The role of Affective Touch in Whole-Body Embodiment Remains Equivocal

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1. Introduction

The feeling that our body belongs to us (i.e. body ownership) is an essential aspect of our sense of self (Gallagher, 2000; Tsakiris, 2016). Research in cognitive neuroscience has predominantly studied body ownership and body awareness based upon the integration of sensory signals (i.e. multisensory integration) from exteroceptive modalities such as vision and touch (de Vignemont, 2010; Graziano & Botvinick, 2002). Indeed, an established experimental method used to study multisensory integration towards body ownership is the Rubber Hand Illusion (RHI), in which individuals experience ownership over a fake hand when it is stroked in synchrony with the participant's own, unseen hand (Botvinick & Cohen, 1998). Such illusory ownership is argued to occur as a result of a three-way weighted interaction between vision, touch, and proprioception (i.e. sense of body position), in which the source of tactile stimulation on one's own, unseen body (part) is attributed to the location of visually perceived fake body (part) when the two are stroked synchronously. The principles of such multisensory integration have been more recently extended to illusory ownership towards another's entire body during the Full Body Illusion. Variations of this illusion exist, in which participants typically perceive a change in self-location which induces an illusory experience of being in a position outside of their physical body (Ehrsson, 2007), or an illusory ownership towards another's body from a third-person perspective (Lenggenhager, Tadi, Metzinger, & Blanke, 2007) or first-person perspective (Petkova & Ehrsson, 2008; Slater, Spanlang, Sanchez-Vives, & Blanke, 2010).

However, recent studies have highlighted the fundamental contribution of interoceptive signals towards body ownership, defined here as incoming afferent sensory channels that monitor the physiological state of one's body (Ceunen, Vlaeyen, & Van Diest, 2016). Such information can arise from within the body (e.g. hunger, thirst, cardiac awareness) and outside the body (e.g. itch, pain, pleasure from touch) (Ceunen et al., 2016; Craig, 2002). Crucially, the successful integration and reciprocal relationship between exteroceptive and interoceptive sensory channels are fundamental in contributing to one's sense of body ownership (Ainley & Tsakiris, 2013; Filippetti, Kirsch, Crucianelli, & Fotopoulou, 2019). Specifically, manipulation of both interoceptive and exteroceptive signals has been shown to influence how the body is perceived during multisensory tasks (Aspell et al., 2013; Filippetti & Tsakiris, 2017; Suzuki, Garfinkel, Critchley, & Seth, 2013; Tsakiris, Tajadura-Jiménez, & Costantini, 2011).

Although research principally uses cardiac-related measures as a proxy for interoceptive awareness (e.g. heartbeat detection task; Schandry, 1981), an increasingly used method to investigate the role of interoceptive signals in body ownership is the use of affective touch. Here, affective touch refers to a dynamic, low-pressure, caress-like tactile stimulation of relatively slow velocity (see below) which has been shown to optimally activate specific slow-conducting, unmyelinated, low-threshold mechanoreceptors (C-tactile (CT) afferent nerve fibres) found only in hairy skin (Vallbo et al., 1999). Microneurography evidence has shown that these fibres respond optimally to stroking velocities between 1 and 10 cm/s, with their activation linearly associated with increased subjective pleasantness ratings (Löken et al., 2009), and maximised at human skin-like temperatures during tactile stimulation (Ackerley et al., 2014). Indeed, recent work has shown how CT-optimal touch has been associated with positive affective state using implicit measures (Pawling, Cannon, McGlone, & Walker, 2017). Whilst other brain areas have been implicated in affective touch, such afferent signals seem to take a distinct pathway to the posterior insular cortex (Björnsdotter, Morrison, & Olausson, 2010; Morrison, 2016; Olausson et al., 2002), which is a key area associated with the early convergence of interoceptive and exteroceptive bodily information (Craig, 2009; Crucianelli et al., 2016; Morrison et al., 2011). Therefore, affective touch is argued to provide an important source of interoceptive information regarding the physiological state of the body that is not provided to the same degree by non-affective touch.

Several studies have shown that affective touch may have an important role in contributing towards the formation of one's body ownership within multisensory integration. Indeed, evidence has shown subtle enhancing effects of affective touch towards the experience of body ownership within the RHI during synchronous multisensory integration amongst healthy individuals, both subjectively (Crucianelli, Krahé, Jenkinson, & Fotopoulou, 2017; Crucianelli et al., 2013; Lloyd, Gillis, Lewis, Farrell, & Morrison, 2013) and behaviourally (van Stralen et al., 2014). Such findings may, in part, be a result of the involvement of bottom-up signals associated with CT-optimal touch, but recent evidence has also highlighted the role of other cross-modal factors in the modulation of body ownership such as the affective certainty and congruency of seen and felt touch (Filippetti et al., 2019). Additionally, the enhancing effects of affective touch have been shown to extend to facial self-recognition during synchronous and congruent multisensory integration in the enfacement illusion, with evidence to suggest that such CT-optimal touch may also reduce 'deafference' (i.e. feeling of numbness in the body) during asynchronous multisensory integration (Panagiotopoulou, Filippetti, Tsakiris, & Fotopoulou, 2017). Indeed, such compelling hypotheses highlight that further research is required to fully understand the subtle, specific contribution of the CT system towards body ownership. More recently, research has investigated whether the enhancing effect of affective touch towards ownership of a rubber hand extends to enhanced ownership over a whole body (de Jong, Keizer, Engel, & Dijkerman, 2017). Such evidence showed that participants did display enhanced subjective ownership towards a full virtual body following affective, but not non-affective touch (Study 1). However, this effect disappeared when asynchronous visuotactile stroking was introduced as a control condition (Study 2), with no difference in subjective ownership observed between affective vs. non-affective touch for both synchronous and asynchronous conditions. Importantly, whilst the enhancing effect of affective touch towards body-part ownership has provided corroborative results, the role of affective touch towards ownership over a full body remains inconclusive, which the present study aims to address.

Critically, research has shown that individuals with anorexia nervosa (AN) display differences in their subjective anticipation or perception of the pleasantness of affective touch compared with healthy controls (Bischoff-Grethe et al., 2018; Crucianelli et al., 2016; Davidovic et al., 2018). This may represent a general anhedonic, reduced bodily pleasure amongst such individuals, which is similarly observed in other clinical disorders such as depression (Pizzagalli, Iosifescu, Hallett, Ratner, & Fava, 2008). Alternatively, such differences amongst AN patients may reflect bottom-up, somatosensory disturbances that have been observed amongst the eating disorder (ED) population (Crucianelli et al., 2016), particlarly in relations to alterations in the perceptions of tactile stimuli (Keizer et al., 2011; Keizer, Smeets, Postma, van Elburg, & Dijkerman, 2014). The latter hypothesis is important to consider in the context of multisensory integration, given the close association between the stability of one's somatosensory processing, interoceptive awareness, and one's body image (Duschek, Werner, Reyes del Paso, & Schandry, 2015; Zamariola, Cardini, Mian, Serino, & Tsakiris, 2017), which refers to the conscious representation of the body based on its perceptual, cognitive and affective evaluations (Badoud & Tsakiris, 2017). Specifically, interoceptive alterations have been implicated with disturbances in body image amongst clinical EDs (Merwin, Zucker, Lacy, & Elliott, 2010; Pollatos et al., 2008, 2016). However, evidence is yet to determine whether ED patients' reduced subjective pleasantness to touch could be a consequence of chronic disordered eating behaviours, or a trait phenomenon that is present *prior* to illness onset (Eshkevari, Rieger, Longo, Haggard, & Treasure, 2014) and may thus contribute to the development of the disorder. Therefore, a key aim within the present study will be to investigate individual differences in the subjective pleasantness of perceived touch amongst healthy individuals in relation to subthreshold ED psychopathology, to better understand the mechanisms that may contribute to a clinical diagnosis (Carey, Crucianelli, Preston, & Fotopoulou, 2019; Preston & Ehrsson, 2014, 2016, 2018).

In the present study, we used an adapted version of an established paradigm (Petkova & Ehrsson, 2008) to investigate the role of affective touch in modulating ownership during multisensory integration within the full body illusion, across two experiments. Experiment 1 aimed to replicate previous research with a similar methodology (de Jong et al., 2017), in which participants received affective (slow; CT-optimal) and non-affective (fast; CT-non-optimal) touch on their forearm in synchrony or asynchrony with the touch administered to the forearm of a mannequin body. Experiment 2 provided an identical set-up, but builds upon Experiment 1 by using a spatially incongruent condition as an alternative control condition, rather than asynchrony (Panagiotopoulou et al., 2017). This was chosen because there is little evidence to suggest that spatial incongruence causes 'deafference' to the same degree as asynchrony. Therefore, using visuotactile congruence in Experiment 2 meant that the illusion can be manipulated whilst maintaining attention and synchrony as a constant. In line with previous research (Crucianelli et al., 2017, 2013; de Jong et al., 2017; Panagiotopoulou et al., 2017), it is hypothesised that affective touch would be perceived as more pleasant, and lead to greater embodiment over a whole body compared with non-affective touch. This effect is expected to occur following synchronous/congruent conditions only, with no difference in embodiment expected between asynchronous/incongruent conditions (Filippetti et al., 2019). Additionally, we wished to investigate whether the subjective perception of touch is associated with subthreshold ED psychopathology amongst healthy individuals, irrespective of body ownership. If previously observed differences in the subjective perception of pleasant touch are a trait feature which can be identified amongst those at risk for an ED, it is hypothesised that there will be a negative relationship between perceived pleasantness of touch during the illusion and ED psychopathology. Conversely, no relationship between these outcomes would suggest that such differences in the hedonic value of affective touch observed in EDs may be a consequence of the disorder, rather than a predisposing factor.

