Examensarbete

HÖGSKOLAN I SKÖVDE

Spatial configuration in rubber-hand illusion research:

A meta-analysis

Master Degree Project (60 credits) in cognitive neuroscience

Second Cycle 30 credits

Autumn term Year

Student: Marloes Eline Jansen

Supervisor: Andreas Kalckert

Examiner: Joel Edward Parthemore

Abstract

In the rubber hand illusion (RHI), a rubber hand is placed in front of the participant with the participant's hand out of sight. If both hands are touched simultaneously, the illusion typically occurs. Between RHI studies, differences can be seen in the setup, and results of the illusion strength are inconsistent. One of these differences can be the moving RHI, where the real and rubber hand make the same movements to induce the illusion. The differences led to uncertainty regarding the influence of spatial configuration (i.e., an arrangement of the setup within three-dimensional space) on the illusion of body ownership. With this meta-analysis, I quantify the illusion strength in the moving RHI to be able to conclude if spatial configuration influences the results. A total of nine studies were included that had a total of 391 participants. The results show that the synchronous condition has a stronger illusory effect than the asynchronous condition. However, due to heterogeneity, the sample size may not represent the general population. Sub-group analysis showed no major difference in the illusion strength between a vertical and horizontal setup. These observations do not correspond with classical RHI studies in which vertical and horizontal setups were compared. However, in this meta-analysis, only moving RHI studies were included. In the moving RHI, the experimenter does not enter the visual receptive field of the participant, which may explain why no differences between the setups were found. The results of this meta-analysis cannot be seen as definitive; more research is necessary.

Keywords: moving rubber-hand illusion, ownership, spatial configuration

Spatial configuration in rubber-hand illusion research: a meta-analysis

For years, the perception of someone's own body has been of interest for numerous disciplines: for example, philosophy, robotics, cognitive science, and neuroscience. Researchers have studied how people experience their bodies and the role the body has in understanding our conscious experience of ourselves and the world around us. Sense of ownership (SO) (i.e., the feeling that a person's body parts belong to her: Gallagher, 2000) is a key aspect in self-recognition, which is often built into movement and perception. Furthermore, body image (i.e., a representation of the physical structure of the body, where the brain uses previous experiences and knowledge to form the representation: Botvinick & Cohen, 1998; Ehrsson, 2020; Kammers et al., 2009b) and SO are connected in a way that body image involves a personal-level experience of the body that involves SO of the body (Gallagher, 2005).

However, body image consists of more than appearances. Body image can incorporate mental representations, beliefs, and attitudes (Gallagher, 2005). How can it be that when a physical therapist moves our arm up and down to assess the shoulder joint, we are still aware that our body part is moved even though we are not the one that is moving it? Is it possible to mistake your own body part for something or someone else's body part? And what is the influence of our body image on how we perceive our body and the world around us?

The rubber-hand illusion

The so-called rubber hand illusion (RHI) was introduced by Botvinick and Cohen (1998). The RHI made it possible to investigate SO. In the RHI, participants observe a body part, which may or may not be their own. The participant has to judge whether it is their body part or not (Tsakiris, 2010). In the RHI, a rubber hand is placed in front of the participant with the participant's hand out of sight. The illusion typically occurs if both hands – i.e., the real hand and the rubber hand – are touched simultaneously (Kalckert, 2017).

The RHI occurs under specific circumstances: for example, a delay between the two stimulations, often used in studies is a delay between 500 – 1000 ms, diminishes the illusion (Ehrsson, 2020). The position of the hand is crucial in achieving the illusion. The rubber hand must be positioned in an anatomically plausible position (Burin et al., 2017; Kalckert, 2017; Kalckert et al., 2019b; Tsakiris & Haggard, 2005). It is known that a difference in distance between the rubber hand and real hand influences the occurrence and strength of the illusion (Kalckert et al., 2019b; Lloyd, 2007). Regardless of whether you move the rubber hand to the left or right, forward (away from the body) or backward (toward the body), the smaller the distance between the rubber and real hand, the stronger the illusion. Consequently, the bigger the distance between the rubber and real hand, the weaker the illusion (Kalckert et al., 2019b; Preston, 2013).

Studies have researched if the rubber hand illusion could be induced using a non-corporeal object in place of the hand, such as a balloon (Kalckert et al., 2019a) or table (Armel & Ramachandran, 2003). More recently, new technological solutions have been used to induce the illusion: for example, video screens and v*irtual reality* (VR). Instead of looking at an artificial rubber hand, participants observe a virtual hand or a virtual scene (Slater et al., 2008). With video screens often a video image of the participants hand is shown, therefore it can be argued how much the brain is mistaken when it considers the video image as its own. With the use of VR the brain can mistake the images as its own; however, with this setup the original RHI paradigm has been changed massively.

To measure the illusion, a questionnaire is often used. The most used questionnaire is the one created by Botvinick and Cohen in 1998; otherwise, the questionnaire is based on the same questions but expanded (Botvinick & Cohen, 1998; Kalckert & Ehrsson, 2012). A seven-point Likert scale is often used to put subjective statements into a quantifiable measurement. In addition to subjective measurements via questionnaires, proprioceptive drift (i.e., the feeling that the location of one's real hand has changed) can also be measured. Most often, proprioception is measured in centimeters: for example, with a pen and paper test. The participant places a dot on the paper where she feels her hand is (Kalckert & Ehrsson, 2012; Riemer et al., 2019; Tsakiris & Haggard, 2005).

The standard interpretation of the RHI is that it creates a sensory conflict by providing incongruent multisensory input: i.e., the felt touch on the real hand and the seen touch on the rubber hand. The brain resolves this conflict by incorrectly identifying the rubber hand as one's own and updates the internal body representation: in other words, the brain updates the perceived body image. A further explanation for the RHI could be that vision possesses more reliability and spatial acuity than proprioception, meaning that the brain prioritizes the visual information it receives. If the apparent visual location lies close to the location suggested by proprioception, people experience their body part at the visual location (Armel & Ramachandran, 2003)

The RHI relies on the integration of multisensory information. Visual systems have more difficulty determining distance than direction. Proprioception uses joint angles to distinguish distance and direction; consequently, proprioceptive localization is more accurate after active movements. Proprioception is more accurate than vision along a line going straight outward from the body, facing forward, while vision is more accurate along a line at right angles to that. Accurate determination of bodily position depends on a dynamic weighting of proprioception and vision: i.e., the central nervous system (CNS) is sensitive to direction-dependent accuracy (van Beers et al., 2002; Kalckert et al., 2019b). Snijders et al. (2007) found a different weighting of visual and proprioceptive information along the horizontal and vertical axes, with the weighting of visual information being most significant on the horizontal axis (Kalckert et al., 2019b; Snijders et al., 2007).

The difference in position has been assessed in only a few studies directly: namely, the studies of Bekrater-Bodmann et al. (2012) and Smit et al. (2018). Bekrater-Bodmann et al. (2012) compared vertical and horizontal setup using the classical RHI. This study indicated a higher illusory embodiment of the rubber hand with the vertical setup than the horizontal setup. Smit et al. (2018) directly compared vertical and horizontal setup with subjective measures (i.e., questionnaires). In their study, Smit et al. (2018) compared vertical with horizontal setup using synchronous and asynchronous stroking (classical RHI) and a hand intending to stroke but not touching. Smit et al. (2018) observed that the vertical setup produced the strongest RHI.

