

Disentangling the sense of agency and the sense of ownership in the virtual hand illusion paradigm

Jing Zhang, Wei Chen, Hengwei Li, Bernhard Hommel, Tifei Yuan

We used the virtual hand illusion paradigm to study the relationship between two aspects of the minimal self: the sense of agency and the sense of (body) ownership. Converging evidence for the (at least) partial independence of agency and ownership was found. For instance, sense of agency was a better predictor of individual anxiety levels than sense of ownership, and males showed stronger effects related to agency, presumably due to gender-specific attribution styles and empathy skills. Taken together, our findings suggest that the sense of agency and the sense of ownership are driven by different kinds of information and related to different psychological functions.

1 **Disentangling the sense of agency and the sense**
2 **of ownership in the virtual hand illusion**
3 **paradigm**

4 Jing Zhang ^{1,2,#}, Wei Chen ^{1,3,#,*}, Hengwei Li ¹, Bernhard Hommel ², Ti-Fei Yuan ^{4,*}

5 ¹Center for the Study of Language and Cognition, Zhejiang University, China

6 ²Institute for Brain and Cognition, Leiden University, Netherlands

7 ³Department of Psychology, Shaoxing University, China

8 ⁴School of Psychology, Nanjing Normal University, China

9 # Note: Zhang J and Chen W contributed equally to this work.

10 * **Correspondence** concerning this article should be addressed to: Dr. Wei Chen,
11 Department of Psychology, Shaoxing University, 900 Chengnan Road, Shaoxing
12 312000, People's Republic of China. Email: anti-monist@163.com; Dr. Ti-Fei YUAN,
13 School of Psychology, Nanjing Normal University, China,

14 **Acknowledgements:** This research was supported by the Fundamental Research
15 Funds for the Central Universities (SSEYD201302), Major Projects about Key Research
16 Institute on Humanities and Social Sciences by Ministry of Education (13JZD004), China
17 Postdoctoral Science Foundation (2014T70578), as well as China Scholarship Council –
18 Leiden University Joint Scholarship Program.

19 **Conflicts of interest:** None declared.

20 **Abstract:**

21 We used the virtual hand illusion paradigm to study the relationship between two
22 aspects of the minimal self: the sense of agency and the sense of (body) ownership.
23 Converging evidence for the at least partial independence of agency and ownership was
24 found. For instance, sense of agency was a better predictor of individual anxiety levels
25 than sense of ownership and males showed stronger effects related to agency ---
26 presumably due to gender-specific attribution styles and empathy skills. Taken together,
27 our findings suggest that the sense of agency and the sense of ownership are driven by
28 different kinds of information and related to different psychological functions.

29 **Keywords:**

30 sense of agency, sense of ownership, virtual hand illusion, anxiety, contribution style,
31 empathy ability

32 1 Introduction

33 The rubber hand illusion is the experience of an artificial body part as being one of the
34 real body parts. This illusion was first reported by Botvinick and Cohen ([Botvinick and](#)
35 [Cohen, 1998](#)) in which a rubber hand was placed in front of the participants while their
36 own hand was hidden from sight. As long as there were synchronous touches existed on
37 both rubber hand and real hand, a perceptual illusion would be felt. Besides recognizing
38 the fake model hand as being part of their own body, participants also reported that they
39 felt as if the touch they sensed originated from the location on the rubber hand where
40 they see the brush touching the rubber hand, rather than from their real hand ([Makin, et](#)
41 [al., 2008](#)).

42 This method is widely used with only minor alternations to induce illusions and
43 investigate individual's self-perception of the body which is critically important for
44 conscious experience of the self ([Folegatti, et al., 2012](#), [Germine, et al., 2013](#),
45 [Jenkinson, et al., 2013](#), [Ocklenburg, et al., 2012](#)). Sense of agency and sense of
46 ownership are considered to be two main aspects of minimal self which according to
47 Gallagher is a basic, immediate, or primitive 'something' that we are willing to call a self
48 ([Gallagher, 2000a](#)) and thus enables us to capture the most primitive sense of self
49 ([Gallese and Sinigaglia, 2010](#)). Therefore, it has attracted considerable empirical and
50 theoretical interest using rubber hand illusion paradigm to study the distinction between
51 sense of agency and sense of ownership in order to explain how we perceive ourselves.