2. Methods

2.1 Experiment 1

2.1.1 Participants

Forty-one female participants (Mean age = 20.10, SD ± 2.48, range = 18-31) were recruited via the University of York research participation scheme, and received course credit for a single 60-minute testing session. All participants had no current or previous neurological or psychological disorders (self-report), and normal or corrected-to-normal vision. Participants had a mean body mass index (BMI) of 21.54 (SD ± 2.41, range = 18.30-28.60). Exclusion criteria included any specific skin conditions (e.g. eczema, psoriasis) or any scarring or tattoos on the left arm. All participants gave informed, written consent to take part in the study. The study received ethical approval from the University of York Departmental Ethics Committee, and was conducted in accordance with the Declaration of Helsinki. One participant was later excluded after self-reporting a previous psychological condition, and a further two participants were excluded as extreme outliers, scoring more than 2 SD below the group mean in pleasantness ratings of affective touch (3 cm/s velocity) during the illusion (Ponzo, Kirsch, Fotopoulou, & Jenkinson, 2018). Therefore, the final sample consisted of thirty-eight participants (Mean age = 19.92, SD ± 2.33, range = 18-31).

2.1.2 Design

The experiment used a 2 (stroking velocity: affective vs. non-affective) x 2 (stroking synchrony: synchronous vs. asynchronous) within-subjects design. Stroking velocity was manipulated by administering slow, affective touch (3 cm/s - CT-optimal), and fast, non-affective touch (18 cm/s - CT-non-optimal) (see Carey et al., 2019; Crucianelli et al., 2013; Panagiotopoulou et al., 2017; Ponzo et al., 2018) to each participants' arm (and mannequin arm) for 60 seconds. Prior to all experimental conditions, participants completed a condition in which no visuotactile stimulation was applied and they merely visually observed the mannequin body from a first-person perspective (*visual capture* condition), for 30 seconds. This was to determine the degree of embodiment experienced by participants due to 'visual capture' of congruent proprioceptive information of the mannequin body with one's own body position (Carey et al., 2019; Crucianelli et al., 2017, 2013). Previous research has shown that as few as 15 seconds is sufficient to elicit visual capture within RHI paradigms, as a two-way sensory integration between vision and proprioception (Martinaud, Besharati, Jenkinson, & Fotopoulou, 2017; Ponzo et al., 2018). Additionally, 60 seconds has been shown to be sufficient to induce changes in measures of body ownership in both RHI and full body illusions involving synchronous touch, as a three-way sensory integration between vision, proprioception, and touch (Crucianelli et al., 2013; Preston & Ehrsson, 2014). Therefore, accounting for the additional use of head-mounted displays in the present study, we chose to implement a 30 second 'visual capture' condition and a 60 second experimental condition.

Dependent variables were: 1) subjective pleasantness of stroking received on participants' arm following each illusion trial (see *Measures* section for measurement details), to investigate whether affective touch was perceived as more pleasant than non-affective touch during the illusion (Crucianelli et al., 2016, 2013). 2) Subjective embodiment experienced by participants, rated after each trial via an *embodiment questionnaire* (see *Measures* section and Table 1 for details). For each condition, the *embodiment questionnaire* was completed pre-stroking (i.e. *visual capture* condition) and post-stroking (i.e. *illusion* condition). In line with previous studies (Crucianelli et al., 2017, 2013), an 'embodiment change' score was calculated by subtracting pre-stroking scores from post-stroking scores to determine the subjective embodiment due to visuotactile integration. Participants completed four *visual capture* conditions, and four *illusion* conditions, for a total of eight trials. The order of all experimental conditions was randomised across participants.

2.1.3 Measures

2.1.3.1 Pleasantness Ratings

Following illusion trials only, a measurement of the perceived pleasantness of the tactile stimulation was taken, to determine whether participants perceived slow, affective touch as more pleasant than fast, non-affective touch (Crucianelli et al., 2016, 2017; Löken et al., 2009). Participants were asked *"How pleasant was the touch of the brush on your arm?"* which was rated on a Visual Analogue Scale (VAS) anchored by *"Not at all pleasant"* (0) and "*Extremely pleasant"* (100).

2.1.3.2 Embodiment Questionnaire

Following each trial, participants rated their subjective embodiment via an *embodiment questionnaire* along a 7-point Likert scale (-3 'strongly disagree' to +3 'strongly agree'). The same questionnaire was completed for both visual capture and illusion conditions, with the addition of one item for illusion conditions (see Table 1). The questionnaire (adapted from Longo, Schüür, et al., 2008) was composed of two subcomponents: *ownership* (i.e. the feeling that the mannequin body belongs to them) and *location* (i.e. the feeling that the mannequin body was in the position of their own body). An overall *embodiment score* was calculated by averaging the above two subcomponent scores (see Table 1). Embodiment questions were identical in both *visual capture* and *illusion* conditions, with the addition of a further embodiment (*Location*) question, regarding the referral of touch in illusion trials. The final two statements were control statements, which served to control for task compliance, suggestibility, and confabulation within each trial. Control statements are similar in being body-related items, but are designed to not capture the phenomenological experience of embodiment.

Table 1. *Embodiment Questionnaire presented to participants following each trial.*

Questionnaire Statement	Component
1. It seemed like I was looking directly at my own body, rather than a mannequin body	Ownership
2. It seemed like the mannequin body belonged to me	Ownership
3. It seemed like the mannequin body was part of my body	Ownership
4. It seemed like the mannequin body was in the location where my body was.	Location
5. It seemed like the touch I felt was caused by the brush touching the mannequin arm*	Location
6. It felt like I had two bodies (at the same time)	Control
7. It felt like my body was made out of rubber	Control

NB. The order of questionnaire statements was randomized for each trial and participant.

*= Item 5 delivered following illusion trials only.

2.1.3.3 Eating Disorder Examination Questionnaire (EDE-Q)

The EDE-Q (Fairburn & Beglin, 1994) is a 28-item questionnaire used as a self-report measure of ED psychopathology. The questionnaire assesses disordered eating behaviours within the past 28 days, in which there are four subscales: Restraint, Eating Concern, Weight Concern and Shape Concern, in which a ‘global’ score is calculated from the average of the four subscales. Items are rated along a seven-point Likert scale (0-6), in which higher scores signify higher ED psychopathology. This scoring is calculated with the exemption of six items in which frequency of eating behaviour is recorded, however, these items do not contribute to the subscale scores. This measure has good internal consistency, with Cronbach's alpha ranging from .78 to .93 in a non-clinical sample (Berg et al., 2012). The overall global EDE-Q measure in the present study had a Cronbach's alpha of .95 in both Experiment 1 and Experiment 2.

2.1.4 Materials

A life-size female mannequin was used to induce the *Full Body Illusion*, which was dressed in a white t-shirt, blue jeans and black socks, with the head removed at the neckline to allow correct positioning of the video cameras. The mannequin body was in a standing position *(Height: 159cm; Shoulders: 94cm; Hips: 87cm; Waist: 62cm)* with arms placed by their side (see Figure 1b). For all trials, participants stood to the right of the mannequin body, separated by an office screen divider (see Figure 1a), and wore a set of head-mounted displays (HMDs) (Oculus Rift DK2, Oculus VR, Irvine, CA, USA), with a resolution of 1200 x 1080 pixels per eye, a refresh rate of 75Hz, and a corresponding nominal visual field of 100°. The HMDs were connected to a stereoscopic camera (USB 3.0 VR stereo camera, Ovrvision Pro, Japan), presenting a real time, video image to participants. The cameras were mounted and positioned downwards, at the eye line of the mannequin, presenting a first-person perspective of the body, consistent with looking down towards one's own body. Tactile stimulation (i.e. stroking) was applied using two identical, cosmetic make-up brushes (Natural hair Blush Brush, N◦7, The Boots Company; brush width ≈ 3cm). All trials and responses were made using PsychoPy 2 (Peirce, 2007) on an Apple iMac desktop computer (1.6GHz dual-core Intel Core i5 processor).

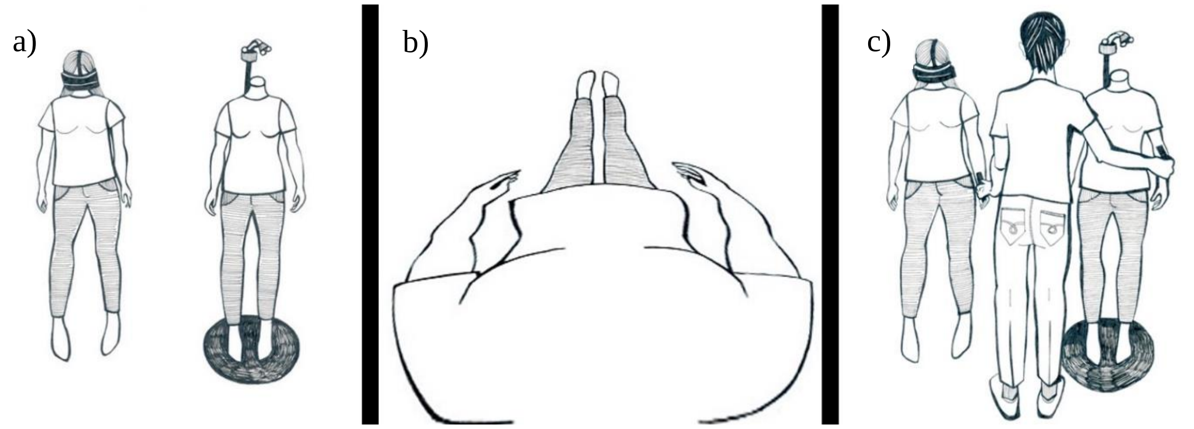

Figure 1. Experimental set-up. a) Visual capture trials, in which participants stood in an identical stance to the mannequin body (NB. Participants were not asked to wear matching clothes to the mannequin during the experiment). b) Participants viewed a live video image of the mannequin body from a first-person perspective, via head mounted displays. c) In illusion trials, the experimenter stroked the left forearm of the mannequin body and the corresponding forearm of the participant, in temporal and anatomical synchrony.

2.1.5 Experimental Procedure

Prior to the experimental trials, two adjacent 9 cm x 4 cm stroking areas were marked on the hairy skin of each participants' left forearm, using a washable marker pen (consistent with previous studies; Crucianelli et al., 2013). This provided a specific anatomical area for which to administer tactile stimulation for participants. Tactile stimulation during all experimental trials was alternated between these two areas, to minimise habituation, prevent CT fibre fatigue, and provided the experimenter with an assigned area to control the pressure of each stroke. Anatomically congruent areas of tactile stimulation were applied to the mannequin arm and participants' own arm within each illusion trial.