Both studies used subjective reports, and it is unknown if other measures (e.g., proprioceptive drift) support this outcome. Both studies argue that a horizontal setup may represent a more distinct visual cue for the mismatch between proprioception and visual cues. In comparison, a vertical setup might complicate observing the mismatch between the seen position and the position of the rubber hand. This may result in experiencing the rubber hand as belonging to the body in the vertical setup.

The moving rubber hand illusion

There are variations of the RHI; the moving RHI is one of these variations (Kalckert & Ehrsson, 2014a; Walsh et al., 2011). The moving RHI was first introduced with the use of recording projections by Tsakiris et al. (2006). However, unlike the RHI, the moving RHI does not involve tactile stimulation (Kalckert, 2017; Walsh et al., 2011). Instead, the real and rubber hand make the same movements, and the participant views the movements of the rubber hand. The real hand and rubber hand are often connected with the use of a rod (most used setup described by Kalckert & Ehrsson, 2012); this way, both the real and the rubber hand move simultaneously. For the asynchronous condition, the rod is disconnected, and the researcher moves the rubber hand with a delay, diminishing the illusion.

The moving rubber hand was introduced to examine the sense of agency (SA) (i.e., I am the one who is creating an action) in conjunction with SO (Kalckert, 2017; Kalckert & Ehrsson, 2012). It has been speculated that SA affects SO. However, when different modes of movements (active and passive) were studied, a breakdown in agency but not in ownership was found in passive movements. Different manipulations affect ownership and agency in specific ways: both are affected by timing; the hand's position affects ownership, and the mode of the movement affects agency (Kalckert, 2017). Despite the variations (i.e., classical and moving RHI), the neurological mechanisms, concepts, and results of the moving RHI stay similar to the classical RHI. Kalckert and Ehrsson (2014a) directly compared the moving RHI with the static RHI and observed that participants experience the illusion irrespective of the illusion paradigm. The strength of the illusion and the number of participants experiencing the illusion was not significantly different in the compared illusion paradigms. These observations suggest that the same illusion was elicited in the moving and classical RHI. This shows that different types of somatosensory and visual information can be integrated to evoke the same changes in SO. The results of Kalckert and Ehrsson (2014a) are in line with the study of Martin Riemer et al. (2013), in which the moving and classical RHI are compared with the use of ownership questionnaires.

As well as the classical RHI, the moving RHI is also performed with the use of VR or video screens. With the moving RHI, a button press can be used. The participant has to press a button when told. When the button is pressed, the rubber hand or finger is moved. However, the researcher can also move the artificial hand without the participant pressing a button. In this way, synchronous and asynchronous conditions can be brought about (Burin et al., 2017).

Neurological mechanisms

Neuroimaging studies – for example, Ehrsson et al. (2004) – observed that activations in the premotor area correlate with participants' subjective ratings of the illusion. This study showed that bilateral activity was greater in the ventral premotor cortex and cerebellum during the RHI than in the control condition. Ehrsson et al. (2005) used an MRI scanner to obtain the neuroimages where the participant needed to press a button with her feet if the illusion occurred (i.e., if she felt the rubber hand was her hand). Ehrsson et al. (2005) used three conditions: illusion, asynchronous, and incongruent. More neuroimaging studies have been performed over the years and show that activations of the ventral premotor cortex (Ehrsson et al., 2004; Ehrsson et al., 2005; Petkova et al., 2011), intraparietal cortex (Ehrsson et al., 2004; Ehrsson et al., 2005; Petkova et al., 2011), putamen (Petkova et al., 2011), and cerebellum (Ehrsson, 2005) are known to be involved in the RHI.

Graziano (1999) performed single-cell recordings in monkeys and showed that neurons in the premotor cortex are bimodal (i.e., these neurons integrate information from two sources: e.g., vision and proprioception). Bimodal neurons have higher activity when receiving information from two modalities from the same location rather than from only one modality. When a bimodal neuron receives information from two locations, it can result in a superadditive response (i.e., an activation greater than the sum of the activation from either source on its own: Stein & Stanford, 2008). Graziano suggested that bimodal neurons use arm-position information to direct reaching movements. Bimodal neurons can also be found in the ventral premotor area (Cléry et al., 2015), intraparietal area (Cléry et al., 2015; Ehrsson et al., 2005), cerebellum, putamen, superior colliculus, and posterior parietal cortex (Stein & Stanford, 2008). These cellular processes occurring in the areas involved in the RHI are hypothesized to be the key process in deriving ownership.

Bimodal neurons allow the brain to, in effect, confuse tactile and visual information. Consequently, a change of representation of hand position may occur (Bekrater-Bodmann et al., 2012; Tsakiris, 2010).

Inconsistencies in RHI studies

Over the years, the number of RHI studies has increased. With time, a variety of methodological differences have emerged. The most common differences are horizontal (real and rubber hand next to each other) versus vertical (one hand above the other) setups and static/classic (hands do not move) RHI versus dynamic (hands or fingers move) RHI.

The horizontal setup (i.e., the rubber and real hand lay side-by-side) introduced by Botvinick and Cohen (1998) remains the most commonly used. Tsakiris et al. (2006) first used the moving RHI, in a vertical setup with video projections. They filmed the participants' hand in first-person perspective during movements and projected the black and white video images onto a black surface. Walsh et al. (2011) were the first who combined the vertical setup with the moving RHI without the use of video projections. The choice of horizontal vs. vertical setup is often dependent on practical issues: for example, which setup will fit best in the MRI scanner or is easiest to use for a moving RHI.

Proprioceptive drift can be affected significantly by setup. For example, the most substantial proprioceptive drift found on the horizontal axis has been 6cm (Kammers et al., 2009a), but only 3cm on the vertical axis (Wen et al., 2016). In addition, Kalckert et al. (2019b) showed that distance affects the RHI not only in the horizontal and vertical setups but also on the distal plane (i.e., forward, away from the body). Kalckert et al. (2019b) showed this by performing the RHI in different positions (e.g., distal near, distal far, distal very far, lateral near, and lateral far). They observed higher illusion scores in the distal position compared to the lateral positions if the distance was kept the same. This shows that distance often influences the illusion strength. That Kalckert et al. (2019b) found a stronger illusion at the distal near position than the lateral near position is unexpected because the rubber hand was located beyond reaching space. Previously it has been argued that bodily illusions (i.e., RHI) are restricted to peripersonal space surrounding the hand (Makin et al., 2008).

With a horizontal setup, the distance most often used is approximately 15cm, while a vertical setup most often uses 12cm (Kalckert & Ehrsson, 2012; Riemer et al., 2013, 2019). A difference in distance can influence the strength of the illusion. For example, it is known that a difference in distance between the rubber hand and real hand influences the occurrence and strength of the illusion (Kalckert et al., 2019b; Lloyd, 2007).

Given these differences, it is not surprising that the literature shows a wide range of results on RHI strength.

The present study

Even though RHI studies have been performed since 1998, the different setups and their effect on the results have not been studied adequately. Studies have used different arrangements; these were motivated by practical constraints (Kalckert et al., 2019b). Very few studies were conducted to compare a horizontal and vertical setup to determine what effect the different setups have on the results. This meta-analysis aims to examine the influence of spatial configuration (horizontal vs. vertical) on results using the moving-RHI paradigm. This will provide an insight into the impact of the setup on the illusion strength. Whether or not the RHI experience differs concerning orientation in space needs to be examined. Given the scarcity of within-participants comparisons in studies (Bekrater-Bodmann et al., 2012; Smit et al., 2018), a meta-analysis such as this one can provide more clarity on the subject. Only moving RHI studies are included since the classical RHI is overwhelmingly performed with a horizontal setup.