52 Sense of agency refers to the pre-reflective experience or sense that I am the cause or
53 author of the movement, while sense of ownership is the pre-reflective experience or
54 sense that I am the subject of the movement, that I am experiencing a certain sensation
55 ([Tsakiris, et al., 2007](#)). In normal experience of voluntary or willed action, sense of
56 agency and sense of ownership coincide and are indistinguishable, in the case of
57 involuntary movement, however, it is quite possible to distinguish between sense of
58 agency and sense of ownership ([Gallagher, 2000b](#)). The distinction between sense of
59 agency and sense of ownership has attracted considerable interests in various fields
60 including psychology, philosophy and cognitive science ([Blakemore, et al., 2002](#), [Marcel,](#)
61 [2003](#), [Tsakiris and Haggard, 2005](#)). Although different methodology we may find in
62 different disciplines, there is a growing consensus on this division between sense of
63 agency and sense of ownership. According to experimental research on normal
64 subjects, sense of agency for action based on that which precedes action and translates
65 intention into action while sense of ownership for motor action can be explained in terms
66 of ecological self-awareness built into movement and perception ([Gallagher, 2000a](#)).
67 Haggard, by considering the logic of involuntary movement where there is a sense of
68 ownership but no sense of agency suggested that in ordinary voluntary movement the
69 sense of ownership is generated by sensory feedback, while the sense of agency is
70 generated by or at least linked to the motor commands sent to the muscles and the
71 accompanying efferent copy that is internally processed within the predictive models of
72 the motor system ([Haggard, 2005](#), [Tsakiris, Schuetz-Bosbach and Gallagher, 2007](#)).
73 However, studies focused on the relationship between sense of agency and sense of
74 ownership did not fully address the issues well. There are some controversial results
75 from previous studies. Santo and Yasuda, by manipulating the discrepancy between the
76 intended and actual consequences of actions, found that a discrepancy between

77 predicted and actual feedback had significant impacts on sense of agency but no effects
78 on sense of ownership, thus suggested that both senses of self are mutually
79 independent ([Sato and Yasuda, 2005](#)) which may not satisfy those who think sense of
80 agency and sense of ownership are at least partially related. Tsakiris and colleagues,
81 using a video-screen-based setup, discovered that the types of proprioceptive drifts
82 differed among different situations. They found localized proprioceptive drifts for tactile
83 and passive stimulation but not for active movement, which means a purely
84 proprioceptive sense of ownership is local and fragmented but the motor sense of
85 agency integrated distinct body parts into a coherent, unified awareness of the body.
86 Their findings not only implied that sense of agency and sense of ownership may involve
87 two mechanisms but also suggested sense of agency modulate sense of ownership
88 during active movement ([Tsakiris, et al., 2006](#)). Kalckert and Ehrsson, using a moving
89 rubber hand setup, varied the relative timing of the figure movements, the mode of
90 movement and the position of the model hand. The results that asynchrony eliminated
91 both agency and ownership, passive movements abolished the sense of agency about
92 not the ownership while incongruent positioning the model hand diminished ownership
93 but not agency provided evidence for a double dissociation of sense of agency and
94 sense of ownership, suggesting they may represent distinct cognitive processes. But,
95 due to the observation that stronger agency was experienced when the model hand was
96 perceived to be a part of one's body, they thought that ownership modulated agency
97 which is just the opposite as what Tsakiris et al., suggested ([Kalckert and Ehrsson,
98 2012](#)).

99 In the present study, we tried to study the relationship between two aspects of the
100 minimal self from a different perspective by using another illusion paradigm, virtual hand
101 illusion which is another way to induce body perception illusion besides rubber hand
102 illusion and its revised version. In the experiment of virtual hand illusion, participants sit
103 in front of a screen where visual 3D image of the virtual hand would be presented while
104 having tactile stimulation on their real hidden hand. It is indicated that the way of
105 inducing virtual hand illusion can achieve the same effect as what rubber hand illusion
106 did. In other words, imposing the same tactile stimulation on both the virtual hand on the
107 screen and the real hand which is hidden from view can let the participants feel the
108 similar experience to that under rubber hand illusion condition ([Ma and Hommel, 2013](#)).
109 Experiment showed that by simply manipulating the temporal delay between
110 participants' real movement and the movement of the virtual hand on the screen, a
111 virtual hand illusion can be induced even in the absence of tactile stimulation ([Sanchez-
112 Vives, et al., 2010](#)). Slater et al., found that there were reliable correlations between the
113 impression of hand ownership and hand-related EMG activation, suggesting a
114 connection between perceived ownership and action control ([Slater, et al., 2008](#)).
115 Compared with rubber hand illusion, virtual hand illusion has the following three major
116 advantages. First, for virtual material, in virtual hand illusion we can have more vivid
117 virtual images of participants' hand while in rubber hand illusion the shape or size of the
118 fake hand are relatively limited. Secondly, for operation, in virtual hand illusion it is very
119 easy to guarantee the synchronicity between virtual and real hand while in rubber hand
120 illusion manual process can't make sure that the brushing on rubber hand is completely
121 synchronizing with that on real hand. Last but not least, for stimulus material, in virtual
122 hand illusion we can use more novel stimuli such as hit the virtual hand with a ball or a
123 knife while in rubber hand illusion it seems brushing is the only suitable stimulus.