For *visual capture* trials, participants wore the HMDs for a 30-second period whilst visually observing the mannequin body (*visual capture* condition). Following this trial, participants removed the HMDs and rated their subjective embodiment towards the mannequin via the *embodiment questionnaire* (see Table 1) on a separate computer. Removing the HMDs following each trial also served as a 'rest period' for participants to move freely and dissociate their subjective experience between trials. For *illusion* trials, participants identically viewed the mannequin body via the HMDs, and the experimenter stroked the left forearm of both the participant and the mannequin body for a 60-second period. In synchronous trials, the experimenter stroked the participants' forearm in complete temporal and anatomical synchrony to the mannequin forearm. In asynchronous trials, a temporal delay (i.e. offset by ~2 seconds) was applied such that the visual strokes seen by the participant on the mannequin were out of time from the felt strokes on the participants' own arm. Participants completed two synchronous trials (affective vs. non-affective) and two asynchronous trials (affective vs. non-affective), each of which were preceded by a 30-second *visual capture* trial. The experimenter was trained to administer each stroke at the precise speed (affective – 3 cm/s or non-affective – 18 cm/s), by counting the number of strokes within a window of 3 seconds per individual stimulation (i.e. one 3 sec-long stroke for 3 cm/s velocity, and six 0.5 sec-long strokes for 18 cm/s velocity). The length of each respective trial duration was auditorily cued for the experimenter, with a short countdown, using PsychoPy 2. Following the illusion trial, participants rated their subjective experience of the illusion once again via the *embodiment questionnaire*, in addition to pleasantness ratings.

Finally, after completing the experimental trials of the illusion, participants completed a short questionnaire which provided their demographic information (i.e. age, height, weight), in addition to the EDE-Q completed privately on the desktop computer.

2.2 Experiment 2

2.2.1 Participants

Forty-three female participants (Mean age = 18.98, SD ± .74, range = 18 - 20) were recruited via the University of York research participation scheme, and received course credit for a single 60-minute testing session. Identical inclusion and exclusion criteria were applied as Experiment 1, and it was ensured that no participants within Experiment 2 had already participated in Experiment 1. Participants had a mean BMI of 21.89 (SD ± 2.67, range = 16.66-28.32). All participants gave informed consent to take part in the study. The study received ethical approval from the University of York Departmental Ethics Committee, and was conducted in accordance with the Declaration of Helsinki. One participant was later excluded after self-reporting a previous psychological condition; one was excluded because of scarring on their arms; and one was excluded following poor comprehension with the experimental procedure. A further participant was excluded as an extreme outlier, scoring more than 2 SD below the group mean in pleasantness ratings of affective touch (3 cm/s velocity) during the illusion (Ponzo et al., 2018). Therefore, the final sample consisted of thirty-nine participants (Mean age = 19.00, SD ± .76, range = 18 - 20).

Table 2. Participant demographic information (Mean and (SD)) with EDE-Q subscale and global scores

	Experiment 1 (*N*=38)	Experiment 2 (*N*=39)	*t*	*p*
Age	19.92 (2.33)	19.00 (.76)	2.32	.025
BMI	21.28 (2.16)	21.94 (2.75)	-1.17	.246
Restraint	.80 (.20-2.25) [a]	.80 (.20-1.80) [a]	-.169[b]	.866
Eating Concern	.60 (.20-1.40) [a]	.60 (.20-1.60) [a]	-.303[b]	.762
Shape Concern	2.25 (1.34-3.66) [a]	2.38 (1.00-3.75) [a]	.000[b]	1.00
Weight Concern	1.40 (.40-2.70) [a]	1.80 (.80-3.20) [a]	-1.01[b]	.315
EDE-Q Global	1.43 (.61-2.21) [a]	1.36 (.60-2.57) [a]	-.265[b]	.791

Note: BMI: Body Mass Index.
[a] Median and interquartile range in parentheses
[b] Mann-Whitney U test - *Z* statistic

2.2.2 Design, Materials, Procedure

Design, Materials and Procedure were identical to Experiment 1. However, in Experiment 2 the spatial congruency of visuotactile stimulation was manipulated during the *Full Body Illusion*, rather than the temporal synchrony (Experiment 1). Participants experienced visuotactile stimulation in a congruent location (i.e. left forearm of both participant and mannequin), or incongruent location (i.e. touch felt on participant left forearm and viewed on mannequin left hand). Participants experienced 2x congruent touch (identical to synchronous trials) and 2x incongruent touch within each stroking velocity (affective/non-affective touch).

2.3 Data Analysis

Statistical analyses were conducted using SPSS version 23.0 (IBM, Chicago, IL, USA). For pleasantness ratings, data were tested for normality and found to be normally distributed for Experiment 1 (Shapiro-Wilk $p > .05$), therefore a parametric 2 (stroking velocity: affective vs. non-affective) x 2 (stroking synchrony: synchronous vs. asynchronous) repeated-measures ANOVA was used for this analysis. Whilst pleasantness ratings data were not normally distributed for Experiment 2 (Shapiro-Wilk $p < .05$), a parametric 2 (stroking velocity: affective vs. non-affective) x 2 (stroking congruency: congruent vs. incongruent) repeated-measures ANOVA was used, to provide direct comparison between experiments. Non-normal distribution looked to be most notably driven by a small, bimodal distribution within the incongruent affective touch condition (see Supplementary Materials, Section 2), in which the incongruency of the seen and felt touch may have been perceived more saliently to some participants to disrupt the feeling of affective touch delivered to their own forearm, and subsequently led to a lower feeling of pleasantness by some. Nevertheless, a non-parametric Wilcoxon signed-rank tests was also undertaken to examine the main effects of (and interaction between) stroking velocity and stroking congruency towards pleasantness ratings, which revealed an identical pattern of results (see Supplementary Materials, Section 2).

For the *embodiment questionnaire*, data were ordinal and found to be non-normally distributed across pre-illusion (*visual capture*) and post-illusion trials for Experiment 1 and 2. Therefore a non-parametric Friedman's ANOVA was first conducted to ensure that embodiment was comparable across each of the four visual capture trials, from which to reliably interpret 'embodiment change' scores in post-illusion trials. Next, non-parametric Wilcoxon signed-rank tests were conducted to examine the main effects of (and interaction between) stroking synchrony (Experiment 1) or congruency (Experiment 2) and stroking velocity towards embodiment change. The above analyses were also conducted for individual *Ownership* and *Location* subcomponents within the *embodiment questionnaire* (see Table 3 & 4, and Supplementary Materials, Sections 1 & 2).

Non-parametric correlational analyses were undertaken to investigate the relationship between pleasantness ratings and subthreshold ED psychopathology (measured using the Eating Disorder Examination Questionnaire; EDE-Q). Additional correlations conducted between pleasantness ratings and BMI are reported in Supplementary Materials (Table S2), with no correlations of interest identified. Effect sizes for parametric tests are indicated by partial eta-squared (η_p^2), and non-parametric Wilcoxon signed-rank tests are indicated by r values (*r*) which are equivalent to Cohen's *d* (Pallant, 2007). Level of significance (α) was set to 0.05, with all post hoc analyses performed using Bonferroni correction.

In addition to a frequentist approach, we supplemented our analysis with a Bayesian analysis (JASP 0.13.1) which presents the ratio of the likelihood of the alternative hypothesis relative to the likelihood of the null hypothesis. A Bayes Factor (BF) greater than 3 indicates evidence for the alternative hypothesis, whereas a BF less than 0.3 indicates evidence for the null hypothesis. A BF between 0.3 and 3 indicates an inconclusive result which is not in favour of either hypothesis. This is possible for both parametric and non-parametric hypothesis testing (van Doorn, Ly, Marsman, & Wagenmakers, 2020).

3. Results

3.1 Experiment 1

3.1.1 Pleasantness Ratings

First, we investigated the main effect of stroking velocity on pleasantness ratings to directly test the hypothesis that slow, affective touch (3 cm/sec) will be perceived as more pleasant than fast, non-affective touch (18 cm/sec) within the illusory set-up. A repeated-measures ANOVA revealed a significant main effect of stroking velocity ($F(1,37) = 4.44$, p =

.042, η_p^2 = .107, BF_{10} = 1.26), with participants rating affective touch (mean = 61.42) as significantly more pleasant than non-affective touch (mean = 58.42). In line with previous research (Crucianelli et al., 2017; Filippetti et al., 2019), a main effect of synchrony was also observed (F (1,37) = 29.85, $p < .001$, η_p^2 = .447, BF_{10} = 5586.7), with a significantly greater perceived pleasantness following synchronous (mean = 67.22) conditions compared with asynchronous (mean = 52.62) conditions (see Figure 2). Finally, no significant interaction was observed between the stroking synchrony and stroking velocity (F (1,37) = .012, p = .914, η_p^2 = .000, BF_{10} = .18).

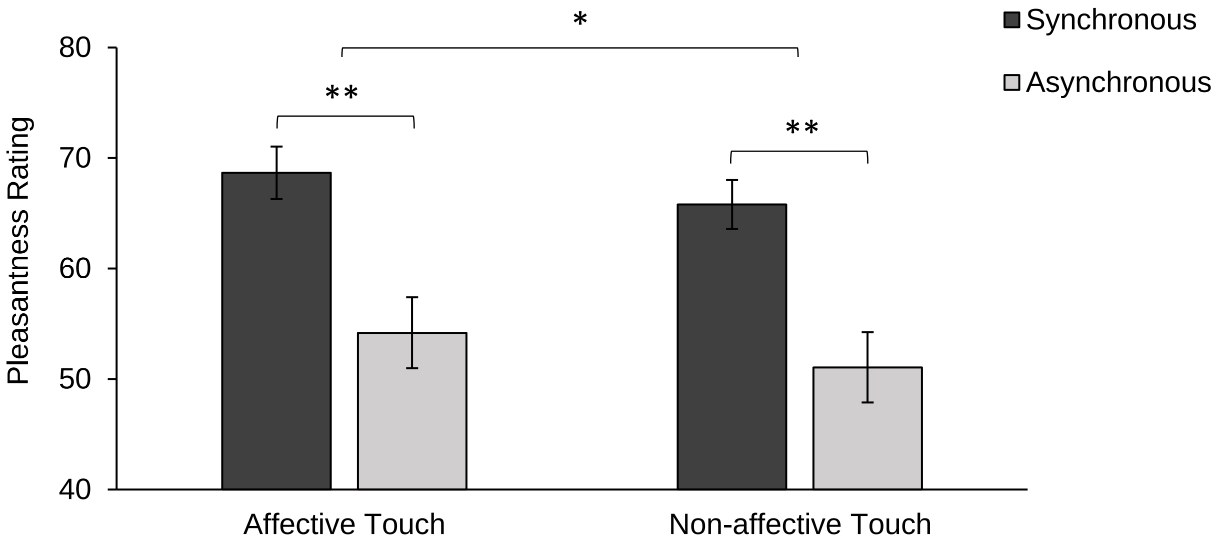

Figure 2. Mean VAS pleasantness ratings (0-100) within the illusion set-up (Experiment 1). Error bars depict standard error of the mean (*= $p < .05$, **= $p < .001$). NB. Means are displayed for illustrative purposes to provide the reader with a more comprehensive view of results.