Method

Search strategy

The search strategy conforms to the PRISMA guidelines (Moher et al., 2009) and Cochrane handbook: an official guide that describes the process for a meta-analysis (Higgins et al., 2021). A search was conducted on the 5th of March 2021 on PubMed, Academic Search Elite, and Scopus using the search string "(rubber hand illusion) AND ownership AND movement". On all databases, the search was performed using the default settings ("all fields" on PubMed and Academic Search Elite, 'title, abstract, and keywords' on Scopus).

If data were missing, means and standard deviations (SD) were, if possible, calculated using quantile estimation (i.e., division of a sample into equally sized divisions: McGrath et al., 2020). If missing data or unanswered questions about the data still appeared, the authors were contacted for further information. The study by Abdulkarim (2020) had to be excluded because the article had not yet been published outside the thesis and the author declined to share the data from the study in advance of publication. The study by Lira et al. (2016) had to be excluded because it is written in a language the researcher does not know.

Inclusion and exclusion criteria

Included studies needed to (1) have an artificial hand that could be mistaken for a human hand or human hand with glove, (2) test healthy human participants, (3) use the moving-RHI paradigm, (4) use questionnaires to measure sense of ownership and (5) use asynchronous movements as a within-group control condition.

Studies were excluded based on one of the following criteria: (1) not performing a moving RHI (63), (2) using VR to produce the moving RHI effect (28), (3) using computer screens to produce the moving RHI effect (2), (4) using a non-human looking artificial hand or other objects in the study (4) (e.g., hand made of clay, robotic looking hand: Arata et al., 2014; Hall & Poliakoff, 2020), (5) not using healthy human participants (5), (6) being of the wrong publication type (11) (e.g., reviews), (7) not using questionnaire data (3), (8) not using asynchronized movements as a control condition (3), (9) using another stimulation method than movements (3), or (10) using data from an already included study (1). When in doubt, the article was discussed with the thesis supervisor for his opinion.

Data extraction

Data was extracted from the questionnaires. The mean value and SD under the synchronous (experimental) and asynchronous (control) conditions, along with the sample size, were extracted. Hedges' g (i.e., a measure of effect size) was used to compute the effect size. The effect size indicates how much the experimental data differ from the control data. Effect sizes between 0 and 0.2 were considered trivial, between 0.2 and 0.5 moderate, and greater than 0.5 high. Effect sizes were computed with the help of the Comprehensive Meta-analysis (CMA) software version 3.0[1].

After each study's effect size was estimated, the effect sizes were summed across subgroups: horizontal and vertical. The presupposition for this meta-analysis was that the included studies would have various differences: e.g., experimental design, number of participants. A random-effect analysis was chosen to compute the total effect size for each setup. The random-effect analysis allows the effect size within and between studies to vary. This leads to a wider standard error of the summary effect, as well as a more balanced weight difference between studies with larger and smaller sample sizes (Borenstein et al., 2009).

In a sub-group analysis, a comparison of the mean effect for different sub-groups was made to establish how the two subgroups (vertical vs. horizontal) differ from each other. A mixed-effects model (i.e., using a random-effects model within sub-groups and a fixed-effects model across sub-groups) was used to compare across sub-groups. A Q-test was used to partition the variance and test the between sub-groups portion of the variance.

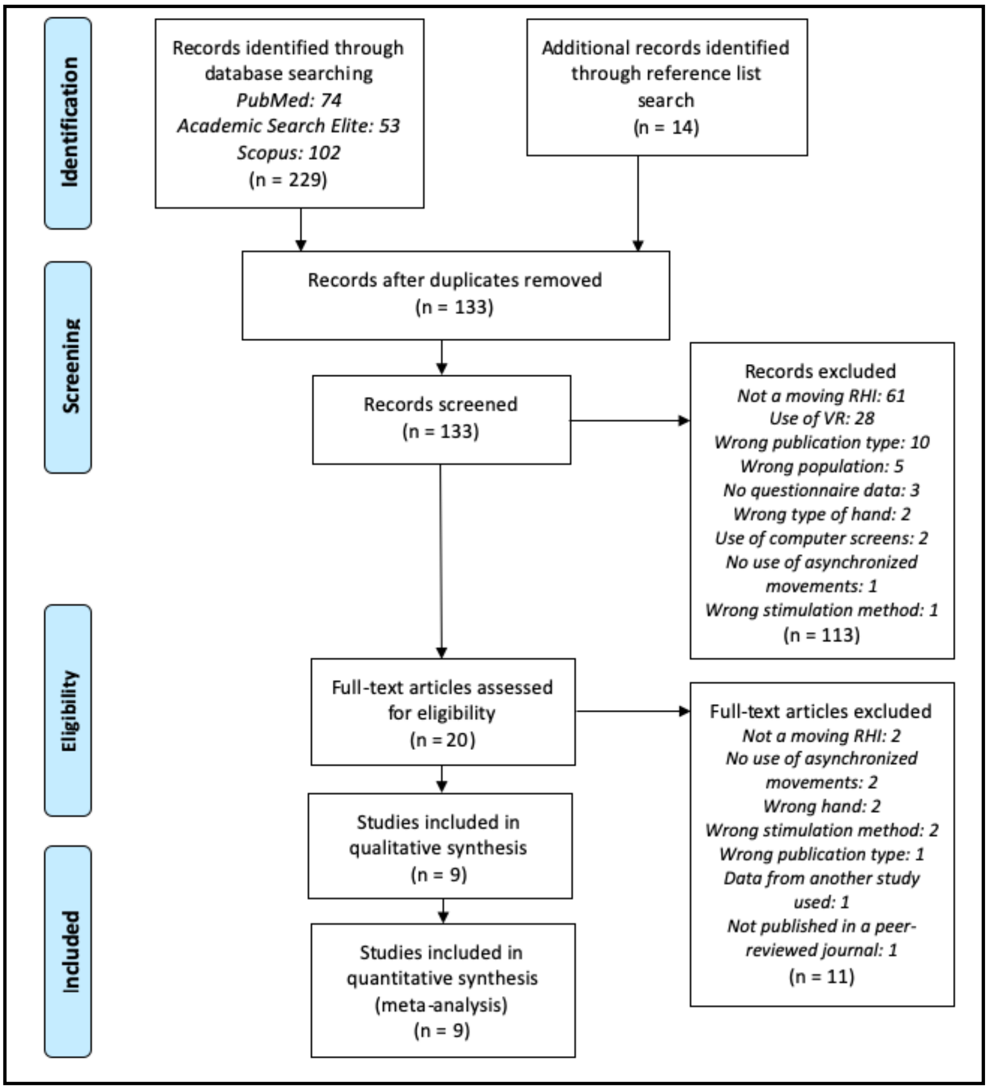
When a random-effects model is used in a meta-analysis, researchers allow themselves a certain level of variation in effect size between studies. This can cause heterogeneity: i.e., a measure of the variation between study outcomes that surpasses what one would anticipate if the studies were all performed the same way, and the variation came from measurement error only. High heterogeneity indicates the probability of subgroups within the data that have dissimilar effects. Heterogeneity was assessed with a Q test (i.e., a measure of the probability that the variation observed in results is between groups of data and not within groups): a low *p*-value indicates high heterogeneity. The Q test only provides a test of significance. To acquire a more descriptive outcome, an I^2 test was performed. An I^2 test indicates the extent of heterogeneity in percentages. A low value indicates low heterogeneity.

[1] https://www.meta-analysis.com/pages/why_use.php?cart=B9YR5390280

Due to the relative lack of published research articles with non-significant results, a publication bias often occurs. The presence of publication bias can be assessed based on a funnel plot, although a funnel plot does not on its own say anything about the significance of the publication bias. An Egger's test (a type of linear regression analysis) was performed to assess whether the publication bias was significant (Lin & Chu, 2018).