124 There are already some studies using this paradigm of virtual hand illusion to investigate
125 the relationship between sense of ownership and the affective resonance in facing with
126 different kind of emotional events. Yuan and Steed designed an experiment to measured
127 SCR responses to what they considered threats to a virtual hand and found similar
128 elevations as with rubber hands. Participants were asked to play games in virtual
129 environment by operating the hand of an avatar. During the game a virtual lamp would
130 fall on the virtual hand operated by the participants at some point, which induced a
131 reliable increase in SCR. They placed the hand with an arrow as the control condition
132 which produced significantly less increase in SCR. Taken together, they suggested that
133 people emotionally “care” about what they perceive as being a part of their body but not,
134 or not so much, about what they perceive as belonging to the body of someone else
135 ([Yuan and Steed, 2010](#)). However, Ma and Hommel thought that two aspects of Yuan
136 and Steed’s study might help explaining this seeming discrepancy. For one, they did not
137 use the standard synchronization technique to induce different degrees of body
138 ownership. For another, the threatening event merely consisted of a virtual lamp falling
139 on the virtual hand. Even though the contact between the lamp and the hand was clearly
140 visible to the participant, it is difficult to judge from the visual display how much pain. Ma
141 and Hommel adopted the standard synchronization technique to induce the illusion of
142 ownership and replaced the falling of a virtual with a knife. Their findings suggest that
143 ownership was stronger if the virtual hand moved synchronously with the participant’s
144 own hand, but his effect was independent from whether the hand was impacted or
145 threatened. In other words, in the face of threat, affective resonance was independent of
146 synchronicity ([Ma and Hommel, 2013](#)).

147 However, we think there are still some problems that need to be dealt with. It is
148 necessary to make a distinction between sense of ownership and sense of agency. As
149 we have mentioned above they are two major aspects of sense of self closely related
150 but are different from one another. Although sense of agency is tightly integrated with
151 sense of ownership, they are two different kinds of conceptions. Therefore, it is
152 necessary to disentangling the sense of agency and the sense of ownership because
153 they may be driven by different kinds of information and related to different psychological
154 functions.

155 We think what the synchronicity of stimulus induces is sense of agency rather than
156 sense ownership while the shape of virtual image can affect the sense of ownership.
157 The aim of the present study is to investigate 1) whether varying the time gap between
158 real hand and virtual hand movements (synchronous versus asynchronous), the shape
159 of virtual image (human hand versus cat claw) can induce different degrees of sense of
160 agency and sense of ownership; 2) whether different situations of agency and ownership
161 will affect participants’ anxiety after performing rewarding/punishing task, namely how
162 sense of agency and ownership will influence people’s experience when facing different
163 emotional events.

164 **2 Experiment 1**

165 **2.1 Method**

166 **2.1.1 Participants**

167

168 The participants were 64 undergraduate students (32 female, 32 male) from two
169 universities in Zhejiang, China, who were unfamiliar with rubber/virtual hand illusion and
170 took part in this study voluntarily. The age of the participants ranged between 17.92 and
171 29.96 (M = 20.83, SD = 2.61). All the participants were right handed with normal naked
172 or corrected visual acuity. Ethical approval for this study was obtained from the Zhejiang
173 university ethics committee (RZYJ201409), and informed written consent was obtained
174 from all subjects.

175 **2.1.2 Stimuli and Materials**

176 **Experimental Setup.**

177 The study was performed in a virtual environment, which was programmed by VB.NET.
178 A virtual human hand or cat claw was presented on the screen moving either strictly in
179 accordance with the movement of the mouse or slightly delayed (350ms to 500ms).
180 Participants were asked to observe the movement of the virtual human hand/cat claw
181 while moving the mouse with their right hands for 3 minutes. After that, they needed to
182 fill out a 7-item questionnaire which was adopted to evaluate the extent of their virtual
183 hand illusion experience.

184 **Questionnaire.**

185 Based on the 12-statement questionnaire that Kalckert and Ehrsson used to assess the
186 feelings of agency and ownership and their control statements ([Kalckert and Ehrsson, 2014a](#)),
187 we readapted the questionnaire according to our design, and the final
188 statements used in our study were as follows (see Appendix 1):

189 Q1-Q3 are related to the experience of perceiving the hand as the “own” hand, Q4-Q6
190 are three control statements for the ownership statements, Q7-Q9 are related to the
191 experience of voluntary control, Q10-Q12 are three control statements for the agency
192 statements. However, during the experiment, the order of these statements were
193 randomized in order to avoid participants’ guess and get more objective data.

194 **2.1.3 Procedure**

195 It was a 2-factor between-subjects design. The two factors were synchronicity
196 (synchronous versus asynchronous) and modality (human hand versus cat claw). The
197 purpose of this experiment was to see whether by varying the time gap between real
198 hand and virtual hand movements and the shape of virtual image can induce different
199 degrees of sense of agency and sense of ownership or not.

