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# RUBBER HAND ILLUSION AND AFFECTIVE TOUCH:

A Systematic Review

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Abstract

The feeling of owning a body part is often investigated by conducting and manipulating the rubber hand illusion, a three-way integration of vision, touch, and proprioception. In the last decade, more research on the role of interoception, the sense of the body's' internal state, in the illusion has been made. One of the studied factors has been the affective touch, a caress-like, gentle, touch that is performed at a slow specific speed (1-10  cm/sec). Affective touch activates the C tactile afferents which send interoceptive signals to the brain, specifically the insula. The present systematic review investigated the role affective touch has on the strength of the rubber hand illusion. A range of electronic databases was searched for papers reporting research findings published in English before March 20, 2020. Twelve different articles were identified, but only five papers met the inclusion criteria. This thesis looked at the results from these five different studies and compared the effect of affective touch and discriminative, regular, touch have on the rubber hand illusion to see whether there is a significant difference. The results could not show a main effect of stroking velocity, site of stimulation, or social touch, which are components of affective touch. The results was based on four different measurements, the subjective experience of the illusion, pleasantness ratings, proprioceptive drift, and temperature difference in the skin. Opposed what was hypothesized, it could not be demonstrated that affective touch would induce a stronger rubber hand illusion than discriminative touch.

*Keywords*: Rubber hand illusion, affective touch, cognitive neuroscience, body ownership, interoception

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# Introduction

The human brain creates the world we see and feel. It projects, for example, the brightness of the sun, the admiration of excellence in a musical piece, and also the feeling of owning a physical body. Damage to a specific part of the brain can result in a distorted sense of self, for example, a stroke in the right-hemisphere may lead to asomatognosia, which is a loss of ownership of a body part (Jenkinson, Moro, & Fotopoulou, 2018). This feeling of ownership can be manipulated experimentally by stimulating different sensory systems in a specific manner. For example, the brain can be tricked to lose ownership of a hand and think that a rubber hand is part of the body.

The aim of the present systematic review was to investigate the role of affective touch on the strength of the rubber hand illusion.The thesis will begin with an overview of body ownership, the rubber hand illusion, and also brain regions connected to these phenomena. This section will also explain why a certain kind of touch, called affective touch, may have an impact on the subjective feeling of body ownership in the rubber hand illusion. Further, the process of finding and evaluating relevant studies will be explained. The main section will present the results of five studies regarding the role of affective touch in the rubber hand illusion. The thesis will end with a discussion of the results and the limitations of the paper, suggestions for future directions will be provided, and a conclusion will be made.

# Background

## Body Ownership

The sense of body ownership is described as a feeling of owning a physical body part or an entire body (Ehrsson, 2020). This happens when the brain combines different sensory cues about the own body that are not accessible from other bodies. This type of information can, for example, come from somatosensation, nociception, vestibular signals, and thermosensation (Kilteni, Maselli, Kording, & Slater, 2015). The sensory cues are integrated by brain regions that contain multisensory neurons, which is needed to get a coherent perception of the own body (Ehrsson, 2020). Blanke and Metzinger (2009) argue that body ownership can be divided into two categories, ownership of body parts (for example, a limb) and global ownership (whole-body), due to that the conscious experience of the two is distinguished from each other. The sense of body ownership can be investigated through bodily illusions such as rubber hand illusions (RHI) and full-body illusions. While RHI investigates the ownership of body parts and full-body illusions investigate global ownership, the paradigm is the same with conflicting tactile and visual information that affects proprioception (Botvinick & Cohen, 1998; Lenggenhager, Tadi, Metzinger, & Blanke, 2007). This thesis will focus on the RHI.

## The Rubber Hand Illusion

The most common form of the RHI is the classic rubber hand illusion where a three-way integration of vision, touch, and proprioception occurs. A visible rubber hand is stroked repeatedly at the same time as the participant's real hidden hand is stroked in the same place and at the same pace. This makes the participants perceive the rubber hand as belonging to their own body, and a sense of body ownership of the rubber hand has taken place (Botvinick & Cohen, 1998).

To know whether an illusion has occurred, different measurements are conducted. A questionnaire is a typical method for assessing the subjective experience of the illusion. The questionnaire consists of questions or statements regarding the illusory feeling of ownership, for example agency, location, and ownership, and other questions or statements which exists for control purpose (Botvinick & Cohen, 1998; Kammers, de Vignemont, Verhagen, & Dijkerman, 2009; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008). An objective measure that is commonly used is the proprioceptive drift measurement. Proprioceptive drift is the degree to which individuals experience their real hand being closer to the rubber hand, it is usually assessed by participants closing their eyes and with their finger trying to locate their real hand. The participants place their finger under the table and move it alongside the table until they think they have found the location of the real hand (Botvinick & Cohen, 1998). For measuring interoceptive signals from the skin, skin conductance for emotional responses, and skin temperature has been measured as well (Armel & Ramachandran, 2003; Moseley et al., 2008). The measurements assess the occurrence and strength of the illusion. The strength of the illusion is affected by some rules and principles, but also if the participants have a neuropsychiatric disorder. Studies on schizophrenia and autism spectrum disorders have suggested that these disorders might affect the strength of the illusion and the feeling of body ownership (Cascio, Foss-Feig, Burnette, Heacock, & Cosby, 2012; Thakkar, Nichols, McIntosh, & Park, 2011). The rules and principles will now be presented in relation to a non-clinical sample.

First, there is a rule called the distance rule. The distance between the real hand and the rubber hand matters when it comes to how strong the illusion will be. Kalckert and Ehrsson (2014) tested the effect of vertical distance on the RHI. The testing of distances 12, 27.5, and 43 cm showed that the illusion becomes weaker when the distance increases. The horizontal distance has been tested by Lloyd (2007). She found that after a distance of 30 cm between the real and the rubber hand, the illusion significantly decreases.

An important principle in RHI is the spatial principle of multisensory integration. This principle implies that the congruence of the felt and seen location of the touch is important for multisensory integration. This is due to the receptive fields of the neurons (Stein & Stanford, 2008). If the locations of the tactile stimulation do not match, for example, the touch is conducted on different fingers, the illusion is eliminated (Kammers, Longo, Tsakiris, Dijkerman, & Haggard, 2009).

Temporal congruence is also an important aspect for the RHI to occur. Armel and Ramachandran (2003) found that when the rubber hand and real hand are touched asynchronously, the illusion is not as strong as when the hands were touched synchronously. Studies about the temporal discrepancy between the touches have shown that a discrepancy of 300ms or less between the visual stimulation and tactile stimulation is correlated with a stronger sensation of the RHI (Shimada, Fukuda, & Hiraki, 2009). The more the delay is increasing, the more the proprioceptive drift is declining (Shimada, Suzuki, Yoda, & Hayashi, 2014). In RHI experiments it is common to use asynchronous touch for the control condition as it is known to not elicit an illusion.

There is a rule for tactile congruence as well. This rule is based on how much accordance the real hand and seen object have, for example features and texture of the fingers (Ehrsson, 2020). It has been suggested that when the visual appearance and predicted tactile consequences are not congruent, the illusion is diminished (Ward, Mensah, & Jünemann, 2015). The congruence of the roughness of the object has been investigated but did not show to affect the illusion on an implicit or explicit level (Schütz-Bosbach, Tausche, & Weiss, 2009). Studies have investigated if the rubber hand could be replaced by other objects, for example a plain wooden block, and still elicit the illusion. The results show that the object the participants see being stroked must have a similar appearance as a human hand (Tsakiris, Carpenter, James, & Fotopoulou, 2010). When the spatiotemporal and tactile congruence criteria are met, the illusion usually takes place. The onset time of the illusion, from the beginning of the touch to the occurrence of the illusion, is something that has been discussed.

Findings on the illusion onset have differed a lot over the years, with findings of shorter onset in earlier studies and longer onset in more recent studies. The earlier findings found the onset to be between 5.6 and 20s (Davies, White, & Davies, 2013; Ehrsson, Spence, & Passingham, 2004; Lloyd, 2007). The later studies showed an onset between 60 and 100s (Lane, Yeh, Tseng, & Chang, 2017; Yeh, Lane, Chang, & Chien, 2017). Kalckert (2018) speculated that the differences may be due to the methodological differences between studies.

These rules and the whole three-way integration of vision, touch, and proprioception is interpreted as a 'bottom-up' process and is considered to be a part of the exteroceptive model of the bodily self, in explanation, the coherent representation of the body is made of available sensory evidence (Tsakiris, 2017). The interoceptive model explains the role of interoception, which is important for allowing the brain to ensure the maintenance of homeostasis. This consists of 'top-down processes' which provide additional information about the body to the brain which can be combined with exteroceptive signals. Interoception can be decomposed to signals that are created within different systems of the body - the cardiovascular, respiratory, gastrointestinal, and urogenital (Tsakiris, 2017).

