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Research article

# The rubber hand illusion is influenced by self-recognition

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ABSTRACT

Susceptibility to the Rubber Hand Illusion (RHI) demonstrates that body ownership can be modulated by visuotactile inputs. In contrast to body-like images, other objects cannot be embodied suggesting that crossmodal interactions on body ownership are based on a 'goodness-of-fit' mechanism relative to one's own body. However, it is not clear whether visual self-recognition influences susceptibility to the RHI, although evidence for individual differences in the perceptual body image on the RHI suggests that this may be the case. We investigated the role of self-recognition on the subjective experience of the RHI and measured proprioceptive drift and onset time of the RHI between two groups, one with the ability to identify an image of their own hand and the other without this ability. A typical RHI response was found overall with no group difference in the subjective experience of the RHI. However, a larger proprioceptive drift and an earlier onset time for the RHI was found for the non-recognisers than the self-recognition group. Our findings provide evidence for a link between a visual representation of one's own body in long-term memory and plasticity of the body representation.

## 1. Introduction

The bodily self is informed by the processing of body-centred multisensory inputs such as visual, tactile and proprioceptive information and the perceptual body image (that is, the stored visual representation of one's own body) [1,2]. Both inputs are thought to play an important role informing sense of body ownership, as demonstrated by susceptibility to the Rubber Hand Illusion (RHI) [1–5]. In the RHI, an individual's real hand and a fake rubber hand are stroked in temporal and spatial synchrony. A sense of ownership over the fake hand, in addition to the referral of touch from the real hand to the fake hand and the perceived displacement of the real hand towards the fake hand (proprioceptive drift), are typically achieved under these conditions, but not when the real and fake hands are stroked asynchronously [2–5]. These effects suggest the incorporation of the fake hand into the body representation, a process that can be accompanied by physiological responses measured on the skin of the real hand [6] and activity in multisensory fronto-parietal areas that are known to be involved in body ownership [7].

Susceptibility to the RHI is significantly reduced if the fake hand is anatomically incompatible with the body or replaced with a (non-hand) object [8,9]. However, the more visually similar the fake hand is to the bodily self, the stronger the illusion [10–12]. The sensitivity of the RHI to the anatomical plausibility of external objects may reflect a process in which the 'goodness-of-fit' between the viewed object (e.g. a fake hand) and the visual representation of one's body is evaluated [2,4]. This comparison may take place at an early stage of information processing [2] in brain regions associated with sensory processing including the right temporo-parietal junction [13].

Whilst the body representation is informed by momentary information about one's self to guide actions, such as limb extension or position [1], it remains unclear to what extent it is based on invariant information relating to body recognition. Indeed, individual differences in susceptibility to the RHI [see 14–17], including reports that between 20 % and 30 % of participants do not experience the illusion [14], suggest a number of influences on the RHI beyond sensory stimulation. Differences in the stored visual representation of the body may play a role. For example, clinical conditions affecting the perceptual body image are associated with increased susceptibility to the RHI [18,19] while a consolidated perceptual body image is associated with reduced susceptibility to the illusion [20, although see 21]. This evidence implies that the reliability of the perceptual body image may affect susceptibility to the RHI such that a weak representation would be associated with a stronger illusion, possibly due to a reweighting of the perceptual body image in favour of the momentary sensory stimulation. A better understanding of the nature of the relationship between the perceptual body image and body plasticity may help shed light on the mechanisms contributing to body ownership.

In the following experiment, we used the ability to recognise one's own hand as a measure of the reliability of the representation of the

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participant's perceptual hand image. We reasoned that the ability to explicitly recognise an image of one's own static hand would be informed by a stored visual representation of their hand in memory [22]. We compared susceptibility to the RHI across two groups of participants; one group were able to recognise an image of their own hand (i.e. self-recognition) whereas the other group could not (non-recognition). We predicted that if recognition of own's own hand influences body plasticity, the self-recognition group would experience a weaker RHI than the non-recognition group.