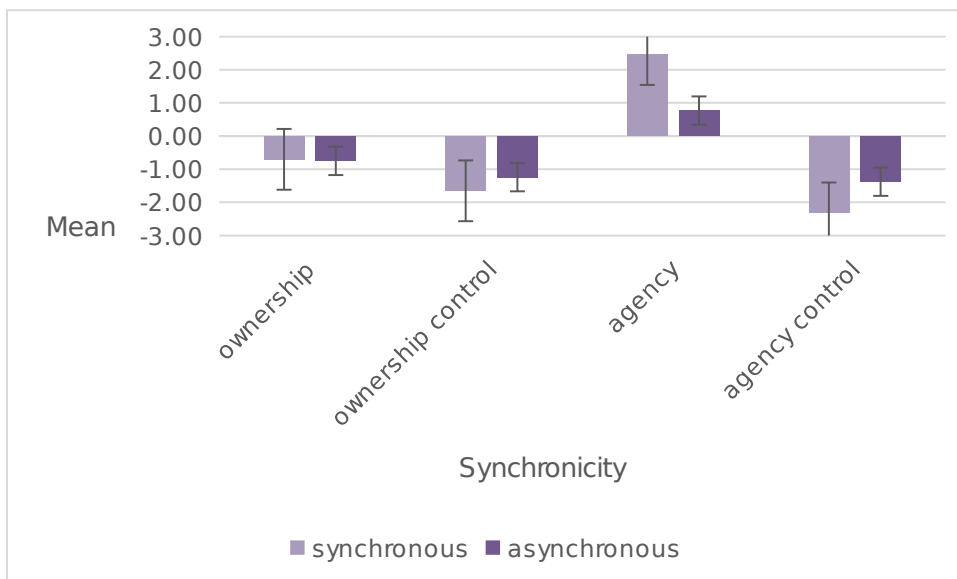
200 Participants were seated in front of a computer screen, and they could move the mouse
201 with their right hand after the activation of the program. Each participant was either
202 involved in each of the following situations: synchronous human hand, asynchronous
203 human hand, synchronous cat claw, asynchronous cat claw. In synchronous cases, the
204 movement of the virtual hand on the screen was exactly the same as that of the
205 participant while in asynchronous cases, virtual image’s movements were delayed from
206 the participant’s actual movements by at least 350ms to utmost 500ms. This delayed
207 time was set according to previous study which indicated that a temporal discrepancy of

208 less than 300ms between visual and tactile stimulation is crucial for the occurrence of
209 the perceptual illusion (Shimada, et al., 2009). The order of the two synchronicity
210 conditions as well as the order of the modality of virtual image were balanced across
211 participants. Participants were asked to manipulate the mouse by moving their hands for
212 3 minutes, and they were told it was a task which was tend to test the sensitivity of the
213 computer. After the completion of this section, participants were asked to finish a
214 questionnaire with 12 items by choosing a score in a 7 point (-3-3) Likert scale, ranging
215 from -3 for “totally disagree” to 3 for “totally agree”.

216 2.2 Results

217 2.2.1 Questionnaire Results for Synchronous versus Asynchronous Movements

218 When virtual image moved synchronously with participants’ real hand, the mean rating
219 for ownership was -0.70 (SD = 1.86), for ownership control was -1.65 (SD = 1.37), for
220 agency was 2.46 (SD = 0.71), and for agency control was -2.32 (SD = 0.87). By
221 contrast, when there was a delay between the movements of virtual image and
222 participants’ real hand, the mean rating for ownership was -0.75 (SD = 1.58), for
223 ownership control was -1.24 (SD = 1.47), for agency was 0.77 (SD = 1.39), and for
224 agency control was -1.38 (SD = 1.09). A significant main effects of synchronicity on the
225 mean score of sense of agency ($F(1, 63) = 37.26, p < 0.001$) and agency control ($F(1,$
226 $63) = 14.79, p < 0.001$) were found, while neither for sense of ownership nor ownership
227 control, there was no significant differences on questionnaire scores (see Figure 1). This
228 indicated that synchronicity was critical for the arousal of sense of agency.

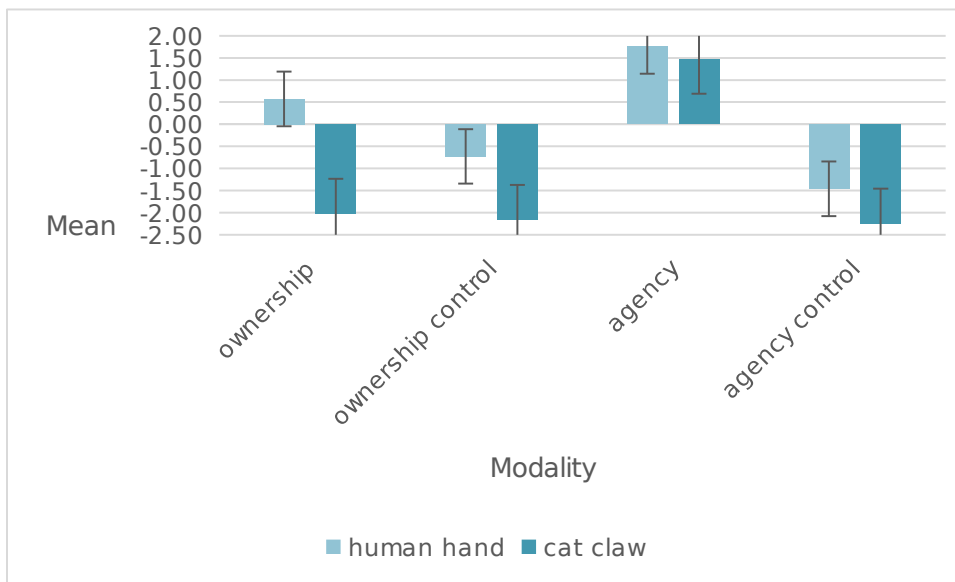


229 Figure 1 Questionnaire Results for Synchronicity

230 2.2.2 Questionnaire Results for Human Hand versus Cat Claw Modality

231 When the virtual image was human hand, the mean rating for ownership was 0.57 (SD =
232 1.21), for ownership control was -0.73 (SD = 1.33), for agency was 1.76 (SD = 1.19),

233 and for agency control was -1.46 (SD = 1.07). When the virtual image was cat claw, the
234 mean rating for ownership was -2.02 (SD = 1.02), for ownership control was -2.16 (SD
235 =1.14), for agency was 1.47 (SD = 1.57), and for agency control was -2.24 (SD = 0.98).
236 A significant main effects of modality on ownership ($F(1, 63) = 86.01, p < 0.001$),
237 ownership control ($F(1, 63) = 21.17, p < 0.001$) as well as agency control ($F(1, 63) =$
238 $9.331, p = 0.003$) were found, but there was no significant effect of modality on agency,
239 which indicated the influence of modality was only on ownership but not agency (see
240 Figure 2).