3.1.2 Embodiment Questionnaire

3.1.2.1 Main Effects

First, to ensure that embodiment scores were comparable across each of the four visual capture (pre-illusion) trials, a Friedman's ANOVA was conducted which showed no significant main effect between visual capture trials towards embodiment (χ^2 (3) = 3.12, p = .373). Next, a Wilcoxon signed-rank test revealed a main effect of stroking synchrony, with significantly greater embodiment change following synchronous (median = .88) stroking conditions compared with asynchronous (median = -.50) stroking conditions (Z = -5.20, p < .001, r = .84, BF_{10} = 28.99). The main effect of stroking velocity on embodiment was non-significant (Z = -1.65, p = .098, r = .27, BF_{10} = .69). To determine any interactions in embodiment change between stroking synchrony and stroking velocity, differences between synchronous and asynchronous scores were calculated for both stroking velocities. No significant difference was observed in embodiment change scores between affective and non-affective touch conditions (Z = -.89, p = .375, r = .14, BF_{10} = .57) (see Figure 3).

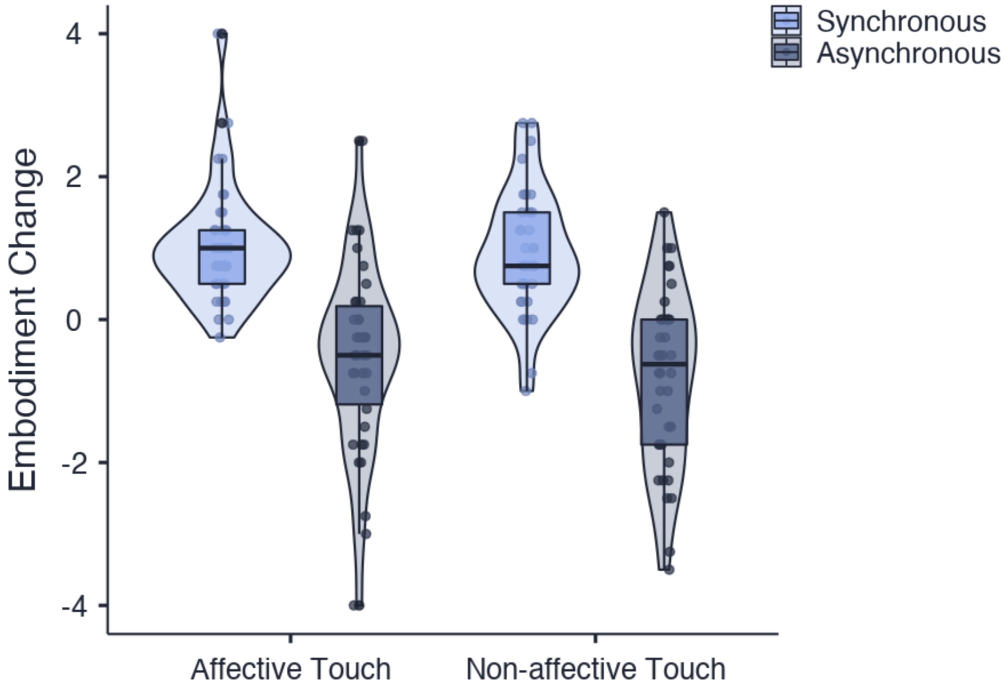

Figure 3. Box plot displaying change in embodiment scores following synchronous and asynchronous conditions. Intersecting line = median; box = upper and lower interquartile range; whiskers = minimum and maximum values. The violin plot (outline) displays kernel probability density - i.e. the width of the shaded area represents the proportion of the data located there.

The above analyses were also conducted for individual *Ownership* and *Location* subcomponents within the *embodiment questionnaire*, which yielded an identical pattern of results (see Table 3 and Supplementary Materials, Section 1).

Table 3. Ownership and Location change within the embodiment questionnaire (Experiment 1)

		Z	*p*	*r*
Ownership Subcomponent	Main Effect (Synchrony)	-5.22	< .001	.85
	Main Effect (Velocity)	-1.13	.261	.18
	Interaction	-.66	.511	.11
Location Subcomponent	Main Effect (Synchrony)	-3.73	< .001	.61
	Main Effect (Velocity)	-1.83	.067	.30
	Interaction	-.94	.348	.15

Note: r values (r) denote effect sizes for non-parametric Wilcoxon signed-rank tests which are equivalent to Cohen's d (Pallant, 2007)

3.1.2.2 Correlational Analysis

Correlational analyses were conducted to investigate the relationship between perceived pleasantness of touch and embodiment change scores during the full body illusion. Difference scores were calculated between affective and non-affective touch pleasantness ratings (averaged across stroking synchrony) to investigate whether individual differences in embodiment change scores were related to the affectivity of touch, irrespective of stroking synchrony. A Spearman's rank correlation revealed no significant correlation between such pleasantness ratings and embodiment change for any conditions (all *ps* > .05). The same analysis was conducted to investigate the role of synchrony, with difference scores calculated between synchronous and asynchronous touch pleasantness ratings (averaged across stroking velocity) to investigate whether individual differences in embodiment change scores were related to the affective certainty and congruency of the touch, irrespective of stroking velocity. A Spearman's rank correlation revealed no significant correlation between such pleasantness ratings and embodiment change for any conditions (all *ps* > .05).

Next, correlational analyses were conducted to investigate the relationship between subthreshold ED psychopathology, measured by the *Eating Disorder Examination Questionnaire* (EDE-Q; Fairburn & Beglin, 1994), and measures of pleasantness ratings and embodiment change scores. First, a Spearman's rank correlation revealed no significant correlation between pleasantness ratings (averaged across stroking synchrony/stroking velocity) and global EDE-Q score ($r = .185$, $p = .267$, $BF_{10} = .45$), or any EDE-Q subscales (all *ps* > .05). Next, difference scores between affective and non-affective touch pleasantness ratings (averaged across stroking synchrony) were used to investigate whether those with higher subthreshold ED psychopathology were less sensitive to differences in the affectivity of touch, irrespective of stroking synchrony. A Spearman's rank correlation revealed no significant correlation between touch difference score and global EDE-Q ($r = -.023$, $p = .892$, $BF_{10} = .22$), or any EDE-Q subscales (all *ps* > .05).

Finally, correlational analyses were conducted to investigate the relationship between subthreshold ED psychopathology and embodiment change due to visuotactile integration, within the full body illusion. A Spearman's rank correlation revealed no significant correlation between embodiment change and global EDE-Q score, or subscale scores (all *ps* > .05).

3.2 Experiment 2

3.2.1 Pleasantness Ratings

The main effect of stroking velocity on pleasantness ratings was investigated to directly test the hypothesis that slow, affective touch (3 cm/sec) will be perceived as more pleasant than fast, non-affective touch (18 cm/sec) within the illusory set-up. A repeated-measures ANOVA revealed a significant main effect of stroking velocity ($F\ (1,38) = 22.13$, $p < .001$, $\eta_p^2 = .368$, $BF_{10} = 668.7$), with participants rating affective touch (mean = 71.21) as significantly more pleasant than non-affective touch (mean = 57.71). Additionally, a main effect of congruency was observed ($F\ (1,38) = 15.35$, $p < .001$, $\eta_p^2 = .288$, $BF_{10} = 76.7$), with a significantly greater perceived pleasantness following congruent (mean = 69.65) conditions compared with incongruent (mean = 59.26) conditions (see Figure 4). Finally, no significant interaction was observed between the stroking synchrony and stroking velocity ($F\ (1,38) = .370$, $p = .547$, $\eta_p^2 = .010$, $BF_{10} = .205$).

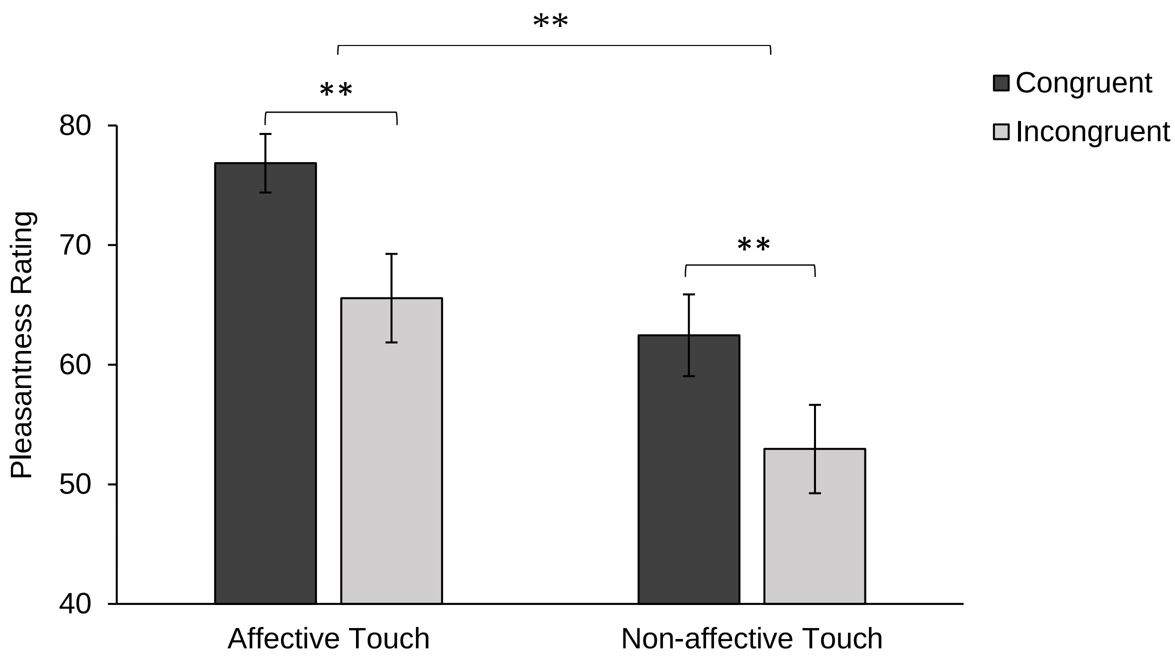

Figure 4. Mean VAS pleasantness ratings (0-100) within the illusion set-up (Experiment 2). Error bars depict standard error of the mean (**= p < .001). NB. Means are displayed for illustrative purposes to provide the reader with a more comprehensive view of results.