## 2. Material and methods

### 2.1. Participants

Thirty participants (6 males) (mean age of 20.1 years, age range of 18–26 years) volunteered to take part in the RHI experiment. Participants were recruited from the student population at Trinity College Dublin and some took part in exchange for course credits. All participants were required to be right-handed, have normal or corrected-to-normal vision and have no tactile impairments to be included in the study. The recruitment procedure also excluded anyone with distinctive markings on their right hand (e.g. scars, birth marks or tattoos). All participants reported to be neurologically healthy and naïve to the RHI and provided informed written consent prior to the experiment. The experiment was approved by the School of Psychology Research Ethics Board (Trinity College Dublin) and conducted in accordance with the Declaration of Helsinki. Data were obtained in accordance with EU General Data Protection Regulation (GDPR).

### 2.2. Stimuli and apparatus

In order to test self-hand recognition, a photographic, colour image of each participant's right hand, palm-down with the index finger outstretched, was taken from an allocentric (i.e. third person) perspective under constant luminance conditions. Participants were instructed to remove any hand jewellery and to have trim nails without nail polish before the image was taken. The 30 images were then used to create the test of self-recognition. The test comprised of a single A4 sheet which contained 8 images of hands presented in a 2 × 4 array (two images in 4 rows). The array contained the participant's image of their right hand and 7 images of unfamiliar hands as distractors. The 7 distractor images in each array were randomly chosen from the larger set and could include male and female hands. All hand images were scaled to approximately the same size (6 cm x 8.5 cm) and positioned at random locations in each array.

For the RHI task, we used a life-sized right hand (7 cm width from thumb to fifth finger, 18 cm length from the tip of the middle finger to the wrist) made from a durable, light yellow plastic. The plastic hand was attached to the inside of a sleeve of a large-sized shirt. The participant was seated at a table on top of which was an opaque screen (60 cm by 5 cm by 68 cm) and an opaque cover which were used to occlude the participant's real right hand during the RHI task (see Fig. 1). The participant wore the shirt by placing their left hand through the available sleeve. The right sleeve, which contained the plastic hand, was then positioned onto the table in front of the participant. A dot on the table was used as a guide for the resting position of the participant's right index finger on the table and was visible to the experimenter only. Two identical paintbrushes were used to stroke the participant's right hand and the fake hand. A ruler (spanning 100 cm) was positioned horizontally across the table, and centred 15 cm in front of the participant's body, to measure proprioceptive drift.

### 2.3. Procedure

There were two main sessions in the study. First, we measured each participant's ability to recognise an image of their own hand by asking each participant to select the image of their own hand within an array of hand images. Participants were informed that their own hand may or may not be in the array and were instructed to provide a verbal response to indicate the position of their hand image in the array which was then recorded by the experimenter. There was no time limit imposed but participants were encouraged to complete the task as fast as possible. The experimenter ensured that each participant did not view at their own right hand for comparison during the task. All participants received feedback on their performance.

Immediately following the recognition task, the participant conducted the RHI task. To that end, each participant was seated at a table and the experimenter sat on the opposite side. The participant was instructed to wear the shirt into which the fake hand was attached by placing their left hand through the left sleeve and draping the remaining fabric over their right shoulder and torso. The participant placed their left and right hand, palm-sides down, on the table in front of their body. Their right hand was occluded from view behind an opaque screen and cover. The (right) fake hand was positioned in front of the participant, aligned with the real right hand, and parallel to the left hand at a distance of 15 cm (see Fig. 1). Each participant was instructed to fixate on the fake hand for the duration of the RHI trial and to avoid moving their real right hand.

