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The Effect of Visual Capture Towards Subjective Embodiment Within the Full Body Illusion

Mark Carey^{1*}, Laura Crucianelli², Catherine Preston^{1†}, and Aikaterini Fotopoulou^{2†}

¹ Department of Psychology, University of York, York, United Kingdom

² Department of Clinical, Educational and Health Psychology, University College London, United Kingdom

† These authors have shared senior authorship

***Corresponding author:**

Mark Carey
Department of Psychology
University of York
Heslington
York, YO10 5DD
United Kingdom
Email: mac541@york.ac.uk

1 **Abstract**

2 Typically, multisensory illusion paradigms emphasise the importance of synchronous visuotactile
3 integration to induce subjective embodiment towards another body. However, the extent to which
4 embodiment is due to the ‘visual capture’ of congruent visuoproprioceptive information alone remains
5 unclear. Thus, across two experiments (total $N = 80$), we investigated how mere visual observation of
6 a mannequin body, viewed from a first-person perspective, influenced subjective embodiment
7 independently from concomitant visuotactile integration. Moreover, we investigated whether slow,
8 affective touch on participants’ own, unseen body (without concomitant touch on the seen mannequin)
9 disrupted visual capture effects to a greater degree than fast, non-affective touch. In total, 40% of
10 participants experienced subjective embodiment towards the mannequin body following mere visual
11 observation, and this effect was significantly higher than conditions which included touch to
12 participants own, unseen body. The velocity of the touch that participants received (affective/non-
13 affective) did not differ in modulating visual capture effects. Furthermore, the effects of visual capture
14 and perceived pleasantness of touch was not modulated by subthreshold eating disorder
15 psychopathology. Overall, this study suggests that congruent visuoproprioceptive cues can be sufficient
16 to induce subjective embodiment of a whole body, in the absence of visuotactile integration and beyond
17 mere confabulatory responses.

18 1. Introduction

19

20 Body ownership, the feeling that our body belongs to us and is distinct from other people's bodies,
21 is a fundamental component of our sense of self^{1,2}. Intuitively, this feeling appears stable and durable
22 amongst humans, yet scientific studies have demonstrated that the sense of body ownership is a fragile
23 outcome of integrating multiple sensory signals. Such signals originate via exteroceptive modalities
24 (i.e. outside the body) such as vision and touch^{3,4}, specifically within the boundaries of peripersonal
25 space surrounding the body^{5,6}. Additionally, incoming signals emerge via interoceptive modalities (i.e.
26 within the body) such as proprioception and heart rate⁷⁻⁹. Together, exteroceptive and interoceptive
27 sensory signals are integrated to create a coherent sense of body ownership through which we interact
28 with our environment².

29

30 Experimental paradigms have been successfully used to investigate how body ownership is
31 shaped by the integration of incoming multisensory information. For example, in the *Rubber Hand*
32 *Illusion (RHI)*¹⁰, individuals experience ownership over a fake (rubber) hand when placed in a congruent
33 anatomical position and stroked in temporal synchrony with their own hand, which is hidden from view.
34 This has been recently extended to ownership over an entire body (*Full Body Illusion*), of which
35 different variations exist. Participants can perceive a change in self-location which induces an illusory
36 experience of being in a position outside of their physical body¹¹, or an illusory ownership towards
37 another's body from a third-person perspective¹² or first-person perspective^{13,14}. In such illusions, the
38 source of tactile stimulation on one's own, unseen body (part) is attributed to the location of the visually
39 perceived fake body (part) when the two are stroked synchronously, which is argued to give rise to
40 subjective self-reports of illusory body ownership and a mislocation in one's own sense of body position
41 (i.e. proprioceptive drift)⁴. Importantly, such effects typically occur within the constraints of top-down
42 contextual factors, including the orientation^{3,15}, visual perspective¹⁶⁻¹⁸, and appearance^{13,19,20} of the
43 embodied body (part). Indeed, research has shown that the strength of the illusion is modulated by the
44 distance between the real and fake body (part), with greater spatial discrepancies decreasing the
45 likelihood of integration between visuoproprioceptive signals²¹⁻²³.

46

47 Importantly, it has long been argued that the synchrony of the perceived touch with vision is a
48 necessary condition for illusory ownership to occur, rather than asynchrony which is typically used as
49 a control condition within multisensory illusion paradigms¹⁵. However, the role of synchronous
50 visuotactile integration as a necessary component to trigger illusory embodiment remains debated^{24,25}.
51 Research has shown that illusory embodiment could still be induced based purely on visual information
52 of a fake body (part) in the absence of visuotactile stimulation^{25–27}, or based on merely expected but
53 not experienced synchronous tactile stimulation²⁸, and even following asynchronous visuo-tactile
54 stimulation, provided that spatial congruence is adhered to between the real and fake body (part)²⁹ (see
55 ²⁴ for review). Such evidence highlights that synchronous visuotactile input can strengthen illusory
56 embodiment, by contributing to the downregulation in the weighting of proprioceptive signals regarding
57 one’s own limb position in relation to vision³⁰. However, from a computational perspective, congruent
58 visuoproprioceptive cues may be sufficient to induce such embodiment, suggesting that subsequent
59 visuotactile input may not be a necessary component to trigger this process^{25,26,31} (see³² for review).

60

61 Studies which have investigated illusory body ownership in the absence of tactile stimulation
62 have predominantly investigated this effect during the RHI (e.g.^{25,33,34}), with little research conducted
63 towards a whole body¹⁶. Among the latter, some have argued that synchronous visuotactile integration
64 is a necessary condition to elicit illusory ownership in the full body illusion¹³, while studies using
65 virtual reality have found evidence to the contrary, following illusory ownership towards a virtual body
66 in the absence of visuotactile integration^{14,16}. Therefore, we wished to investigate whether subjective
67 visual capture of embodiment could occur towards a real mannequin body with a static field of view,
68 from a first-person visual perspective in the ‘physical world’. In this context, ‘visual capture’ is defined
69 as the degree of embodiment due solely to passive, visual perception of the fake body (part) viewed
70 from a first-person perspective, independent from tactile stimulation (hereafter referred to as ‘visual
71 capture of embodiment’)^{35,36}.

72

73 Interestingly, a tendency to weight visual information over other somatosensory signals has
74 been recently observed in neuropsychological, right hemisphere patients with body representation
75 deficits (e.g.^{36–39}). Moreover, alterations in the weighting and integration of sensory information has

76 been implicated within neurodevelopmental disorders such as autism ^{40,41}, and psychiatric disorders
77 such as schizophrenia ⁴²⁻⁴⁴, and eating disorders ^{45,46}. Importantly, such alterations are argued to reflect
78 an instability in the bodily self within these populations ^{47,48}. However, whilst ‘pure’ visual capture
79 conditions have been tested in right hemisphere patients, evidence for heightened visual dominance
80 within eating disorder patients derives from multisensory illusion studies finding that both synchronous
81 and asynchronous visuotactile stimulation led to alterations in an individual’s body representation
82 ^{45,46,49,50}. Thus, direct investigation of visual capture of embodiment from congruent visuoproprioceptive
83 cues alone (i.e. in the absence of tactile stimulation) has been less studied with regard to eating disorder
84 psychopathology.