The induction of the RHI has shown to affect the homeostasis in the form of a change in skin temperature. Moseley et al. (2008) found that the skin temperature of the real hand decreased when an RHI occurred. To understand the role interoception plays in the RHI, research on the effect of cardiac awareness and affective touch in the RHI has been conducted (e.g Crucianelli, Krahé, Jenkinson, & Fotopoulou, 2018). Affective touch will be explained later in the introduction. Individual differences in interoceptive sensitivity, as measured by a heartbeat detection task, have been shown to play a role in the strength of the perception of the RHI (Tsakiris, Jiménez, & Costantini, 2011). Participants with a lower interoceptive sensitivity perceived a stronger RHI compared to participants with higher interoceptive sensitivity. Tsakiris (2017) suggested that the exteroceptive model of self foregrounds the plasticity of body ownership and that the interoceptive model of self sees over the stability of the body as a reaction to changes in the environment. So far this thesis has described the multisensory processes in the RHI. The following section will present evidence for the involvement of multisensory brain regions in the illusion, i.e., the experience of ownership.

**Neural Correlates of the Rubber Hand Illusion**

The brain has multisensory regions where body-related signals in the space surrounding the body, the peripersonal space, are integrated. These regions contain multisensory neurons that respond to inputs in an additive, linear, or superadditive, nonlinear, fashion (Gentile, Petkova, & Ehrsson, 2011). Additive means that the response to visuotactile stimulation does not surpass the sum of the responses to visual and tactile stimulation separately. Superadditive means that the response of visuotactile stimulation is significantly greater than the sum of the responses to unisensory visual and tactile stimulation (Stein & Stanford, 2008). Visual and tactile integration hotspots for the hand have been found through a functional magnetic resonance imaging (fMRI) study by Gentile et al. (2011). Multisensory additive responses showed in the posterior, and inferior parietal cortex, and dorsal, and ventral premotor cortex. Superadditive responses showed in the insula, dorsal premotor cortex, the putamen, and in the cortical lining of the left anterior intraparietal sulcus (Gentile et al., 2011). Studies with fMRI as a tool of measurement have found that the premotor cortex and intraparietal cortex have neurons with receptive fields that respond to visual and tactile stimulation. This co-registration of visual and tactile receptive fields is essential in the RHI, concerning specific parts of the body (Ehrsson et al., 2004; Lloyd, Shore, Spence, & Calvert, 2003; Makin, Holmes, & Zohary, 2007). This is very similar to the brain regions that have been found in the brain of macaque monkeys' (Avillac, Hamed, & Duhamel, 2007; Bremmer et al., 2001). Studies on monkeys have put forward evidence of visual-proprioceptive neurons that are located within the premotor cortex (Graziano, 1999).

The first fMRI study of the RHI showed an increased BOLD signal in both the intraparietal cortex and premotor cortex, especially in the ventral part of the premotor cortex. The premotor cortex activity has been shown to correlate with the subjective strength of the RHI (Ehrsson et al., 2004). These brain areas have also been found to have a role in the ownership of an individual's real hands as well (Gentile, Guterstam, Brozzoli, & Ehrsson, 2013). Gentile et al. (2013) found that when multisensory information is incongruent, a feeling of disownership towards the real hand occurs. This is due to the need for a simultaneous match between visual and proprioceptive information for the multisensory integration effect to happen. The role of the premotor cortex in limb ownership is supported by a study with participants that had damage to the right premotor and motor cortices. The authors found that damage to these areas can lead to a loss of awareness of a body part (Arzy, Overney, Landis, & Blanke, 2006).

The extrastriate body area (EBA) is another brain area that has been found to have more activation during the RHI compared to control conditions (Limanowski, Lutti, & Blankenburg, 2014). The EBA is located in lateral occipital cortices and is mostly known for processing visual information about body parts (Downing, Jiang, Shuman, & Kanwisher, 2001). Limanowski et al. (2014) showed that the contralateral primary somatosensory cortex had stronger connectivity with EBA in the RHI and stronger interaction with temporo-parietal multisensory areas compared to control conditions. The authors also found stronger activity in the bilateral anterior insula and middle occipital gyrus when an RHI had occurred.

In the RHI, tactile and proprioceptive cues influence the visual processing through a stream that goes through parietal regions which may lead to help the visual self-recognition (Ehrsson, 2020). Several studies have found evidence that the cerebellum is involved in the experience of the RHI. Ehrsson et al. (2004) suggest that the premotor cortex is responsible for multisensory integration of self-attribution of body parts, and it may be since it is a part of a pathway that includes the cerebellum and the parietal cortex. fMRI studies that were conducted later also found that cerebellar cortices, as well as parietal and premotor cortices, are involved in the multisensory integration process when it comes to our perception of our limbs (Gentile et al., 2013; Guterstam, Gentile, & Ehrsson, 2013). A somatic rubber hand illusion experiment, where the participants were blindfolded, showed that the illusion was associated with activity in the ventral premotor and intraparietal cortices as well as the cerebellum. The study did not include the visual processing in the RHI and showed that the mentioned areas play a role in the processing of multisensory signals from one’s own body even when visual information is absent (Ehrsson, Holmes, & Passingham, 2005).

The role of the different parts of the insula in limb ownership has also been investigated. Studies have suggested that the right posterior insula plays a crucial role in the sense of limb ownership, this was shown first by Tsakiris, Hesse, Boy, Haggard, and Fink

(2007) and supported by Baier and Karnath (2008). Baier and Karnath (2008) found that individuals with a lesion in the right posterior insula showed a disturbed sensation of limb ownership. Studies have found that activation in the anterior insula correlate with positive emotional responses, and also emotional awareness overall by combining interoceptive signals with top-down predictions (Gu, Hof, Friston, & Fan, 2013; Leibenluft, Gobbini, Harrison, & Haxby, 2004). It is involved in bodily self-awareness as well (Craig, 2009). The dorsal posterior insula has the primary cortical representation of the interoceptive pathways which report physiological states of internal organs, muscles, skin, and joints (Cechetto & Saper, 1987; Craig, 2003).

To summarize, functional neuroimaging studies about brain areas that relate to body ownership have suggested a network composed of the cerebellum, insula, putamen, ventral premotor cortex, parietal and intraparietal cortices, and EBA. These areas have neurons, or are connected to areas which have this type of neurons, that execute multisensory integration. Multisensory integration is critical to combine different sensory information and by that project the feeling of what belongs to the self and what does not. The multisensory integration process has been explained in the form of theoretical models, two of the most accepted ones to this day will now be presented.

## Theoretical Approaches

One theoretical model called Predictive coding (PC) explains brain processes that underlie action, perception, and interoception. The theory says that the brain collects incoming sensory data and compares it with the, according to the brain, most likely environmental causes that affect the nervous system (Friston, 2010). A key ingredient in the PC theory is the free-energy principle which can be explained as the minimization of free-energy in the brain when adaptive changes happen, regardless of whether they happen during natural selection or perceptual synthesis (Friston, 2009). To minimize prediction errors, the learned probability model of what environmental stimuli that alerts the sensory system needs to be updated or actions that will maintain the support of the models need to be taken. The model can be updated through learning new sensory deductions (Seth, 2013). In the context of RHI, it would mean that the brain is trying to minimize the prediction errors that occur when the visual and tactile information do not match. To minimize errors, a merging of the spatial representations of the real hand and the rubber hand takes place (Apps & Tsakiris, 2014). The anterior insula has been suggested by Gu et al. (2013) to have a role in the PC approach by minimizing interoception prediction errors.

Other theoretical models that are put forward are Bayesian causal inference models. These models suggest that when two different channels, for example, vision and somatosensation, signal stimulation, the brain calculates whether the signals have the same cause or not. A combination of the information will then be made from the inference (Körding et al., 2007). This type of learning has been suggested in one of the earlier studies of the RHI to explain the induction of the illusion (Armel & Ramachandran, 2003), but it has been criticized due to that the nature of the claim comes from the likelihood of sensory data (Tsakiris & Haggard, 2005). The Bayesian model explains the induction of the RHI as a mathematical equation that calculates the probability of the existence of one hand vs. the existence of two hands by examining available sensory data with already existing knowledge. The induction depends on the likelihood of there being only one hand, which in turn depends on the rules and principles which were described earlier, suggestibility to bodily illusions and previous experience of the RHI (Kilteni et al., 2015).

## Affective Touch

The finding of the insula as being involved in body ownership and the integration of sensory signals has cleared a path for a new component to be investigated in the context of the RHI, the affective touch. Affective touch is a caress-like, gentle touch that has an emotional component and is performed at a slow specific speed (1-10 cm/sec). When affective touch is conducted on hairy skin, it activates receptors called C tactile (CT) afferents. The affective touch has been reported to be more pleasurable than discriminative touch (Löken, Wessberg, McGlone, & Olausson, 2009). Discriminative touch triggers A-beta afferents (Aβ) which transfer signals of vibration, pressure, slip, and texture to the brain, in other words for sensing rather than feeling (McGlone, Vallbo, Olausson, Löken, & Wessberg, 2007). The intensity and even the quality of the pleasantness evoked by the affective touch depend on the state of deprivation and context (McGlone et al., 2007).