Figure 1

Flowchart of the study selection process.



Note: Graph adapted from: Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G, & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLOS Medicine, 6*(7), p. 3, e1000097. https://doi.org/10.1371/journal.pmed.1000097

Results

All studies (see Table 1) used asynchronous movements as a control condition and measured ownership by using questionnaires.

Two of the studies used a horizontal setup. Dummer et al. (2009) used three movement conditions (active, passive, and asynchronous) to assess if synchronous conditions of movement would generate more reports of the illusion. The movement conditions were compared to a visual-tactile condition. Riemer et al. (2013) used a horizontal setup to assess the impact of tactile sensations and voluntary movements concerning an artificial hand. In addition to the ownership questionnaire, pointing movements towards one's own hand were used to assess proprioceptive drift. To induce the illusion, the classical RHI and movements were both used. After the induction period, a motor and perceptual task were performed.

The following studies all used a vertical setup in their research. Caspar et al. (2015) report on the development of a robotic, user- and computer-controllable hand. The robotic hand was covered with a glove; the participant was also wearing a glove, which made both hands look similar and realistic. To validate the robotic hand, they carried out three experiments. The first experiment used active vs. passive conditions; the second used active synchronous vs. asynchronous conditions; and the third used congruent vs. incongruent conditions.

Kalckert and Ehrsson (2012) used synchronous vs. asynchronous movements (experiments 1 and 2), active vs. passive conditions (experiments 3 and 4), and congruent vs. incongruent positions (experiments 3 and 4) to show that voluntary finger movements elicit a robust illusion of ownership over the rubber hand and that SO and SA can be dissociated over the rubber hand. Kalckert and Ehrsson (2014a) directly compared the classical RHI with the moving RHI. Two experiments were conducted. In experiment one, the illusion strength was quantified using an ownership questionnaire, whereas in experiment two, proprioceptive drift was measured. Kalckert and Ehrsson (2014b) performed one questionnaire experiment (experiment 1) and two proprioceptive drift experiments (experiment 2 proprioceptive drift,

Table 1

Overview of the included studies, their setup, and the collected data.

Study							*Synchronous*		*Asynchronous*	
	Setup	**Experiment included**	**Distance between hands**	**Consistency of the artificial hand**	**Stimulation period**	**N**	**Mean**	**SD**	**Mean**	**SD**
Dummer et al. (2009)	horizontal		50 cm	Rubber human-looking hand with a brace. The participant is also wearing a brace.	10 minutes	52	4.3	1	2.5	1.1
Riemer et al. (2013)	horizontal	induction method	15 cm	Wooden hand with a skin-colored rubber glove.	3 minutes	40	3.65	1.98	2.53	1.63
Caspar et al. (2015)	vertical	experiment number 2	8 cm	Robotic hand with a glove. The participant was wearing a similar glove.	3 minutes	14	1.05	1.28	-1.19	1.36
Kalckert & Ehrsson (2012)	vertical	experiment number 1	12 cm	Wooden hand with a latex glove.	2 minutes	20	1.63	1.27	-0.99	1.5
Kalckert & Ehrsson (2014a)	vertical	experiment number 1	12 cm	Wooden hand wearing a latex glove. The participant was also wearing a latex glove.	90 seconds	40	1.06	1.81	-0.93	1.85
Kalckert & Ehrsson (2014b)	vertical	experiment number 1	12 cm	Wooden hand wearing a latex glove. The participant was also wearing a latex glove.	90 seconds	40	1.11	1.71	-1.12	1.65
Pyasik et al. (2019)	vertical		15 cm	Plastic glove filled with flour. The participant was also wearing a plastic glove.	2 minutes	20 pianists	-0.24	2.03	-1.81	1.53
						20 control	-1.63	1.5	-2.1	1.2
Kalckert & Ehrsson (2017)	vertical		12 cm	Wooden hand wearing a latex glove. The participant was also wearing a latex glove.	2 minutes	117	1.63	1.61	-1.34	1.56
Braun et al. (2014)	vertical		7.5 cm	Life-size plaster of a female hand covered with a thin-gauge garden glove. The artificial index finger was equipped with a bounding joint. Participants also wore a garden glove.	1 minute	28	1.97	1.31	1.52	1.64

Note: All studies included used questionnaires as a sense of ownership measurement tool.

experiment 3 proprioceptive drift in the classical RHI) to investigate the effect of distance (12, 27,5, and 43 cm) on the moving and classical RHI. Pyasik et al. (2019) administered the RHI paradigm to expert pianists. They compared the illusory effect of visuo-tactile stimulation and active/passive movements among a group of pianists and a control group of non-musicians. To research how long it takes participants to experience ownership over the rubber hand, Kalckert and Ehrsson (2017) measured the average onset time in active and passive movements conditions. Braun et al. (2014) examined the relationship between SA and SO using four experimental conditions, congruent – self-agent, congruent – other-agent, incongruent – self-agent, and incongruent – other-agent.

The effect sizes conducted from each study are shown in Table 2. The Q test and I^2 show significant heterogeneity between the studies (Q = 54.4, $p < 0.001$; $I^2 = 83.5\%$).

Table 2

Moving-hand illusion effect sizes expressed as Hedges' g values.

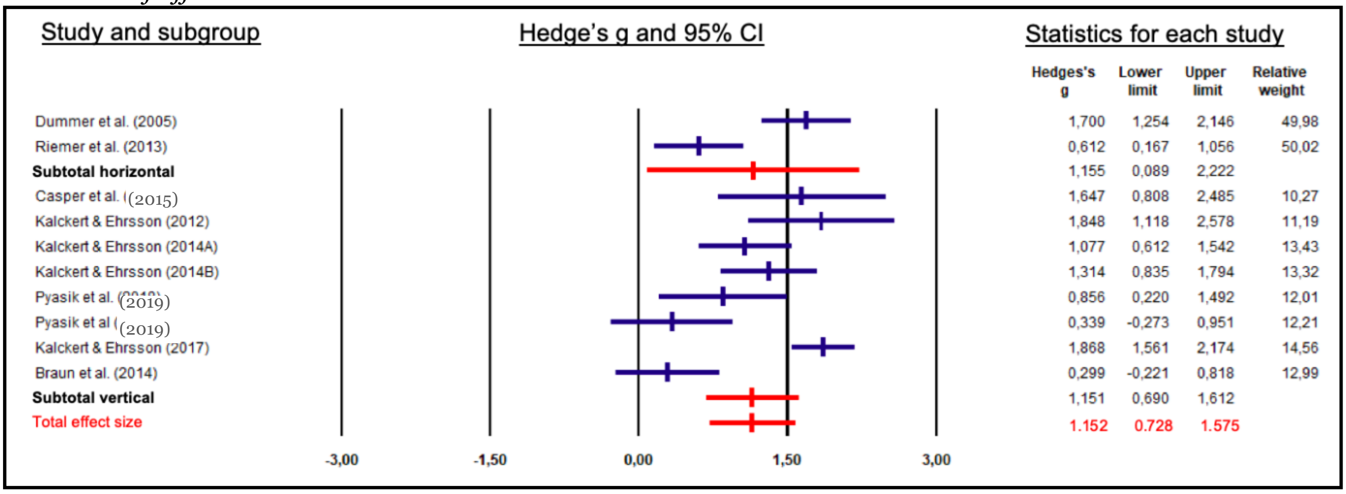
Study	***Setup***	***Hedges' g***	***Standard error***	***Within-study variance***	***p-value***
Dummer et al. (2009)	horizontal	1.70	0.23	0.05	<0.001
Riemer et al. (2013)	horizontal	0.61	0.23	0.05	0.007
Caspar et al. (2015)	vertical	1.65	0.43	0.18	<0.001
Kalckert & Ehrsson (2012)	vertical	1.85	0.37	0.14	<0.001
Kalckert & Ehrsson (2014a)	vertical	1.08	0.24	0.06	<0.001
Kalckert & Ehrsson (2014b)	vertical	1.31	0.25	0.06	<0.001
Pyasik et al. (2019)	vertical	0.86	0.32	0.11	0.008
		0.34	0.31	0.10	0.277
Kalckert & Ehrsson (2017)	vertical	1.87	0.16	0.02	<0.001
Braun et al. (2014)	vertical	0.30	0.27	0.07	0.259

Note: Data used in this meta-analysis consisted of only the ownership questionnaire data. Some studies described multiple experiments; the ones used in this meta-analysis are mentioned in this table. The p-value indicates if the true effect size is zero.