85

86 Importantly, greater illusory embodiment in acute eating disorder patients has been shown to
87 persist to some degree amongst recovered patients, suggesting that such heightened sensitivity to visual
88 information pertaining to the body may be a trait phenomenon ⁴⁹. Therefore, such visual dominance
89 over other sensory information may be independent from a status of malnutrition, and may occur *prior*
90 to illness onset which could influence an individual’s body perception and body satisfaction ⁵¹⁻⁵³. Thus,
91 it may be that healthy individuals who display an increased visual capture of embodiment towards a
92 fake body (part) show an increased visual dominance over other sensory information, which may link
93 with a greater risk of developing distortions in body image. Consequently, the present study aimed to
94 investigate whether subthreshold eating disorder psychopathology and body concerns may modulate
95 the subjective embodiment shown towards a fake body as a result of mere visual capture.

96

97 In addition to research investigating visuoproprioceptive integration, the importance of
98 interoception in multisensory integration and body ownership has only recently been investigated ^{9,54,55}.
99 Interoception refers to information about the internal states of the body, processing sensations from
100 within the body (e.g. hunger, thirst), but also outside the body (e.g. pleasure, pain), which is conveyed
101 by a particular afferent pathway ⁸. Affective touch - i.e. slow, caress-like touch – is associated with
102 increased pleasantness and has been found to activate specific C-Tactile (CT) afferents found only in
103 the hairy skin, responding maximally to stroking velocities between 1 and 10 cm/sec ⁵⁶. Importantly,
104 affective tactile stimulation appears to be dissociable from exteroceptive, discriminatory stimulation

105 such as non-affective touch⁵⁷. Such CT afferents are hypothesised to take a distinct pathway to the
106 posterior insular cortex^{58,59}, an area associated with the early convergence of interoceptive information
107 with exteroceptive bodily signals^{8,60,61}.

108

109 Increasing evidence has shown that the velocity of perceived touch during visuotactile
110 integration plays an influential role within the sense of body ownership. Specifically, touch delivered
111 at CT-optimal velocities has been shown to increase embodiment during the RHI paradigm compared
112 with fast, non-affective touch^{35,62-64}, however, evidence of this effect in the full body illusion remains
113 equivocal⁶⁵. Moreover, recent research has shown that individuals with anorexia nervosa (AN) display
114 a reduced subjective pleasantness to touch, relative to healthy controls⁶⁰; however, it is yet to be
115 investigated how eating disorder psychopathology may modulate the extent to which individuals show
116 alterations in their experience of touch, or vice versa. Therefore, within our second experiment,
117 individual differences in the perception of touch will be investigated in relation to subthreshold eating
118 disorder psychopathology.

119

120 In addition to enhancement of embodiment via interoceptive signals, evidence from patient
121 populations with chronic pain has shown how feelings of body ownership can be disturbed^{66,67} (but see
122⁶⁸ for review). Changes in interoceptive information (e.g. increased limb temperature) has been shown
123 to disrupt the feelings of embodiment by *decreasing* the strength of the effect within multisensory
124 illusions⁶⁹. Therefore, in addition to mere visual capture towards subjective embodiment (*visual*
125 *capture* condition), the present study aimed to investigate the effects of tactile stimulation administered
126 to participants' own, unseen arm during visual observation of the mannequin body, as a control
127 condition designed to 'disrupt' visual capture by introducing sensory input that is incongruent with
128 participants' visual information (*tactile disruption* condition). Furthermore, we aimed to investigate
129 whether CT-optimal, affective touch (i.e. touch administered in CT-optimal velocities) would provide
130 additional interoceptive information on one's own body which would be expected to disrupt visual
131 capture of embodiment to a greater extent compared with discriminatory, non-affective touch. Previous
132 research has suggested that the perception of interoceptive signals depends on an individual's ability to
133 regulate the balance between interoceptive and exteroceptive information in ambiguous contexts^{9,35,70}.

134 Thus, differences in an individual's sensitivity and balance between these two streams of information
135 may determine the degree of embodiment change shown during tactile disruption conditions.

136

137 In brief, we investigated whether mere visual observation of a mannequin body would lead to
138 subjective embodiment when visuoproprioceptive cues are congruent with one's own body. Based on
139 previous research ^{16,25}, we predicted that a compatible first-person perspective of a mannequin body
140 would be sufficient to elicit subjective embodiment amongst participants, independent of concomitant
141 tactile stimulation. In addition, we investigated the extent to which subjective embodiment towards the
142 mannequin body was reduced when visual capture of proprioception was disrupted by tactile
143 stimulation to participant's own, unseen arm. We manipulated the velocity of tactile stimulation that
144 participants received, to investigate whether slow, affective touch had a differential effect on the
145 disruption of embodiment compared with fast, non-affective touch. Specifically, we predicted that the
146 increased interoceptive information associated with affective touch would disrupt the downregulation
147 of proprioceptive signals by visual capture to a greater extent compared to non-affective touch. Finally,
148 we investigated whether subthreshold eating disorder psychopathology modulated any individual
149 differences in subjective embodiment from visual capture. We hypothesized that higher eating disorder
150 vulnerability would be associated with an increased weighting of visual information, and thus increased
151 visual capture of embodiment. The above measures were replicated across two experiments, with the
152 addition of a separate touch task in Experiment 2, designed to investigate the role of subjective
153 pleasantness of touch in relation to subthreshold eating disorder psychopathology. Extending upon
154 findings from clinical populations ⁶⁰, we expected to observe a negative relationship between the above
155 two measures, such that individuals with higher eating disorder psychopathology were hypothesised to
156 display a reduced pleasantness to both affective touch and non-affective touch.

157 **2. Methods**

158 **2.1 Experiment 1**

159 **2.1.1 Participants**

160 Forty-one healthy female participants (Mean age = 20.10, SD \pm 2.48, range = 18-31) were
161 recruited via the University of York research participation scheme and received course credit for a
162 single 60-minute testing session. Participants had a mean BMI of 21.48 (SD \pm 2.40, range = 18.30-
163 28.60), no current or previous neurological or psychological disorders (self-report), and normal or
164 corrected-to-normal vision. Exclusion criteria included any specific skin conditions (e.g. eczema,
165 psoriasis) or any scarring or tattoos on the left arm. All participants gave informed consent to take part
166 in the study. The study received ethical approval from the University of York Departmental Ethics
167 Committee and was conducted in accordance with the Declaration of Helsinki. One participant was
168 later excluded because she self-reported a previous psychological condition, therefore, the final sample
169 consisted of forty participants (Mean age = 20.15, SD \pm 2.49, range = 18-31). **Post-hoc power analyses**
170 **using G*Power 3.1.9.2 ⁷¹ indicated that this number of participants resulted in 99% and 97% power to**
171 **obtain significant effects following *visual capture* and *tactile disruption* conditions, respectively (see**
172 **Section 2.3).**