Each participant first completed a baseline task in which they were instructed to verbally report the felt position of the index finger of their unseen right hands using the markings on the ruler. The responses were recorded by the experimenter on a computer. The experimenter then attempted to induce the RHI in each participant by stroking their right hand and the visible fake hand using the tip of identical paintbrushes. There were two stroking conditions: synchronous and asynchronous. In the synchronous stroking condition, the dorsal surface of each of the spatially congruent five digits of the right and fake hands were stroked in temporal synchrony (i.e. same stroking onset). The digits were stroked in one of two orders, which was counterbalanced, from first to fifth digit or vice versa. In the spatiotemporal asynchronous stroking condition, the surface of each spatially incongruent digit of the fake and real hand was stroked (e.g. middle digit of the fake hand but index finger of the real hand) and in temporal asynchrony with a delay of 1 s in the onset of stroking across hands. Spatial incongruence was included to ensure a robust control condition to the RHI and because the detection of visuotactile temporal asynchronies is known to be influenced by other factors such as individual differences in the temporal binding window [14,17]. The direction, speed and force of the stroking were kept as consistent as possible across stroking conditions and participants. The stroking conditions were blocked and the order of the stroking conditions was counterbalanced across participants. The stroking in each condition lasted for a duration of two minutes, as measured with an electronic stopwatch. Following each stroking condition, the participant verbally reported the felt position of the index finger of their unseen right hand using the markings on the ruler. Then they completed an adapted version of Botvinick and Cohen's RHI questionnaire [3], consisting of 9 items that were slightly modified to refer to a plastic hand. Responses were made using a 7-point Likert rating scale ranging from "strongly disagree" (-3) to "strongly agree" (+3), with "neither agree nor disagree" as the midpoint (0). Finally, consistent with [23], RHI onset times were measured by repeating the synchronous stroking condition 3 times for participants who reported an RHI following synchronous but not asynchronous stroking (N = 26). Participants verbally indicated the earliest timepoint at which they experienced the RHI and onset times were recorded with an electronic stopwatch. Participants were instructed to shake their right hand after each recording to minimise carry-over effects of embodiment.

### 2.4. Design

The experiment was based on a 2 by 2 mixed-factors design, with stroking type (synchronous, asynchronous) as the within-subjects factor

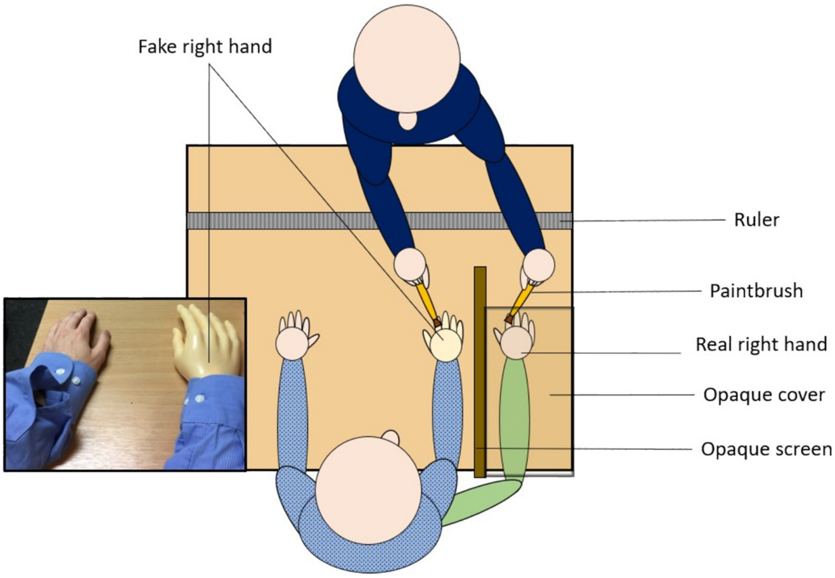


**Fig. 1.** An illustration of the set-up of the RHI task used in the present study. The participant's real right hand was occluded behind an opaque screen and covered to prevent any viewing of that hand (shown as a transparent surface for illustrative purposes). Both the real and fake right hand were stroked by the experimenter. A ruler was positioned on the table, within the participant's view.

and recognition group (self-recognition, non-recognition) as the between subjects factor. The RHI questionnaire ratings, proprioceptive drift (cm position) and onset times (s) were the dependent variables.

## 3. Results

Based on the results of the hand recognition test, participants were sorted into two groups: self-recognition and non-recognition. Of the 30 participants tested, 13 (5 males) failed to correctly identify an image of their own hand (3 incorrectly reported that their hand was not in the array and 10 incorrectly identified a distractor image of a hand as their own)[1] . Of these, one participant reported an RHI following asynchronous stroking (suggestive of a response bias) and their data were removed from further analyses. The other 17 participants all correctly identified the image of their own hand but 3 failed to experience the RHI and their data were not included. The data analysis was conducted on the remaining 26 participants (12 non-recognisers, 14 self-recognisers) using R via Rstudio (version 3.5.0) [24,25]. For the ANOVAs, the ez package [26] was used with type 3 sum of squares to test for main effects and interactions. Significance values are reported with Greenhouse-Geisser corrections in cases where sphericity was violated. Bonferroni correction was used for all multiple comparisons.