3.2.2 Embodiment Questionnaire

3.2.2.1 Main Effects

First, to ensure that embodiment scores were comparable across each of the four visual capture (pre-illusion) trials, a Friedman's ANOVA was conducted which showed no significant main effect between visual capture trials towards embodiment (χ^2 (3) = .691, p = .875). Next, a Wilcoxon signed-rank test revealed a main effect of stroking congruency, with significantly greater embodiment change following congruent (median = .75) stroking conditions compared with incongruent (median = -.25) stroking conditions (Z = -5.12, p < .001, r = .82, BF_{10} = 10.44). The main effect of stroking velocity on embodiment was non-significant (Z = -1.48, p = .139, r = .27, BF_{10} = .63). To determine any interactions in embodiment change between stroking congruency and stroking velocity, differences between congruent and incongruent scores were calculated for both stroking velocities. No significant difference was observed in embodiment change scores between affective and non-affective touch conditions (Z = -.27, p = .791, r = .04, BF_{10} = .57) (see Figure 5).

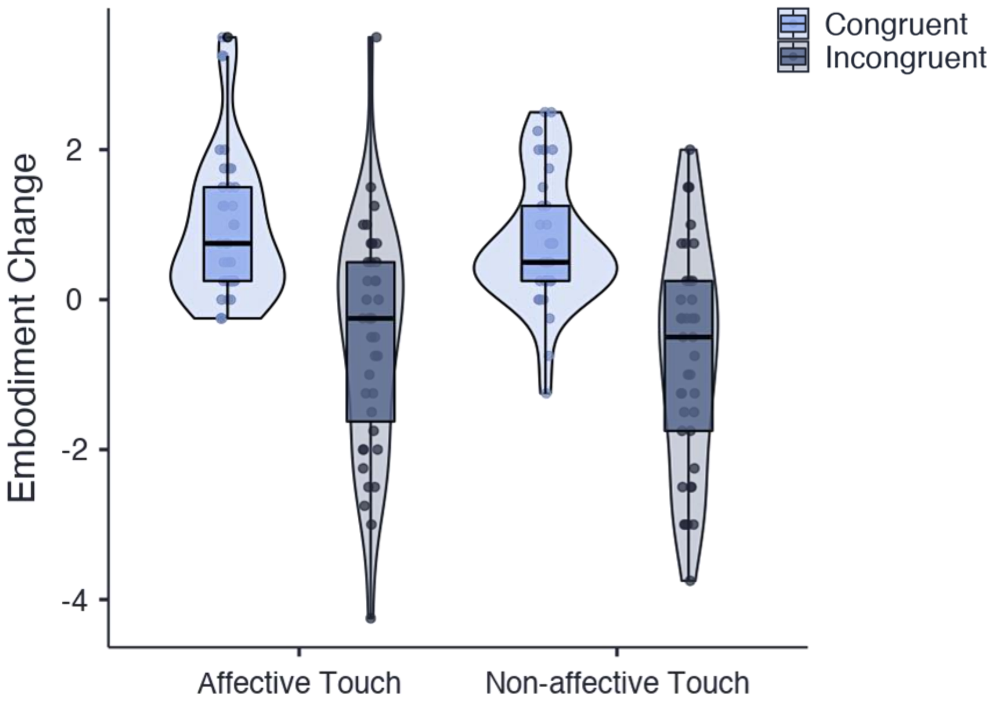

Figure 5. Box plot displaying change in embodiment scores following congruent and incongruent conditions. Intersecting line = median; box = upper and lower interquartile range; whiskers = minimum and maximum values. The violin plot (outline) displays kernel probability density - i.e. the width of the shaded area represents the proportion of the data located there.

The above analyses were also conducted for individual *Ownership* and *Location* subcomponents within the *embodiment questionnaire,* which yielded an identical pattern of results (see Table 4 and Supplementary Materials, Section 2).

Table 4. Ownership and Location change within the embodiment questionnaire (Experiment 2)

		Z	*p*	*r*
Ownership Subcomponent	Main Effect (Congruency)	-5.09	< .001	.82
	Main Effect (Velocity)	-1.69	.091	.27
	Interaction	-.69	.487	.11
Location Subcomponent	Main Effect (Congruency)	-3.93	< .001	.63
	Main Effect (Velocity)	.322	.747	.05
	Interaction	-.91	.362	.15

Note: r values (r) denote effect sizes for non-parametric Wilcoxon signed-rank tests which are equivalent to Cohen's d (Pallant, 2007)

3.2.2.2 Correlational Analysis

Correlational analyses were conducted to investigate the relationship between perceived pleasantness of touch and embodiment change scores during the full body illusion. Difference scores were calculated between affective and non-affective touch pleasantness ratings (averaged across stroking congruency) to investigate whether individual differences in embodiment change scores were related to the affectivity of touch. A Spearman's rank correlation revealed no significant correlation between such pleasantness ratings and embodiment change for any conditions (all *ps* > .05). The same analysis was conducted to investigate the role of congruency, with difference scores calculated between congruent and incongruent touch pleasantness ratings (averaged across stroking velocity) to investigate whether individual differences in embodiment change scores were related to the affective certainty and congruency of the touch, irrespective of stroking velocity. A Spearman's rank correlation revealed no significant correlation between such pleasantness ratings and embodiment change for any conditions (all *ps* > .05).

Correlational analyses were conducted to investigate the relationship between subthreshold ED psychopathology (measured by EDE-Q scores) and measures of pleasantness ratings and embodiment change scores. First, a Spearman's rank correlation revealed no significant correlation between pleasantness ratings (averaged across stroking congruency/stroking velocity) and global EDE-Q score (r = -.275, p = .090, BF_{10} =.45). When corrected for multiple comparisons (Bonferroni-corrected α = .013), no significant correlations were observed between averaged pleasantness rating and EDE-Q subscales (all *ps* > .03). Next, difference scores between affective and non-affective touch pleasantness ratings (averaged across stroking congruency) were used to investigate whether those with higher subthreshold ED psychopathology were less sensitive to differences in the affectivity of touch. A Spearman's rank correlation revealed no significant correlation between touch difference score and global EDE-Q (r = .014, p = .931, BF_{10} = .22), or any EDE-Q subscales (all *ps* >.45).

Finally, correlational analyses were conducted to investigate the relationship between subthreshold ED psychopathology and embodiment change due to visuotactile integration, within the full body illusion. A Spearman's rank correlation revealed no significant correlation between embodiment change and global EDE-Q score, or subscale scores (all *ps* > .05).

4. Discussion

The present study used an adapted version of the *Full Body Illusion* (Petkova & Ehrsson, 2008) to investigate the role of slow, CT-optimal, affective touch towards ownership over a whole body, across two experiments. Specifically, we investigated whether this type of affective touch would lead to increased perceived pleasantness and enhanced subjective embodiment towards a whole mannequin body, compared with fast, non-affective touch. In line with previous research (Crucianelli et al., 2017, 2013; de Jong et al., 2017; Löken et al., 2009), our results showed that participants perceived affective touch as significantly more pleasant than non-affective touch, across both experiments, although Bayes Factor analysis suggested the effect in Experiment 1 (using an asynchronous control condition) was statistically inconclusive. Moreover, both synchronous (Experiment 1) and spatially congruent (Experiment 2) touch was perceived as more pleasant than asynchronous and incongruent touch, respectively – irrespective of stroking velocity. This supports previous research in suggesting that perceived pleasantness is determined by more than CT-optimal touch, with the top-down affective certainty between the seen and felt touch playing a role in such perceived pleasantness (Filippetti et al., 2019). As expected, synchronous, and spatially congruent, visuotactile stimulation led to higher subjective embodiment towards the mannequin body compared with asynchronous (Experiment 1) or spatially incongruent (Experiment 2) visuotactile stimulation. However, contrary to our hypothesis, the velocity of perceived touch did not further modulate the subjective experience of the illusion, with comparable embodiment change scores between affective and non-affective touch conditions. Bayes Factor analysis revealed a score between 0.3 and 3, which does not provide a conclusive result in favour of the null or the alternative hypothesis. Therefore, it remains unclear whether affective touch can lead to greater embodiment during the full body illusion. Finally, it was found that the perceived pleasantness of touch was not modulated by subthreshold ED psychopathology, amongst healthy females.

In both experiments, greater subjective embodiment was reported when the multisensory information was synchronous, and spatially congruent, between participant's own body and the mannequin body, which supports the role of exteroceptive multisensory integration towards body ownership (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). However, in contrast to previous research using multisensory illusion paradigms (Crucianelli et al., 2017; Lloyd et al., 2013; Panagiotopoulou et al., 2017), no interaction between the synchrony, or congruency, and the velocity of touch (affective/non-affective) was observed, which suggests that tactile affectivity did not play a significant role in the subjective embodiment of a whole body. Whilst the Bayes Factor analysis produced an inconclusive finding, it may be that the influence of affective touch in enhancing multisensory integration could be body-part specific, following previous research which has shown such effects using the hand (Crucianelli et al., 2017, 2013; Lloyd et al., 2013) and face (Panagiotopoulou et al., 2017). Indeed, neuropsychological evidence has shown the role of affective touch to increase partial body ownership following right-hemisphere stroke (Jenkinson et al., 2020), but to our knowledge there has been no such neuropsychological evidence for rare delusions of whole-body misidentification.