The mixed-effects analysis between the sub-groups indicates a small difference in the effect size (horizontal effect size is 0.004 higher than the vertical effect size); consequently, the strength of the RHI is similar (vertical: Hedges' g = 1.15, 95% CI [0.69 - 1.61], p<0.001, horizontal: Hedges' g = 1.16, 95% CI [0.09 - 2.22], p = 0.034; see Figure 2). In both setups, the heterogeneity was extremely high (vertical: Q = 42.4, p <0.001, I^2 = 83.5%; horizontal: Q = 11.5, *p* = <0.001, I^2 = 91.3%). This meta-analysis contains nine studies; it is not possible to identify a specific study characteristic as the cause of the heterogeneity.

Figure 2

Forest Plot of Effect Size Across Studies

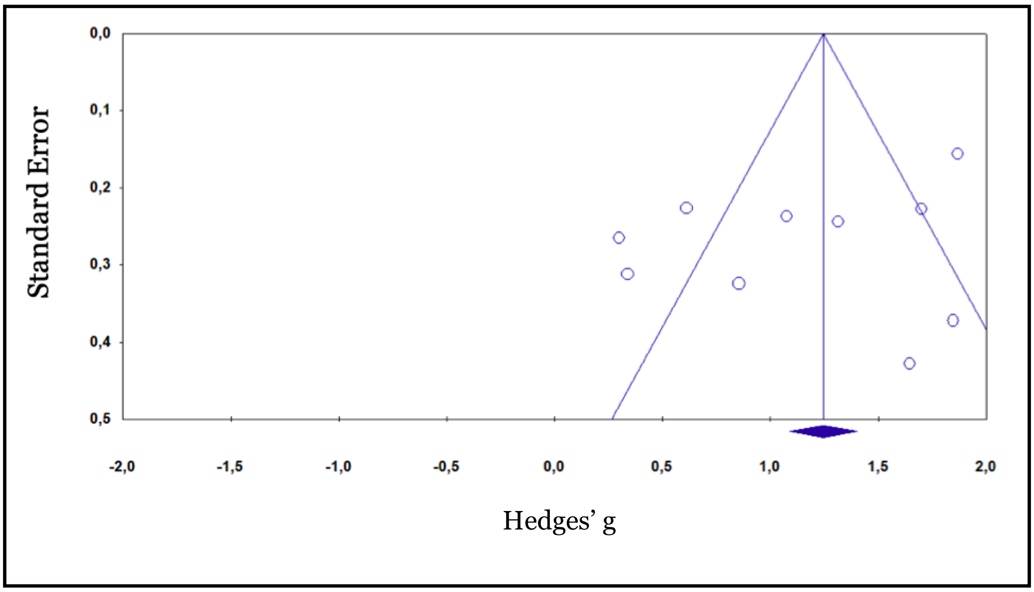


Note: The vertical lines indicate the effect size (Hedges' g), the horizontal lines the 95% confidence interval (CI). The blue lines are for individual studies, the red lines for the two subgroups – horizontal and vertical – and for the overall effect size.

As shown in Figure 3, the funnel plot was asymmetrically distributed. The Egger's test gives a more precise indication and reveals no significant publication bias (Egger's test = -3.22, 95% CI [-9.68 – 3.23], p = 0.283).

Figure 3

Funnel plot of standard error by Hedge's g.



Note: The line going down in the middle of the inverted funnel and the blue diamond on the bottom stand for the total effect size. The 95% confidence interval (CI) is represented by the lines forming the inverted funnel. Each dot represents a study.

Discussion

This meta-analysis is the first to evaluate quantitative data from available resources to examine the spatial configurations in moving RHI studies. More specifically, this meta-analysis examines if a difference in spatial configuration (horizontal vs. vertical setup) impacts the outcome of the perceived strength of ownership over the moving rubber hand.

Between the studies, the heterogeneity was significant; this means that the dissimilarities were high. This can indicate that the studies used in this meta-analysis do not represent the general population or that there are methodological differences that have not been made clear yet. The sub-group analysis suggests that the vertical and horizontal setup produce similar illusory ownership over the rubber hand. However, due to the differences (i.e., distance between the rubber and real hand and products used to make the rubber hand) between the studies and the relatively small number of included studies, more definitive conclusions cannot be taken from the present findings of the meta-analysis.

Inconsistencies between the sub-groups

In the sub-group analysis, the effect sizes for both setups showed a small difference (horizontal effect size is 0.004 higher than the vertical effect size). These observations do not correspond with Smit et al. (2018), in which the vertical and horizontal setup were directly compared with subjective measures (i.e., questionnaires). Smit et al. compared the vertical with the horizontal setup using synchronous and asynchronous stroking (classical RHI) and a hand intending to stroke but not touching. The results indicate that the illusion of ownership was significantly stronger in the vertical setup. The vertical setup also evoked more reactions from the participants compared to the horizontal setup. However, these responses were diverse and varied from positive to more negative. According to Smit et al. (2018), the reason behind these findings is that in a vertical setup, the participant's hand is placed under the rubber hand. Therefore, when the researcher approaches the rubber hand, the participant's hand is also approached. This could influence the strength of the ownership illusion. With the horizontal setup, the researcher does not approach both hands (i.e., the rubber hand and the participant's hand) with the same seen movement (Smit et al., 2018).

Like Smit et al. (2018), Bekrater-Bodmann et al. (2012) also found a higher illusory embodiment of the rubber hand with the vertical setup than the horizontal setup. Bekrater-Bodmann et al. suggested that horizontal displacement of the rubber hand and the participant's hand can portray a more distinct visual cue for the discrepancy between visual and proprioceptive input, while a vertical displacement can complicate the estimation of deviance between the seen position of the rubber hand and the felt position of the participant's hand in depth. This might result in higher ownership ratings, where the rubber hand is more likely to be experienced as belonging to the participant's body in the vertical setup (Bekrater-Bodmann et al., 2012).

However, despite all this information it can be argued that because the RHI relies on the integration of multisensory information, higher ownership rating would be expected for the horizontal setup. It is known that visual systems have more difficulties determining distance than direction. Proprioception uses joint angles to determine positions of the body. This would mean that proprioception is expected to be more precise along the distal plane, while vision would be expected to be more precise on the horizontal plane. Vision, in many situations, receives higher weighting from the central nervous system (van Beers et al., 2002; Kalckert et al., 2019b). Suppose vision is expected to be more precise on the horizontal plane and receives a higher weighting. Then higher ownership ratings would be expected for the horizontal setup.