In an interoceptive perspective, CT afferents are thin unmyelinated slow fibers that are easily fatigued and project to the posterior insula as well as to the mid-anterior orbitofrontal cortex (McGlone et al., 2012; Morrison, Björnsdotter, & Olausson, 2011). Interestingly, CT afferents in contrast to the afferents of discriminative touch do not project to primary and secondary somatosensory areas, according to an fMRI analysis, even though CT afferents also signal tactile information (Olausson et al., 2002). The signal takes a different distinct pathway to the posterior insula and a different part of the thalamus (Olausson et al., 2002). When targeting CT-afferents on the arm of participants, a network of brain regions including the right posterior superior temporal sulcus and the medial prefrontal cortex/dorsal anterior cingulate cortex activate. These brain regions are known to have a role in social cognition and social perception (Bennett, Bolling, Anderson, Pelphrey, & Kaiser, 2014; Gordon et al., 2013). The affective sensation from the CT afferents projects to the posterior ventral medial nucleus and the ventral caudal part of the medial dorsal nucleus, which correlate with the emotional motivational and sensory aspects of feelings from the body (McGlone et al., 2007).

**The Present Research**

Studies have argued for the importance of interoceptive signals from the skin in an individual's feeling of body ownership and suggest that affective touch in RHI is correlated with a stronger experience of the illusion (Crucianelli, Metcalf, Fotopoulou, & Jenkinson, 2013; Lloyd, Gillis, Lewis, Farrell, & Morrison, 2013; van Stralen et al., 2014). The question is, does affective touch induce a stronger illusion than discriminative touch? And if so, to what degree?

This thesis will answer these questions by looking into studies regarding the RHI and affective touch to see whether a common pattern can be found and a conclusion can be drawn from the data of the studies. The aim of this thesis is, therefore, to investigate whether affective touch produces a stronger RHI than discriminative touch. The author hypothesizes that when affective touch is conducted, a stronger RHI will occur due to additional interoceptive cues that are signaling to the brain.

# Method

## Selection of Studies

The sample of studies was selected through a search in databases (Web of Science, Scopus, and PubMed) for articles published before March 20, 2020, using the search terms “Affective Touch” AND “Rubber Hand Illusion” AND “Body Ownership”/”Affective Touch” AND “Rubber Hand Illusion”. The literature search got 60 hits. Twelve different articles were identified after duplicates were removed, all written in English and published in peer-reviewed journals.

There were three inclusion criteria for the systematic review. First, studies needed to investigate the classical rubber hand illusion and not other bodily illusions, for example, the full-body illusion or the virtual body illusion. Second, studies needed to have an experimental design with a nonclinical human sample. Lastly, studies needed to have one condition where the stroking velocity was within the range of affective touch, 1 - 10 cm/s on hairy skin.

After a brief overview of the article's abstract, six studies were excluded due to the inclusion/exclusion criteria. One study was excluded due to a non-human sample, another for not being an experimental study, two more for not conducting the rubber hand illusion, and two for having a clinical sample. After examining the articles more carefully, one more study was excluded due to that vestibular stimulation was conducted. There was a SHAM condition in the study which makes it a borderline case, but the condition had an additional stimulation as well which makes it uncomparable to the other studies. A flowchart describes the process of finding articles for the systematic review (Figure 1).

## Selection of Comparison Within Studies

Comparisons between the experimental conditions of affective touch and discriminative touch were made. The most common forms of manipulation in experimental conditions were stroking velocity. Site of stimulation and different forms of social touch were also observed. Conditions in the studies which did not investigate the connection between affective touch and the RHI were excluded from the review.

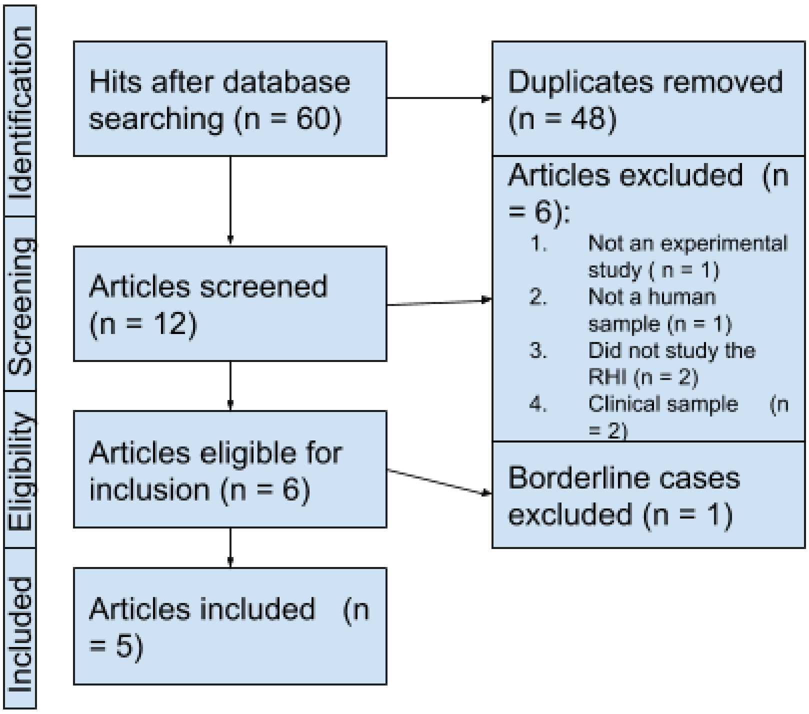


*Figure* 1. The process of finding articles for the review.

## Data Extraction

Statistical values (standard deviations, standard errors, chi-squares, means, medians and *Z*, *t*, *p*, *r*, and *F* values) were extracted from the five studies included in the review. The data were extracted from the studies' measurement of the subjective experience of the illusion, pleasantness, proprioceptive drift, and temperature difference.

# Results

## Studies

Table 1 shows the 12 identified studies and whether they got included or excluded. Before going into the results of the studies there will be a short description of each one, including aim and methods.

**Table 1. An overview of the included and excluded articles.**

| Study | Included/excluded | Reason for exclusion |
|---|---|---|
| Crucianelli et al. (2013) | Included | |
| Lloyd et al. (2013) | Included | |
| van Stralen et al. (2014) | Included | |
| Gentsch et al. (2016) | Excluded | Not an experimental study |
| de Jong et al. (2017) | Excluded | Did not study the RHI |
| Crucianelli et al. (2018) | Included | |
| Ponzo et al. (2018) | Excluded | Provided an additional stimulation which the other studies did not have |
| Fahey et al. (2019) | Included | |
| Carey et al. (2019) | Excluded | Did not study the RHI |
| Smit et al. (2019) | Excluded | Clinical sample (Tumour resection in the right temporoparietal cortex) |
| Crucianelli et al. (2019) | Excluded | Clinical sample (anorexia nervosa) |
| Buckmaster et al. (2020) | Excluded | Not a human sample |

**Bodily pleasure matters: Velocity of touch modulates body ownership during the rubber hand illusion (Crucianelli et al., 2013).** Crucianelli et al. (2013) mainly investigated whether seeing another individual's hand being stroked would reduce the illusion compared to seeing a rubber hand being stroked. The real hand and rubber hand were stroked in a slow velocity and a fast velocity.

The authors conducted a 2 x 2 x 2 mixed factorial design. The experiment had fifty-two participants which all were right-handed women, three were excluded from the analysis due to not finishing the experiment and not following the instructions. The conditions were seen hand (rubber vs. real), stroking mode (synchronous vs. asynchronous), and stroking velocity (slow: 3cm/s vs. fast: 18cm/s). The dependent variables were subjective pleasantness, subjective experience of the illusion, and proprioceptive drift. The authors measured the dependent variables in three ways. First, subjective pleasantness was measured through a seven-point Likert scale where -3 was considered to be not at all pleasant, and +3 was considered to be extremely pleasant. The purpose was to see which kind of touch was subjectively more pleasant. Second, an embodiment questionnaire that was obtained from Longo et al. (2008) was used to measure the subjective experience of the illusion. Thirteen statements were answered by the participants on a seven-point Likert scale, -3 was strongly disagree and +3 was strongly agree. The questionnaire consisted of four subcomponents: felt ownership, felt location, felt agency, and affect. The questionnaire was answered before and after each condition. Finally, proprioceptive drift was measured to see how much the real hand was perceived to be closer to the rubber hand after each condition.

Results were analyzed with the non-parametric tests of the Wilcoxon signed-rank test and the Mann-Whitney U test (Crucianelli et al., 2013).

**Pleasant touch moderates the subjective but not objective aspects of body perception (Lloyd et al., 2013).** Lloyd et al. (2013) investigated how interoceptive signals influence body representation, and whether subjective pleasantness would affect the illusion.

The sample size consisted of 24 right-handed female participants. A 2 x 2 within-participants design was conducted with the conditions stroking velocity (3 cm/s vs. 30 cm/s) and stimulation site (back of the hand vs. palm). Condition A conducted slow stroking to back of the hand, Condition B conducted fast stroking to back of the hand, Condition C conducted slow stroking to the palm, and Condition D conducted fast stroking to the palm. The subjective strength of the illusion was measured through a questionnaire that was adapted from Botvinick and Cohen (1998). The questionnaire consisted of five questions, the first three were supposed to assess different qualities of the perception of the illusion, and the other two functioned as control questions. The participants rated their level of agreement on a seven-point Likert scale. Pleasantness was measured through how much the participants agreed on how pleasant the touch was on a seven-point Likert scale. Proprioceptive drift was also measured before and after each condition.

