated electrodes were attached to the participant's right hand using the appropriate adhesive collar and electro-conductive saline paste. The skin conductance device was connected to an Acer Extensa 5220 laptop, which ran the PsychLab™ software for skin conductance recording and analysis. We used a Likert scale from 1 to 10 where participants rated how much they agreed with the sentence "Please rate how much the drawn hand felt like your own on a 1–10 scale, with a 1 meaning the hand felt nothing like your hand, and a 10 meaning it felt exactly like your hand" (see Armel and Ramachandran, 2003).

### *2.3. Procedure*

After gaining participants' consent and providing the instructions (they were warned that a paper-cutter was going to be used), each participant placed his/her dominant hand with its palm down on a vertically oriented white A4 sheet and the experimenter drew the contour of his/her hand — two identical copies were taken to be used in two different experimental blocks (see Fig. 1). Participants were subsequently seated at the table with their arm placed into the black box through its hand-sized hole. While inside the box, participants were connected to the electrodes; their index and middle fingers' second phalanxes were connected to one electrode each. One drawing of their hand was placed on the table within the hemispace of the concealed hand (Cadieux *et al.*, 2011). Before each of the two blocks (see below), by using their 'free' hand (i.e., the one not concealed into the box) and by keeping their eyes closed, participants pointed under the table where they felt the tip of the middle finger of their concealed hand was located. The experimenter marked the position under the table as the baseline point for measuring the 'proprioceptive drift' (e.g., Tsakiris and Haggard, 2005). Participants were asked to point again at the end of each experimental block; the distance between the pointing before (baseline) and the pointing after the blocks represented the proprioceptive drift. Positive values of the proprioceptive drift (in cm) indicated that the perceived location of the hand drifted towards the drawn hand, while negative values

**Figure 1.** Example of a drawn hand used in the experiment.

indicated a drift towards the real hand. Participants pointed once before and once after each block (totally four times).

Then participants were asked to look at the drawn hand while their real hand was uninterruptedly stroked for six minutes in two blocks (e.g., Pavani and Zampini, 2007; Tsakiris and Haggard, 2005). In one block the stroking was synchronous (i.e., stroking the same location at the same time on both the real and paper hands) and on the other block stroking was random (i.e., stroking different locations at different times). At the end of the 6-min stroking the experimenter activated the skin conductance recorder and, by using a paper-cutter, the drawn hand was cut five times (first at the fingertips level and then down to the wrist). After ‘cutting’, in both blocks participants were requested to repeat the proprioceptive pointing procedure (i.e., pointing underneath the table), and then they marked on the 1–10 Likert scale how much they perceived the illusion. Between the two blocks, participants went to another room to complete an online questionnaire unrelated to the task for about 10 min. Half of the participants performed the synchronous block first, and the other half performed the random block first. The entire experiment lasted about 35 min. Participants received £5 for their time.

The data output of each recording was visually inspected as presented on the PsychLab™ software. The recordings presented a pre-cutting baseline, an ascending slope in correspondence of the cutting, and a post-cutting plateau, which then degraded down to the baseline. A one-second window was isolated immediately prior to the beginning of the slope and labelled pre-manipulation window, and another one-second window was isolated immediately at the peak of the slope and labelled post-manipulation window. Within both those one-second windows, the skin conductance values were recorded at 0.1 s intervals, providing ten values for each window. The averages were used for the statistical analysis.

## 3. Results

On this dataset we conducted a two-way within-subjects ANOVA with Type of Stroking (synchronous *vs.* random) and Time (pre-manipulation *vs.* post-manipulation) as variables. The Type of Stroking was significant [$F(1, 14) = 11.01$, $p < 0.01$] suggesting that synchronous stroking produced stronger skin conductance responses (on average 0.43 µSiemens) than random stroking (0.34 µSiemens). Time was also significant [$F(1, 14) = 29.05$, $p < 0.01$] showing that skin conductance response was stronger after the cutting (0.40 µSiemens) than before (0.37 µSiemens). Finally, the interaction Type of Stroking by Time was significant too [$F(3, 11) = 10.72$, $p < 0.01$]. We further analysed this interaction with Bonferroni *post-hoc* contrasts, which confirmed that for synchronous stroking there was a significant difference between pre-manipulation and post-manipulation (all $p < 0.05$), which was not present for random stroking (see Fig. 2). We also verified that these results were not affected by the order of the two blocks, that might have triggered stronger skin conductance response in the first block due the ‘surprise’ effect. Thus, we subdivided our participants in two groups according to the order of the blocks (i.e., synchronous first or random first) and ran a two-way within-subjects ANOVA with Block Order (Block 1 *vs.* Block 2) and Time (pre-manipulation *vs.* post-manipulation) as variables. Block Order was not significant [$F(1, 14) < 1$]; as expected Time was significant [$F(1, 14) = 29.05$, $p < 0.01$] showing that skin conductance response was