In this meta-analysis, the fact that similar illusion strengths have been found between the setup groups can be seen as surprising. It can be argued that the differences in distance between the rubber hand and participant's hand impact the illusion strength. Dummer et al. (2009) used a distance between the hands of approximately 50 cm on the horizontal plane, which is farther apart than preferable (i.e., illusion strength decreases from 27.5 centimeters: Lloyd, 2007) and farther apart than in the other studies. Having stated this, the incongruence between the felt and seen position in the vertical setup appears smaller than in the horizontal setup. This will even be the case if the distances are similar to each other. Consequently, distance affects the RHI, but the relative position of the participant's hand and the rubber hand to one another influences the strength of the perceived illusion as well (Bekrater-Bodmann et al., 2012; Lloyd, 2007).

Kalckert and Ehrsson's (2014b) study is one of few which examined the role of distance within the moving RHI paradigm. This study shows spatial constraints for how close the participant's hand and the artificial hand must be placed to elicit the moving RHI. Kalckert and Ehrsson observed that the illusion effect becomes weaker with increasing distance. This is in line with observations in the classical RHI (Lloyd, 2007). However, the researchers also observed that the moving RHI might obey a narrower spatial constraint than the classical RHI. The classical version elicits the illusion with a distance of 12 cm and 27 cm, whereas the moving RHI only robustly elicits the illusion at 12 cm (Kalckert & Ehrsson, 2014b). These results would show that differences in obtaining the RHI do exist between the different paradigms.

Differences between this meta-analysis's results compared to the existing literature may be explained by the induction method: i.e., stroke vs. movement. The classical RHI was used to compare the different setups in the studies from Smit et al. (2018) and Bekrater-Bodmann et al. (2012). In this meta-analysis, the included studies used a moving RHI paradigm.

It is known that some inconsistencies in RHI results are due to active vs. passive movements. Kalckert and Ehrsson (2014a) found no differences between active and passive movements; however, Dummer et al. (2009) observed a more considerable illusion strength in active movements; and, at last, a more substantial illusionary effect has been found in passive movements by Walsh et al., (2011).

Premotor neurons respond to both the seen and felt position of the hand and fire when the hand is stroked or when a visual stimulus is near the hand (Ehrsson, 2020). In the vertical vs. horizontal setup, the visual receptive field (RF) is placed at a different angle from the participant (Cléry et al., 2015). In the moving RHI, the experimenter is not entering the visual RF of the participant. In the classical RHI the hand of the researcher entering the visual RF and approaching both hands is a difference between the vertical and horizontal setup. However, in the moving RHI this is not a difference between the setups; this could explain that no differences in effect sizes are found between the different setups in this meta-analysis.

In monkeys, the parietal area contains body-matching neurons. These neurons respond to visual stimuli that appear close to a specific body part of the monkey and to visual stimuli that appear near to the corresponding body part of the human researcher. Most of these neuron responses are dependent on the researcher's position to the monkey. A shared representation for space close to oneself and close to others has been found in humans. This means that the parietal node (parieto-premotor) may facilitate the construction of the representations of our own body and the body of others (Cléry et al., 2015).

The premotor cortex is known to be involved in the RHI. Ehrsson et al. (2005) showed that bilateral activity was greater in the ventral premotor cortex during the RHI than in the control condition. Thus, the premotor cortex reflects the SO, and activity in this brain area is related to the experience that the seen body belongs to oneself (Ehrsson et al., 2004).

Inconsistencies within sub-groups

Within the sub-groups, differences can be found in the effect size. If both horizontal studies are compared, the study of Riemer et al. (2013) yields a smaller effect size than Dummer et al. (2009). Riemer et al. (2013) used a distance between the artificial hand and the participant's hand of 15 cm, and the artificial hand consisted of a wooden hand covered with a skin-colored rubber clove. In comparison, Dummer et al. (2009) used an artificial human-looking rubber hand connected to a rod via a brace and a distance of approximately 50 cm between the rubber hand and the participant's hand. Furthermore, the stimulation period between these studies differs. Dummer et al. (2009) have a stimulation period of 10 minutes, while Riemer et al. (2013) had a stimulation period of 3 minutes. However, these stimulation periods both exceed the minimum time of 60 seconds, which is needed to induce the illusion in most participants (Kalckert & Ehrsson, 2017). When comparing the studies, there does not seem to be a clear explanation for the smaller effect size of Riemer et al. (2013). Considering that the setup of Dummer et al. (2009) uses a distance between the hands that exceeds the spatial limit, in fact, to other studies (Lloyd, 2007), a smaller effect size would be expected.

Within the included vertical setup studies, the studies of Pyasik et al. (2019) and Braun et al. (2014) stand out the most. In these studies, the effect size is smaller compared to the other studies. Pyasik et al. (2019) used a distance between the participant's hand and the artificial hand of 15 cm, and Braun et al. (2014) used a distance of 7.5 cm, which are the smallest and largest distances in the vertical setup group. Pyasik et al. (2019) used a plastic glove filled with flour; the participant was also wearing a plastic glove. It can be questioned if movements of a glove filled with flour represent hand or finger movements to a point where the movements can be mistaken for a real hand. Braun et al. (2014) used a life-size plaster of a female hand covered with a thin-gauge garden glove; the participant was also wearing a glove. The artificial finger was equipped with a bounding joint to make the movements look realistic. The other studies often used a wooden hand with a glove; the participant was also wearing a glove. In this regard, the study that stood out was Caspar et al. (2015); they used a robotic hand covered with a glove, the participant was also wearing a glove, which made both hands look similar and realistic.

All the studies use approximately the same stimulation period. No study uses a stimulation period lower than 60 seconds, which aligns with the minimum induction period in which most participants experience the illusion (Kalckert & Ehrsson, 2017).

The sample size of the studies included ranges from 14 to 117 participants. The studies from Braun et al. (2014) and Pyasik et al. (2019) had a sample size of 20 and 28 participants, which is an unlikely reason for a small effect size. It is often noted that studies with smaller sample sizes tend to have larger effect sizes (Slavin & Smith, 2008). Furthermore, Kalckert and Ehrsson (2012) also had a sample size of 20 and did not show a small effect size. Except from the sample size and the fact that Pyasik et al. (2019) used a glove filled with flour as an artificial hand, there is no apparent reason why these studies (Braun et al., 2014; Pyasik et al., 2019) show a smaller effect size. All these inconsistencies between the sub-groups and within the sub-groups may have caused the results to show the high heterogeneity.

Limitations

There are several limitations to this meta-analysis that need to be mentioned: first, the literature search. Due to the set exclusion criteria, a narrow search was performed; studies that used other forms of induction methods than self-performed movements, unhealthy participants, other measures than questionnaires or subjective measures (i.e., fMRI, EEG), as well as VR were excluded. This resulted in a relatively low number of nine included studies.

Second, there is a sizeable difference in the number of included horizontal (two) and vertical (seven) studies. The distribution between the subgroups is not similar, which may affect the outcome of this meta-analysis. The reason for these differences is that the moving RHI is commonly performed in a vertical setup. However, if a classic RHI would have been chosen, the vertical setup is not commonly used. Even if both (i.e., classic and moving) RHI paradigms were included, the difference in numbers would have existed, but with the higher number of studies included for the horizontal setup.

