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What is embodiment? A psychometric approach

Matthew R. Longo [a,b,*], Friederike Schüür [a,c], Marjolein P.M. Kammers [a,d], Manos Tsakiris [a,e], Patrick Haggard [a,b]

[a] *Institute of Cognitive Neuroscience, University College London, 17 Queen Square, London WC1N 3AR, United Kingdom*
[b] *Department of Psychology, University College London, United Kingdom*
[c] *Nijmegen Institute for Cognition and Information, Radboud University Nijmegen, The Netherlands*
[d] *Helmholtz Research Institute, Utrecht University, The Netherlands*
[e] *Department of Psychology, Royal Holloway, University of London, United Kingdom*

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Abstract

What is it like to have a body? The present study takes a psychometric approach to this question. We collected structured introspective reports of the rubber hand illusion, to systematically investigate the structure of bodily self-consciousness. Participants observed a rubber hand that was stroked either synchronously or asynchronously with their own hand and then made proprioceptive judgments of the location of their own hand and used Likert scales to rate their agreement or disagreement with 27 statements relating to their subjective experience of the illusion. Principal components analysis of this data revealed four major components of the experience across conditions, which we interpret as: *embodiment of rubber hand*, *loss of own hand*, *movement*, and *affect*. In the asynchronous condition, an additional fifth component, *deafference*, was found. Secondary analysis of the *embodiment of runner hand* component revealed three subcomponents in both conditions: *ownership*, *location*, and *agency*. The ownership and location components were independent significant predictors of proprioceptive biases induced by the illusion. These results suggest that psychometric tools may provide a rich

* Corresponding author. Address: Institute of Cognitive Neuroscience, University College London, 17 Queen Square, London WC1N 3AR, United Kingdom. Tel.: +44 773 834 5095.
E-mail address: m.longo@ucl.ac.uk (M.R. Longo).

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method for studying the structure of conscious experience, and point the way towards an empirically rigorous phenomenology.

Keywords: Embodiment; Body representation; Self-consciousness; Psychometrics

1. Introduction

What is it like to have a body? The sense of one's own body, variously termed "embodiment" (Arzy, Overney, Landis, & Blanke, 2006), "coenaesthesia" (Critchley, 1953), "bodily self-consciousness" (Bermúdez, 1998; Legrand, 2006), or "corporeal awareness" (Berlucchi & Aglioti, 1997; Critchley, 1979), has often been described as a non-conceptual, somatic, form of knowledge, different in kind from other types of knowledge (e.g., Kant, 1781/2003; Bermúdez). In addition, many authors have suggested embodiment is a necessary prerequisite for other types of sensation and knowledge (Kant, 1781/2003; Johnson, 1987; Lakoff, 1987; Merleau-Ponty, 1945/1962; Piaget, 1937/1954). On that view, embodiment would be the cornerstone of mental life, the "storm-center" of experience as James (1905) put it. The sense of one's own body is also intimately related to the sense of self, and is often taken as the starting point of individual psychological identity (Cassam, 1997; Edelman, 2004). However, recognition of the importance of embodiment has not been matched by theoretical clarity about what embodiment is or involves. Neurological and neuropsychological investigations have generally provided a framework for embodiment by proposing dissociations between different subcomponents of body representation, such as *body image* and *body schema* (e.g., Gallagher & Cole, 1995; see also Head & Holmes, 1911/1912). Use of these terms, however, has been plagued by confusion, disagreement, and inconsistent usage (cf. Gallagher, 2005; Poeck & Orgass, 1971). This confusion arises in part because the sense of embodiment is both rich and complex on the one hand, and elusive and hard to describe on the other (Gallagher, 2005; Haggard & Wolpert, 2005).