In the results, Friedman's ANOVA was conducted to analyze the variance across the conditions, Wilcoxon signed-rank test to compare the different factors and repeated measures ANOVA to examine proprioceptive drift. To determine the relative contribution of each factor a multiple regression analysis was conducted (Lloyd et al., 2013).

**Affective touch modulates the rubber hand illusion (van Stralen et al., 2014).** van Stralen et al. (2014) conducted two experiments, the first aimed to investigate the effects of affective touch on the rubber hand illusion by manipulating the stroking velocity and stroking material. In the second experiment, the authors manipulated the site of stimulation as well as adding a slower velocity.

For the first experiment, a 2 x 2 within-subject design was conducted with 21 participants, one participant got excluded from the analysis. The factors were stroking material (soft vs. rough) and stroking velocity (slow 3 cm/s vs. fast 30 cm/s). Pleasantness was assessed through a five-point Likert scale. The subjective strength of the illusion was measured through a questionnaire that was adapted from Botvinick and Cohen (1998) and Kammers et al. (2009a). The questionnaire consisted of 10 statements which were answered in terms of agreement. The first three statements were related to the illusion, and the following seven were control statements. Statement one assessed whether the participants felt the touch at the location where they saw the rubber hand being stroked. Statement two measured whether the touch they felt was caused by the stimulation on the rubber hand. The third statement was whether the participants felt as if the rubber hand was their own hand. Proprioceptive drift and temperature difference between pre- and post condition were also measured.

The second experiment was conducted similarly as the first experiment. Twenty-eight participants did the experiment, four got excluded in the proprioceptive drift and temperature difference analyses, three in the pleasantness analyses, and one in the subjective strength of the illusion analyses. An additional stroking velocity of 0.3 cm/s was added, and also the site of stimulation was manipulated (palm vs. back of the hand).

An ANOVA repeated measure was used for analyzing the results from the measurements.

**Interoceptive ingredients of body ownership: Affective touch and cardiac awareness in the rubber hand illusion (Crucianelli et al., 2018).** Crucianelli et al. (2018) tested in two experiments whether cardiac awareness and affective touch perception were related. The authors further investigated whether the effect of interoceptive cues about body ownership is due to the visual information or the interpretation of interoceptive information. The first experiment did not measure the subjective experience of the illusion which made only the second experiment relevant for this thesis.

The second experiment had a within-subjects design for affective touch on a rubber hand illusion task. Sixty-nine right-handed females participated, but six participants got excluded from the analysis due to uncertainty whether the participants had followed the experimental instructions in the right manner. The stroking velocities tested were slow (3 cm/s), borderline (9 cm/s), and fast (18 cm/s). The subjective experience of the illusion was measured through an embodiment questionnaire, adapted from Longo et al. (2008), which consisted of 13 statements in four subcomponents (ownership, location, agency, affect) which were answered in the level of agreement on a seven-point Likert scale. The questionnaire was also used for visual capture measure, i.e., vision alone. The participants answered the questionnaire before and after the stroking procedure and difference was interpreted as subjective embodiment change in the results. A subjective pleasantness rating was conducted to measure the pleasantness of the tactile stimulation of each condition, the participants rated pleasantness from 0-100. Finally, the temperature difference was assessed (Crucianelli et al., 2018).

Wald tests were conducted for analyzing the results.

**Affective judgement of social touch on a hand associated with hand embodiment (Fahey, Santana, Kitada, & Zheng, 2019).** Fahey et al. (2019) examined the affective judgment, an individual's' judgment about the overall states of feeling, of social touch in the RHI. Social touch in the study referred to the experimenter touching the participants' hands which was was expected to elicit hedonic responses. Neutral touch was not meant to elicit hedonic responses and could be, for example, knocking on the rubber hand. The experimenter would in this condition treat the rubber hand as an object rather than a hand. The authors conducted three experiments, the first experiment was of interest to this thesis. The sample size included 35 right-handed females.

The authors measured the subjective experience of the illusion through a six-statement questionnaire adapted from Botvinick and Cohen (1998). Three of the statements were about the illusion while the other three were control statements. The statements were the same as the statements in van Stralen et al. (2014). The participants rated their level of agreement on each statement on a seven-point scale, one equaled disagree strongly and seven equaled agree strongly. The second measure was proprioceptive drift. Lastly, the participants rated pleasantness on a seven-point Likert scale after each act of touch. One equaled unpleasant, four equaled neutral, and seven equaled pleasant. Fahey et al. (2019) investigated the affective judgment of social touch by subtracting the pleasantness rating of each social touch in the baseline condition from the pleasantness rating of the same touch in the experimental condition. The changes for the affective touch block and non-affective, discriminative, touch block were averaged separately, this gave two different scores for affective change. Additional questionnaires were included to measure the general attitude towards affective touch, i.e., which dimension the participants' feel the touch belongs to, and the participants' emotions in the present moment. The general attitude towards affective touch was assessed through Seven Touch Scales which consists of self-reports on seven different dimensions of touch: touch aversion, discomfort with public touch, coercive control, desiring touch, affectionate proximity, sexual touch, and haven touch (Brennan, Wu, & Loev, 1998). The participants' emotions were assessed through Positive and Negative Affect Schedule (PANAS), a questionnaire where the participants rate the intensity of 10 positive and 10 negative emotions on a scale from one to five (Watson, Clark, & Tellegen, 1988).

Six acts of social touch were performed, three of them counted as the affective touch block or CT-touch, while the other three were counted as the non-affective touch block. The affective touch acts included three different movements, circling, rubbing, and stroking, all performed in a 3 cm/s velocity. The other three acts, measuring discriminative touch were tapping, flicking, and hand-touching. The social touch set was conducted seven times, six experimental conditions and one baseline condition. The baseline condition was observing touch on the rubber hand before the experiment. The results were analyzed with a two-way repeated-measures analysis of variance (Fahey et al., 2019).

**Subjective Experience of the Illusion**

On the subjective experience of the illusion, which includes the strength of the illusion, neither Crucianelli et al. (2013) or Lloyd et al. (2013) found a significant main effect of stroking velocity: $Z = -1.64$, $p = 0.1$, $r = -0.17$ (Crucianelli et al., 2013), and stroking velocity and site of stimulation, $x^2$ (3) = 4.492, $p = 0.213$ (Lloyd et al., 2013). See Table 2. Crucianelli et al. (2013) found, however, a main effect of stroking velocity on the affect subcomponent where slow velocity provided higher scores, median 0.50, compared to fast stroking, median = 0.25, $Z = -2.33$, $p = 0.02$, $r = -0.33$. The subcomponents of ownership, agency, and location did not show any significant main effect of stroking velocity. The change in ownership scores was, however, higher in the slow stroking condition, median = 1.2, compared to fast stroking condition, median = 0.6, but this was not statistically significant (Crucianelli et al., 2013). Lloyd et al. (2013) revealed a significant contribution of pleasantness to the subjective illusion strength in Condition D (Palm, 30 cm/s), $\beta = 0.288$, $p < 0.05$). Proprioceptive drift contributed significantly to the illusion in Condition A (Back of hand, 3 cm/s), $\beta = 0.412$, $p < 0.05$, and B (Back of hand), $\beta = 0.417$, $p < 0.05$. van Stralen et al. (2014) did, as opposed to the other mentioned studies, show significant results on parts of the questionnaire. In the first experiment, the first statement (I was feeling the touch at the location where I saw the rubber hand being stroked) revealed a significant main effect of stroking velocity, $F(1,19) = 9.10$, $p < .01$, but no significant main effect could be found on statement two (The touch I felt was caused by the stimulation on the rubber hand) or three (I felt as if the rubber hand was my own hand). The second experiment, specifically 2a, revealed a main effect of stroking velocity for the first two statements, $F(2, 52) = 3.44$, $p < 0.05$ and $F(2, 52) = 4.63$, $p < 0.05$. On the first statement (I was feeling the touch at the location where I saw the rubber hand being stroked), 3 cm/s stroking yielded a significantly higher rating than the 0.3 cm/s stroking, $F(1,26) = 5.29$, $p < 0.05$, but not compared to the 30 cm/s stroking. On the second statement (The touch I felt was caused by the stimulation on the rubber hand), no significant difference could be found, but a trend towards a difference between the 3 cm/s stroking and the 0.3 cm/s existed, $F(1,26) = 3.78$, $p = 0.063$. No main effect showed for statement three (I felt as if the rubber hand was my own hand). It should be mentioned that experiment 2b did not show a main effect of either stroking velocity or site of stimulation on any of the statements that relate to the illusion. The results of Fahey et al. (2019) were in line with van Stralen et al. (2014) on statement three (I felt as if the rubber hand was my own hand), there was no main effect of social touch block, $p = 0.14$. On statement two (The touch I felt was caused by the stimulation on the rubber hand) or three (I felt as if the rubber hand was my own hand), no main effect of social touch block could either be found (Fahey et al., 2019). Crucianelli et al. (2018) found an effect of stroking velocity, specifically on embodiment change scores, $x^2$ (2) = 9.47, $p = 0.009$. Borderline stroking got the highest scores, M = 1.30, SE = 0.16, followed by slow stroking, M = 1.20, SE = 0.16, and fast stroking, M = 0.91, SE = 0.16. Borderline and fast stroking differed from each other significantly, $p = 0.009$. Slow and fast stroking revealed a trend for significance, $p = 0.077$ (Crucianelli et al., 2018).