173

174 **2.1.2 Design**

175 The experiment employed a within-subjects design to investigate the effects of visual and tactile
176 signals towards the subjective embodiment of a mannequin body. First, during *visual capture* trials
177 participants visually observed the mannequin body for 30 seconds, from a first-person perspective,
178 independent of any tactile stimulation. Second, participants also undertook trials identical to the *visual*
179 *capture* condition, but with the addition of tactile stimulation applied (only) to participant's own, unseen
180 arm, designed to disrupt such visual capture (*tactile disruption* condition) for 60 seconds. Stimulation
181 was administered at two different velocities to give rise to affective (3cm/s) and non-affective (18 cm/s)
182 *tactile disruption*. The dependent variable was the subjective embodiment experienced by participants,
183 rated after each trial via an *embodiment questionnaire* (see *Measures* section and Table 1 for details).
184 The same *embodiment questionnaire* was completed for both *visual capture* and *tactile disruption*
185 conditions. Participants completed two *visual capture* trials, each followed by an affective or non-

186 affective *tactile disruption* trial in counterbalanced order between participants, resulting in a total of 4
187 trials per participant (see Figure 1).

188

189 INSERT FIGURE 1

190

191 2.1.3 Measures

192 2.1.3.1 Embodiment Questionnaire

193 Following each trial, participants rated their subjective embodiment via an *embodiment*
194 *questionnaire* (see Table 1) along a 7-point Likert scale (-3 strongly disagree to +3 strongly agree). This
195 questionnaire (adapted from Longo et al., 2008) was composed of two subcomponents: *ownership* (i.e.
196 the feeling that the mannequin body belongs to them) and *location* (i.e. the feeling that the mannequin
197 body was in the position of their own body). An overall *embodiment score* was calculated by averaging
198 the above two subcomponent scores. **The final two statements were control statements, in which an**
199 **overall *control score* was similarly calculated by averaging across the two control items. These scores**
200 **served to control for task compliance, suggestibility, and confabulation within the visual capture**
201 **condition to compare with embodiment scores. Such control statements are similar, body-related items**
202 **to those of the embodiment statements, but importantly do not capture the phenomenological experience**
203 **of embodiment. Consequently, comparisons between *embodiment* and *control* scores acted to indicate**
204 **whether a significant sense of embodiment occurred following the *visual capture* condition.**

205

206 2.1.3.2 Eating Disorder Examination Questionnaire (EDE-Q) 6.0

207 The EDE-Q is a 28-item questionnaire used as a self-report measure of eating disorder
208 psychopathology⁷² amongst community populations. The questionnaire assesses frequency of
209 disordered eating behaviours (6 items), as well as eating behaviours and attitudes (22 items) within the
210 past 28 days, along four subscales: *Dietary Restraint*, *Eating Concern*, *Weight Concern* and *Shape*
211 *Concern*, which are also averaged for a *Global EDE-Q Score*. Items are rated along a 7-point (0-6)
212 Likert scale, with higher scores signifying greater eating disorder psychopathology. This measure has
213 good internal consistency, with Cronbach's alpha ranging from .78 to .93 in a non-clinical sample⁷³.

214 The overall global EDE-Q measure in the present study had a Cronbach's alpha of .95 in both
215 Experiment 1 and Experiment 2.

216

217

218 **2.1.4 Materials**

219 A life-size female mannequin was used within the experimental set-up. The mannequin was
220 dressed in a white t-shirt, blue jeans and black socks, with the head removed at the neckline to enable
221 correct positioning of the video cameras. The body had a waist circumference of 62cm and was in a
222 standing position with arms placed by their side (see Figure 2). During all trials, participants wore a set
223 of head-mounted displays (HMDs) (Oculus Rift DK2, Oculus VR, Irvine, CA, USA), with a resolution
224 of 1200 x 1080 pixels per eye, a refresh rate of 75Hz, and a corresponding nominal visual field of 100°.
225 The HMDs were connected to a stereoscopic camera (Ovrvision Pro USB 3.0 VR stereo camera, Japan),
226 presenting a real time, video image to participants. The cameras were mounted and positioned
227 downwards, at the eye line of the mannequin, capturing a first-person perspective of the body,
228 compatible with looking down towards one's own body. During *tactile disruption* trials, tactile
229 stimulation was applied using a cosmetic make-up brush (Natural hair Blush Brush, N°7, The Boots
230 Company). All experimental trials and responses were made using PsychoPy 2 ⁷⁴ on an Apple iMac
231 desktop computer (1.6GHz dual-core Intel Core i5 processor).

232

233 INSERT FIGURE 2

234

235 **2.1.5 Experimental Procedure**

236 Prior to the experiment, two adjacent 9 cm x 4cm stroking areas were marked on the hairy skin of
237 each participants' left forearm, using a washable marker pen ^{62,75}. This provided a specific area for
238 which to administer tactile stimulation for participants. Stimulation alternated between these two
239 stroking areas within each *tactile disruption* trial, to minimise habituation, and provide the experimenter
240 with an assigned area to control the pressure of each stroke. For all experimental trials, participants
241 stood to the right of the mannequin body, separated by an office screen divider (see Figure 2a), whilst
242 wearing the HMDs. Participants were instructed to remain still, place their arms by their side, and look

243 down as though towards their own body. A live video image (delay ~ 60ms) of the mannequin body,
244 viewed from a first-person perspective, appeared in place of their own body through the HMDs (see
245 Figure 2b).

246

247 For *visual capture* trials, participants visually observed the mannequin body for a 30-second period,
248 without any tactile stimulation. Immediately after the trial, participants removed the HMDs and rated
249 their subjective embodiment towards the mannequin via the *embodiment questionnaire* (see Table 1)
250 on a separate computer. Removing the HMDs following each trial also served as a rest period for
251 participants to move freely and dissociate their subjective experience between trials. For *tactile*
252 *disruption* trials, participants identically visually observed the mannequin body, with the experimenter
253 stroking participants' own, unseen arm for a 60-second period. Stroking velocity was manipulated by
254 administering slow, affective touch (3cm/s), and fast, non-affective touch (18cm/s). The experimenter
255 was trained to administer each stroke at the precise speed within the assigned stroking area (9cm x
256 4cm), by counting the number of strokes within a window of 3 seconds per individual stimulation (i.e.
257 one 3s-long stroke for 3 cm/s velocity, and six 0.5s-long strokes for 18 cm/s velocity). Identically,
258 immediately after *tactile disruption* trials, participants removed the HMDs and rated their subjective
259 embodiment towards the mannequin via the *embodiment questionnaire*. Individual questionnaire items
260 were presented in a randomized order across all trials.

