



SHIFTING THE PERIPERSONAL SPACE WITH THE RUBBER HAND ILLUSION

Can the rubber hand illusion create a sense of peripersonal space around a fake hand?

Abstract

The rubber hand illusion (RHI) is a way to manipulate the sense of body ownership. It is induced by placing a fake rubber hand next to one's own hidden hand and stroking them in synchrony. In this research it is hypothesized that the peripersonal space shifts from the real hand to the fake hand with the RHI. The peripersonal space (PPS) is the region surrounding the body, functional for body protection or goal directed action.

Participants were confronted with a random set of landmarks and they had to determine whether a landmark was to the left or right from the middle, before and after they experienced the RHI. After the illusion, they determined the landmark significantly more as left. This research suggests that a shift in body ownership causes a shift in peripersonal space. Since the PPS is anchored to the body, and the RHI caused the rubber hand to be experienced as one's real hand, the rubber hand becomes the new relevant action space. It is hypothesized that the shift in PPS causes the landmark to appear within the PPS of the left hand, where objects are more strongly represented in the brain, causing the landmark to seem left.

Keywords: Rubber hand illusion, Body ownership, Peripersonal space

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Introduction

In everyday life people use objects without thinking about it, but in order to do so, multiple (cognitive) functions are needed. For example, to successfully grab a cup you need motor function, but you also need information about the size and location of your own body, i.e. body representation (Bassolino, Finisguerra, Canzoneri, Serino & Pozzo, 2015). Furthermore, you need information about the space directly surrounding your body, e.g. to assess the relative distance to the cup. In this research we focus on those two concepts combined: the awareness of your own body and the action space surrounding it.

The feeling that your body belongs to you is known as body ownership (Gallagher, 2000). This sense of ownership is closely related to the location where you perceive your body, i.e. proprioception (Maselli, 2015; Serino, Alsmith, Costantini, Mandrigin, Tajadura-Jiminez & Lopez, 2013). Interestingly, the feeling of body ownership can be experimentally manipulated; a well-known way to do so is called the Rubber Hand Illusion (RHI) (Botvinick & Cohen, 1998). In the RHI a rubber hand is placed next to a subjects own hand. Both hands will be stroked in synchrony at the same location, with only the rubber hand being visible. Watching the rubber hand being stroked, while simultaneously feeling the strokes as well, may cause the rubber hand to be attributed to one's own body (Tsakiris & Haggard, 2005). To induce a sense of ownership over the rubber hand, it is important that both the rubber hand and real hand are anatomically aligned, for an integration in body representation (Makin, Holmes & Ehrsson, 2008). Thinking that the rubber hand is your own, changes the sense of location of your hand. The perception of one's own hand typically 'drifts' towards the rubber hand after inducing the illusion. This phenomenon is known as proprioceptive drift (Rohde, Di Luca & Ernst, 2011). Thus, the RHI is known to induce multiple interesting changes in bodily perception.

When we go back to the example of grabbing a cup, another phenomenon is important. When this cup is close to the body it is processed differently than when it is located further away from the body. The space surrounding the body is known as the peripersonal space (PPS). It is speculated that the PPS is functional for goal-directed action and protection of the body (Rizzolatti, Fadiga, Fogassi & Gallese, 1997; Holmes & Spence, 2004; De Vignemont & Iannetti, 2015). The PPS provides information on the position of objects in the surrounding environment, in respect to the body, by

integrating multisensory cues (Makin et al., 2008). Now the question of the current study arises. Since the PPS is anchored to one's own body, does it shift to the rubber hand if the RHI caused a feeling of ownership over that hand?

As stated by Cardinali, Brozzoli and Farnè (2010) no evidence is yet available to support an association nor dissociation between the peripersonal space and body ownership. The outcome of this research could be relevant for neuropsychological patients, e.g. to reverse the effects of unilateral neglect. It is possible a change in peripersonal space could shift their attention to the visual neglected area.