241 Figure 2 Questionnaire Results for Modality

242 The questionnaire data clearly indicated that the participants experienced a strong
243 sense of agency over its movements in the synchronous condition, which was significant
244 different from that in the asynchronous condition. However, for sense of ownership, even
245 significant difference between groups was observed, participants' sense of ownership
246 over the virtual hand was not as strong as we expected (see Figure 3). And it is also
247 much weaker compared with previous studies ([Kalckert and Ehrsson, 2012](#), [Kalckert](#)
248 [and Ehrsson, 2014b](#)).



249 Figure 3. Experiment 1: Results of the questionnaire data.

250 2.2.3 Statistical Analysis of Questionnaire Data

251 We analyzed all the statements by means of a 2 (synchronicity) × 2 (modality) ANOVA.
 252 Means and standard deviation (in brackets) for all the statements are listed in Table 1.

253 Table 1. Experiment1: Means and Standard Deviation (in brackets) of all the Categories
 254 (Ownership, Ownership Control, Agency, Agency Control)

	Ownership	Ownership Control	Agency	Agency Control
Synchronous	-0.75 (1.58)	-1.24 (1.47)	0.77 (1.39)	-1.38 (1.09)
Asynchronous	-0.70 (1.86)	-1.65 (1.37)	2.46 (0.71)	-2.32 (0.87)
Human Hand	0.57 (1.21)	-0.73 (1.33)	1.76 (1.19)	-1.46 (1.07)
Cat Claw	-2.02 (1.02)	-2.16 (1.14)	1.47 (1.57)	-2.24 (0.98)
p (Synchronicity)	0.848	0.195	0.000***	0.000***
p (Modality)	0.000***	0.000***	0.296	0.001
p (Interaction)	0.015*	0.525	0.370	0.556

255 The outcome is clear: we were able to disassociate sense of agency from sense of
 256 ownership with our setup. We confirmed what the synchronicity of stimulus induces is
 257 sense of agency rather than sense of ownership while the shape of virtual image can
 258 affect the sense of ownership. Varying the time gap between real hand and virtual hand
 259 movements and the shape of virtual image can induce different degrees of sense of
 260 agency and sense of ownership. The lack of interaction significance on ownership

261 control, agency, and agency control may suggest that sense of ownership and sense of
262 agency are driven by different psychological processes or functions, even in normal
263 experience they are related intimately. Thus we performed the second experiment to
264 examine how sense of agency and sense of ownership could affect anxiety in different
265 situations.

266 **3 Experiment 2**

267 **3.1 Method**

268 **3.1.1 Participants**

269 The participants were 96 undergraduate students (48 female, 48 male) from two
270 universities in Zhejiang, China, who were unfamiliar with rubber/virtual hand illusion and
271 took part in this study voluntarily. The age of the participants ranged between 17.95 and
272 29.35 (M = 21.01, SD = 2.53). All the participants were right handed with normal naked
273 or corrected visual acuity. Ethical approval for this study was obtained from the relevant
274 university ethics committee.

275 **3.1.2 Stimuli and Materials**

276 **Experimental Setup.**

277 The study was performed in a virtual environment, which was programmed by VB.NET.
278 Experiment 2 composed of two parts. The first part is the same in experiment 1, a virtual
279 human hand or cat claw was presented on the screen moving either strictly in
280 accordance with the movement of the mouse or slightly delayed (350ms to 500ms), and
281 participants were asked to observe the movement of the virtual human hand/cat claw
282 while moving the mouse with their right hands for 3 minutes. Second part appeared right
283 after the end of the first part. In the second part, there were knives or coins falling on the
284 screen, and participants needed to catch coins as well as avoid knives. After finishing
285 the task, participants were asked to complete a State-Anxiety Inventory (S-AI).

286 **Questionnaire.**

287 We adopted S-AI to assess participants' anxiety level after the treatment of experiment
288 (See Appendix 2).

289 **3.1.3 Procedure**

290 It was a 2-factor between-subjects design. The two factors were synchronicity
291 (synchronous or asynchronous) and modality (human hand or cat's claw). The purpose
292 of this experiment was to study whether different situations of agency and ownership will
293 affect participants' anxiety after performing rewarding/punishing task or not, namely how
294 sense of agency and ownership will influence people's experience when facing different
295 emotional events.