One study by Abdulkarim (2020) using a horizontal setup could not be included in this meta-analysis because the article had not yet been published outside the thesis and the author declined to share the data from the study in advance of publication. Including this study in the meta-analysis would have provided extra data for the horizontal setup and decrease the difference between the numbers of included studies. \

Further research

Between RHI studies, several inconsistencies in the strength of the illusion occur. These contrasting results and methodological differences lead to unreliability concerning the processes of sensorimotor influence on the RHI. A consensus on methodological aspects would minimize this problem and ensure that RHI results can be compared in further meta-analyses. The methodological aspects should mainly focus on the measurements used (i.e., questionnaires or proprioceptive drift) and experimental setups. It should be noted that a consensus can provide comparable results; however, it should not mean that different ways to induce the illusion should not be researched.

Before this consensus of the methodological aspects is arrived at, more research on the impact of the vertical and horizontal setup of the RHI should be performed. To research the impact of the setup, it is recommended to use the moving RHI and compare both setups directly. This way, the speculations made in this meta-analysis about finding different results due to the classical or moving RHI can be quantified. A distance of 12cm between the real hand and artificial hand in both setups would be preferred; 12cm can be used in both setups and provides robust illusion outcomes (Lloyd, 2007).

Both setups need to be investigated/examined within the same participant group. This way, both setups can directly be compared with each other. With the outcomes of this research, a substantiated choice for setup can be made and be included in a consensus on methodological aspects.

Conclusions

The results showed sizeable illusion strength for the synchronous movement condition compared to the asynchronous condition. Nevertheless, the heterogeneity across the studies was considerable, which indicates that the total effect size can be unreliable. The setups (i.e., horizontal vs. vertical) yielded a small difference in effect sizes (horizontal effect size is 0.004 higher than the vertical effect size), indicating a similar illusion strength of body ownership in both setups. This does not correspond with previous classical RHI studies, such as Bekrater-Bodmann et al. (2012) and Smit et al. (2018). A consensus on methodological aspects is needed to help obtain consistent results within the RHI paradigm. The results of this meta-analysis extend the literature regarding the impact of spatial discrepancies on the results in moving RHI studies. However, these results cannot be seen as definitive conclusions; more research is necessary to make definitive conclusions about the influence of spatial configuration on the RHI strength.

Acknowledgments

I want to express my gratitude to Dr. Andreas Kalckert, my research supervisor, for his useful critiques, encouragement, and constructive suggestions during the development of this thesis. I would also like to thank my examiner, Dr. Joel Parthemore, for his critical comments and suggestions for improving my thesis. At last, I want to thank all the authors of the included studies for providing me with the needed data.

References

Abdulkarim, Z. (2020). Study IV. In Abdulkarim, Z., *Limb ownership and voluntary action: Human behavioral and neuroimaging studies* (PhD thesis). Karolinska Institutet. http://openarchive.ki.se/xmlui/handle/10616/47314

Arata, J., Hattori, M., Ichikawa, S., & Sakaguchi, M. (2014). Robotically enhanced rubber hand illusion. *IEEE Transactions on Haptics*, *7*(4), 7. https://ieeexplore-ieee-org.libraryproxy.his.se/document/6732936

Armel, K. C., & Ramachandran, V. S. (2003). Projecting sensations to external objects: Evidence from skin conductance response. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *270*(1523), 1499–1506. https://doi.org/10.1098/rspb.2003.2364

van Beers, R. J., Wolpert, D. M., & Haggard, P. (2002). When feeling is more important than seeing in sensorimotor adaptation. *Current Biology*, *12*(10), 834–837. https://doi.org/10.1016/S0960-9822(02)00836-9

Bekrater-Bodmann, R., Foell, J., Diers, M., & Flor, H. (2012). The perceptual and neuronal stability of the rubber hand illusion across contexts and over time. *Brain Research*, *1452*, 130–139. https://doi.org/10.1016/j.brainres.2012.03.001

Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (Eds.). (2009). *Introduction to meta-analysis*. John Wiley & Sons.

Botvinick, M., & Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature*, *391*(6669), 756–756. https://doi.org/10.1038/35784

Braun, N., Thorne, J. D., Hildebrandt, H., & Debener, S. (2014). Interplay of agency and ownership: The intentional binding and rubber hand illusion paradigm combined. *PLoS ONE*, *9*(11), e111967. https://doi.org/10.1371/journal.pone.0111967

Burin, D., Pyasik, M., Salatino, A., & Pia, L. (2017). That's my hand! Therefore, that's my willed action: How body ownership acts upon conscious awareness of willed actions. *Cognition*, *166*, 164–173. https://doi.org/10.1016/j.cognition.2017.05.035

Caspar, E. A., De Beir, A., Magalhaes De Saldanha Da Gama, P. A., Yernaux, F., Cleeremans, A., & Vanderborght, B. (2015). New frontiers in the rubber hand experiment: When a robotic hand becomes one's own. *Behavior Research Methods*, *47*(3), 744–755. https://doi.org/10.3758/s13428-014-0498-3

Cléry, J., Guipponi, O., Wardak, C., & Ben Hamed, S. (2015). Neuronal bases of peripersonal and extrapersonal spaces, their plasticity and their dynamics: Knowns and unknowns. *Neuropsychologia*, *70*, 313–326. https://doi.org/10.1016/j.neuropsychologia.2014.10.022

Dummer, T., Picot-Annand, A., Neal, T., & Moore, C. (2009). Movement and the rubber hand illusion. *Perception*, *38*(2), 271–280. https://doi.org/10.1068/p5921

Ehrsson, H. H. (2005). Touching a rubber hand: Feeling of body ownership is associated with activity in multisensory brain areas. *Journal of Neuroscience*, *25*(45), 10564–10573. https://doi.org/10.1523/JNEUROSCI.0800-05.2005

Ehrsson, H. H. (2020). Multisensory processes in body ownership. In K. Sathian & V. S. Ramachandran (Eds.), *Multisensory perception* (pp. 179–200). Elsevier. https://doi.org/10.1016/B978-0-12-812492-5.00008-5

Ehrsson, H. H., Holmes, N. P., & Passingham, R. E. (2005). Touching a rubber hand: Feeling of body ownership is associated with activity in multisensory brain areas. *Journal of Neuroscience*, *25*(45), 10564–10573. https://doi.org/10.1523/JNEUROSCI.0800-05.2005

Ehrsson, H. H., Spence, C., & Passingham, R. E. (2004). That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. *Science*, *305*(5685), 875–877. https://doi.org/10.1126/science.1097011

Gallagher, S. (2000). Philosophical conceptions of the self: Implications for cognitive science. *Trends in Cognitive Sciences*, *4*(1), 14–21. https://doi.org/10.1016/S1364-6613(99)01417-5

Gallagher, S. (2005). *How the body shapes the mind*. Oxford University Press. https://oxford.universitypressscholarship.com/view/10.1093/0199271941.001.0001/acprof-9780199271948

Graziano, M. S. A. (1999). Where is my arm? The relative role of vision and proprioception in the neuronal representation of limb position. *Proceedings of the National Academy of Sciences*, *96*(18), 10418–10421. https://doi.org/10.1073/pnas.96.18.10418

Hall, A., & Poliakoff, E. (2020). The clay hand illusion and the embodiment of unfeasible objects. *Perception*, *49*(9), 988–993. https://doi.org/10.1177/0301006620948502

Higgins, J., Thomas, J., Cumpston, M., Li, T., Page, M., & Welch, V. (Eds.). (2021). *Cochrane handbook for systematic reviews of interventions version 6.2*. Cochrane. www.training.cochrane.org/handbook

Kalckert, A. (2017). I am moving my hand: Ownership, agency, and the body. In T. Grünbaum & M. S. Christensen (Eds.), *Sensation of movement* (pp. 9–29). Routledge. https://doi.org/10.4324/9781315627618