In the current study we aim to test whether the peripersonal space transfers from someone's real hand to the rubber hand as a result of a change in ownership caused by the rubber hand illusion. In order to test whether the peripersonal space shifts towards the rubber hand, a landmark task will be used. This task requires the participant to indicate whether a transection mark is located to the left or right. Typically, healthy participants have an attention bias to the left hemisphere, i.e. pseudoneglect, resulting in a leftwards bias in the landmark task (Thomas & Elias, 2009). We expect that participants in this experiment will indicate the transection mark even more to the left after the rubber hand illusion is induced, provided that the illusion is well established. This expectation is based on the idea that the perceived direction of the body's sagittal axis, i.e. the egocentric reference (ER) shifts to the right as a consequence of feeling ownership over a rubber left hand that is located more to the right than one's real left hand (Mars, Honoré, Richard & Coquery, 1998; Kazandjian et al., 2009). If the ER shifts to the right, the landmark will consequently seem more to the left. The ER will be measured by the subjective straight ahead pointing task. This task requires participants to point straight ahead while blindfolded, where they think their bodily midline would project in front of them. In order to test whether a change in proprioception occurs, the perceived finger location will be measured. If the illusion is strong, a stronger proprioceptive drift towards the rubber hand is expected (Longo, Schüür, Kammers, Tsakiris & Haggard, 2008). The degree of the RHI will be measured with the Embodiment Questionnaire (Botvinick & Cohen, 1998). The landmark task, subjective straight-ahead and proprioceptive drift will be pretested as a control. The RHI will then be induced and thereafter the proprioceptive drift, landmark task and straight-ahead pointing will be conducted again.

Materials and Methods

Participants

In this study 47 undergraduate and graduate students participated, from which 28 were included in the analysis. There were 17 participants in the experimental group (2 male, mean age 21.4 years) and 11 in the control group (2 male, mean age 21.4 years), see table 1.

Table 1. Participant demographics (number, mean scores and standard deviation).

	N	Male-Female	Age
Experimental group	17	2-15	M: 21,41 SD: 2,27
Control group	11	2-9	M: 21,36 SD: 1,57

To determine whether participants could be included in the experiment, the responses on the Embodiment Questionnaire (see attachment A) were examined. For the experimental group it was required to have an average score above 5 in the first five questions and an average below 5 on the last five questions. The control group was required to have an average score below 5 on all questions. See figure 1 for the mean scores on the Embodiment Questionnaire of the included participants. Based on these conditions, 16 people were excluded from the analysis. The remaining 31 participants were checked for outliers in the data. Participants that deviated more than two standard deviations of the mean score were excluded. This excluded another 3 participants, hence 28 participants remained.

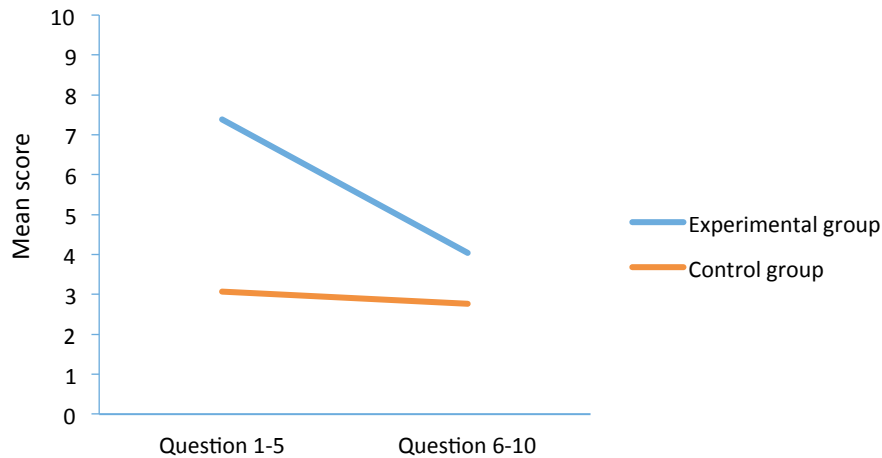


Figure 1. Mean score on the Embodiment Questionnaire of the included 28 participants.