296 The procedure was very similar to that in the experiment 1, the movement between the
297 virtual image and participant's real hand was either synchronous or asynchronous, and
298 the virtual image was either human hand or cat claw, except for participants needed to

299 perform a rewarding/punishing task while moving their real hands and watching the
300 movements of the virtual image on the screen after 3-minute's moving and observing.
301 Participants saw a virtual coin or knife coming down from the top of the screen, and
302 what they needed to do was to catch as many coins as they can or avoiding the cut of
303 the falling knife. There were scores of their performance during the game displayed on
304 the top right corner of the screen. Catching a coin or avoiding a knife would add a point
305 while losing a coin or cutting by a knife would lose a point. There were 12 situations in
306 this experiment. Each participant encountered one. They were asked to play this
307 catching/avoiding game for 3 minutes. At the end of the task, there would be a message
308 printed on the screen which told them the results of their performances. After the
309 experiment, participants needed to fill out the S-AI.

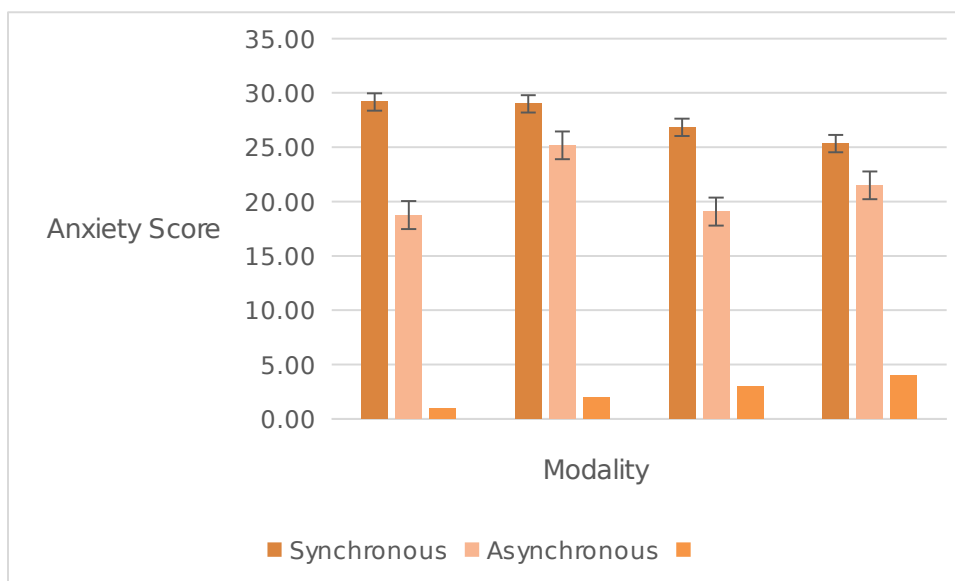
310 **3.3 Results**

311 Considering that anxiety level may not be so sensitive to measure, especially for those
312 statements describing their anxious states, so we only calculated the results of those
313 reverse scoring statements (No. 1, 2, 5, 8, 10, 11, 15, 16, 19, 20) of S-AI. Thus the
314 anxiety score of this study was the sum of scores for question 1, 2, 5, 8, 10, 11, 15, 16,
315 19 and 20.

316 **3.3.1 Anxiety Results for Synchronous versus Asynchronous**

317 **Movements**

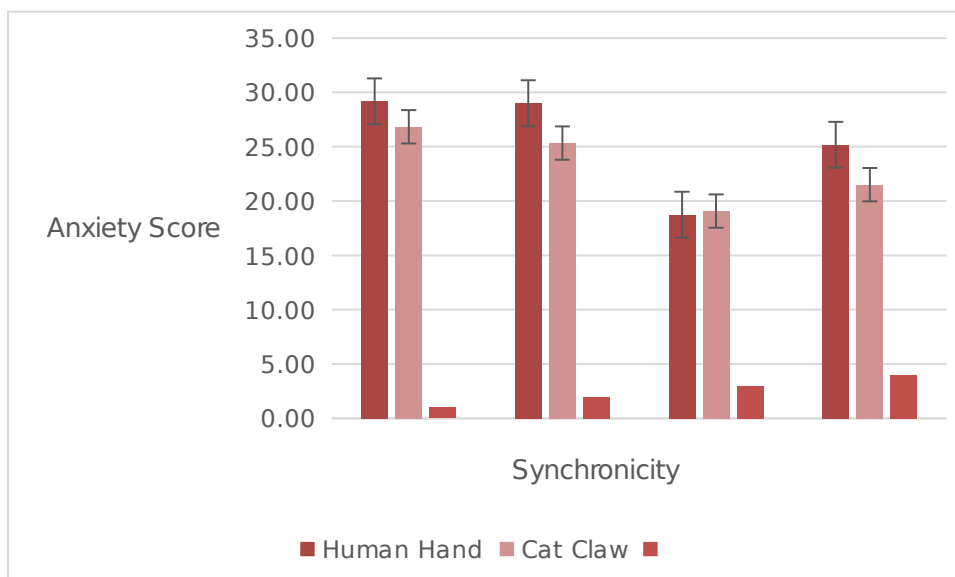
318 When virtual image moved synchronously with participants' real hand, the mean anxiety
319 score was 27.52 (SD = 4.43). However, when there was a delay between the
320 movements of virtual image and participants' real hand, the mean anxiety score was
321 -21.13 (SD = 5.31). A significant main effect of synchronicity on anxiety ($F(1, 95) =$
322 $41.84, p < 0.001$) was found, which indicated that when people felt he/she could control
323 something, then the results of something would affect them more dramatically. An even
324 more interesting thing is for male, this difference is more significant compared with
325 female (See Figure 4). For male, stronger effects related to sense of agency was
326 observed ($F(1, 96) = 45.90, p < 0.001$), but no significance was found in females. That
327 may because males prefer to do inner attribution which made them feel more anxiety
328 about their performance during the rewarding/punishing task whenever they had a
329 strong sense of agency.