The phenomenological tradition, has provided rich descriptive characterizations of embodiment, and has used it as a starting point for theories of the self (e.g., Merleau-Ponty, 1945/1962). However, it has not offered the operational working definitions and measures needed for rigorous empirical research. What is needed is a more systematic, and principled approach to decomposing the bodily self. Such a project should have two aims. First, it should produce theoretically useful and clearly dissociable subcomponents of embodiment. Second, it should generate testable predictions about human experience which can be directly measured. The present study provides an initial step towards these goals, by applying psychometric methods to structured introspective reports of a conscious experience of embodiment. If embodiment is a coherent psychological construct, rigorous measurement and analysis should clarify what it is, and what its subcomponents are.

Embodiment is clearly a kind of experience, but psychology's traditional methods of studying experience have difficulty in capturing its nature. On the one hand, the introspectionist approach seems unsuitable because one's body so often forms the background of mental life rather than the foreground. In addition, the verbal labels that people most readily use when describing the body enumerate the different physical parts of the body, but not the experience that those parts jointly constitute the self (de Vignemont, Tsakiris, & Haggard, 2006). The objective methods of psychophysics successfully capture the occurrence and magnitude of a single identifiable experience or quale (e.g., whether a stimulus is red or green in colour), but do not easily capture more complex experiences such as the sense of one's own body.

An ideal experimental approach to embodiment would involve comparing one condition in which a participant has a body, and another in which they do not. But such 'brain in a vat' experiments are confined to philosophy (Putnam, 1982), because the body is "always there" (James, 1890). Nevertheless, it is possible to manipulate the perceived incorporation of an external object into the representation of the body. In the so-called *rubber hand illusion*, for example, a prosthetic hand brushed synchronously with a participant's own hand is perceived as actually being part of the participant's own body (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). The same visual and tactile stimulation delivered asynchronously has a quite different phenomenology. The rubber hand illusion provides one of the few means of manipulating embodiment, and has been so used in a number of recent studies (Armel & Ramachandran, 2003; Austen, Soto-Faraco, Enns, & Kingstone, 2004; Costantini & Haggard, 2007; Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007; Ehrsson, Holmes, & Passingham, 2005; Ehrsson, Spence, & Passingham, 2004; Ehrsson, Wiech, Weiskopf, Dolan, & Passingham, 2007; Farnè, Pavani, Meneghello, & Làdavas, 2000; Holmes, Snijders, & Spence, 2006; Kanayama, Sato, & Ohira, 2007; Pavani, Spence, & Driver, 2000; Press, Heyes, Haggard, & Eimer, 2008; Rorden, Heutink, Greenfield, & Robertson, 1999; Schaefer, Flor, Heinze, & Rotte, 2006; Tsakiris, Hesse, Boy, Haggard, & Fink, 2007a; Tsakiris, Prabhu, & Haggard, 2006; Walton & Spence, 2004). However, most studies simply report the occurrence of the illusion, or a behavioural or neural proxy of it such as a change in the perceived position of the participant's own hand, without systematic description or quantitative measurement of the changed sense of embodiment.

In this study, we investigate the structure of embodiment by taking a psychometric approach to introspective reports of the rubber hand illusion. Participants observed a rubber hand that was stroked either synchronously or asynchronously with their own hand and then made proprioceptive judgments of the location of their own hand and used a Likert scale to rate their agreement or disagreement with 27 statements relating to their subjective experience of the illusion. We used a classic factor analytic approach, based on principal components analysis (PCA), to investigate the latent structure of participants' experience, and to quantify the complex experience of embodiment.

2. Methods

2.1. Participants

One hundred and thirty one current and prospective students (75 female) at University College London participated with local ethical approval. All but six were right handed, as assessed by the Edinburgh Inventory (Oldfield, 1971), *M*: 71.62, range: −90.91 to 100. Participants were recruited at open days offered by the University and volunteered to participate. There were no restrictions on participation.