261 2.2 Experiment 2

262 2.2.1 Participants

263 Forty-three healthy female participants (Mean age = 18.98, SD \pm .74, range = 18 - 20) were
264 recruited via the University of York research participation scheme and received course credit for a
265 single 60-minute testing session. Participants had a mean BMI of 21.89 (SD \pm 2.67, range = 16.66-
266 28.32), no current or previous neurological or psychological disorders (self-report), and normal or
267 corrected-to-normal vision. Exclusion criteria included any specific skin conditions (e.g. eczema,
268 psoriasis) or any scarring or tattoos on the left arm. All participants gave informed consent to take part
269 in the study. The study received ethical approval from the University of York Departmental Ethics
270 Committee and was conducted in accordance with the Declaration of Helsinki. Three participants were
271 later excluded; one following a self-reported previous psychological condition; one excluded with
272 scarring on their arms, and one excluded following poor comprehension with the experimental
273 procedure. Therefore, the final sample consisted of forty participants (Mean age = 18.98, SD \pm .77,
274 range = 18 - 20). **Post-hoc power analyses using G*Power 3.1.9.2 ⁷¹ indicated that this number of**
275 **participants resulted in 99% power to obtain significant effects following both *visual capture* and *tactile***
276 ***disruption* conditions(see Section 2.3).**

277

278 2.2.2 Design, Materials, Measures, Procedure

279 Design, Materials, Measures and Procedures were identical to Experiment 1, with the addition
280 of a separate *Touch Task* completed prior to the *Full Body Illusion*, which explored subjective
281 pleasantness ratings of affective vs. non-affective touch based solely on tactile input, in relation to
282 subthreshold eating disorder psychopathology amongst healthy females.

283

284 Touch Task

285 Participants were asked to place their left arm on the table with their palm facing down and
286 wore a blindfold over their eyes to prevent any visual feedback to tactile stimulation. Tactile stimulation
287 was administered using an identical cosmetic make-up brush (see *Materials* above) for 3 seconds per
288 trial, at the same velocities as those in the *tactile disruption* conditions (affective touch - 3 cm/sec and
289 non-affective touch - 18 cm/sec). There was a total of six trials per velocity condition, for a total of 18

290 trials, with all trials presented in a randomized order for each participant. Following each trial,
291 participants verbally reported the pleasant of the touch, using the pleasantness rating VAS scale,
292 anchored from 0 (*Not at all pleasant*) to 100 (*Extremely pleasant*)⁶⁰. An average score across the six
293 trials was calculated to obtain a single score, per participant, for each of the two tactile conditions.

294

295 **2.3 Data Analysis**

296 All statistical analyses were conducted using SPSS version 23.0 (IBM, Chicago, IL, USA).
297 Data from the *embodiment questionnaire* were ordinal and found to be non-normal via a Shapiro-Wilk
298 test ($p < .05$), thus, appropriate non-parametric tests were used for analysis. Data for pleasantness ratings
299 in the *Touch Task* were normally distributed ($p > .05$), therefore parametric tests were used to analyse
300 this data. Effect sizes for parametric tests are indicated by Cohen's d , and non-parametric Wilcoxon
301 signed-rank tests are indicated by r values (r) which are equivalent to Cohen's d ⁷⁶.

302

303 First, to indicate whether a significant sense of subjective embodiment occurred following mere
304 visual observation of a mannequin body (i.e. *visual capture* effect), we used a Wilcoxon signed-rank
305 test to compare *embodiment* scores with *control* scores within the *embodiment questionnaire* (see Table
306 1 for *embodiment questionnaire* items). Such comparisons were made to ensure that positive subjective
307 embodiment was specific to the visual capture effect and not due to task compliance or suggestibility,
308 with control items not expected to score highly, irrespective of illusory experience. Second, to
309 investigate whether subjective embodiment was significantly reduced when visual capture was
310 disrupted by tactile stimulation to participant's own, unseen arm (*tactile disruption*), a further Wilcoxon
311 signed-rank test was conducted to compare subjective *embodiment* scores between *visual capture* and
312 *tactile disruption* conditions. Moreover, we assessed whether slow, affective touch on participants own
313 arm led to greater disruption in subjective embodiment within participants compared with fast, non-
314 affective touch, using a Wilcoxon signed-rank test to compare *embodiment* scores between the two
315 stroking velocities (affective vs. non-affective *tactile disruption*). The above analyses were also
316 conducted for individual *Ownership* and *Location* subcomponents within the *embodiment questionnaire*
317 (see Supplementary Materials, Sections 1 and 2). In addition, in Experiment 2 we examined the effect

318 of stroking velocity on pleasantness ratings using a paired-samples t-test, to first establish whether slow,
319 affective touch was indeed perceived as significantly more pleasant than fast, non-affective touch
320 (manipulation check). The perception of touch was then investigated in relation to subthreshold eating
321 disorder psychopathology (as measured by the EDE-Q 6.0), using a non-parametric Spearman's
322 correlation.

323

324 To establish individual differences in reported visual capture of embodiment, we calculated
325 percentage frequencies across the combined samples of Experiment 1 and 2, of those who reported
326 visual capture of embodiment (average scores of $\geq +1$ in response to the *embodiment questionnaire*^{3,77}),
327 those who neither affirmed or denied embodiment (average scores of $< +1$ and > -1 in response to the
328 *embodiment questionnaire*) and those who denied visual capture (average scores of < -1 in the
329 *embodiment questionnaire*). Finally, we wished to explore whether such individual differences in
330 subjective embodiment from visual capture related to subthreshold eating disorder psychopathology
331 (EDE-Q 6.0). Therefore, we conducted a non-parametric Spearman's correlational analysis between the
332 psychometric EDE-Q measure and subjective embodiment scores from *visual capture*.

333 3. Results

334 3.1 Experiment 1

335 3.1.1 Embodiment Questionnaire

336 Preliminary analysis showed that there was no effect of trial order across visual capture trials,
337 with a Wilcoxon signed-rank test revealing no significant difference in embodiment scores between
338 visual capture trial 1 vs. trial 2 ($Z = -.084, p = .933$). Therefore, *embodiment questionnaire* scores were
339 collapsed across the two visual capture trials to provide an overall *visual capture* embodiment score,
340 per participant.

341

342 3.1.1.1 Main effect: Visual Capture

343 To examine the effects of mere visual capture towards subjective embodiment of the mannequin
344 body, we compared *embodiment* scores with *control* scores in the *embodiment questionnaire*. A
345 Wilcoxon signed-rank test revealed a main effect of visual capture, with significantly higher
346 embodiment scores compared with control scores ($Z = -4.04, p < .001, r = .64$) (see Figure 3).

347

348 3.1.1.2 Main effect: Tactile Disruption

349 In order to determine whether tactile disruption to participants' own unseen arm would disrupt
350 subjective embodiment, we compared *embodiment* scores between *tactile disruption* and *visual capture*
351 conditions. A Wilcoxon signed-rank test revealed a main effect of condition, in which participants
352 showed significantly lower subjective embodiment following *tactile disruption* trials (median = $-.38$)
353 compared with *visual capture* trials (median = $.82$) ($Z = -3.74, p < .001, r = .59$).