All participants were right-handed by self-report. They could receive course credits or 6 euros as a compensation for their time. They were naïve to the purpose of the study and a written informed consent (attachment B) was obtained from all individual participants prior to the experiment. This study was conducted in accordance with the standards of the local ethical committee and the declaration of Helsinki.

Procedure/Task/Stimuli

The experiment was conducted in a laboratory at Utrecht University. The participant was asked to remove all jewellery (i.e. rings and watches). The participant then took place at the long end of a table, in front of a large horizontally tilted screen (55inch), see figure 2. During the experiment, the participant's head was stabilised with a chinrest. Multiple assessments were done in this study, for a complete timeline of the design, see figure 3.

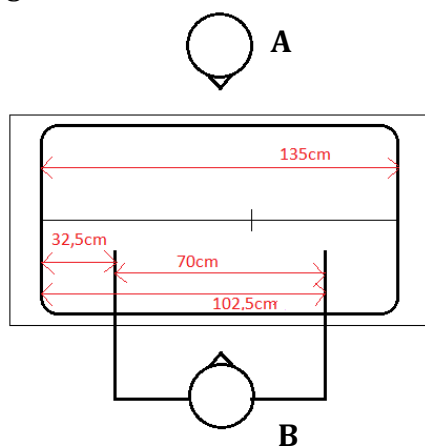


Figure 2. The pre-condition setup, A=experimenter, B=participant.

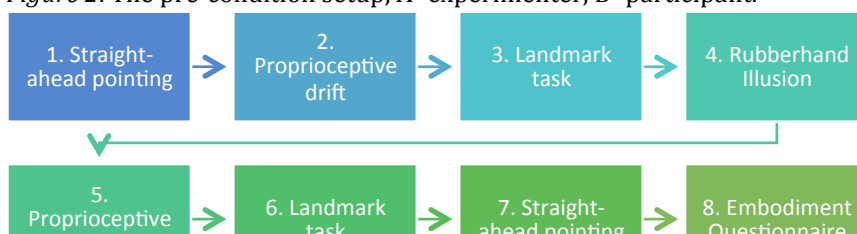


Figure 3. Timeline of the design.

Straight ahead pointing

Firstly, for the straight ahead pointing, the participant needed to put his lower arms on the screen, in front of his body (at 32.5 and 102.5cm from the left side of tablet). The participant was asked to point blind at his own body midline and then forwards to where his midline would be on the table, with his right and left hand alternately (random sequence). This point was measured in cm from the left side of the tablet. The participant was not allowed to see the result, to avoid that he would use this information next time. The difference between this location pre and post illusion is included in the analysis.

Proprioceptive drift

Next the pre-measure of proprioception was conducted. A cardboard box is placed over both hands to make them invisible, see figure 4. The experimenter moved a stick from left to right (or backwards, random sequence) across the table behind the tablet and the participant needed to say stop when he had the feeling that the stick was in length of his left or right index fingertip (random sequence). The experimenter noted the exact place (cm from the left of tablet) where the participant thought one's index fingertip was located and where it actually was located. The difference between this location pre and post illusion is included in the analysis. Thereafter, the cardboard box was removed.

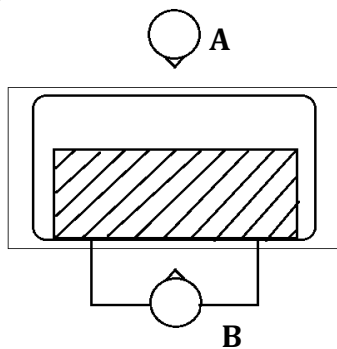


Figure 4. Set up of proprioceptive drift, A = experimenter, B = participant with a cardboard box covering the lower arms.