330 Figure 4 Anxiety Results Compared between Synchronicity

331 3.2 Anxiety Results for Human Hand versus Cat Claw Modality

332 When the virtual image was human hand, the mean the mean anxiety score was 25.52
 333 (SD = 5.66). When the virtual image was cat claw, the mean anxiety score was 23.19
 334 (SD = 5.86). A significant main effect of modality on anxiety ($F(1, 95) = 3.94, p = 0.05$)
 335 was also found, but the level of significance was obvious different from that of
 336 synchronicity. Moreover, when we looked into the effects of modality on anxiety in terms
 337 of sex, there was also difference between males and females. As we have mentioned
 338 above, for male, stronger effects related to sense of agency was observed, while for
 339 female, stronger effects related to sense of ownership was found, although the
 340 difference is not significant (See Figure 5). The possible explanation for this may be the
 341 different empathy ability between male and female.

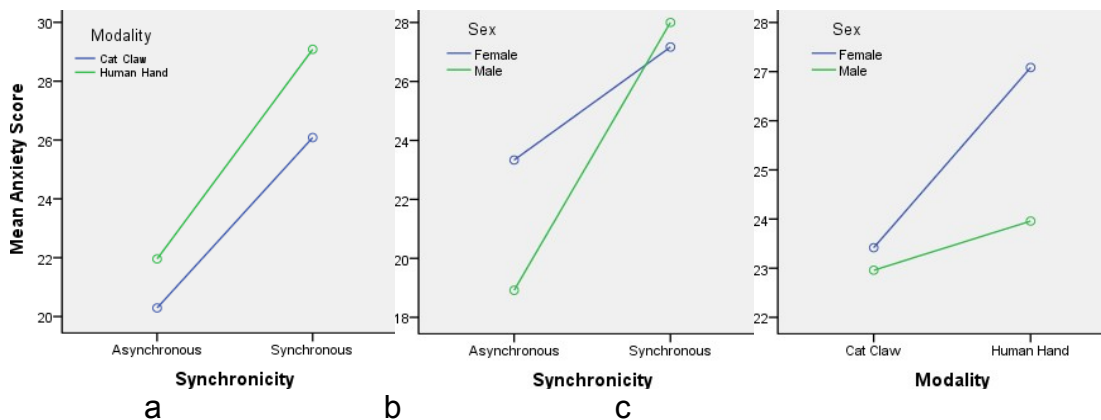


342 Figure 5 Anxiety Results Compared between Modality

343 3.3.3 Statistical Analysis of Anxiety Data

344 We analyzed the anxiety scores by means of a 2 (synchronicity) × 2 (modality) × 2 (sex)
345 ANOVA. A significant main effect of synchronicity ($F(1, 95) = 48.62, p < 0.001$)
346 showed that participants had higher average anxiety scores under synchronous
347 conditions than those under asynchronous conditions did. And the significant main effect
348 of modality ($F(1, 95) = 6.34, p = 0.014$) suggested that different virtual images would
349 lead to participants' different anxious feelings. The anxious score differed between sex,
350 but did not reach the significant threshold ($F(1, 95) = 3.74, p = 0.056$). There was also a
351 significant interaction effect between synchronicity and sex, which indicated when
352 involving indifferent sense of agency, men and women reacted differently.

353 Since the interaction effect of synchronicity, modality and sex is not significant, we ran
354 three other analysis of anxiety scores by means of 2 (synchronicity) × 2 (modality), 2
355 (synchronicity) × 2 (sex), and 2 (modality) × 2 (sex) respectively. For 2 (synchronicity) ×
356 2 (modality) analysis, the main effects of synchronicity ($F(1, 95) = 43.70, p < 0.001$) and
357 modality ($F(1, 95) = 5.70, p = 0.019$) on anxiety are significant, but no interaction
358 effect was found (See Figure 6a). For 2 (synchronicity) × 2 (sex) analysis, significant
359 effects of synchronicity ($F(1, 95) = 45.90, p < 0.001$) was found as well as the
360 interaction effect ($F(1, 95) = 7.58, p = 0.07$) (See Figure 6b). And for 2 (modality) × 2
361 (sex) analysis, a significant effect of modality on anxiety ($F(1, 95) = 4.01, p = 0.048$)
362 was found (See Figure 6c).



363

364 Figure 6. Experiment2: Statistical Analysis of Anxiety Data

365 4 General Discussion

366 As two major components of minimal self, sense of agency and sense of ownership
367 have attracted more and more study interests. These basic aspects of an individual's
368 self-perception of the body are critically important for self-consciousness, subjective
369 embodiment, and self-other discrimination. Besides that, they may even affect how we
370 perceive the outside world or how we feel about or react to different emotional events.