The pattern of results in the present study are in line with previous research which investigated the role of affective touch applied to participants' abdomen within a virtual full body illusion (de Jong et al., 2017). Whilst de Jong et al. (2017) observed an enhanced effect of affective touch when solely manipulating stroking velocity, no such effects were observed when the additional variable of stroking synchrony was added. Here, it is important to note that CT afferent density appears to be different across the body (Corniani and Saal 2020), between the face (Nordin 1990), forearm (Vallbo, Olausson, and Wessberg 1999), and leg (Edin 2001) with no afferents found in the glabrous palm of the hand (Olausson et al. 2010). This is particularly pertinent when comparing the results of the present study with de Jong et al. (2017) in the context of the full body illusion - i.e. tactile stimulation on the forearm and stomach, respectively. Thus, future research would benefit from investigating possible differences in tactile bodily innervation (e.g. hand vs. arm vs. stomach vs. face vs. leg), and the consequences this has for multisensory integration.

Whilst there was no observed effect of the stroking velocity towards the subjective experience of the illusion, such findings may be due to the disruptive sensory input of the visuotactile synchrony, and spatial congruency during the illusion. Within this set-up, it may be that the interoceptive, affective information is conflicting with the exteroceptive somatosensory information which was present across all illusory trials. Indeed, causal inference and optimal integration models of multisensory integration suggest that any conflicting sensory input, however minimal, is likely to influence the feeling that such signals are coming from the same source (Chancel & Ehrsson, 2020; Ehrsson & Chancel, 2019; Kilteni, Maselli, Kording, & Slater, 2015; Samad, Chung, & Shams, 2015; van Beers, Sittig, & Gon, 1999; van Beers, Wolpert, & Haggard, 2002). Therefore, it may be that the conflicting signals between the interoceptive affective touch and exteroceptive spatial synchrony/congruency could have been disruptive to the subjective experience of the illusion and thus weakened the influence of the affective touch.

This assertion is supported in our own results, in which the effect of pleasantness was reduced in Experiment 1 when the control condition was asynchronous. This is shown in both the effect size and the inconclusive Bayes Factor statistic. Indeed, the difference in pleasantness ratings between Experiments (whereby the mean affective touch rating was higher in Experiment 2 vs. Experiment 1) may be driven by the greater saliency of the visual asynchrony disrupting such casual inference to a greater degree than incongruent touch, and even influence how synchronous touch is perceived in subsequent trials within the illusion. Furthermore, we also collapsed across synchrony and congruency in each Experiment to get an overall score for affective touch and non-affective touch, so it may be that the asynchronous touch in Experiment 1 was overly salient and interfered with the feelings of pleasantness elicited by the more subtle input of affective touch. Indeed, this is shown in Figure 2 in which the asynchronous affective touch condition has a pleasantness rating that is 14 points lower than synchronous affective touch. Thus, this influences the overall affective touch score to a greater extent than the difference in the congruent/incongruent affective touch conditions in Experiment 2 (pleasantness difference of 11 points). This was a key reason for conducting Experiment 2, in which spatial incongruence is likely to cause 'deafference' (i.e. feeling of numbness in the body) to a lesser degree than asynchrony during multisensory integration, and would thus not be expected to be perceived as saliently.

However, previous research has observed objective, behavioural changes (i.e. proprioceptive drift) following affective touch within the RHI, in the absence of subjective, self-report changes in embodiment (van Stralen et al., 2014). Indeed, evidence has shown dissociable effects between self-report and behavioural measures within multisensory illusion paradigms (Abdulkarim & Ehrsson, 2016; Panagiotopoulou et al., 2017; Rohde, Luca, & Ernst, 2011). Whilst objective and physiological measures of the illusion (e.g. proprioceptive drift, skin temperature, skin conductance) were not recorded in the present study, future research should investigate the mechanisms of affective touch in its dissociable influence towards subjective and objective components of whole-body representation (Dijkerman & de Haan, 2007).

Whilst the present study did show that participants perceived slow, affective touch as more pleasant than fast, non-affective touch, the effects of CT-optimal touch must be considered alongside top-down mechanisms, given that the perception of pleasant touch is not exclusively influenced by bottom-up CT afferents (Ellingsen, Leknes, Løseth, Wessberg, & Olausson, 2016; Ellingsen et al., 2014; Gallace & Spence, 2010; Keizer, de Jong, Bartlema, & Dijkerman, 2017). The role of top-down, social modulation of affective touch must be considered, as, unlike previous research (Crucianelli et al., 2013; de Jong et al., 2017), participants in the present study were healthy females and were tested by a male experimenter. Indeed, research has shown that an individual's beliefs of the gender of the toucher can influence their perception of the pleasantness of touch (Gazzola et al., 2012; Scheele et al., 2014). Therefore, within the present study, affective touch administered on participants' hairy skin represents a bottom-up, CT afferent process, which may also be attenuated by top-down influences of the social context (e.g. gender of the experimenter) before the subjective experience of touch is appraised. Furthermore, research has shown that CT afferents respond more actively to touch stimuli delivered at typical skin temperature (~32°C) compared to cooler (18°C) or warmer (42°C) stimuli, which correlated with subjective pleasantness ratings (Ackerley, Backlund Wasling, et al., 2014). This suggests that CT firing alone does not lead to uniform pleasantness, and the response in relation to specific characteristics of a gentle caress may be influenced by top-down mechanisms beyond such CT firing.

With evidence that alterations in sensory processing may be a trait phenomenon in ED patients which could be a risk factor in the development of the disorder (Eshkevari et al., 2014), we investigated whether the perceived pleasantness of touch was related to subthreshold ED psychopathology amongst healthy individuals. Indeed, previous research has highlighted relationships between body-related perception and subthreshold ED psychopathology, demonstrating a direct link between perceptual and cognitive-affective components of body image in the healthy population (Preston & Ehrsson, 2014, 2016, 2018). However, despite alterations observed in the perception of affective touch in clinical ED groups (Crucianelli et al., 2016), subthreshold ED psychopathology did not relate to the subjective pleasantness of touch amongst healthy individuals in either experiment within the present study. This may suggest that reduced pleasantness of touch in clinical ED patients is a consequence of the disorder rather than a predisposing factor, particularly within clinical populations such as EDs in which psychiatric comorbidity and body-related anhedonia is common (Davidovic et al., 2018). Notably, no such relationship may reflect a lack of variation in EDE-Q scores across each experimental sample, as all non-clinical participants that were recruited were healthy females who had no current or previous psychological conditions. Interestingly, Bayes Factor analysis did not provide strong evidence in favour of the null hypothesis, suggesting further research is needed to discover the relationship between interoception and specifically affective touch and subthreshold ED psychopathology. Investigation of such sensory processing is important to study in relation to body image within non-clinical samples, in order to dissociate which factors might be directly linked with the pathology of the disorder, and which are implicated as a by-product of a clinical diagnosis.

It is important to consider a number of methodological decisions within the present study. Firstly, participants experienced visuotactile stimulation in an incongruent location in Experiment 2, where the touch was felt on participant’s left forearm and viewed on the mannequin’s left hand. Whilst such stimulation was spatially incongruent, the forearm and hand are close together on the body, and may have influenced perception. Thus, it would be interesting for future research to repeat this condition with more salient spatial incongruencies between the participant’s body and mannequin’s body (e.g. hand vs. leg). Secondly, the velocity of the slow (3cm/s) and fast (18cm/s) touch was chosen for each experiment as it has been shown to be optimal and non-optimal, respectively, for eliciting feelings of pleasantness (Löken et al., 2009; Gentsch et al., 2015), with these same velocities having also been validated in previous studies (e.g. Crucianelli et al., 2013, Panagiotopoulou et al., 2017). The decision to use a stroking speed of 18 cm/s as a control condition was chosen following excessive piloting and published research that has revealed that 30cm/s is perceived as a very fast and ‘somewhat unnatural’ social touch condition when stroked manually by a human (e.g. von Mohr et al., 2017). Therefore, with evidence showing that humans regularly stroke other humans of 10cm/s or more (Strauss, Bytomski, & Croy, 2020), a stroking speed of 18cm/s was sufficiently different as a control condition without feeling unnatural to the participant. Thirdly, the present study stroked participants’ forearm as a method to induce the full body illusion, which does differ from typical versions of the full body illusion that principally stroke the abdomen as a core region of the body (de Jong et al., 2017; Petkova & Ehrsson, 2008). Whilst research has evidenced induction of the full body illusion by stroking participants’ hand, arm or leg (Gentile et al. 2015; Petkova et al. 2011; van der Hoort, Guterstam, and Ehrsson 2011), findings within the present study may not have induced embodiment over a full body to the same degree as other versions of the illusion. This is particularly important to consider when comparing between previous research which has investigated the full body illusion in relation to affective touch (de Jong et al., 2017).

Finally, the present study chose to use a unipolar pleasantness scale (*Not at all pleasant – Extremely pleasant*) rather than a bipolar scale (*Unpleasant – Pleasant*). This scale is in line with previous research (e.g. Crucianelli et al., 2013, 2017), and was chosen to allow greater sensitive in participants’ response because stroking was delivered with a soft brush in each condition and was thus unlikely to be perceived as *unpleasant*. However, this decision does limit the comparability with other studies in the literature which use bipolar scales (Ackerley, Carlsson, Wester, Olausson, & Backlund Wasling, 2014; Croy, Bierling, Sailer, & Ackerley, 2020; Pawling et al., 2017) and thus the present study may have produced different results to such research which uses differing scales.