### 3.1. RHI questionnaire

The ratings to the RHI questionnaire were submitted to a 2 by 9 within-subjects ANOVA with stroking type (synchronous, asynchronous) and questionnaire item as factors. This analysis revealed a main effect of stroking type ($F(1, 24) = 65.90$, $p < 0.001$, $\eta_G^2 = 0.27$), with higher ratings to synchronous than asynchronous stroking, and an effect of questionnaire item ($F(8, 192) = 17.10$, $p < 0.001$, $\eta_G^2 = 0.20$). A significant interaction between the factors was also found ($F(8, 192) = 18.64$, $p < 0.001$, $\eta_G^2 = 0.19$). As shown in Fig. 2, only questionnaire items 1, 2 and 3 (Means = 2 ± 0.75; 1.65 ± 0.63 and 1.38 ± 0.75 respectively) were afforded positive ratings following synchronous stroking. Post-hoc pairwise comparisons confirmed that ratings to these three items were significantly higher than those to all other items of the RHI questionnaire and to a rating of 0 (i.e. the midpoint of the scale; all ps < 0.001).

Based on each participant's responses to the RHI questionnaire, we calculated the difference in the mean ratings across these three items (1–3) relative to the mean ratings to the remaining items (4–9) and used this difference as an overall RHI index [as in [29]]. These RHI index scores were analysed using a 2 by 2 mixed-factors ANOVA with stroking type (synchronous, asynchronous) as a within-subjects factor and recognition group (self-recognition, non-recognition) as the between-subjects factor. The effect of stroking type was significant ($F(1, 24) = 101.34$, $p < 0.001$, $\eta_G^2 = 0.64$) with higher ratings to synchronous (M = 2.58 ± 0.98) than asynchronous (M = 0.08 ± 0.94) stroking. The effect of group ($p = 0.32$) and the interaction between group by stroking type ($p = 0.64$) both failed to reach significance.

### 3.2. Proprioceptive drift

A between-groups *t*-test confirmed no difference between groups for the baseline estimates of hand location ($t(23.47) = -0.11$, $p = 0.92$). The proprioceptive drift for each participant was therefore calculated as the difference between estimates of hand location at baseline and following stroking. These baseline-corrected drift scores were analysed with a 2 by 2 mixed-factors ANOVA with stroking type (synchronous, asynchronous) as a within-subjects factor and recognition group (self-recognition, non-recognition) as a between-subjects factor. This analysis revealed a main effect of group ($F(1, 24) = 5.50$, $p = 0.03$, $\eta_G^2 = 0.12$) and stroking type ($F(1, 24) = 53.30$, $p < 0.001$, $\eta_G^2 = 0.48$) and an interaction between group and stroking type ($F(2, 48) = 5.04$, $p = 0.03$, $\eta_G^2 = .08$) shown in Fig. 3. Consistent with the rating results, the proprioceptive drift was larger following synchronous than asynchronous stroking. A post-hoc between-groups *t*-test confirmed that the non-recognition group had a larger proprioceptive drift (M = 3.10 cm ± 0.96) following synchronous stroking than the recognition group (M = 1.93 cm ± 1.37) ($t(23.16) = 2.55$, $p = 0.02$, 95 % CI = 0.22–2.12). However, proprioceptive drift following asynchronous stroking did not differ between the self-recognition (M = 0.75 cm ± 0.56) and non-recognition (M = 0.88 cm ± 0.42) groups ($t(23.62) = 0.65$, $p = 0.52$).

[1] In a follow-up study, a further 19 participants were tested on the hand recognition test only. All successfully recognised an image of their own hand in an array, suggesting that the prevalence of non-recognisers may be lower (26%) than reported here (43%). Although is not clear why such a large proportion of participants in the present study failed to recognise an image of their own hand, the results of the RHI task suggest that there may be a range of perceptual functions associated with an inability to recognise one's own body [see also [27][28],].