354

355 3.1.1.3 Main effect: Tactile Velocity

356 Next, we examined whether tactile velocity had an effect in disrupting the subjective
357 embodiment towards the mannequin body within *tactile disruption* trials. A Wilcoxon signed-rank test

358 revealed that there was no significant difference in embodiment scores between affective and non-
359 affective tactile disruption trials ($Z = -.104, p = .918, r = .02$), which suggests that interoceptive affective
360 touch did not disrupt visual capture of embodiment to a greater degree than exteroceptive, non-affective
361 touch.

362

363 3.2 Experiment 2

364 3.2.1 Touch Task (Manipulation Check)

365 A further one participant was later excluded within the *Touch Task* analysis as an extreme
366 outlier, scoring more than 2 SD below the group mean in pleasantness ratings of affective touch (3cm/s
367 velocity)³⁴. Therefore, the final sample for this analysis consisted of 39 participants. As expected, a
368 paired samples t-test revealed an effect of stroking velocity within the touch task, with significantly
369 higher subjective pleasantness ratings following affective touch (3cm/s) (mean = 74.27) compared with
370 non-affective touch (18cm/s) (mean = 52.94) ($t(38) = 7.93, p < .001, d = 1.27$). Moreover, correlational
371 analyses were conducted to investigate the relationship between pleasantness ratings and subthreshold
372 eating disorder psychopathology (measured by the *Eating Disorder Examination Questionnaire*; EDE-
373 Q 6.0). First, a Spearman's rank correlation revealed an approaching significant correlation between
374 pleasantness ratings (average affective/non-affective touch) and global EDE-Q score ($r = -.316, p =$
375 $.05$). Next, difference scores were calculated between affective and non-affective touch pleasantness
376 ratings to determine whether those with higher subthreshold eating disorder psychopathology were less
377 sensitive to differences in the affectivity of touch. However, a Spearman's rank correlation revealed no
378 significant correlation between touch difference score and global EDE-Q ($r = .014, p = .935$). Thus, the
379 results suggest a trend in which those scoring higher in subthreshold eating disorder psychopathology
380 may show a reduced pleasantness to all tactile stimulation, however this may not be further modulated
381 by the affectivity of the touch that they receive.

382

383

384

385 3.2.2 Embodiment Questionnaire

386 Preliminary analysis showed that there was no effect of trial order across visual capture trials,
387 with a Wilcoxon signed-rank test revealing no significant difference in embodiment scores between
388 visual capture trial 1 vs. trial 2 ($Z = -.958, p = .338$). Therefore, *embodiment questionnaire* scores were
389 collapsed across the two visual capture trials to provide an overall *visual capture* embodiment score,
390 per participant.

391

392 3.2.2.1 Main effect: Visual Capture

393 To examine the effects of mere visual capture towards subjective embodiment of the mannequin
394 body, we compared *embodiment* scores with *control* scores in the *embodiment questionnaire*. A
395 Wilcoxon signed-rank test revealed a main effect of visual capture, with significantly higher
396 embodiment scores compared with control scores ($Z = -4.30, p < .001, r = .68$) (see Figure 3).

397

398 3.2.2.2 Main effect: Tactile Disruption

399 In order to determine whether tactile disruption to participants' own unseen arm would disrupt
400 subjective embodiment, we compared embodiment scores between *tactile disruption* and *visual capture*
401 conditions. A Wilcoxon signed-rank test revealed a main effect of condition, in which participants
402 showed significantly lower subjective embodiment following tactile disruption trials (median = $-.23$)
403 compared with visual capture trials (median = $.59$) ($Z = -4.08, p < .001, r = .65$).

404

405 3.2.2.3 Main effect: Tactile Velocity

406 Next, we examined whether tactile velocity had an effect in disrupting the subjective
407 embodiment towards the mannequin body within *tactile disruption* trials. A Wilcoxon signed-rank test
408 revealed that there was no significant difference in embodiment scores between affective and non-

409 affective tactile disruption trials ($Z = -.354, p = .723, r = .06$), which suggests that interoceptive
410 affective touch did not disrupt embodiment to a greater degree than exteroceptive, non-affective touch.

411

412 INSERT FIGURE 3

413

414 3.3 Combined Samples

415 3.3.1 Visual Capture of Embodiment – Individual Differences

416 Across the combined, total sample ($N=80$), 32 participants (40%) experienced a degree of
417 embodiment over the mannequin from mere visual capture, with average scores of $\geq +1$ in response to
418 the *embodiment questionnaire* (hereafter referred to as ‘visual capture’ (VC) group). To confirm this
419 percentage was not a consequence of participant compliance, a Wilcoxon signed rank test was
420 conducted which revealed a significant difference between *embodiment* and *control* scores ($Z = -4.71,$
421 $p < .001, r = .74$), with only 4 participants (12.5%) of the VC group scoring $\geq +1$ in response to *control*
422 items. 36 participants (45%) seemed to neither affirm or deny embodiment over the mannequin, with
423 average scores of $< +1$ and > -1 in response to the *embodiment questionnaire* (hereafter referred to as
424 ‘borderline’ group). 12 participants (15%) of the total sample denied any subjective embodiment from
425 visual capture, with average scores of < -1 in the *embodiment questionnaire* (hereafter referred to as
426 ‘no visual capture’ (no-VC) group).

427

428 3.3.3 Subthreshold Eating Disorder Psychopathology

429 Finally, correlational analyses were conducted to investigate the relationship between visual capture
430 effects and subthreshold eating disorder psychopathology (measured by the *EDE-Q 6.0*). EDE-Q
431 subscale and global scores across both experiments are presented in Table 2. A Spearman’s rank
432 correlation revealed no significant correlation between visual capture embodiment scores and global
433 EDE-Q scores ($r = .030, p = .79$), or any EDE-Q subscale scores (all $ps > .05$). Similarly, no significant
434 correlations were observed when analysing subcomponent (*Ownership* and *Location*) scores within the
435 *embodiment questionnaire* with EDE-Q scores (see Supplementary Materials, Section 3). This suggests

436 that subthreshold attitudes and behaviours regarding to eating and body image did not relate to the
437 degree of subjective embodiment of a mannequin body due to mere visual capture.

438

439 INSERT TABLE 1

440

441 **Data Availability**

442 The datasets analysed during the current study are available from the corresponding author on
443 reasonable request.

444 4. Discussion

445

446 The present study investigated the extent to which mere visual observation of a mannequin body,
447 viewed from a first-person perspective, influenced subjective embodiment independently from
448 concomitant visuotactile integration. Across two experiments, our results showed that congruent
449 visuoproprioceptive cues between one's own physical body and a mannequin body was sufficient to
450 induce subjective embodiment in 40% of our total sample. Furthermore, as expected, embodiment was
451 significantly reduced when 'visual capture' of embodiment was disrupted by tactile stimulation to
452 participant's own, unseen arm, confirming that the visual capture effect on embodiment was not due to
453 confabulatory or social desirability responses. Contrary to our secondary hypothesis regarding
454 interoception, this tactile disruption effect was not modulated by stroking velocity, with comparable
455 changes in embodiment following slow, affective (CT-optimal) and fast, non-affective touch. Finally,
456 subthreshold eating disorder psychopathology was not found to modulate the effects of embodiment in
457 visual capture or tactile disruption conditions.