In conclusion, across two experiments our findings provide supportive evidence that affective touch is perceived as more pleasant than non-affective touch amongst healthy individuals. However, such effects of stroking velocity during multisensory integration did not modulate the subjective embodiment towards a whole mannequin body within the full body illusion, with a Bayes factor analysis providing an inconclusive result which was neither in favour of the null nor the alternative hypothesis. We speculate that such findings may reflect the salience of exteroceptive sensory information during multisensory integration, in which the subtlety of interoceptive, CT-optimal stroking was not sufficiently potent to further influence subjective embodiment. Indeed, even the perceived pleasantness of affective touch compared to non-affective touch could be reduced in the presence of highly salient asynchronous control conditions. Alternatively, as previous research has shown an enhancement of embodiment due to affective touch towards a fake hand, such effects may be body-part specific, and may not generalize to increased subjective embodiment towards a whole body. Moreover, the present study must be considered and investigated further in the context of top-down, social modulations of affective touch in addition to bottom-up sensory information. Future research should explore the relationship between interoceptive and exteroceptive sensory integration towards body ownership, body image and its distortions within clinical ED populations.

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Author Contributions:

MC, LC, CP and AF designed the experiment. MC performed data collection and analysed the data, under supervision of CP, LC and AF. MC drafted the manuscript, and CP, LC and AF provided critical revisions. All authors approved the manuscript before submission.

Competing Interests:

The authors declare no competing interests.

References

Abdulkarim, Z., & Ehrsson, H. H. (2016). No causal link between changes in hand position sense and feeling of limb ownership in the rubber hand illusion. *Attention, Perception, and Psychophysics*, *78*(2), 707–720. https://doi.org/10.3758/s13414-015-1016-0

Ackerley, R., Backlund Wasling, H., Liljencrantz, J., Olausson, H., Johnson, R. D., & Wessberg, J. (2014). Human C-tactile afferents are tuned to the temperature of a skin-stroking caress. *Journal of Neuroscience*, *34*(8), 2879–2883. https://doi.org/10.1523/JNEUROSCI.2847-13.2014

Ackerley, R., Carlsson, I., Wester, H., Olausson, H., & Backlund Wasling, H. (2014). Touch perceptions across skin sites: Differences between sensitivity, direction discrimination and pleasantness. *Frontiers in Behavioral Neuroscience*, *8*(FEB), 1–10. https://doi.org/10.3389/fnbeh.2014.00054

Ainley, V., & Tsakiris, M. (2013). Body Conscious? Interoceptive Awareness, Measured by Heartbeat Perception, Is Negatively Correlated with Self-Objectification. *PLoS ONE*, *8*(2). https://doi.org/10.1371/journal.pone.0055568

Aspell, J. E., Heydrich, L., Marillier, G., Lavanchy, T., Herbelin, B., & Blanke, O. (2013). Turning Body and Self Inside Out: Visualized Heartbeats Alter Bodily Self-Consciousness and Tactile Perception. *Psychological Science*, *24*(12), 2445–2453. https://doi.org/10.1177/0956797613498395

Badoud, D., & Tsakiris, M. (2017). From the body's viscera to the body's image: Is there a link between interoception and body image concerns? *Neuroscience and Biobehavioral Reviews*, *77*(December 2016), 237–246. https://doi.org/10.1016/j.neubiorev.2017.03.017

Berg, K. C., Peterson, C. B., Frazier, P., & Crow, S. J. (2012). Psychometric evaluation of the eating disorder examination and eating disorder examination-questionnaire: A systematic review of the literature. *International Journal of Eating Disorders*, *45*(3), 428–438. https://doi.org/10.1002/eat.20931

Bischoff-Grethe, A., Wierenga, C. E., Berner, L. A., Simmons, A. N., Bailer, U., Paulus, M. P., & Kaye, W. H. (2018). Neural hypersensitivity to pleasant touch in women remitted from anorexia nervosa. *Translational Psychiatry*, *8*(1). https://doi.org/10.1038/s41398-018-0218-3

Björnsdotter, M., Morrison, I., & Olausson, H. (2010). Feeling good: On the role of C fiber mediated touch in interoception. *Experimental Brain Research*, *207*(3–4), 149–155. https://doi.org/10.1007/s00221-010-2408-y

Botvinick, M., & Cohen, J. (1998). Rubber hand feels touch that eyes see. *Nature*, *391*, 756. https://doi.org/10.1038/35784

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), 2889. https://doi.org/10.1038/s41598-019-39168-4

Ceunen, E., Vlaeyen, J. W. S., & Van Diest, I. (2016). On the origin of interoception. *Frontiers in Psychology*, *7*(MAY), 1–17. https://doi.org/10.3389/fpsyg.2016.00743

Chancel, M., & Ehrsson, H. H. (2020). Which hand is mine? Discriminating body ownership perception in a two-alternative forced choice task, (1998). https://doi.org/10.31234/osf.io/thjer

Corniani, G., & Saal, H. P. (2020). Tactile innervation densities across the whole body. *BioRxiv*, 2020.04.27.063263. https://doi.org/10.1101/2020.04.27.063263

Craig, A. D. (2002). How do you feel? Interoception: the sense of the physiological condition of the body. *Nature Reviews Neuroscience*, *3*(8), 655. https://doi.org/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. https://doi.org/10.1038/nrn2555

Croy, I., Bierling, A., Sailer, U., & Ackerley, R. (2020). Individual Variability of Pleasantness Ratings to Stroking Touch Over Different Velocities. *Neuroscience*. https://doi.org/10.1016/j.neuroscience.2020.03.030

Crucianelli, L., Cardi, V., Treasure, J., Jenkinson, P. M., & Fotopoulou, A. (2016). The perception of affective touch in anorexia nervosa. *Psychiatry Research*, *239*, 72–78. https://doi.org/10.1016/j.psychres.2016.01.078

Crucianelli, L., Krahé, C., Jenkinson, P. M., & Fotopoulou, A. (Katerina). (2017). Interoceptive ingredients of body ownership: Affective touch and cardiac awareness in the rubber hand illusion. *Cortex*, 1–13. https://doi.org/10.1016/j.cortex.2017.04.018

Crucianelli, L., Metcalf, N. K., Fotopoulou, A., & Jenkinson, P. M. (2013). Bodily pleasure matters: Velocity of touch modulates body ownership during the rubber hand illusion. *Frontiers in Psychology*, *4*, 1–7. https://doi.org/10.3389/fpsyg.2013.00703

Davidovic, M., Karjalainen, L., Göran, S., Elisabet, W., Björnsdotter, M., & Olausson, H. (2018). Abnormal brain processing of gentle touch in anorexia nervosa. *Psychiatry Research: Neuroimaging*. https://doi.org/10.1016/j.pscychresns.2018.08.007

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*, *0*(0), 0. https://doi.org/10.1007/s00221-017-4912-9

de Vignemont, F. (2010). Body schema and body image-Pros and cons. *Neuropsychologia*, *48*(3), 669–680. https://doi.org/10.1016/j.neuropsychologia.2009.09.022

Dijkerman, H. C., & de Haan, E. H. F. (2007). Somatosensory process subserving perception and action. *Behavioral and Brain Sciences*, *30*(2007), 189–239.

Duschek, S., Werner, N. S., Reyes del Paso, G. a., & Schandry, R. (2015). The Contributions of Interoceptive Awareness to Cognitive and Affective Facets of Body Experience.

Journal of Individual Differences, *36*(2), 110–118. https://doi.org/10.1027/1614-0001/a000165

Edin, B. B. 2001. “Cutaneous Afferents Provide Information about Knee Joint Movements in Humans.” *Journal of Physiology* 531 (1): 289–97. https://doi.org/10.1111/j.1469-7793.2001.0289j.x.

Ehrsson, H. H. (2007). The experimental induction of out-of-body experiences. *Science*, *317*(5841), 1048. https://doi.org/10.1126/science.1142175

Ehrsson, H. H., & Chancel, M. (2019). Premotor cortex implements causal inference in multisensory own-body perception. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(40), 19771–19773. https://doi.org/10.1073/pnas.1914000116

Ellingsen, D. M., Leknes, S., Løseth, G., Wessberg, J., & Olausson, H. (2016). The neurobiology shaping affective touch: Expectation, motivation, and meaning in the multisensory context. *Frontiers in Psychology*, *6*(JAN), 1–16. https://doi.org/10.3389/fpsyg.2015.01986

Ellingsen, D. M., Wessberg, J., Chelnokova, O., Olausson, H., Laeng, B., & Leknes, S. (2014). In touch with your emotions: Oxytocin and touch change social impressions while others’ facial expressions can alter touch. *Psychoneuroendocrinology*, *39*(1), 11–20. https://doi.org/10.1016/j.psyneuen.2013.09.017

Eshkevari, E., Rieger, E., Longo, M. R., Haggard, P., & Treasure, J. (2014). Persistent body image disturbance following recovery from eating disorders. *International Journal of Eating Disorders*, *47*(4), 400–409. https://doi.org/10.1002/eat.22219

Fairburn, C. G., & Beglin, S. (1994). Assessment of eating disorders: interview or self- report questionnaire? *Int J Eat Disord*, *16*(4), 363–370. https://doi.org/10.1002/1098-108X(199412)16:4

Filippetti, M. L., Kirsch, L. P., Crucianelli, L., & Fotopoulou, A. (2019). Affective certainty and congruency of touch modulate the experience of the rubber hand illusion. *Scientific Reports*, *9*(1), 2635. https://doi.org/10.1038/s41598-019-38880-5

Filippetti, M. L., & Tsakiris, M. (2017). Heartfelt embodiment: Changes in body-ownership and self- identification produce distinct changes in interoceptive accuracy. *Cognition*, *159*, 1–10. https://doi.org/10.1016/j.cognition.2016.11.002

Gallace, A., & Spence, C. (2010). The science of interpersonal touch: An overview. *Neuroscience and Biobehavioral Reviews*, *34*(2), 246–259. https://doi.org/10.1016/j.neubiorev.2008.10.004

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

Gazzola, V., Spezio, M. L., Etzel, J. A., Castelli, F., Adolphs, R., & Keysers, C. (2012). Primary somatosensory cortex discriminates affective significance in social touch. *Proceedings of the National Academy of Sciences*, *109*(25), E1657–E1666. https://doi.org/10.1073/pnas.1113211109