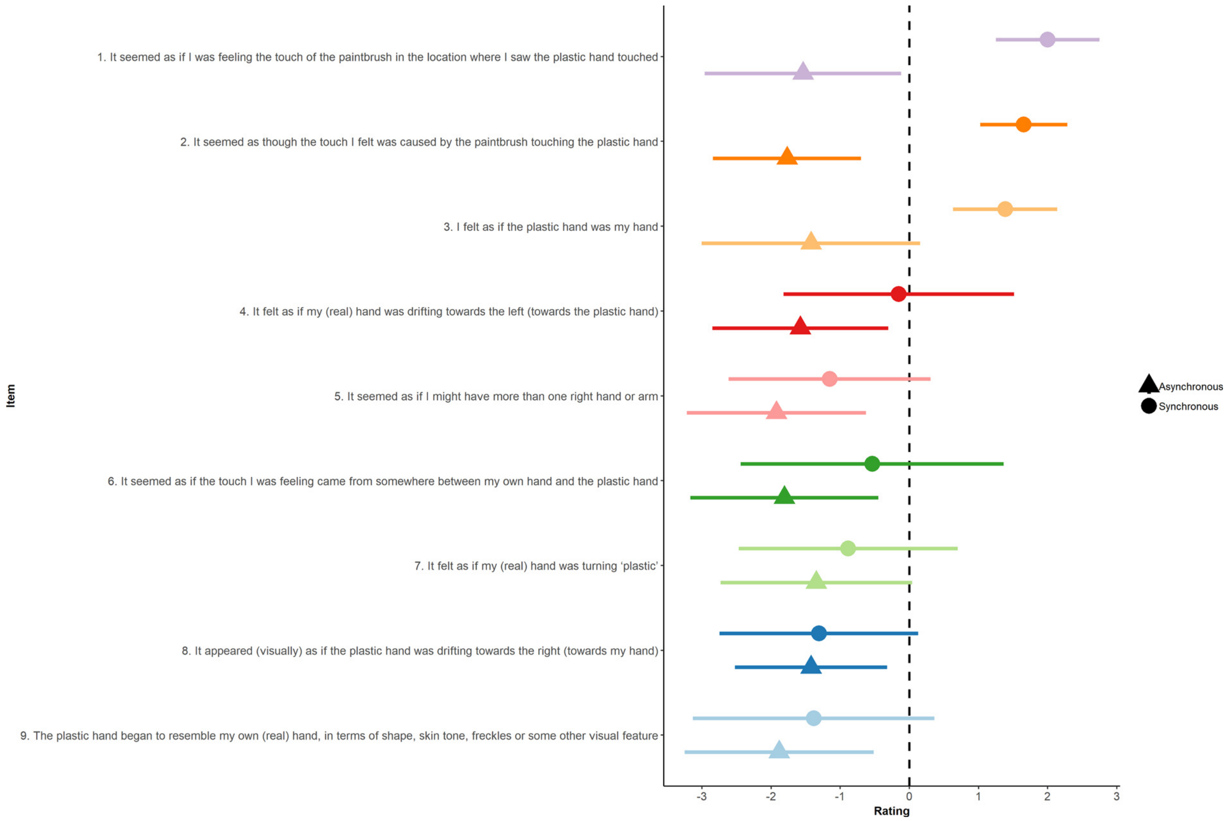


**Fig. 2.** Plot showing the mean ratings to each item of the RHI questionnaire per stroking type. Error bars represent 95 % CIs.

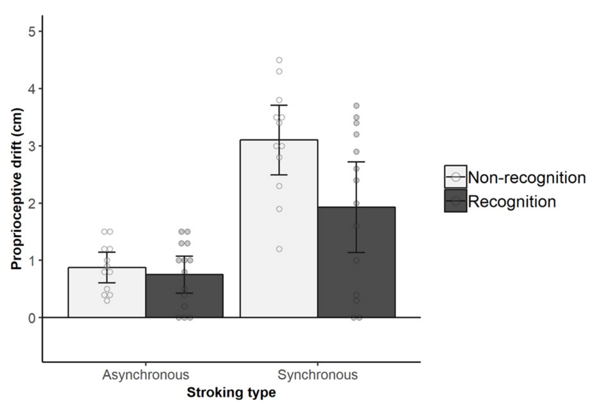


**Fig. 3.** Plot showing proprioceptive drift (cm) following synchronous and asynchronous stroking for both the self-recognition and non-recognition groups. Individual drift scores are shown as filled circles. Error bars represent 95 % CIs.