458

459 Our findings support previous research which argues that synchronous visuotactile stimulation is
460 not a necessary condition amongst all individuals in triggering subjective embodiment within bodily
461 illusions. Research has shown that visual capture of proprioception can be sufficient to elicit
462 embodiment towards a fake hand ^{25,36} and whole body ¹⁶ in some individuals. Indeed, whilst Maselli
463 and Slater (2013) have shown this effect using a full body within an immersive, virtual environment,
464 the present study is the first to explore this effect towards a full body in the 'physical world'. Our results
465 suggest that multisensory illusion paradigms would benefit from a baseline measure based on the mere
466 visual observation of the fake body (part) (i.e. visual capture effect), which is unbiased by concomitant
467 visuotactile stimulation ^{35,62}. Indeed, this is in support of research which argues that asynchronous
468 stimulation in multisensory illusion paradigms is not strictly a neutral, control condition within
469 multisensory body illusions ^{29,33}, with visuotactile asynchrony instead providing somatosensory conflict
470 ^{29,78}.

471

472 The present data showed that a substantial percentage of participants displayed a degree of
473 subjective embodiment towards the mannequin body following mere visual observation. Indeed, it was
474 confirmed that such individuals who did display visual capture of embodiment were not simply
475 complying with all items in the *embodiment questionnaire*, shown by significantly higher responses in
476 *embodiment* scores compared with *control* scores (see *Results* section). However, congruent
477 visuoproprioceptive signals did not induce subjective embodiment amongst all individuals to the same
478 degree. We speculate that such individual differences may be due to a number of processes; for example,
479 some individuals may have weaker proprioceptive signals which would give rise to greater sensory
480 weighting towards the salient visual cues of the mannequin body within the illusion. Indeed, our own
481 hypothesis that individual differences in visual capture may relate to subthreshold eating disorder
482 psychopathology was not confirmed (see below for further discussion). **Thus, further research is**
483 **required to establish how individual differences in the weighting of distinct sensory cues contribute to**
484 **modulating body ownership in mere visual capture conditions, and how increased visual weighting may**
485 **thus influence the perception of visuotactile synchrony within typical multisensory illusion paradigms.**
486

487 Furthermore, our results showed that tactile stimulation to participants own, unseen arm
488 significantly disrupted subjective embodiment towards the mannequin body, by delivering
489 somatosensory information that was incongruent with participants visuoproprioceptive cues. This result
490 further highlights that the embodiment shown from visual capture conditions were not due to participant
491 compliance, as disruption to such visual capture resulted in significantly lower embodiment scores.
492 **From a computational approach to multisensory integration^{25,30,79}, such incongruent tactile information**
493 **is likely to have disrupted the sensory weighting that is occurring between visual and proprioceptive**
494 **body signals³².** Indeed, predictive coding accounts of multisensory illusions argue that illusory
495 embodiment typically occurs by the brain downregulating the precision of conflicting, bottom-up
496 somatosensory signals, which allows top-down predictions to resolve any sensory ambiguity about the
497 body (i.e. *the body (part) I see is mine*)³⁰. Therefore, in the present study, additional tactile input to
498 participants' own, unseen arm added further somatosensory information which could not be
499 downregulated or "explained away" by top-down predictions, given its incongruency with the visually
500 perceived mannequin body⁸⁰, thus leading to reduced subjective embodiment.

501

502 Moreover, it was expected that the interoceptive properties associated with slow, affective touch ³⁵
503 would disrupt subjective embodiment to a greater degree than fast, non-affective touch. This is
504 following evidence that affective touch led to enhanced embodiment during RHI paradigms ⁶²⁻⁶⁴, which
505 is argued to be due to the additional interoceptive information conveyed by this CT-optimal touch ⁸¹.
506 Further, research has shown that manipulation of interoceptive information (e.g. changes in body
507 temperature) can *disrupt* feelings of body ownership ⁶⁹. However, contrary to our predictions and
508 previous findings, our results showed that the interoceptive, affective tactile stimuli did not appear to
509 disrupt visual capture of embodiment to a greater extent than non-affective tactile stimuli. Such findings
510 may be because the salience of incongruent visuotactile information was sufficient in disrupting
511 embodiment towards the mannequin, with the subtlety of increased interoceptive information from the
512 arm following affective touch providing no additional value to multisensory integration in this context.
513 Furthermore, the previously observed effects of affective touch in enhancing body ownership during
514 the RHI (which involves concomitant felt and seen touch on the rubber hand) may also be explained by
515 the vicarious affectivity of the *seen* touch in addition to the interoceptive nature of the felt touch
516 (Filippetti et al., submitted). Indeed, CT-optimal velocities have been shown to have distinct vicarious
517 touch effects in behavioural ⁸² and neuroimaging ⁶¹ studies. However, visual cues of affective touch
518 were not present in the current study, therefore the felt affectivity of the touch may have been attenuated
519 by participants receiving only tactile stimulation that was not visually observed.

520

521 The present results must be considered in relation to the top-down, cognitive constraints within
522 which illusory ownership is argued to occur. Research has shown that the embodied fake body (part)
523 must be in an anatomically plausible position ^{3,15,22,23}, must represent a corporeal object ^{13,19,20}, and must
524 be viewed from a first-person visual perspective ¹⁶⁻¹⁸. Indeed, it has been shown that when these
525 constraints are violated, illusory effects diminish or disappear ^{24,83,84}, suggesting that the perceived fake
526 body (part) is required to fit with a reference model of the body based on top-down information ²⁰. The
527 above conditions were closely adhered to in the present study, which was particularly salient using the
528 HMDs, allowing a high degree of spatial overlap by *replacing* the first-person perspective of one's own
529 body with the identical perspective of a mannequin body. This provided a greater congruence of

530 visuoproprioceptive cues which cannot be as closely matched within the RHI set-up without the use of
531 computer-generated technology. However, further research should investigate the specific boundaries
532 within which mere visual capture is sufficient in inducing embodiment towards a whole body, in the
533 absence of visuotactile stimulation ^{16,85}, by systematically manipulating the above conditions within
534 which the illusion can typically occur.

535

536 Finally, following evidence that acute eating disorder patients display a dominance in weighting to
537 visual information related to the body ^{45,46}, which is shown to persist after recovery ⁴⁹, we explored
538 whether this trait phenomenon would exist amongst healthy individuals, in relation to subthreshold
539 eating disorder symptomology. However, no significant correlations were observed between EDE-Q
540 scores and subjective embodiment following *visual capture*. This finding is in line with previous
541 research in which those higher in subthreshold eating disorder symptoms did not experience a stronger
542 *subjective* embodiment within the full body illusion ⁵³, despite relationships observed between EDE-Q
543 scores and subsequent behavioural measures (e.g. body satisfaction) following the illusion (see also ⁵⁰
544 for similar effects in AN patients). This suggests that previous findings which highlight differences in
545 subjective embodiment in relation to eating disorder psychopathology may be body part specific ^{45,46,86}.
546 Nevertheless, studying eating disorder characteristics within healthy individuals remains clinically
547 important to identify factors associated with the development of eating disorders without the confounds
548 of physical consequences of the disorder ^{87,88}.