Landmark task

Now the pre-landmark task started. Each trial started with a dot on the left and right side of the screen alternately. The participant needed to follow these dots with his gaze, so he would not be able to refer to any previous stimulus. A horizontal baseline across the tablet was shown, with each trial a vertical line of 200 pixels on a different spot across the horizontal line. The colour of these lines was dark grey (code 313131), the background colour was light grey (code 353535). The possibilities where the vertical line was shown were at -40, -10, -5, -4, -3, -2, -1, 0 (centre), 1, 2, 3, 4, 5, 10 and 40 pixels, see figure 5. This vertical line was shown for 750ms. Thereafter a mask of vertical lines was shown, to avoid after effect. A verbal response is required from the participant whether the vertical line was located either to the left or right from the centre of the screen. The experimenter pressed 'A' if the answer was 'left' and 'L' if the answer was right. Then the next trial started, this went on for 60 trials, 4 trials for each of the 15 locations. The duration of this task is about 10 minutes.

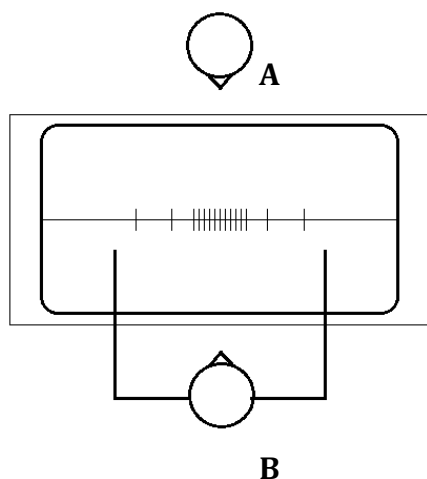


Figure 5. All possibilities of the landmark.

Note: Picture is not drawn to scale, the distance between the landmarks is smaller in reality. Only one landmark is shown each trial.

Rubber hand illusion

After this task the left arm was covered up by the cardboard box and the rubber hand illusion was set up, see figure 6. While the participant had his eyes closed, the rubber hand was placed next to the real left hand in the same position, at a distance of 15cm (Lloyd, 2007). To optimise the illusion, a cloth was placed over the shoulder of the participant, so the attachment of the arm was invisible too. In the experimental condition, the illusion was established by stroking the index finger of the real and rubber hand simultaneously with a soft brush for 90s, while the participant was visually

focused on the rubber hand. In the control condition, the stroking was asynchronous, this kept the participants' attention the same, yet did not induce the illusion.

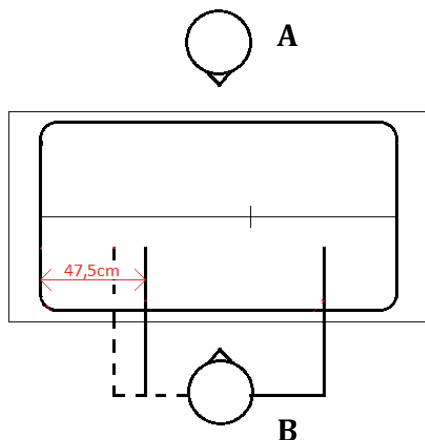


Figure 6. The illusion setup, A=experimenter, B=participant. The dotted line is the invisible real hand, next to the visible rubber hand. A landmark is shown as example.

After inducing the illusion, the rubber hand was taken away and both real hands were covered up by the cardboard (figure 4). The proprioceptive drift was now measured for the second time. The cardboard was then removed, so both hands were visible again, as in starting position (figure 2). Then the landmark task started for the second time. Afterwards, the straight ahead pointing task was done.

Embodiment questionnaire

The participant then needed to fill out the Embodiment Questionnaire (attachment A). This questionnaire contained 10 items on a 10-point Likert scale, to measure the experience of the rubber hand illusion. For example: *'It seemed like the rubber hand was my own'* and *'It seemed like I had more than two hands'*. On this scale 0=totally disagree and 10=totally agree. All together the duration of the experiment was about 30 minutes.