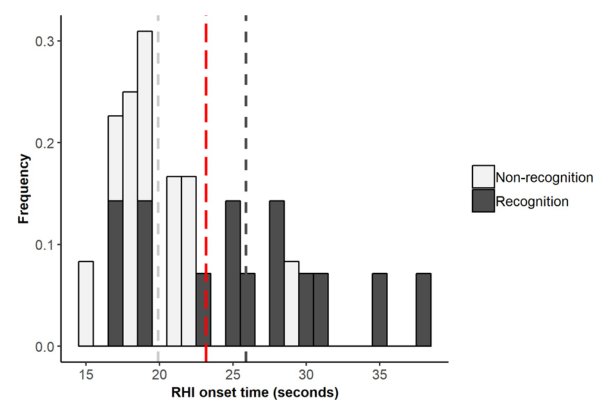


**Fig. 4.** Plot showing the distribution of RHI onset times (seconds) across all participants. The vertical dashed lines show the mean onset time overall (red long-dash line) and of the recognition (dark grey short-dash line) and non-recognition (light grey short-dash line) groups.

### 3.3. RHI illusion onset

The average onset time of the RHI was 22.5 s ( ± 7.9; range of 15.3 s – 38.4 s) across all participants (see Fig. 4). The average onset times for the non-recognition and self-recognition groups were compared using a between-groups *t*-test which revealed a significantly faster onset time of the illusion for the non-recognition group (M = 19.9 s ± 3.3) compared to the recognition group (M = 25.9 s ± 6.3; $t(20.32) = 3.02$, $p = 0.007$, 95 % CI = 1.87–10.19).

### 3.4. Relationship between RHI measures

We conducted separate Pearson's correlation analyses to examine the relationships between the measures of the RHI across all participants. Firstly, neither the relationship between RHI onset time and either proprioceptive drift ($t(24) = -0.30$, $p = 0.76$, $r = -0.06$) or RHI index scores ($t(24) = -1.06$, $p = 0.30$, $r = -0.21$) following synchronous stroking was significant. To measure the relationship between the strength of the RHI and proprioceptive drift, we compared the difference in the mean index scores and proprioceptive drift after synchronous and asynchronous stroking [29]. This difference failed to reach significance ($t(24) = 0.93$, $p = 0.36$, $r = 0.19$).

## 4. Discussion

We examined whether susceptibility to the RHI is influenced by self-recognition of one's hand. Accordingly, ratings provided to a standardised RHI questionnaire [3], as well as measures of proprioceptive drift and illusion onset were compared across a group of self-recognisers and a group of non-recognisers. We found no difference between the two recognition groups on the ratings to the RHI questionnaire, suggesting that the phenomenological experience of the illusion was not influenced by self-recognition. However, the non-recognition group had a larger proprioceptive drift and a faster onset time for experiencing the RHI than the self-recognition group, implying that non-recognisers experienced a more robust embodiment of the plastic hand.

The result that the ability to recognise one's own body affects the illusion onset and proprioceptive drift extends previous findings for a role of the perceptual body image in body plasticity [2,4,8–12,18–20]. Our results are particularly compatible with those of Lira et al. [12], who found that differences in skin colour between a participant's hand and a fake hand reduced the extent of proprioceptive drift and delayed the illusion onset time. These findings suggest that one's perceptual body image can influence specific outcomes of the RHI. Our findings suggest that a robust representation of one's own body in visual memory, allowing for efficient self-recognition, may reduce the outcomes of RHI because the perceived similarity between the fake hand and representation of the real hand is low. This may result in a higher weighting of the visual body representation during the RHI relative to the visuotactile cues on the hand, thus weakening the embodiment of the fake hand. In contrast, a less robust or accessible representation of one's own body, linked to poor self-recognition, may be more amenable to incorporating a fake hand, producing a stronger RHI. The reported evidence for a weaker RHI in response to objects that are visually incongruent with the perceptual body image [8–12] is consistent with this account. However, we found no evidence for a difference in the subjective report of the RHI as measured using ratings, and the group difference was found for the arguably more objective measures of embodiment.