549

550 Taken together, the present findings are in accordance with previous research which highlights the
551 dynamic mechanisms that lead to illusory body ownership ¹⁶. First, there exists a two-way interaction
552 between visual information of the fake body (part) and proprioceptive information of one's own body
553 (part), which is combined to inform an estimate of an individual's current spatial position. When the
554 fake body (part) is in an anatomically plausible position with one's own body, sensory information
555 between competing visual and proprioceptive cues is weighted in favour of the salient visual
556 information ^{79,89}, which for many is sufficient to induce feelings of embodiment to occur *prior* to
557 visuotactile integration ^{16,25}. Subsequently, the addition of synchronous visuotactile information creates
558 a three-way weighted interaction between vision, touch and proprioception, with the visually perceived

559 touch processed in a common reference frame based on the visuoproprioceptive cues. The subsequent
560 ‘visual capture’ of synchronous visuotactile stimulation acts to further weaken one’s own
561 proprioceptive signals, which can lead to increased illusory embodiment^{24,84}. Thus, future studies which
562 compare the two-way vs. three-way interaction between sensory inputs would be informative in
563 quantifying the additive effect that visuotactile stimulation plays within such paradigms. This could
564 also be used to further investigate individual differences in the susceptibility to integrate
565 visuoproprioceptive information to a greater degree than the additional integration of tactile stimuli
566 during the illusion.

567

568 In conclusion, the present study suggests that mere visual observation of a mannequin body, viewed
569 from a first-person perspective, can elicit subjective embodiment amongst individuals. Congruent
570 visuoproprioceptive cues between one’s own physical body (part) and a fake body (part) was shown to
571 be sufficient to induce subjective embodiment in 40% of our total sample in the absence of concomitant
572 visuotactile stimulation, which is typically used to induce illusory embodiment within multisensory
573 illusion paradigms. In addition, tactile stimulation delivered to participants own, unseen arm acted to
574 disrupt reported subjective embodiment, however, this was not influenced to a greater degree by slow,
575 affective touch compared with fast, non-affective touch. This suggests that interoceptive information
576 about one’s body does not have the potency of discriminatory tactile signals, when the integration of
577 vision and proprioception need to be moderated by touch. **Future studies should explore this possibility**
578 **using other interoceptive modalities such as cardiac awareness, and further investigate how the**
579 **perception and integration of sensory signals are implicated within a distorted sense of self amongst**
580 **clinical eating disorder 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.

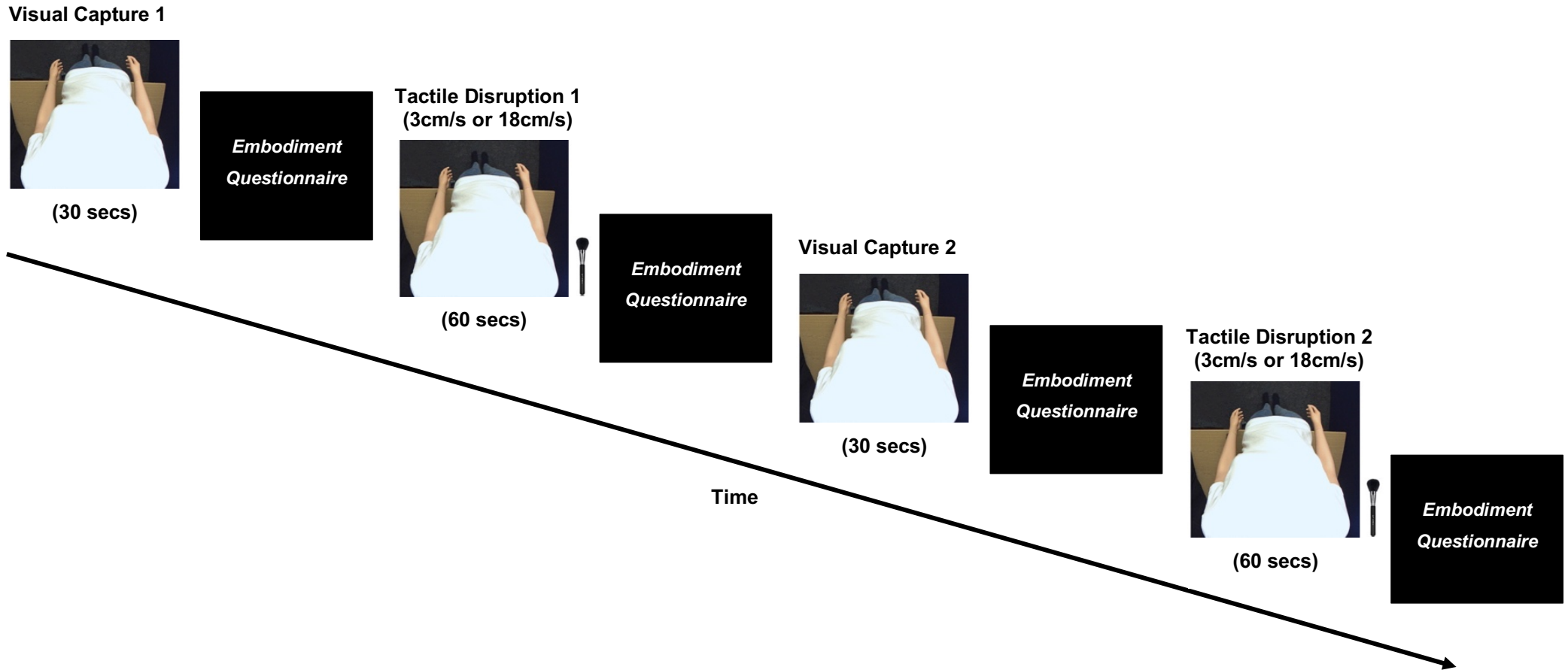


Figure 1. Timeline of experimental procedure. Participants completed two *visual capture* (30 secs) conditions and two *tactile disruption* (60 secs) conditions (1x affective touch; 1x non-affective touch). Tactile disruption order was counterbalanced across participants. Participants removed the HMDs following each trial and completed the *Embodiment Questionnaire* on a separate computer.