Hardware/Software

The landmark task was conducted on a HP computer with Windows 7 operating system. The computer was connected to a large flat screen monitor (Philips, BDT5530EM/06, 122x68cm). The landmark task was created using Matlab R2015b. To analyse the data IBM SPSS Statistics Data Editor 20 was used, as well as Microsoft Office Excel 2013.

Analysis

Firstly the outliers were eliminated from the data, see participants section for the exclusion criteria. To analyse the data of the landmark task a paired samples t-test was done for the point of subjective equality (PSE) of the participants pre and post illusion. The PSE is the point where no differences between left and right can be detected by the participant, also known as the point of non-discrimination (Colman, 2014). For both the proprioceptive drift and the straight ahead pointing task, paired sample t-tests were done. These analyses were done for both the experimental group and the control group. It was concluded that the assumptions of normality and normality of difference scores were not violated after outputting and visually inspecting the relevant histograms. The alpha was set at .05 for all analyses.

Results

Experimental group

Straight ahead pointing

A paired samples t-test was used to compare the mean scores of the participants pre RHI (M = 67.04, SD = 2.23) and post RHI (M = 67.29, SD = 2.34) on the straight ahead pointing task. On average, the participants shifted .08cm to the right in the post RHI condition. This difference was statistically not significant, $t(16) = -.47, p = .64$.

Proprioceptive drift

A paired samples t-test was used to compare the mean scores of the participants on the proprioceptive drift for the left hand pre RHI (M = 38.65, SD = 4.03) and post RHI (M = 42.18, SD = 5.35). On average, the participants shifted 3.53cm to the right in the post RHI condition. This difference was statistically significant, $t(16) = -2.58, p = .02$, and medium $d = -.75$. The same analysis is done for the right hand pre RHI (M = 95.24, SD = 4.19) and post RHI (M = 94.12, SD = 4.15). On average, the participants shifted 1.12cm to the left in the post RHI condition. This difference was statistically not significant, $t(16) = 1.53, p = .15$. The difference score in proprioception is shown in figure 7.

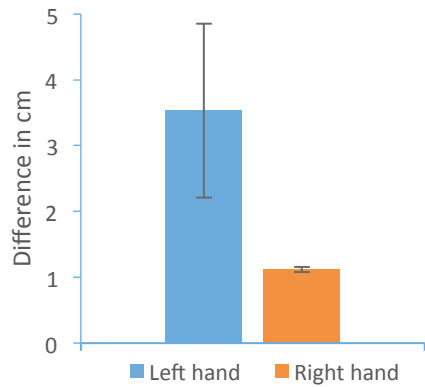


Figure 7. Difference in distance from left side of the tablet pre and post rubber hand illusion for both hands in cm.

Landmark task

A paired samples t-test was used to compare the mean PSE of the participants pre RHI ($M = -1.26$ $SD = 8.18$) and post RHI ($M = 2.75$, $SD = 5.97$) in the experimental group, see figure 8 for the PSE scores. On average, the participants had a 4.02 higher PSE in the post RHI condition than they had in the pre RHI condition. This difference was statistically significant, $t(16) = -3.85$ $p = .001$, and medium $d = -.57$. Indicating that the landmark is more often determined as 'left' after inducing the RHI.