**Table 2. A brief presentation of the studies' findings on the subjective experience of the illusion.**

| Study | Main effect |
|---|---|
| Crucianelli et al. (2013) | No main effect of stroking velocity. |
| Lloyd et al. (2013) | No main effect of stroking velocity or site of stimulation. |
| van Stralen et al. (2014). Exp. 1 | Main effect of stroking velocity on statement one |
| van Stralen et al. (2014). Exp 2a | Main effect of stroking velocity on statements one and two |
| van Stralen et al. (2014). Exp 2b | No main effect of stroking velocity or site of stimulation. |
| Crucianelli et al. (2018) | Main effect of stroking velocity. |
| Fahey et al. (2019) | No main effect of social touch block. |

**Pleasantness Ratings**

In summary (see Table 3.), slow stroking was rated as significantly more pleasant compared to fast stroking, Z = 4.94, $p < 0.001$ (Crucianelli et al., 2013), $x^2$ (3) = 13.845, $p$ = 0.003 (Lloyd et al., 2013). The scores were also higher when slow stroking was conducted on the back of the hand than compared to fast stroking, M = 1.4 vs. 0.6, respectively; $p$ = 0.006 (Lloyd et al., 2013). An effect that was approaching significance was found on the palm at the slower vs. faster stroking velocities, M = 1.5 vs. 1.0; $p$ = 0.018 (Lloyd et al., 2013). In the first experiment of van Stralen et al. (2014), the slow stroking was reported as more pleasant regardless of the stroking material, soft material $T$ = 136, $r$ = 0.6, $p$ < .01, rough material $T$ = 85.5, $r$ = 0.46, $p$ < 0.01. In the second experiment, pleasantness ratings showed a trend towards a significant level for stroking velocity, $F$(46,2) = 3.1, $p$ = 0.055. The 3 cm/s stroking velocity was rated as significantly more pleasant than the lower, $F$(1, 23) = 5.66 $p$ < 0.05 and higher velocities, $F$(1,23) = 4.56, $p$ < 0.05. A significant interaction effect between stroking velocity and stimulation site was found, $F$(1,24) = 11.10, $p$ < .01. The ratings differed significantly between 3 cm/s stroking and 30 cm/s stroking when stimulation was applied to the dorsal side, $F$(1,23) = 4.56, $p$ < .05 (van Stralen et al., 2014). In Crucianelli et al. (2018)

pleasantness was significantly predicted by stroking velocity, $x^2$ (2) = 45.62, $p < 0.001$. Slow stroking got the highest rating, M = 82.35, SE = 2.17, followed by borderline, M = 78.17, SE = 2.17 and fast stroking, M = 71.79, SE = 2.17. All conditions differed from each other in a significant manner, 3 cm/s vs. 9 cm/s, $p = 0.016$; 3 cm/s vs. 18 cm/s, $p < 0.001$; 9 cm/s vs. 18 cm/s, $p < 0.001$ (Crucianelli et al., 2018). Fahey et al. (2019) could not find a significant main effect of social touch, $p = 0.09$, on affective judgement. It is worth mentioning that the authors did not assess pleasantness as the other studies, instead the ratings were used to investigate the affective judgment by subtracting the pleasantness rating of each social touch in the baseline condition from the pleasantness rating of the same touch in the experimental condition.

**Table 3. A brief presentation of the studies' findings on pleasantness.**

| Study | Main effect/Interaction effect |
|---|---|
| Crucianelli et al. (2013) | Main effect of stroking velocity. |
| Lloyd et al. (2013) | Main effect of stroking velocity. No main effect of site of stimulation. |
| van Stralen et al. (2014). Exp. 1 | Main effect of stroking velocity. |
| van Stralen et al. (2014). Exp 2a | Main effect of stroking velocity trending towards significance. |
| van Stralen et al. (2014). Exp 2b | Interaction effect between stroking velocity and site of stimulation |
| Crucianelli et al. (2018) | Main effect of stroking velocity. |
| Fahey et al. (2019) | No main effect of social touch block on affective judgment. |

**Proprioceptive Drift**

Results on the proprioceptive drift showed a main effect of stroking velocity in one study while the other three did not find a main effect of velocity (see Table 4.). van Stralen et al. (2014) found a main effect of stroking velocity in both of the experiments. In the first experiment, slow stroking produced a greater drift than fast stroking, $F(1,20) = 12.4$ $p < .01$. In the second experiment, the 3 cm/s stroking differed from the 30 cm/s stroking significantly on the dorsal side, $t(23) = 2.43$, $p < .05$. For the ventral side, the difference between the two velocities was not significant. An interaction effect was found between the 3 and 30 cm/s stroking on the dorsal side, $F(1,23) = 4.61$, $p < 0.05$, the slower condition yielded a significantly higher mean in proprioceptive drift than the faster stroking (van Stralen et al., 2014). This stands in contrast to Lloyd et al. (2013) who did not find a significant interaction effect. As mentioned, Crucianelli et al. (2013), Lloyd et al. (2013), and Crucianelli et al. (2018) did not find a main effect of stroking velocity. Lloyd et al. (2013) did, however, find a main effect of stimulation site, with larger drift measures for stimulation conducted to the back of the hand compared to the palm, $F(1,23) = 5.317$, $p = 0.03$. Pleasantness contribution to proprioceptive drift was approaching significance in Condition B (Back of hand, 30 cm/s), $\beta = 0.386$, $p = 0.062$, the other conditions had no significant contribution of pleasantness. Fahey et al. (2019) did not find a main effect of social touch block, $p = 0.98$.

**Table 4. A brief presentation of the studies' findings on proprioceptive drift.**

| **Study** | **Main effect/Interaction effect** |
|---|---|
| Crucianelli et al. (2013) | No main effect of stroking velocity. |
| Lloyd et al. (2013) | No main effect of stroking velocity. Main effect of site of stimulation. No interaction effect. |
| van Stralen et al. (2014). Exp. 1 | Main effect of stroking velocity. |
| van Stralen et al. (2014). Exp 2a | Main effect of stroking velocity. |
| van Stralen et al. (2014). Exp 2b | Interaction effect between stroking velocity and site of stimulation. |
| Crucianelli et al. (2018) | No main effect of stroking velocity. |
| Fahey et al. (2019) | No main effect of social touch block. |

**Temperature Difference**

The first experiment of van Stralen et al. (2014) revealed a significant effect of stroking velocity on the skin temperature, $F(1,20) = 5.93$, $p < 0.05$, the slow velocity generated a higher temperature drop, $t(19) = -3.14$, $p < 0.001$. The second experiment did not, however, show a significant main effect of stroking velocity or of site of stimulation on skin temperature. Crucianelli et al. (2018) could not find a main effect of stroking velocity (see Table 5.).

**Table 5. A brief presentation of the studies' findings on the temperature difference.**

| **Study** | **Main effect** |
|---|---|
| Crucianelli et al. (2013) | Did not measure temperature difference. |
| Lloyd et al. (2013) | Did not measure temperature difference. |
| van Stralen et al. (2014). Exp. 1 | Main effect of stroking velocity. |
| van Stralen et al. (2014). Exp 2a | No main effect of stroking velocity. |
| van Stralen et al. (2014). Exp 2b | No main effect of stroking velocity or site of stimulation. |
| Crucianelli et al. (2018) | Did not measure temperature difference. |
| Fahey et al. (2019) | Did not measure temperature difference. |

**Correlations**

Lloyd et al. (2013) investigated the correlation between the scores on the subjective experience of the illusion, pleasantness ratings and proprioceptive drift in Condition A (Back of hand, 3 cm/s), B (Back of hand, 30 cm/s), C (Palm, 3 cm/s), and D (Palm, 30 cm/s). Correlations between the scores on the different scales revealed a significant positive correlation between subjective illusion and proprioceptive drift in Conditions A (Back of hand, 3 cm/s), $r = 0.51$, B (Back of hand, 30 cm/s), $r = 0.486$, and C (Palm, 3 cm/s), $r = 0.370$. A significant correlation was also found between subjective experience of the illusion and pleasantness in Conditions A (Back of hand, 3 cm/s), $r = 0.434$, B (Back of hand, 30 cm/s), $r = 0.340$, and D (Palm, 30 cm/s), $r = 0.441$. Pleasantness and proprioceptive drift were only significantly correlated in Condition B (Back of hand, 30 cm/s), $r = 0.486$. Fahey et al. (2019) found a correlation between change in pleasantness and proprioceptive drift, $r = 0.58$, $p = 0.001$, but no correlation between pleasantness and the subjective experience of the illusion, $r = 0.32$, $p = 0.087$.