2.2. Apparatus and materials

Participants sat at a table across from the experimenter, with their stimulated hand placed inside a specially constructed box. There were separate boxes for the right- and left-hand stimulation groups, which were mirror reflections of each other. Participants were randomly assigned to either the right- ($N = 67$) or left-hand ($N = 64$) apparatus. The boxes measured 36.5 cm in width, 19 cm in height, and 29 cm in depth. One hole was cut in front, through which the participant placed their hand; another was cut on top, through which the participant could see the rubber hand; and most of the back of the box was removed, allowing the experimenter to brush both hands. The inside of the box was lined with grey felt, and a small Velcro disk indicated where the tip of the participant's index finger should be placed. A black cover (59.5 cm by 29 cm) was connected to the box by two hinges. When the cover was open, the rubber hand could be seen by the participant, but the experimenter was hidden from view; when it was closed, the opposite was true. Participants wore a cloth smock which was attached to the front edge of the box, such that their arms were out of view throughout the experiment. The rubber hands were life sized prosthetic hands, one of a right hand, the other of a left hand.

2.3. Procedure

The experiment consisted of two blocks. At the beginning of each block the experimenter made sure the cover was lowered and asked the participant to place the appropriate hand inside the box, with the tip of their index finger resting on the Velcro disk. A pre-test proprioceptive location judgment was obtained by asking the participant to indicate where it felt like the tip of their index finger was located by reporting the corresponding number along a ruler laid across the box top, parallel to their frontal plane. A random ruler offset that varied from trial to trial was used to discourage participants from re-using remembered verbal labels from prior trials.

Following the pre-test judgment, the cover was raised and a 60-s induction phase began in which both the rubber hand and the participant's hand were brushed with two identical paintbrushes (Winsor & Newton, London). In the *synchronous* condition, the hands were brushed at the same time, while in the *asynchronous* condition they were brushed 180° out of phase. The order of the synchronous and asynchronous conditions was alternated across participants. Sixty-six participants completed the synchronous condition first; sixty-five completed the asynchronous condition first. Brush strokes were made at approximately 1 Hz.

After the induction, the cover was lowered and a post-test proprioceptive location judgment was made in the same manner as the pre-test. Following this proprioceptive judgment, participants were asked to remove their hand from the box and the questionnaire was administered. Participants were asked to indicate the extent of their agreement or disagreement with 27 statements in each block, using a 7-item Likert scale. A response of +3 indicated that they "strongly agreed" with the statement, −3 that they "strongly disagreed", and 0 that they "neither agreed nor disagreed", though any intermediate value could be used. Before the questionnaire in the first block, the scale was explained to the participant. A sheet of paper showing the scale and the 7 possible responses was placed on the box in front of the participant throughout the questionnaire. The first two items presented were always items (20 and 21) relating to the experience being interesting and enjoyable; the order of subsequent items was randomized separately for each participant in each condition.

We used more questionnaire items than previous studies of rubber hand illusion studies (typically 8–10). We designed 27 items based on qualitative research with five participants, who were asked to freely report their experiences during the illusion. Analysis of these transcripts motivated a selection of questionnaire items. The items covered a wide range of themes, and were designed to reflect many types of possible experiences participants might have, including hypothesized constructs such as the senses of ownership and agency over the body (cf. Gallagher, 2000; Tsakiris et al., 2006).

3. Results

The mean and standard deviation for the raw item scores in each condition are given in Supplementary Table 1.

3.1. Structure underlying subjective reports

PCA with varimax orthogonal rotation was used to investigate the structure of experience of the rubber hand illusion. Separate PCAs were conducted for the synchronous and asynchronous conditions. In the synchronous condition, analysis of the scree plot and eigenvalues led to the extraction of four components which together accounted for 55.3% of variance in the data (see Table 1). The first component, which accounted for substantially more variance than any other (26.3%), we termed *embodiment of rubber hand*. It comprised items relating to the feelings that: the rubber hand belonged to the participant, the participant had control over the rubber hand, the rubber hand and real hand were in the same location, and the rubber hand had taken on features of the actual hand (items 1–10). The second component we termed *loss of own hand*. Items loading on this component related to the feelings of: being unable to move one's hand, one's hand disappearing, and one's hand being out of one's control. The third component we termed *movement*; it