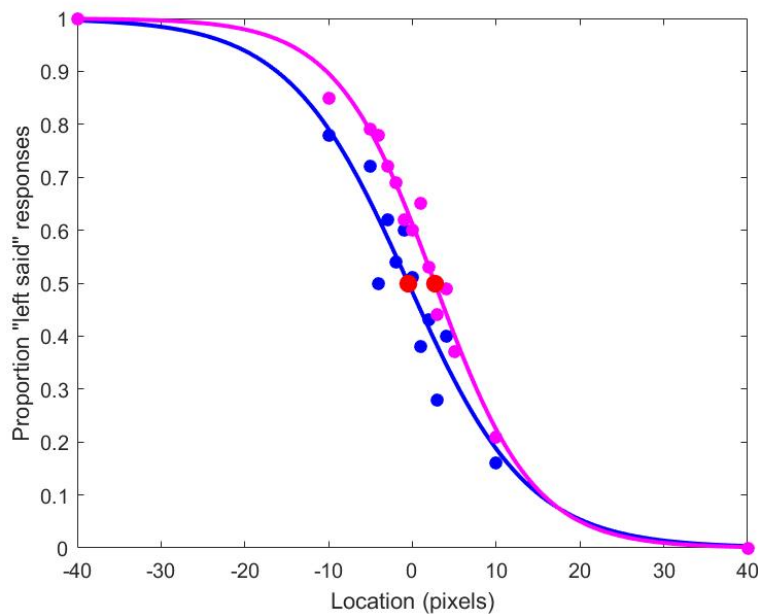


Figure 8. Proportion left responses pre (blue) and post (pink) rubber hand illusion, and the point of subjective equality (red dot).

Control group

Proprioceptive drift

A paired samples t-test was used to compare the mean scores of participants on the proprioceptive drift for the left hand pre RHI ($M = 37.55$, $SD = 3.64$) and post RHI ($M = 37.27$, $SD = 4.20$). On average, the participants shifted .27cm to the left in the post RHI condition. This difference was statistically not significant, $t(10) = .29$, $p = .78$.

The same analysis is done for the right hand, comparing pre RHI ($M = 97.82$, $SD = 2.36$) and post RHI ($M = 96.91$, $SD = 2.34$). On average, the participants shifted .91cm to the left in the post RHI condition. This difference was statistically not significant, $t(10) = 1.67$, $p = .13$. The differences in proprioception are shown in figure 9.

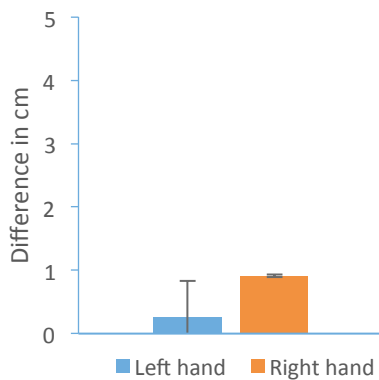


Figure 9. Difference in distance from left side of the tablet pre and post rubber hand illusion for both hands in cm.

Landmark task

For the control group the same analyses are done as the experimental group. A paired samples t-test was used to compare the mean PSE of participants pre RHI ($M = -.39$, $SD = 9.40$) and post RHI ($M = .14$, $SD = 6.82$). These PSE scores can be seen in figure 10. On average, the participants had a .53 higher PSE in the post RHI condition than they had in the pre RHI condition. This difference was statistically not significant, $t(10) = -.43$, $p = .68$.