**Seven Touch Scales and PANAS**

The Seven Touch Scales scores did not show any evidence of difference in the scores, t(58) = 0.83, $p$ = 0.41 (Fahey et al., 2019). The score on PANAS showed no significant change in positive or negative emotions from before and throughout the experiment, $F$(2, 35, 68, 08) = 1.69, $p$ = 0.19 (Fahey et al., 2019).

## Discussion

This thesis aimed to investigate whether affective touch produces a stronger RHI than discriminative touch. The rationale was that interoception has a role in body ownership (Tsakiris, 2017), and studies have suggested that additional interoceptive signals that can be combined with exteroceptive signals may lead to a stronger RHI (e.g Crucianelli et al., 2018).

The following interpretations can be made from the results. First, the affective touch did not show to affect the subjective experience of the illusion significantly across all studies. Crucianelli et al. (2013) did not find a main effect of stroking velocity on the overall questionnaire scores, from the subjective experience of the illusion measurement, or the subcomponent ownership, even though the slow stroking did, however, produce a higher change in ownership than fast stroking. van Stralen et al. (2014) reported that stroking velocity had a main effect on statement one (I was feeling the touch at the location where I saw the rubber hand being touched) in the first experiment and statement one (I was feeling the touch at the location where I saw the rubber hand being touched) and two (The touch I felt was caused by the stimulation on the rubber hand) in experiment 2a. The statement that did not reach a significant level in either experiment was the one regarding whether the participant felt as if the rubber hand was their own hand, this was also shown by Fahey et al. (2019). The study by Crucianelli et al. (2018) found a main effect of stroking velocity on the subjective experience of the illusion, the affective touch conditions produced higher embodiment change scores than the non-affective touch condition. The study differed in the sense of an additional borderline stroking condition which is right below the affective touch stroking speed limit. The fact that the 9 cm/s velocity was the only velocity that differed from the non-affective touch condition stands as opposed to earlier suggestions of 3 cm/s stroking as the optimal stroking speed for the CT afferents (Löken et al., 2009). However, the difference between the slow and borderline stroking velocity was not significant and thus should not be interpreted as a suggestion of change for the optimal velocity for affective touch. Crucianelli et al. (2013) suggested that affective touch would produce stronger subjective ownership of the hand, this suggestion is not supported by the results of this thesis. Crucianelli et al. (2013) suggested that affective touch produces higher levels of subjective embodiment in the RHI compared to discriminative touch. The results of the study did not support this claim. The author of this thesis did a post-hoc calculation of the effect size to investigate the discrepancy between the claim and the result from Crucianelli et al. (2013). The effect size was 0.35, which is interpreted as small/medium according to *Cohen's d* guidelines (Cohen, 1992). A small/medium effect size makes the claim more comprehensible but it is still doubtful to state it as a fact based on the results. Lloyd et al. (2013) acknowledged the effect of stroking velocity on the subjective experience of the illusion. Slow stroking would produce a stronger subjective strength of the illusion than fast stroking according to their interpretation. The result of the questionnaire does not match the interpretation. No significant main effect could be found. Further analysis was not made due to that it was stroking velocity and not affective touch specifically they built their argument on. It should be mentioned that the studies have some truth in their claims, given the mean scores on the questionnaire for the affective touch were higher. The results, however, indicate that it may be due to chance, and that a type I error may have occurred. Again, to suggest that affective touch or stroking velocity would induce stronger body ownership in the RHI on those terms is rather debatable.

Second, pleasantness ratings were higher in the affective touch conditions than in the discriminative touch conditions. This was regardless of whether the comparison was with the same velocity on glabrous skin or a non-affective touch stroking velocity. This is consistent with the findings that affective touch is rated as more pleasurable than discriminative touch when performed in the same context (Löken et al., 2009). Two studies investigated the correlation between the subjective experience of the illusion and pleasantness. The results were not unanimous as Lloyd et al. (2013) found a correlation in Condition A (Back of hand, 3 cm/s), B (Back of hand, 30 cm/s), and D (Palm, 30 cm/s) while Fahey et al. (2019) did not find a correlation at all. The studies differed in the way they manipulated the independent variables, Lloyd et al. (2013) manipulated stroking velocity and site of stimulation while Fahey et al. (2019) manipulated social touch. More studies that investigate the correlation between the subjective experience of the illusion, pleasantness, and proprioceptive drift are needed to get a consistent picture. The relative contribution of pleasantness in Lloyd et al. (2013) revealed that pleasantness did contribute significantly to the subjective illusion scores, but only in Condition D (Palm, 30 cm/s). This indicates that if the subjective experience of the illusion is associated with pleasantness, it is not due to the information from the CT afferents. Stroking on the palm, which does not have CT afferents, with a velocity of 30 cm/s activates the Aβ afferents. The pleasant information that comes from the palm is processed differently than the information from the CT afferents. Pleasant information from the palm has shown to activate the orbitofrontal cortex and anterior cingulate cortex more than neutral or painful information from the palm (Rolls et al., 2003). If pleasantness has a significant impact on the subjective experience of the illusion, it would have contributed significantly in all conditions. Also, because the affective touch produced a stronger feeling of pleasantness than discriminative touch across all studies, the subjective experience of the illusion scores would have been higher in the affective touch condition. The subjective experience of the illusion was, however, not considered to be significantly stronger. This does not deny the fact that pleasantness might be a factor in the strength of the subjective experience of the illusion, but as the RHI is determined by other signals as well it might not be the case that a stronger sense of pleasantness leads to a stronger illusion. This might reflect the fact that integrated exteroceptive signals, visual and tactile, processed in these areas are the strongest determinant of the RHI. Interoceptive signals from CT afferents might not be enough to induce a significant change of strength in the illusion. This is supported by the contribution of proprioceptive drift to the subjective experience of the illusion, which had a stronger contribution than pleasantness in the affective touch condition (van Stralen et al., 2014).

Lastly, the results do not show that affective touch would produce a greater proprioceptive drift than discriminative touch. Even though the results from van Stralen et al. (2014) showed both a main effect of stroking velocity and an interaction effect between stroking velocity and site of stimulation, the other studies did not show any significant result on the measurement.

van Stralen et al. (2014) was the only study that had a sample that included males, left-handed, and ambidextrous participants. The other studies had only a sample consisting of right-handed females. The studies did not state why the sample only included females, the author speculates that it might be due to that females have been found to score slightly higher than males in hypnotic suggestibility (Page & Green, 2007). The inclusion of only right-handed participants was not discussed in any of the studies. Crucianelli et al. (2013) only explained why they applied the RHI paradigm to the left hand, which was because the right insula has been reported to be connected to interoceptive awareness, awareness of action, and body ownership. It can be questioned whether the implications of the results can be applied to a general population. The result by van Stralen et al. (2014) that was not in line with the other studies was the proprioceptive drift, but the sample differed as it included females, males, right-handed, left-handed, and ambidextrous. With this in mind, it does not indicate that gender or handedness would be a factor for the affective touch in proprioceptive drift. It should be mentioned that the results on the temperature difference in the experiments in van Stralen et al. (2014) were not in line with each other. This may be interpreted that affective touch may not affect the temperature difference. The results suggest that it is more likely that the effect comes from stroking velocity, if there is a significant effect. When the results from Crucianelli et al. (2018) is are into consideration, the indication is that there is no significant effect of stroking velocity either.

It is rather difficult to assess how the observations can be explained by the theoretical approaches to RHI, such as Predictive Coding (Friston, 2010) or Bayesian causal inference models (Körding et al., 2007). PC and Bayesian causal inference models are general theories, and, for example, PC can be applied to general statements about brain processes. Nevertheless, the author does not see how the theories could explain why affective touch would not induce a stronger RHI than discriminative touch.

**Limitations**

This thesis has several limitations. First, the search result revealed a small number of published articles on the topic. The process of finding articles only identified 12 different articles which may indicate that the field of interest is too narrow at the moment or that the search was too specific. It can be due to that affective touch in the RHI is a relatively new topic with the first article published in 2013, but only five articles included after the exclusion process is still a small number. Another limitation is that the review only searched for articles in English, this could mean that there are more articles on the topic but in other languages. It also only included published articles which makes it difficult to conclude that publication bias does not exist on the topic of interest. The small range of studies forced the inclusion process to be based on eligibility rather than study quality. To deal with this problem, the review could have included other interoceptive signals, for example, cardiac awareness, or included the role of interoceptive sensitivity. A next step would be to quantify the existing literature with a meta-analysis to better understand the effect of affective touch on the strength of the RHI.

### Future Directions

The hypothesis that affective touch would lead to a stronger RHI than discriminative touch cannot be proven by this thesis. The additional interoceptive signals did not show to affect the RHI in a significant manner overall. There were, however, results in the studies which implicated that affective touch could enhance the illusion, but more research on the topic is needed. Future directions for research on the topic could be to conduct a meta-analysis with the available studies since none investigates affective touch and the RHI to this date. It could also be to investigate the role of affective touch in other forms of the RHI, for example the somatic rubber hand illusion or the full-body illusion, to see whether it could have a significant effect in those illusions. A review of a comparison between the effect of different interoceptive signals might also be of interest. It would then be revealed how the affective touch stands in comparison to other likeworthy interoceptive processes. For future experiments, a more controlled protocol for the stroking frequency could be applied and clearly stated in the publications. For example, in the reviewed studies, the frequency of the stroking was not presented.