Kalckert, A., Bico, I., & Fong, J. X. (2019a). Illusions with hands, but not with balloons – Comparing ownership and referral of touch for a corporal and noncorporal object after visuotactile stimulation. *Perception*, *48*(5), 447–455. https://doi.org/10.1177/0301006619839286

Kalckert, A., & Ehrsson, H. H. (2012). Moving a rubber hand that feels like your own: A dissociation of ownership and agency. *Frontiers in Human Neuroscience*, *6*. https://doi.org/10.3389/fnhum.2012.00040

Kalckert, A., & Ehrsson, H. H. (2014a). The moving rubber hand illusion revisited: Comparing movements and visuotactile stimulation to induce illusory ownership. *Consciousness & Cognition*, *26*, 117–132. https://doi.org/10.1016/j.concog.2014.02.003

Kalckert, A., & Ehrsson, H. H. (2014b). The spatial distance rule in the moving and classical rubber hand illusions. *Consciousness and Cognition*, *30*, 118–132. https://doi.org/10.1016/j.concog.2014.08.022

Kalckert, A., & Ehrsson, H. H. (2017). The onset time of the ownership sensation in the moving rubber hand illusion. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00344

Kalckert, A., Perera, A. T.-M., Ganesan, Y., & Tan, E. (2019b). Rubber hands in space: The role of distance and relative position in the rubber hand illusion. *Experimental Brain Research*, *237*(7), 1821–1832. https://doi.org/10.1007/s00221-019-05539-6

Kalckert, A., Perera, A. T.-M., Ganesan, Y., & Tan, E. (2019b). Rubber hands in space: The role of distance and relative position in the rubber hand illusion. *Experimental Brain Research*, *237*(7), 1821–1832. https://doi.org/10.1007/s00221-019-05539-6

Kammers, M. P. M., de Vignemont, F., Verhagen, L., & Dijkerman, H. C. (2009a). The rubber hand illusion in action. *Neuropsychologia*, *47*(1), 204–211. https://doi.org/10.1016/j.neuropsychologia.2008.07.028

Kammers, M. P. M., Longo, M. R., Tsakiris, M., Dijkerman, H. C., & Haggard, P. (2009b). Specificity and coherence of body representations. *Perception*, *38*(12), 1804–1820. https://doi.org/10.1068/p6389

Lin, L., & Chu, H. (2018). Quantifying publication bias in meta-analysis. *Biometrics*, *74*(3), 785–794. https://doi.org/10.1111/biom.12817

Lira, M., Dall'Agnol, P. A., Boggio, S. A., & Boggio, P. S. (2016). Ilusão da mão de borracha induzida por estímulos controlados por equipamento eletrônico. *Psicologia - Teoria e Prática*, *18*(1), 129–140. https://doi.org/10.15348/1980-6906/psicologia.v18n1p129-140

Lloyd, D. M. (2007). Spatial limits on referred touch to an alien limb may reflect boundaries of visuo-tactile peripersonal space surrounding the hand. *Brain and Cognition*, *64*(1), 104–109. https://doi.org/10.1016/j.bandc.2006.09.013

Makin, T. R., Holmes, N. P., & Ehrsson, H. H. (2008). On the other hand: Dummy hands and peripersonal space. *Behavioural Brain Research*, *191*(1), 1–10. https://doi.org/10.1016/j.bbr.2008.02.041

McGrath, S., Zhao, X., Steele, R., Thombs, B. D., & Benedetti, A., the DEPRESsion Screening Data (DEPRESSD) Collaboration. (2020). Estimating the sample mean and standard deviation from commonly reported quantiles in meta-analysis. *Statistical Methods in Medical Research*, *29*(9), 2520–2537. https://doi.org/10.1177/0962280219889080

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLOS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Petkova, V. I., Björnsdotter, M., Gentile, G., Jonsson, T., Li, T.-Q., & Ehrsson, H. H. (2011). From part- to whole-body ownership in the multisensory brain. *Current Biology*, *21*(13), 1118–1122. https://doi.org/10.1016/j.cub.2011.05.022

Preston, C. (2013). The role of distance from the body and distance from the real hand in ownership and disownership during the rubber hand illusion. *Acta Psychologica*, *142*(2), 177–183. https://doi.org/10.1016/j.actpsy.2012.12.005

Pyasik, M., Salatino, A., & Pia, L. (2019). Do movements contribute to sense of body ownership? Rubber hand illusion in expert pianists. *Psychological Research*, *83*(1), 185–195. https://doi.org/10.1007/s00426-018-1137-x

Riemer, M., Kleinböhl, D., Hölzl, R., & Trojan, J. (2013). Action and perception in the rubber hand illusion. *Experimental Brain Research*, *229*(3), 383–393. https://doi.org/10.1007/s00221-012-3374-3

Riemer, M., Trojan, J., Beauchamp, M., & Fuchs, X. (2019). The rubber hand universe: On the impact of methodological differences in the rubber hand illusion. *Neuroscience and Biobehavioral Reviews*, *104*, 268–280. https://doi.org/10.1016/j.neubiorev.2019.07.008

Slater, M., Perez-Marcos, D., Ehrsson, H. H., & Sanchez-Vives, M. V. (2008). Towards a digital body: The virtual arm illusion. *Frontiers in Human Neuroscience*, *2*. https://doi.org/10.3389/neuro.09.006.2008

Slavin, R., & Smith, D. (2008). Effects of sample size on effect size in systematic reviews in education. *Best Evidence Encyclopedia*, 10. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.522.6374&rep=rep1&type=pdf#:~:text=Studies%20with%20sample%20sizes%20below,to%20lack%20of%20random%20assignment.

Smit, M., Brummelman, J. T. H., Keizer, A., van der Smagt, M. J., Dijkerman, H. C., & van der Ham, I. J. M. (2018). Body ownership and the absence of touch: Approaching the rubber hand inside and outside peri-hand space. *Experimental Brain Research*, *236*(12), 3251–3265. https://doi.org/10.1007/s00221-018-5361-9

Snijders, H. J., Holmes, N. P., & Spence, C. (2007). Direction-dependent integration of vision and proprioception in reaching under the influence of the mirror illusion. *Neuropsychologia*, *45*(3), 496–505. https://doi.org/10.1016/j.neuropsychologia.2006.01.003

Stein, B. E., & Stanford, T. R. (2008). Multisensory integration: Current issues from the perspective of the single neuron. *Nature Reviews Neuroscience*, *9*(4), 255–266. https://doi.org/10.1038/nrn2331

Tsakiris, M. (2010). My body in the brain: A neurocognitive model of body-ownership. *Neuropsychologia*, *48*(3), 703–712. https://doi.org/10.1016/j.neuropsychologia.2009.09.034

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(1), 80–91. https://doi.org/10.1037/0096-1523.31.1.80

Tsakiris, M., Prabhu, G., & Haggard, P. (2006). Having a body versus moving your body: How agency structures body-ownership. *Consciousness & Cognition*, *15*(2), 423–432. https://doi.org/10.1016/j.concog.2005.09.004

Walsh, L. D., Moseley, G. L., Taylor, J. L., & Gandevia, S. C. (2011). Proprioceptive signals contribute to the sense of body ownership. *Journal of Physiology*, *589*(12), 3009–3021. https://doi.org/10.1113/jphysiol.2011.204941

Wen, W., Muramatsu, K., Hamasaki, S., An, Q., Yamakawa, H., Tamura, Y., Yamashita, A., & Asama, H. (2016). Goal-directed movement enhances body representation updating. *Frontiers in Human Neuroscience*, *10*, 329. https://doi.org/10.3389/fnhum.2016.00329