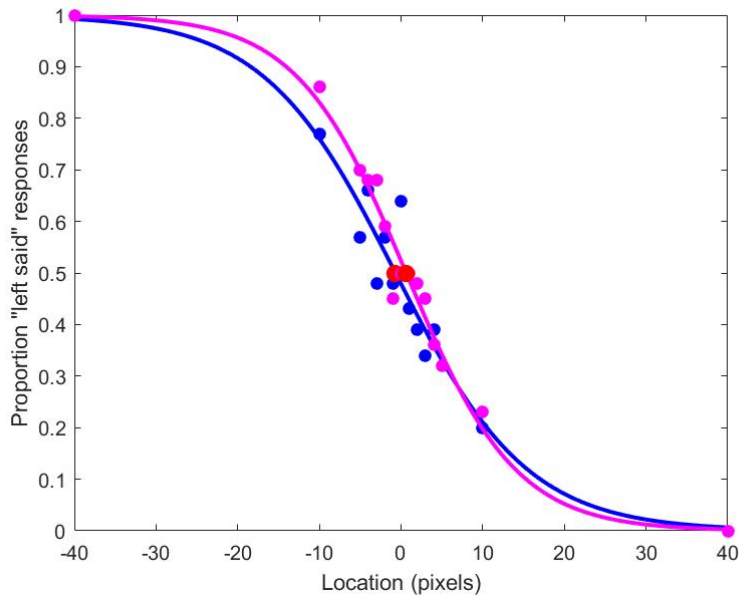


Figure 10. Proportion left responses pre (blue) and post (pink) rubber hand illusion, and the point of subjective equality (red dot).

Straight ahead pointing

Another paired samples t-test was used to compare the mean scores of the participants on straight ahead pointing pre RHI (M = 68.11, SD = 1.44) and post RHI (M = 68.02, SD = .85) in the control group. On average, the participants shifted .09cm to the left in the post RHI condition. This difference was statistically not significant, $t(10) = .51, p = .88$.

Taken together, no significant results are found in the control group. In the experimental group, there was a significant change in both proprioception and the landmark task, however no change was found in the subjective straight ahead.

Discussion

The aim of this research was to examine whether a change in ownership induces a shift in the peripersonal space. To investigate this question, a landmark task was used. The results were described by plots of the point of subjective equality (PSE), i.e. the point where no discrimination in location of the landmark is made by the participant. We hypothesized that the landmark would be more often determined as 'left' after inducing the RHI. This would be reflected by a higher PSE after the illusion, because that means the point of equality shifts to the right. We also hypothesized a proprioceptive drift from the left fingertip towards the rubber hand and a shift in body midline to the right.

As expected the results showed a change in perceived finger location, the left hand seemed to drift towards the rubber hand. There was no change in perceived location of the right hand. These results are consistent with previous research stating that the RHI induces a proprioceptive drift towards the rubber hand (Rohde et al., 2011; Longo et al., 2008; Tsakiris, 2010).

Confirming our expectations, the results showed an increase in PSE after the RHI was induced in the experimental group. The participants determined the landmark more often as 'left' in the post RHI condition. However, no significant change is found in the subjective straight ahead, which is against our expectations. Since the subjective straight ahead remains unchanged, the increase in 'left' answers on the landmark task cannot be explained by a shift in body midline. We now suggest that the change in the landmark task is the result of a change in body ownership. Body ownership is among others based on proprioceptive information (Bassolino et al., 2015; Tsakiris, Prabhu & Haggard, 2006). The RHI changes the proprioceptive information of the left hand towards the rubber hand (Rohde et al., 2011; Longo et al., 2008; Tsakiris, 2010). The feeling of body ownership will now be formed on this new proprioceptive information, causing the rubber hand to feel as one's own hand. Since the rubber hand now feels like a part of the body, the space surrounding it consequently becomes the relevant action space, thus the peripersonal space. Visual targets appearing in the peripersonal space are represented more strongly than targets appearing in the extrapersonal space (Reed, Betz, Garza & Roberts, 2010). In the pre-condition the peripersonal space of both hands is equally far apart from the central landmark. However, if the peripersonal space shifts from the left hand to the rubber hand after inducing the illusion, the PPS will now be closer to the central landmark. This would mean that the landmark now appears more often in the peripersonal space of the rubber (left) hand. Since people have an attention bias for objects in their peripersonal space, it would explain the increase in 'left' answers on the landmark task.

It is also possible that the egocentric reference in fact did change, but the amount of time between the induction of the illusion and the conduction of the straight ahead pointing task was too high. In this experiment the rubber hand is taken away after inducing the illusion, causing the illusion to slowly fade away. If the straight ahead pointing task was done right after inducing the RHI, it might lead to different results. In

the current study it was chosen not to do the straight ahead pointing task immediately, because the pointing requires to move the arms, which also diminishes the illusion.