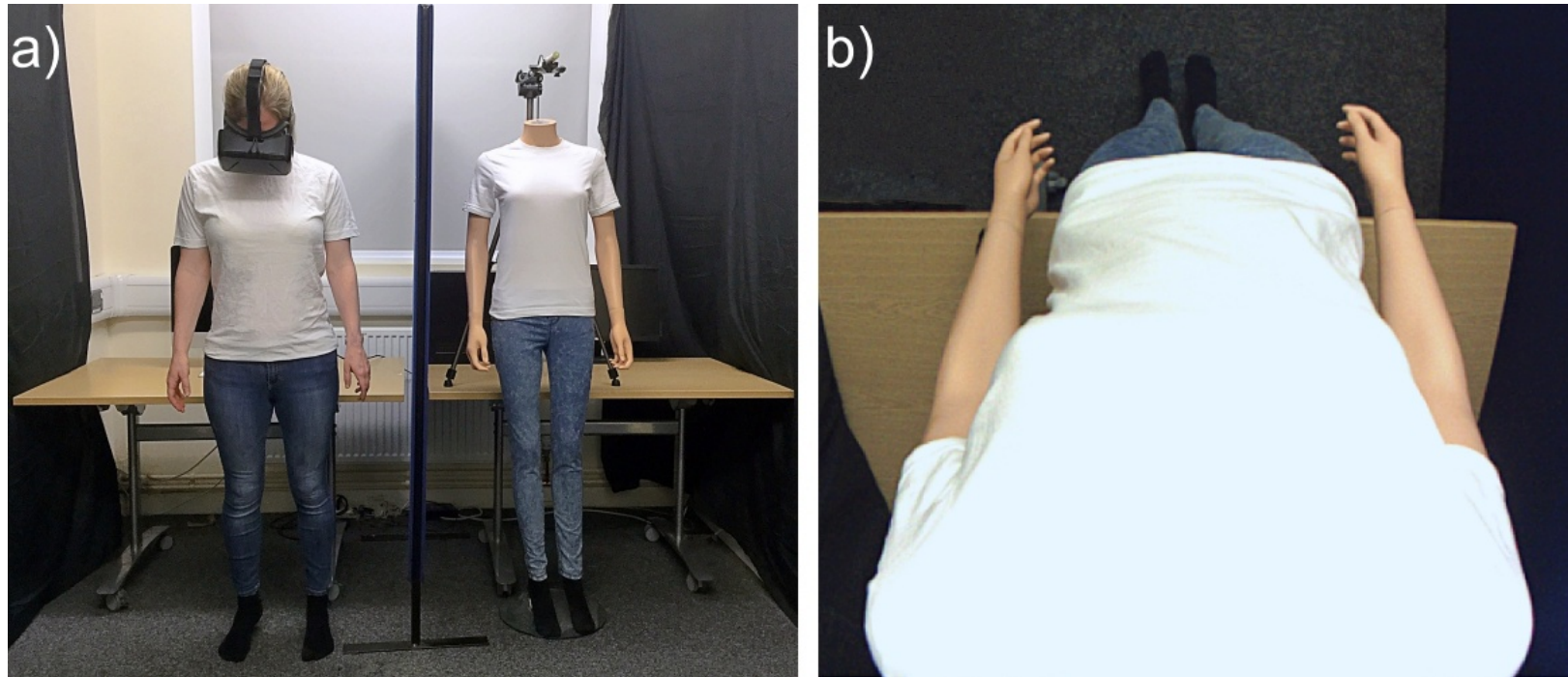


Figure 2. Experimental set-up. a) In *visual capture* trials, participants stood in an identical stance to the mannequin body, separated by a screen divider. b) Participants viewed a live video image of the mannequin from a first-person perspective, via head mounted displays.

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Figure 3. Box plot displaying embodiment scores and control scores within the *embodiment questionnaire*. Intersecting line = median; box = upper and lower interquartile range; whiskers = minimum and maximum values. ** = $p < .001$.

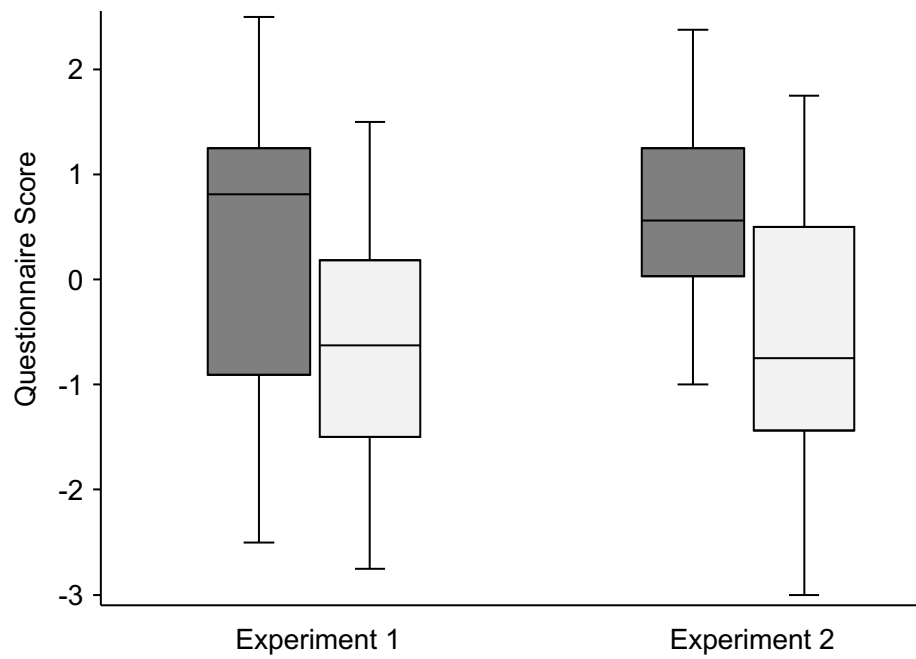


Table 1. *Embodiment Questionnaire presented to participants following each trial.*

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 felt like I had two bodies (at the same time)	Control
6. It felt like my body was made out of rubber	Control

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

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

	Total (N=80)	Experiment 1 (N=40)	Experiment 2 (N=40)	<i>t</i>	<i>p</i>
Age	19.56 (1.92)	20.15 (2.49)	18.98 (.77)	2.86	.006
BMI	21.70 (2.56)	21.48 (2.40)	21.93 (2.71)	-.772	.442
Restraint	.80 (.20-1.80) ^a	.80 (.20-2.15) ^a	.90 (.25-1.75) ^a	-.101 ^b	.919
Eating Concern	.60 (.20-1.40) ^a	.60 (.20-1.40) ^a	.60 (.20-1.55) ^a	-.567 ^b	.571
Shape Concern	2.25 (1.16-3.72) ^a	2.06 (1.25-3.63) ^a	2.31 (1.00-3.75) ^a	-.106 ^b	.916
Weight Concern	1.40 (.40-3.00) ^a	1.40 (.40-2.55) ^a	1.70 (.50-3.20) ^a	-.960 ^b	.337
EDE-Q Global	1.33 (.60 -2.32) ^a	1.31 (.60-2.17) ^a	1.35 (.65-2.52) ^a	-.380 ^b	.704

Note: BMI: Body Mass Index.

^a Median and interquartile range in parentheses

^b Mann-Whitney U statistic