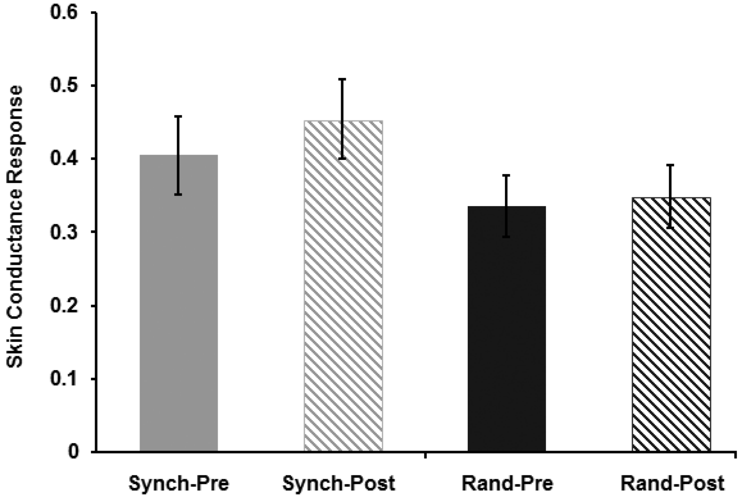

**Figure 2.** Average skin conductance responses (in μSiemens) across the experimental conditions (‘Synch’ stands for synchronous stroking; ‘Rand’ for random stroking; ‘Pre’ is the value before cutting the drawn hand; ‘Post’ is the value after cutting the drawn hand). Error bars represent ±SE.

stronger after the cutting than before. Finally, the interaction of Block Order by Time was not significant [$F(3, 11) < 1$]. This suggests that our results were produced by the experimental manipulation we performed rather than the mere testing order.

Then, we looked at the proprioceptive drift, which on average was $+1.2$ cm (SD $= 2.00$) after synchronous stroking (i.e., when asked to point to their concealed hand participants’ pointing drifted towards the drawn hand) and $-0.27$ cm (SD $= 2.02$) after random stroking (i.e., participants’ pointing slightly drifted towards the real hand). A paired-samples $t$-test confirmed this difference [$t(14) = 2.22$, $p < 0.05$]. Subjective reports on the vividness of the rubber-hand illusion recorded by the Likert scale showed that synchronous stroking produced a stronger illusion (4.7 points on average, SD $= 1.62$) than random stroking (2.63, SD $= 2.07$); the difference was significant [$F(1, 14) = 11.36$, $p < 0.01$].

## 4. Discussion

By showing that ‘hurting’ the depiction of somebody’s hand ‘hurts’ also its owner (i.e., Dorian Gray hand illusion) we showed that body ownership extended to a two-dimensional samples of hand. This finding extends previous results of studies using three-dimensional hands that were integrated in one’s own body representation (e.g., Capelari *et al.*, 2009; Ehrsson *et al.*, 2008; Haans *et al.*, 2008; Tsakiris and Haggard, 2005; Tsakiris *et al.*, 2010). It appears that hand-shaped objects, whether two-dimensional or three dimensional, are most likely incorporated into one's own body representation. Thus the results of Armel and Ramachandran (2003) were not replicated by other studies (e.g., Tsakiris and Haggard, 2005) due to the lack of a hand-shaped stimulus (see also Pavani and Galfano, 2007, for the effect of shadows on body ownership). As our 'dummy' hand was more degraded than the 'realistic' three-dimensional hands used in earlier studies, then we found evidence that the rubber hand illusion is more mediated by top–down processes than it was thought before; top–down processing involves the abstract concept of one's own hand (Ehrsson *et al.*, 2004, 2005; Kammers *et al.*, 2009; Tsakiris *et al.*, 2008). For example, top–down processes involving long- and short-term memory have been found to influence both early (Gilbert and Sigman, 2007) and late (Otsuru *et al.*, 2014) stages of visual perception, such as visual perceptual learning (Li *et al.*, 2004) and multisensory perceptual learning (Proulx *et al.*, 2014). Therefore, it is conceivable that our visuo-tactile illusion can be produced by top–down projections from brain areas involved in memory and visual imagining (e.g., prefrontal cortex, Tomita *et al.*, 1999), which exert an effect on the function of 'lower level' (i.e., more perceptual) brain areas (e.g., primary somatosensory cortex, Otsuru *et al.*, 2014). Finally, top–down processes such as self-consciousness (Blanke, 2012; Heydrich *et al.*, 2010) have been found to play a role in body representation in medical conditions such as schizophrenia (Thakkar *et al.*, 2011), alimentary disorders such as bulimia (Mussap and Salton, 2006), and unusual phenomena such as the out-of-body experience (Olivé and Berthoz, 2012).

An alternative hypothesis is that, rather than top–down projection, bottom–up multisensory integration is the responsible for the illusion and for the altered sense-of-ownership; in particular multisensory integration of visual and tactile stimuli might remap the personal space to include the fake hand (Brozzoli *et al.*, 2012; Costantini and Haggard, 2007; Gentile *et al.*, 2013). Additionally, bottom–up information has been found to affect body-representation relative to the hand (Dempsey-Jones and Kritikos, 2014), the face (Mazzurega *et al.*, 2011), and the whole body (Slater *et al.*, 2010). Therefore, multisensory and bottom–up information might explain the altered sense-of-ownership. Nevertheless, the role of top–down projections (e.g., memory) was supported by the striking finding that rubber-hand illusion can be elicited also in amputees who do not possess a hand for the remapping of bottom–up multisensory information (Ehrsson *et al.*, 2008).

In sum, by using the rubber hand illusion paradigm with our original approach we found evidence that the illusion extends to two-dimensional hand-like stimuli, suggesting that two-dimensional stimuli should resemble hands (Dorian Gray hand illusion) to be incorporated into one's own body, thus providing an explanation to previous discrepant results (Armel and Ramachandran, 2003; Haans *et al.*, 2008; Tsakiris and Haggard, 2005). Additionally, we found evidence that top–down processes might be more involved in body representation than it was thought before.

### *Acknowledgements*

This work was supported by a Marie Curie IEF (grant number: PIEF-GA-2010-274163) and a grant from the EPSRC (EP/J017205/1).

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