Another possible explanation for the bias to the left in the landmark task could be the focus during the induction of the RHI. Healthy subjects often show pseudoneglect, they bisect a line slightly to the left due to an attentional bias of the right hemisphere (Thomas & Elias, 2009; Cicek, Deouell, & Knight, 2009). In this experiment, the participant is focussed on the left hand for at least 90 seconds, while the hand is being stroked. This focus could cause a larger bias to the left visual field. The control group should have excluded this possibility, yet due to a lack of power it cannot be ruled out. The effect size of the landmark task in the control group is very small, $d = .07$. For further research the control group should be expanded. If in a larger control group a significant effect is still not found, it would rule out the possibility that the effect is caused by merely the focus on stroking.

In conclusion, this research sheds a new light on the current view of body ownership and the peripersonal space. It is hypothesized that the PPS is not anchored to the body itself, but to what people perceive as their body.

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Attachment A: Embodiment Questionnaire

De onderstaande vragen gaan over hoe jij de illusie beleefd hebt. Probeer zo nauwkeurig mogelijk een antwoord te vormen op een schaal van 1 (“helemaal niet mee eens”) tot 10 (“helemaal mee eens”). Omcirkel het cijfer wat je ervaring het beste weergeeft (5 betekent “neutraal”).

1. Het leek alsof ik de aanraking voelde op de plaats waar ik de rubber hand aangeraakt zag worden

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

2. Het leek alsof ik de aanraking voelde die veroorzaakt werd door aanraking op de rubber hand

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

3. Het leek alsof de rubberen hand mijn eigen hand was

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

4. Het leek alsof mijn echte hand verplaatste in de richting van de rubber hand

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

5. Het leek alsof ik meer dan twee handen had

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

6. Het leek alsof de aanraking die ik voelde ergens tussen mijn echte en de rubberen hand veroorzaakt werd

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

7. Het leek alsof mijn echte hand “rubberachtig” werd

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

8. Het leek alsof de rubberen hand zich verplaatste in de richting van mijn echte hand

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

9. Het leek alsof de rubberen hand op mijn echte hand begon te lijken, bijv. qua vorm, kleur, etc.

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

10. Het leek alsof de rubberen hand en mijn echte hand dichter bij elkaar lagen dan werkelijk het geval was

Helemaal niet mee eens 1 2 3 4 5 6 7 8 9 10 helemaal mee eens

Attachment B: Informed consent

Rubber Hand Illusie en Peripersoonlijke ruimte.

In dit onderzoek wordt gekeken of er een ervaring van peripersoonlijke ruimte bestaat rondom een rubberen hand. Dit zal worden getest door middel van de rubber hand illusie. Na afloop van de proef dient er een vragenlijst ingevuld te worden.

'Ik verklaar hierbij op voor mij duidelijke wijze te zijn ingelicht over de aard en methode van het onderzoek. Mijn vragen zijn naar tevredenheid beantwoord. Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud daarbij het recht deze instemming weer in te trekken zonder dat ik daar een reden voor op hoeft te geven en ik besef dat ik op elk moment mag stoppen met het experiment.

Indien mijn onderzoeksresultaten gebruikt zullen worden in wetenschappelijke publicaties, dan wel op een andere manier openbaar worden gemaakt, zal dit volledig geanonimiseerd gebeuren. Mijn persoonsgegevens zullen niet door derden worden ingezien zonder mijn toestemming. Als ik nog verdere informatie over het onderzoek zou willen krijgen, nu of in de toekomst, heb ik een e-mailadres waar ik mij toe kan wenden.

Datum:.....

Naam Proefpersoon:.....

E-mailadres:.....

Handtekening:.....

Voor de onderzoeker:

'Ik heb een mondelinge en schriftelijke toelichting gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beëindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.'

Naam onderzoeker: Veerle Kurstjens

Handtekening:.....