Table 1
Component loading from the top-level PCA

Item	During the block…	Synchronous					Asynchronous					
		Embodiment of rubber hand	Loss of own hand	Move-ment	Affect	Commu-nalities	Embodiment of rubber hand	Deaf-ference	Move-ment	Loss of own hand	Affect	Commu-nalities
1	…it seemed like I was looking directly at my own hand, rather than at a rubber hand.	0.817				0.698	0.703					0.625
2	…it seemed like the rubber hand began to resemble my real hand.	0.747				0.675	0.759					0.698
3	…it seemed like the rubber hand belonged to me.	0.854				0.793	0.845					0.819
4	…it seemed like the rubber hand was my hand.	0.878				0.824	0.858					0.768
5	…it seemed like the rubber hand was part of my body.	0.838				0.747	0.802					0.762
6	…it seemed like my hand was in the location where the rubber hand was.	0.733				0.655	0.702					0.594
7	…it seemed like the rubber hand was in the location where my hand was.	0.728				0.606	0.586					0.549
8	…it seemed like the touch I felt was caused by the paintbrush touching the rubber hand.	0.641				0.590	0.546					0.542

(*continued on next page*)

Table 1 (*continued*)

Item	During the block...	Synchronous					Asynchronous					
		Embodiment of rubber hand	Loss of own hand	Move-ment	Affect	Commu-nalities	Embodiment of rubber hand	Deaf-ference	Move-ment	Loss of own hand	Affect	Commu-nalities
9	...it seemed like I could have moved the rubber hand if I had wanted.	0.651				0.542	0.621					0.472
10	...it seemed like I was in control of the rubber hand.	0.740				0.610	0.726					0.583
11	...it seemed like my own hand became rubbery.					0.457	0.514					0.468
12	...it seemed like I was unable to move my hand.		0.700			0.628				0.582		0.644
13	...it seemed like I could have moved my hand if I had wanted.		-0.681			0.468				-0.768		0.599
14	...it seemed like I couldn't really tell where my hand was.		0.575			0.487						0.517
15	...it seemed like my hand had disappeared.		0.609			0.489				0.608		0.646
16	...it seemed like my hand was out of my control.		0.603			0.594				0.559		0.701
17	...it seemed like my hand was moving towards the rubber hand.			0.747		0.617			0.718			0.621

18	...it seemed like the rubber hand was moving towards my hand.			0.667		0.580			0.640			0.600
19	...it seemed like I had three hands.			0.616		0.538						0.442
20	I found that experience enjoyable.				0.840	0.724					0.845	0.739
21	I found that experience interesting.				0.618	0.427					0.548	0.599
22	...the touch of the paintbrush on my finger was pleasant.				0.755	0.643					0.749	0.634
23	...I had the sensation of pins and needles in my hand.					0.128		0.580				0.446
24	...I had the sensation that my hand was numb.					0.372		0.780				0.668
25	...it seemed like the experience of my hands was less vivid than normal.					0.331		0.711				0.654
26	...I found myself liking the rubber hand.					0.524						0.380
27	...it seemed like I was feeling the touch of the paintbrush in the location where I saw the rubber hand being touched.					0.199						0.277
	Eigenvalues	9.52	2.21	1.78	1.44		9.74	2.02	1.73	1.40	1.16	
	Percent variance explained	26.3	12.2	9.0	7.8		24.6	9.6	9.2	8.4	7.6	

Note. Component loadings less than 0.5 are not displayed.

was comprised of two items relating to perceived motion of one's own hand, and to movement of the rubber hand. The fourth component we termed *affect*; items loading on this component included items relating to the experience in the block being interesting and enjoyable, and the touch of the paintbrush is being pleasant (cf. affective touch, Rolls et al., 2003). Further components consisted of single items, and were therefore judged uninformative.