## Conclusion

This thesis investigated, with a systematic literature review, whether affective touch produces a stronger RHI than discriminative touch. This thesis does not demonstrate that affective touch would induce a stronger RHI than discriminative touch, regardless of whether the measurement was the subjective experience of the illusion, proprioceptive drift, or temperature difference. Even though studies have indicated that it might have a small effect, more studies on the topic are needed.

**References**

Apps, M. A., & Tsakiris, M. (2014). The free-energy self: A predictive coding account of self-recognition. *Neuroscience & Biobehavioral Reviews*, *41*, 85-97. doi:10.1016/j.neubiorev.2013.01.029

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. doi:10.1098/rspb.2003.2364

Arzy, S., Overney, L. S., Landis, T., & Blanke, O. (2006). Neural mechanisms of embodiment: Asomatognosia due to premotor cortex damage. *Archives of Neurology*, *63*(7), 1022-1025. doi:10.1001/archneur.63.7.1022

Avillac, M., Hamed, S. B., & Duhamel, J. R. (2007). Multisensory integration in the ventral intraparietal area of the macaque monkey. *Journal of Neuroscience*, *27*(8), 1922-1932. doi: 10.1523/JNEUROSCI.2646-06.2007

Baier, B., & Karnath, H. O. (2008). Tight link between our sense of limb ownership and self-awareness of actions. *Stroke*, *39*(2), 486-488. doi:10.1161/STROKEAHA.107.495606

Bennett, R. H., Bolling, D. Z., Anderson, L. C., Pelphrey, K. A., & Kaiser, M. D. (2014). fNIRS detects temporal lobe response to affective touch. *Social Cognitive and Affective Neuroscience*, *9*(4), 470-476. doi:10.1093/scan/nst008

Blanke, O., & Metzinger, T. (2009). Full-body illusions and minimal phenomenal selfhood. *Trends in Cognitive Sciences*, *13*(1), 7-13. doi:10.1016/j.tics.2008.10.003

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

Bremmer, F., Schlack, A., Shah, N. J., Zafiris, O., Kubischik, M., Hoffmann, K. P., ... & Fink, G. R. (2001). Polymodal motion processing in posterior parietal and premotor cortex: A human fMRI study strongly implies equivalencies between humans and monkeys. *Neuron*, *29*(1), 287-296. doi:10.1016/S0896-6273(01)00198-2

Brennan, K. A., Wu, S., & Loev, J. (1998). Adult romantic attachment and individual differences in attitudes toward physical contact in the context of adult romantic relationships. In J. A. Simpson & W. S. Rholes (Eds.), *Attachment theory and close relationships* (p. 394–428). New York, NY: Guilford Press.

Buckmaster, C. L., Rathmann-Bloch, J. E., de Lecea, L., Schatzberg, A. F., & Lyons, D. M. (2020). Multisensory modulation of body ownership in mice. *Neuroscience of Consciousness*, *2020*(1), niz019. doi:10.1093/nc/niz019

Carey, M., Crucianelli, L., Preston, C., & Fotopoulou, A. (2019). The effect of visual capture towards subjective embodiment within the full body illusion. *Scientific Reports*, *9*(1), 1-12. doi:10.1038/s41598-019-39168-4

Cascio, C. J., Foss-Feig, J. H., Burnette, C. P., Heacock, J. L., & Cosby, A. A. (2012). The rubber hand illusion in children with autism spectrum disorders: Delayed influence of combined tactile and visual input on proprioception. *Autism*, *16*(4), 406-419. doi:10.1177%2F1362361311430404

Cechetto, D. F., & Saper, C. B. (1987). Evidence for a viscerotopic sensory representation in the cortex and thalamus in the rat. *Journal of Comparative Neurology*, *262*(1), 27-45. doi:10.1002/cne.902620104

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155-159. doi:10.1037/0033-2909.112.1.155

Craig, A. D. (2003). Interoception: The sense of the physiological condition of the body. *Current Opinion in Neurobiology*, *13*(4), 500-505. doi:10.1016/S0959-4388(03)00090-4

Craig, A. D. (2009). How do you feel now? The anterior insula and human awareness. *Nature Reviews Neuroscience*, *10*(1), 59-70. doi:10.1038/nrn2555

Crucianelli, L., Krahé, C., Jenkinson, P. M., & Fotopoulou, A. K. (2018). Interoceptive ingredients of body ownership: Affective touch and cardiac awareness in the rubber hand illusion. *Cortex*, *104*, 180-192. doi:10.1016/j.cortex.2017.04.018

Crucianelli, L., Metcalf, N. K., Fotopoulou, A. K., & Jenkinson, P. M. (2013). Bodily pleasure matters: Velocity of touch modulates body ownership during the rubber hand illusion. *Frontiers in Psychology*, *4*(10), 703. doi:10.3389/fpsyg.2013.00703

Crucianelli, L., Serpell, L., Paloyelis, Y., Ricciardi, L., Robinson, P., Jenkinson, P., & Fotopoulou, A. (2019). The effect of intranasal oxytocin on the perception of affective touch and multisensory integration in anorexia nervosa: Protocol for a double-blind placebo-controlled crossover study. *British Medical Journal Open*, *9*(3), e024913. doi: 10.1136/bmjopen-2018-024913

Davies, A. M. A., White, R. C., & Davies, M. (2013). Spatial limits on the nonvisual self-touch illusion and the visual rubber hand illusion: Subjective experience of the illusion and proprioceptive drift. *Consciousness and Cognition*, *22*(2), 613-636. doi:10.1016/j.concog.2013.03.006

de Jong, J. R., Keizer, A., Engel, M. M., & Dijkerman, H. C. (2017). Does affective touch influence the virtual reality full body illusion? *Experimental Brain Research*, *235*(6), 1781-1791. doi:10.1007/s00221-017-4912-9

Downing, P. E., Jiang, Y., Shuman, M., & Kanwisher, N. (2001). A cortical area selective for visual processing of the human body. *Science*, *293*(5539), 2470-2473. doi:10.1126/science.1063414

Ehrsson, H. H. (2020). Multisensory processes in body ownership. In *Multisensory Perception* (pp. 179-200). Cambridge, MA: Academic Press. doi: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. doi: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. doi:10.1126/science.1097011

Fahey, S., Santana, C., Kitada, R., & Zheng, Z. (2019). Affective judgement of social touch on a hand associated with hand embodiment. *Quarterly Journal of Experimental Psychology*, *72*(10), 2408-2422. doi:10.1177%2F1747021819842785

Friston, K. (2009). The free-energy principle: A rough guide to the brain? *Trends in Cognitive Sciences*, *13*(7), 293-301. doi:10.1016/j.tics.2009.04.005

Friston, K. (2010). The free-energy principle: A unified brain theory? *Nature Reviews Neuroscience*, *11*(2), 127-138. doi:10.1038/nrn2787

Gentile, G., Guterstam, A., Brozzoli, C., & Ehrsson, H. H. (2013). Disintegration of multisensory signals from the real hand reduces default limb self-attribution: An fMRI study. *Journal of Neuroscience*, *33*(33), 13350-13366. doi:10.1523/JNEUROSCI.1363-13.2013

Gentile, G., Petkova, V. I., & Ehrsson, H. H. (2011). Integration of visual and tactile signals from the hand in the human brain: An fMRI study. *Journal of Neurophysiology*, *105*(2), 910-922. doi:10.1152/jn.00840.2010

Gentsch, A., Crucianelli, L., Jenkinson, P., & Fotopoulou, A. (2016). The touched self: Affective touch and body awareness in health and disease. In H. Olausson et al. (Eds.), *Affective touch and the neurophysiology of CT afferents* (pp. 355-384). New York, NY: Springer. doi.org/10.1007/978-1-4939-6418-5_21

Gordon, I., Voos, A. C., Bennett, R. H., Bolling, D. Z., Pelphrey, K. A., & Kaiser, M. D. (2013). Brain mechanisms for processing affective touch. *Human Brain Mapping*, *34*(4), 914-922. doi:10.1002/hbm.21480

Graziano, M. S. (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. doi:10.1073/pnas.96.18.10418

Gu, X., Hof, P. R., Friston, K. J., & Fan, J. (2013). Anterior insular cortex and emotional awareness. *Journal of Comparative Neurology*, *521*(15), 3371-3388. doi:10.1002/cne.23368

Guterstam, A., Gentile, G., & Ehrsson, H. H. (2013). The invisible hand illusion: Multisensory integration leads to the embodiment of a discrete volume of empty space. *Journal of Cognitive Neuroscience*, *25*(7), 1078-1099. doi:10.1162/jocn_a_00393

Jenkinson, P., Moro, V., & Fotopoulou, A. (2018). Definition: Asomatognosia. *Cortex*. *101*(4), 300-301. doi:10.1016/j.cortex.2018.02.001

Kalckert, A. (2018). Commentary: Switching to the Rubber Hand. *Frontiers in Psychology*, *9*(5), 588. doi:10.3389/fpsyg.2018.00588