A number of studies have found that the responses to the RHI questionnaire can be a sensitive measure of body plasticity [e.g. [3,8–12]]. However, the findings reported by Eshkevari et al. [19] are consistent with the present results in that they found no difference in responses to the RHI questionnaire between individuals with an unhealthy perceptual body image and a healthy control group. However, they did find a group difference in the estimated hand size reported following the RHI, which was more reduced for the unhealthy than the control group. Together with our results, these findings suggest that implicit measures of body plasticity taken from the RHI may be more sensitive to individual differences in perceptual body image than self-reports. However, methodological differences across studies need to be taken into account in future research investigating this relationship.

Several studies have demonstrated that the embodiment of a fake limb in which the visual properties conflict with one's perceptual body image (for example in size or colour) can occur in response to congruent visuotactile inputs [e.g. [30,31]]. The self-recognition group also experienced the RHI, including a positive referral of touch, sense of ownership over the fake hand and physical proprioceptive drift, despite clear visual differences between the fake and their real hand. Moreover, we found that the difference in performance across the self- and non-recognition groups was small for both proprioceptive drift (1.17 cm) and RHI onset time (6 s). As such, the ability to visually recognise one's own hand did not solely determine whether the fake hand was embodied in response to visuotactile inputs, but instead had an influence on the strength and speed of embodiment. It may be the case that perceptual body image influences body plasticity more robustly when there is a particularly pronounced conflict between this representation and an external object, such as when the object is anatomically incompatible with the body (e.g. in terms of posture) [8] or possesses no anatomical features [9]. It is worth noting that the fake hand used in the present study was slightly larger than any of the participant's real hands and, as is typical in RHI experiments, also visually differed in colour and 'skin' texture to their real hands. A weaker RHI may have occurred for the recognition group due to these visual differences between the fake hand and the representation of their own hand. It is possible, therefore, that attempts to manipulate the similarity between the fake and real hand would have a direct effect on susceptibility to the RHI in the self-recognition group only: decreased similarity would be expected to reduce the occurrence of the RHI in this group whereas increased similarity (e.g. a realistic fake hand in virtual or augmented reality) should increase the RHI. In contrast, it would be expected that only large differences between the fake and real hand would disrupt the RHI in the non-recognition group.

The pattern of participants' rating responses to the RHI questionnaire used in this study aligned closely with the classic RHI profile [e.g. [3]]. In particular, the absence of a reported proprioceptive drift, despite evidence for a physical drift, is not unprecedented [29] and likely represents discrepancies between subjective and implicit measures of the RHI. However, the magnitude of the proprioceptive drift found in this study was smaller than previous reports [e.g. 29] and it may be that differences in the apparatus set-up, such as the positioning and oblique viewing angle of the ruler, influenced the participants' judgements of hand position. Finally, the mean onset time of the RHI was 22.5 s which is close to the onset time previously reported by Kalckert and Ehrsson [23] although there is variability in the reported RHI onset times across studies possibly due to methodological factors [14].

## 5. Conclusions

We investigated whether the ability to recognise an image of one's own hand influences the subjective experience, proprioceptive drift and onset time of the RHI. We found no difference in susceptibility to the RHI between a self-recognition and non-recognition group as measured by responses to the RHI questionnaire. However, the non-recognition group experienced a larger proprioceptive drift and an earlier RHI onset time than the self-recognition group. These findings demonstrate that the visual representation of one's own hand influences specific elements of the RHI and, furthermore, suggest that variations in the perceptual body image across individuals can have an influence on their body plasticity. Future research is required to elucidate the exact role of the perceptual body image, and whether it is the reliability of the representation itself or its influence on crossmodal interactions on the body, that reflects individual differences in susceptibility to the RHI.

## Author contributions

A.O'D. and F.N.N. designed and planned the study. A.O'D. collected and analysed the data. A.O'D. and F.N.N. wrote the manuscript.


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## CRediT authorship contribution statement

**A. O'Dowd:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization. **F.N. Newell:** Conceptualization, Methodology, Data curation, Writing - original draft, Writing - review & editing, Supervision.

## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neulet.2020.134756.

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