Gentile, G., Björnsdotter, M., Petkova, V. I., Abdulkarim, Z., & Ehrsson, H. H. (2015). Patterns of neural activity in the human ventral premotor cortex reflect a whole-body multisensory percept. *NeuroImage*, *109*, 328–340. https://doi.org/10.1016/j.neuroimage.2015.01.008

Graziano, M. S. A., & Botvinick, M. M. (2002). How the brain represents the body: insights from neurophysiology and psychology. *Common Mechanisms in Perception and Action (Attention and Performance XIX)*. Retrieved from https://www.princeton.edu/~graziano/Papers/Attn_Perf19.pdf

Herbert, B. M., & Pollatos, O. (2014). Attenuated interoceptive sensitivity in overweight and obese individuals. Eating Behaviors, 15(3), 445–448. https://doi.org/10.1016/j.eatbeh.2014.06.002

Jenkinson, P. M., Papadaki, C., Besharati, S., Moro, V., Gobbetto, V., Crucianelli, L., … Fotopoulou, A. (2020). Welcoming back my arm: affective touch increases body ownership following right-hemisphere stroke. Brain Communications, 2(1). https://doi.org/10.1093/braincomms/fcaa034

Keizer, A., de Jong, J. R., Bartlema, L., & Dijkerman, C. (2017). Visual perception of the arm manipulates the experienced pleasantness of touch. *Developmental Cognitive Neuroscience*, (September), 0–1. https://doi.org/10.1016/j.dcn.2017.09.004

Keizer, A., Smeets, M. A. M., Dijkerman, H. C., van den Hout, M., Klugkist, I., van Elburg, A., & Postma, A. (2011). Tactile body image disturbance in anorexia nervosa. *Psychiatry Research*, *190*(1), 115–120. https://doi.org/10.1016/j.psychres.2011.04.031

Keizer, A., Smeets, M. a. M., Postma, A., van Elburg, A., & Dijkerman, H. C. (2014). Does the experience of ownership over a rubber hand change body size perception in anorexia nervosa patients? *Neuropsychologia*, *62*, 26–37. https://doi.org/10.1016/j.neuropsychologia.2014.07.003

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*(March), 141. https://doi.org/10.3389/fnhum.2015.00141

Lenggenhager, B., Tadi, T., Metzinger, T., & Blanke, O. (2007). Video ergo sum: manipulating bodily self-consciousness. *Science (New York, N.Y.)*, *317*(5841), 1096–1099. https://doi.org/10.1126/science.1143439

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*(December), 207. https://doi.org/10.3389/fnbeh.2013.00207

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

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

Martinaud, O., Besharati, S., Jenkinson, P. M., & Fotopoulou, A. (2017). Ownership Illusions in Patients with Body Delusions: Different Neural Profiles of Visual Capture and Disownership. *Cortex*, 174–185. https://doi.org/10.1016/j.cortex.2016.09.025

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. https://doi.org/10.1111/j.1460-9568.2012.08092.x

Morrison, I. (2016). ALE meta-analysis reveals dissociable networks for affective and discriminative aspects of touch. *Human Brain Mapping*, *37*(4), 1308–1320. https://doi.org/10.1002/hbm.23103

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. https://doi.org/10.1523/JNEUROSCI.0397-11.2011

Nordin, B Y Magnus. 1990. “Low-Threshold Mechanoreceptive and Nociceptive Units With Unmyelinated (C) Fibres in the Human Supraorbital Nerve.” *Journal of Physiology*, no. 426: 229–40.

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. https://doi.org/10.1038/nn896

Olausson, Håkan, Johan Wessberg, India Morrison, Francis McGlone, and Åke Vallbo. 2010. “The Neurophysiology of Unmyelinated Tactile Afferents.” *Neuroscience and Biobehavioral Reviews* 34 (2): 185–91. https://doi.org/10.1016/j.neubiorev.2008.09.011.

Pallant, J. (2007). *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using SPSS for Windows Version 15*.

Panagiotopoulou, E., Filippetti, M. L., Tsakiris, M., & Fotopoulou, A. (2017). Affective Touch Enhances Self-Face Recognition During Multisensory Integration. *Scientific Reports*, *7*(1), 12883. https://doi.org/10.1038/s41598-017-13345-9

Pawling, R., Cannon, P. R., McGlone, F. P., & Walker, S. C. (2017). C-tactile afferent stimulating touch carries a positive affective value. *PLoS ONE*, *12*(3), 1–15. https://doi.org/10.1371/journal.pone.0173457

Peirce, J. W. (2007). PsychoPy—Psychophysics software in Python. *Journal of Neuroscience Methods*, *162*(1–2), 8–13. JOUR. https://doi.org/http://dx.doi.org/10.1016/j.jneumeth.2006.11.017

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

Petkova, V. I., & Ehrsson, H. H. (2008). If I were you: perceptual illusion of body swapping. *PLoS One*, *3*(12), e3832. https://doi.org/10.1371/journal.pone.0003832

Pizzagalli, D. A., Iosifescu, D., Hallett, L. A., Ratner, K. G., & Fava, M. (2008). Reduced hedonic capacity in major depressive disorder: Evidence from a probabilistic reward task. *Journal of Psychiatric Research*, *43*(1), 76–87. https://doi.org/10.1016/j.jpsychires.2008.03.001

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*(June), 311–321. https://doi.org/10.1016/j.neuropsychologia.2018.06.020

Preston, C., & Ehrsson, H. H. (2014). Illusory Changes in Body Size Modulate Body Satisfaction in a Way That Is Related to Non-Clinical Eating Disorder Psychopathology. *PLoS ONE*, *9*(1), e85773. https://doi.org/10.1371/journal.pone.0085773

Preston, C., & Ehrsson, H. H. (2016). Illusory obesity triggers body dissatisfaction responses in the insula and anterior cingulate cortex. *Cerebral Cortex*, 1–11. https://doi.org/10.1093/cercor/bhw313

Preston, C., & Ehrsson, H. H. (2018). Implicit and explicit changes in body satisfaction evoked by body size illusions : Implications for eating disorder vulnerability in women. *PloS One*, *13*(6), 1–31. https://doi.org/e0199426

Rohde, M., Luca, M., & Ernst, M. O. (2011). The rubber hand illusion: Feeling of ownership and proprioceptive drift Do not go hand in hand. *PLoS ONE*, *6*(6). https://doi.org/10.1371/journal.pone.0021659

Samad, M., Chung, A. J., & Shams, L. (2015). Perception of body ownership is driven by Bayesian sensory inference. *PLoS ONE*, *10*(2), 1–23. https://doi.org/10.1371/journal.pone.0117178

Schandry, R. (1981). Heart beat perception and emotional experience. *Psychophysiology*, *18*(4), 483–488.

Scheele, D., Kendrick, K. M., Khouri, C., Kretzer, E., Schläpfer, T. E., Stoffel-Wagner, B., … Hurlemann, R. (2014). An oxytocin-induced facilitation of neural and emotional responses to social touch correlates inversely with autism traits. *Neuropsychopharmacology*, *39*(9), 2078–2085. https://doi.org/10.1038/npp.2014.78

Slater, M., Spanlang, B., Sanchez-Vives, M. V., & Blanke, O. (2010). First person experience of body transfer in virtual reality. *PLoS ONE*, *5*(5), 1–9. https://doi.org/10.1371/journal.pone.0010564

Strauss, T., Bytomski, A., & Croy, I. (2020). The Influence of Emotional Closeness on Interindividual Touching. *Journal of Nonverbal Behavior*, *44*(3), 351–362. https://doi.org/10.1007/s10919-020-00334-2

Suzuki, K., Garfinkel, S. N., Critchley, H. D., & Seth, A. K. (2013). Multisensory integration across exteroceptive and interoceptive domains modulates self-experience in the rubber-hand illusion. *Neuropsychologia*, *51*(13), 2909–2917. https://doi.org/10.1016/j.neuropsychologia.2013.08.014

Tsakiris, M. (2016). The multisensory basis of the self: from body to identity to others. *Quarterly Journal of Experimental Psychology*, *0218*(August), 1–28. https://doi.org/10.1080/17470218.2016.1181768

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: visuotactile integration and self-attribution. *J Exp Psychol Hum Percept Perform*, *31*(1), 80–91. https://doi.org/10.1037/0096-1523.31.1.80

Tsakiris, M., Tajadura-Jiménez, A., & Costantini, M. (2011). Just a heartbeat away from one’s body: interoceptive sensitivity predicts malleability of body-representations. *Proceedings. Biological Sciences / The Royal Society*, *278*(1717), 2470–2476. https://doi.org/10.1098/rspb.2010.2547

Vallbo, Å. B., Olausson, H., & Wessberg, J. (1999). Unmyelinated afferents constitute a second system coding tactile stimuli of the human hairy skin. *Journal of Neurophysiology*, *81*(6), 2753–2763. https://doi.org/10.1152/jn.1999.81.6.2753

van Beers, R. J., Sittig, A. C., & Gon, J. J. D. van der. (1999). Integration of Proprioceptive and Visual Position-Information: An Experimentally Supported Model. *Journal of Neurophysiology*, *81*(3), 1355–1364.

van Beers, R. J., Wolpert, D. M., & Haggard, P. (2002). When Feeling Is More Important Than Seeing in Sensorimotor Adaptation. *Current Biology*, *12*, 834–837. https://doi.org/10.26634/jps.2.1.2835

van der Hoort, B., Guterstam, A., & Ehrsson, H. H. (2011). Being barbie: The size of one's own body determines the perceived size of the world. *PLoS ONE*, *6*(5). https://doi.org/10.1371/journal.pone.0020195

van Doorn, J., Ly, A., Marsman, M., & Wagenmakers, E. J. (2020). Bayesian rank-based hypothesis testing for the rank sum test, the signed rank test, and Spearman's ρ. Journal of Applied Statistics, 1-23.

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

Zamariola, G., Cardini, F., Mian, E., Serino, A., & Tsakiris, M. (2017). Can you feel the body that you see? On the relationship between interoceptive accuracy and body image. *Body Image*, *20*, 130–136. https://doi.org/10.1016/j.bodyim.2017.01.005