Kalckert, A., & Ehrsson, H. H. (2014). The spatial distance rule in the moving and classical rubber hand illusions. *Consciousness and Cognition*, *30*(11), 118-132. doi:10.1016/j.concog.2014.08.022

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

Kammers, M. P., Longo, M. R., Tsakiris, M., Dijkerman, H. C., & Haggard, P. (2009). Specificity and coherence of body representations. *Perception*, *38*(12), 1804-1820. doi:10.1068%2Fp6389

Kilteni, K., Maselli, A., Kording, K. P., & Slater, M. (2015). Over my fake body: Body ownership illusions for studying the multisensory basis of own-body perception. *Frontiers in Human Neuroscience*, *9*(3), 141. doi:10.3389/fnhum.2015.00141

Körding, K. P., Beierholm, U., Ma, W. J., Quartz, S., Tenenbaum, J. B., & Shams, L. (2007). Causal inference in multisensory perception. *PLoS one*, *2*(9), e943. doi:10.1371/journal.pone.0000943

Lane, T., Yeh, S. L., Tseng, P., & Chang, A. Y. (2017). Timing disownership experiences in the rubber hand illusion. *Cognitive Research: Principles and Implications*, *2*(1), 4. doi:10.1186/s41235-016-0041-4

Leibenluft, E., Gobbini, M. I., Harrison, T., & Haxby, J. V. (2004). Mothers' neural activation in response to pictures of their children and other children. *Biological Psychiatry*, *56*(4), 225-232. doi:10.1016/j.biopsych.2004.05.017

Lenggenhager, B., Tadi, T., Metzinger, T., & Blanke, O. (2007). Video ergo sum: Manipulating bodily self-consciousness. *Science*, *317*(5841), 1096-1099. doi:10.1126/science.1143439

Limanowski, J., Lutti, A., & Blankenburg, F. (2014). The extrastriate body area is involved in illusory limb ownership. *Neuroimage*, *86*(2), 514-524. doi:10.1016/j.neuroimage.2013.10.035

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. doi:10.1016/j.bandc.2006.09.013

Lloyd, D. M., Gillis, V., Lewis, E., Farrell, M. J., & Morrison, I. (2013). Pleasant touch moderates the subjective but not objective aspects of body perception. *Frontiers in Behavioral Neuroscience*, *7*(12), 207. doi:10.3389/fnbeh.2013.00207

Lloyd, D. M., Shore, D. I., Spence, C., & Calvert, G. A. (2003). Multisensory representation of limb position in human premotor cortex. *Nature Neuroscience*, *6*(1), 17-18. doi:10.1038/nn991

Löken, L. S., Wessberg, J., McGlone, F., & Olausson, H. (2009). Coding of pleasant touch by unmyelinated afferents in humans. *Nature neuroscience*, *12*(5), 547-548. doi:10.1038/nn.2312

Longo, M. R., Schüür, F., Kammers, M. P., Tsakiris, M., & Haggard, P. (2008). What is embodiment? A psychometric approach. *Cognition*, *107*(3), 978-998. doi:10.1016/j.cognition.2007.12.004

Makin, T. R., Holmes, N. P., & Zohary, E. (2007). Is that near my hand? Multisensory representation of peripersonal space in human intraparietal sulcus. *Journal of Neuroscience*, *27*(4), 731-740. doi:10.1523/JNEUROSCI.3653-06.200

McGlone, F., Olausson, H., Boyle, J. A., Jones‐Gotman, M., Dancer, C., Guest, S., & Essick, G. (2012). Touching and feeling: Differences in pleasant touch processing between glabrous and hairy skin in humans. *European Journal of Neuroscience*, *35*(11), 1782-1788. doi:10.1111/j.1460-9568.2012.08092.x

McGlone, F., Vallbo, A. B., Olausson, H., Löken, L., & Wessberg, J. (2007). Discriminative touch and emotional touch. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, *61*(3), 173. doi:10.1037/cjep2007019

Morrison, I., Björnsdotter, M., & Olausson, H. (2011). Vicarious responses to social touch in posterior insular cortex are tuned to pleasant caressing speeds. *Journal of Neuroscience*, *31*(26), 9554-9562. doi:10.1523/JNEUROSCI.0397-11.2011

Moseley, G. L., Olthof, N., Venema, A., Don, S., Wijers, M., Gallace, A., & Spence, C. (2008). Psychologically induced cooling of a specific body part caused by the illusory ownership of an artificial counterpart. *Proceedings of the National Academy of Sciences*, *105*(35), 13169-13173. doi:10.1073/pnas.0803768105

Olausson, H., Lamarre, Y., Backlund, H., Morin, C., Wallin, B. G., Starck, G., ... & Bushnell, M. C. (2002). Unmyelinated tactile afferents signal touch and project to insular cortex. *Nature Neuroscience*, *5*(9), 900-904. doi:10.1038/nn896

Page, R. A., & Green, J. P. (2007). An update on age, hypnotic suggestibility, and gender: A brief report. *American Journal of Clinical Hypnosis*, *49*(4), 283-287. https://doi.org/10.1080/00029157.2007.10524505

Ponzo, S., Kirsch, L. P., Fotopoulou, A., & Jenkinson, P. M. (2018). Balancing body ownership: Visual capture of proprioception and affectivity during vestibular stimulation. *Neuropsychologia*, *117*, 311-321. doi:10.1016/j.neuropsychologia.2018.06.020

Rolls, E. T., O'Doherty, J., Kringelbach, M. L., Francis, S., Bowtell, R., & McGlone, F. (2003). Representations of pleasant and painful touch in the human orbitofrontal and cingulate cortices. *Cerebral Cortex*, *13*(3), 308-317. https://doi.org/10.1093/cercor/13.3.308

Schütz-Bosbach, S., Tausche, P., & Weiss, C. (2009). Roughness perception during the rubber hand illusion. *Brain and Cognition*, *70*(1), 136-144. doi:10.1016/j.bandc.2009.01.006

Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. *Trends in Cognitive Sciences*, *17*(11), 565-573. doi:10.1016/j.tics.2013.09.007

Shimada, S., Fukuda, K., & Hiraki, K. (2009). Rubber hand illusion under delayed visual feedback. *PloS One*, *4*(7), e6185. doi:10.1371%2Fjournal.pone.0006185

Shimada, S., Suzuki, T., Yoda, N., & Hayashi, T. (2014). Relationship between sensitivity to visuotactile temporal discrepancy and the rubber hand illusion. *Neuroscience Research*, *85*(8), 33-38. doi:10.1016/j.neures.2014.04.009

Smit, M., Van Stralen, H. E., Van den Munckhof, B., Snijders, T. J., & Dijkerman, H. C. (2019). The man who lost his body: Suboptimal multisensory integration yields body awareness problems after a right temporoparietal brain tumour. *Journal of Neuropsychology*, *13*(3), 603-612. doi:10.1111/jnp.12153

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. doi:10.1038/nrn2331

Thakkar, K. N., Nichols, H. S., McIntosh, L. G., & Park, S. (2011). Disturbances in body ownership in schizophrenia: Evidence from the rubber hand illusion and case study of a spontaneous out-of-body experience. *PloS One*, *6*(10), e27089 doi:10.1371%2Fjournal.pone.0027089

Tsakiris, M. (2017). The multisensory basis of the self: From body to identity to others. *The Quarterly Journal of Experimental Psychology*, *70*(4), 597-609. doi:10.1080/17470218.2016.1181768

Tsakiris, M., Carpenter, L., James, D., & Fotopoulou, A. (2010). Hands only illusion: Multisensory integration elicits sense of ownership for body parts but not for non-corporeal objects. *Experimental Brain Research*, *204*(3), 343-352. doi.org/10.1007/s00221-009-2039-3

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. doi:10.1037/0096-1523.31.1.80

Tsakiris, M., Hesse, M. D., Boy, C., Haggard, P., & Fink, G. R. (2007). Neural signatures of body ownership: A sensory network for bodily self-consciousness. *Cerebral Cortex*, *17*(10), 2235-2244. doi:10.1093/cercor/bhl131

Tsakiris, M., Jiménez, A. T., & Costantini, M. (2011). Just a heartbeat away from one's body: interoceptive sensitivity predicts malleability of body-representations. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1717), 2470-2476. doi:10.1098/rspb.2010.2547

van Stralen, H. E., van Zandvoort, M. J., Hoppenbrouwers, S. S., Vissers, L. M., Kappelle, L. J., & Dijkerman, H. C. (2014). Affective touch modulates the rubber hand illusion. *Cognition*, *131*(1), 147-158. doi:10.1016/j.cognition.2013.11.020

Ward, J., Mensah, A., & Jünemann, K. (2015). The rubber hand illusion depends on the tactile congruency of the observed and felt touch. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(5), 1203-1208. doi:10.1037/xhp0000088

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063-1070. doi:10.022-35l4/88/$00.75

Yeh, S. L., Lane, T. J., Chang, A. Y., & Chien, S. E. (2017). Switching to the rubber hand. *Frontiers in Psychology*, *8*(12), 2172. doi:10.3389/fpsyg.2017.02172