371 In the present study we investigated how the status of sense of agency and sense of
372 ownership can have impacts on anxious feelings. We performed two experiments to do
373 the research. Experiment 1 was aim to demonstrate that by varying the time gap
374 between real hand and virtual hand movements (synchronous versus asynchronous),
375 the shape of virtual image (human hand versus cat claw) can induce different degrees of
376 sense of agency and sense of ownership. The second experiment was designed to
377 reveal how different situations of agency and ownership will affect participants' anxiety
378 after performing rewarding/punishing task, namely how sense of agency and ownership
379 will influence people's experience when facing different emotional events.

380 The results of our first experiment showed that we can dissociate sense of agency from
381 sense of ownership, and the synchronicity affected participants' sense of agency while
382 the modality influenced their sense of ownership. However, we did not collect enough
383 evidence to prove whether sense of agency modulated sense of ownership or vice
384 versa. Instead, the lack of interaction significance on those categories of sense of self
385 may suggest that sense of agency and sense of ownership pare driven by different
386 psychological processes or functions.

387 Our second experiment showed that in general, synchronous conditions had higher
388 anxiety scores than asynchronous one, no matter for male or female, and has nothing to
389 do with the modality of virtual image, which indicated that sense of agency may bring us
390 more sense of responsibility to connect the stress of performing well with anxiety level.
391 By contrast, the absence of sense of agency can lead people to attribute their bad
392 performance in rewarding/punishing task to the computer which they cannot control,
393 which in turn reduce the anxiety in asynchronous conditions. Besides, we found
394 synchronicity had more impacts on people's anxiety level than modality did. In other
395 words, sense of agency played more important role in emotional mediation than sense
396 of ownership did, even the latter was also crucial to anxiety level according to our study.

397 However, things were a little bit different when we considered the sex factor. Sense of
398 agency seemed to affect male more than female while sense of ownership placed more
399 influence on female than on male. To be specific, men showed more differences
400 between synchronous and asynchronous conditions than women did, and women
401 showed more differences between human hand and cat claw conditions than men did.
402 This finding may because the different contribution styles and empathy abilities between
403 men and women.
404 Viewing a human hand was easier to arouse participants' anxious feelings than facing a
405 cat claw. That may because of the affection of sense of ownership on emotional feelings.
406 Even for a virtual image, a body part that was similar with our own body could make us
407 have more empathy than others, such as a cat claw. That is why we are more likely to
408 have sympathy for our friend generation. As far as we can tell, women are more sensible
409 than men, so they should felt more anxious than men. However, in our present study, the
410 anxiety scores were affected by people's sense of agency and sense of ownership,
411 which determined that participants' attribution styles were also crucial. Because women
412 are more likely to do external attribution while men prefer internal attribution ([Rim, 1990](#),
413 [Wang, et al., 2013](#)), when dealing with the emotional feelings aroused by the
414 rewarding/punishing task, the attribution style of female helped them to ease.

415 **5 Conclusion**

416 Based on the paradigm of rubber/virtual hand illusion, we could induce different level of
417 sense of agency and sense of ownership by manipulating the synchronicity and modality
418 in a virtual environment, which meant sense of agency and sense of ownership were at
419 least partially independent. The status of sense of agency and sense of ownership could
420 further affect participants' anxiety when they were dealing with stress situations. Sense
421 of agency was a better predictor of individual anxiety levels than sense of ownership,
422 and males seemed to be more sensitive to the effects of sense of agency while females
423 tended to be affected by sense of ownership more compared with males. Taken
424 together, our findings suggest that the sense of agency and the sense of ownership are
425 driven by different kinds of information and related to different psychological functions.
426

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486 **Appendix 1 Statements used in Experiment1 to measure the experience of agency**
 487 **and ownership during different situations.**

Category	Statement
Agency	I felt as if I could cause movements of the virtual hand.
	I felt as if I could control movements of the virtual hand.
	The virtual hand was obeying my will and I can make it move just like I want it.
Agency Control	I felt as if the virtual hand was controlling my will.
	It seemed as if the virtual hand had a will of its own.
	I felt as if the virtual hand was controlling me.
Ownership	I felt as if I was looking at my own hand.
	I felt as if the virtual hand was part of my body.
	I felt as if the virtual hand was my hand.
Ownership Control	It seems as if I had more than on right hand.
	It felt as if I had no longer a right hand, as if my right hand had disappeared.
	I felt as if my real hand was turning virtual.

488 **Appendix 2 Questions from State-Anxiety Inventory**

1	I feel calm.	11	I feel self-confident.
2	I feel safe, secure.	12	I feel nervous, irritable.
3	I feel tense, nervous.	13	I feel scared, alarmed, afraid.
4	I feel stressed.	14	I feel uncertain.
5	I feel peaceful, good about myself.	15	I am relaxed, at ease.
6	I feel upset, overwhelmed.	16	I am satisfied.
7	I worry over possible misfortunes.	17	I am anxious, worried.
8	I feel happy.	18	I feel disconcerted, disoriented.
9	I feel frightened.	19	I feel collected, composed.
10	I feel at ease.	20	I feel pleasant, in a good mood.