A similar analysis of the asynchronous condition led to the extraction of five components, together accounting for 59.4% of the variance in the data. The same four components appeared in this data, and again the embodiment component accounted for the bulk of the variance (24.6%). However, the major difference was that an entirely new component appeared which we termed *deafference.* This related to the sensation of pins-and-needles and numbness in one's hand, and the experience of the hand being less vivid than normal. The order of the other components was slightly different than in the synchronous condition, but the importance of each component, as indexed by the proportion of variance explained, was comparable. The presence of the same four components in the two conditions provides convergent evidence that the PCAs are reliably decomposing the structure of bodily experience. The emergence of an additional component in the asynchronous condition only suggests that the structure underlying conscious experience in the two conditions, while similar, is not identical.

The *embodiment of rubber hand* component accounted for a large proportion of variance in both conditions and was composed of diverse items. We therefore suspected that further structure might exist within this component, but had been masked by the subcomponents' mutual similarity relative to other components extracted in our first analysis. We therefore conducted additional PCAs on only those items loading strongly (>0.50; cf. Hair, Black, Babin, Anderson, & Tatham, 2006; Nunnally & Bernstein, 1994) on the *embodiment of rubber hand* component, both in the synchronous and asynchronous conditions. Ten such items were identified (1–10). For both synchronous and asynchronous conditions three subcomponents of *embodiment of rubber hand* were identified, together account for 79.0% and 76.2% of the variance in the two conditions, respectively. We termed these the senses of *ownership*, *location*, and *agency* (see Table 2). *Ownership* comprised a large portion of the variance (35.4% and 34.3% in the synchronous and asynchronous conditions, respectively), and was composed of items related to the feeling that the rubber hand was part of one's body, the feeling of looking directly at one's hand, and the rubber hand taking on the characteristics of one's own hand. *Location* related to the feeling that the rubber hand and one's own hand were in the same place, and also to sensations of causation between the seen and felt touches. *Agency* related to the feelings of being able to move the rubber hand, and control over it. This is in contrast to the *loss of own hand* component which emerged in the primary analysis, which included feelings of lack of agency over one's own hand. Thus, while these three components of experience bundled together in the primary analysis, suggesting that they are tightly interrelated in experience, more focused analysis was able to separate them, suggesting that they are dissociable components of experience.

Table 2
Component loadings from the secondary PCA on the embodiment of rubber hand component

		Synchronous				Asynchronous			
Item	During the block...	Ownership	Location	Agency	Communalities	Ownership	Location	Agency	Communalities
1	...it seemed like I was looking directly at my own hand, rather than at a rubber hand.	0.696			0.732	0.611	0.521		0.673
2	...it seemed like the rubber hand began to resemble my real hand.	0.811			0.784	0.754			0.733
3	...it seemed like the rubber hand belonged to me.	0.779			0.822	0.802			0.845
4	...it seemed like the rubber hand was my hand.	0.757			0.859	0.689			0.727
5	...it seemed like the rubber hand was part of my body.	0.801			0.820	0.853			0.838
6	...it seemed like my hand was in the location where the rubber hand was.		0.776		0.805	0.522	0.653		0.713
7	...it seemed like the rubber hand was in the location where my hand was.		0.831		0.821		0.842		0.800
8	...it seemed like the touch I felt was caused by the paintbrush touching the rubber hand.		0.670		0.608		0.714		0.699
9	...it seemed like I could have moved the rubber hand if I had wanted.			0.843	0.847			0.843	0.823
10	...it seemed like I was in control of the rubber hand.			0.745	0.798			0.720	0.767
	Eigenvalues	6.49	0.75	0.66		6.07	0.84	0.71	
	Percent variance explained	35.4	24.8	18.8		34.3	23.7	18.2	

Note. Component loadings less than 0.5 are not displayed.

3.2. Presence and absence of experiences

Having established the similar *structure* of experience in synchronous and asynchronous conditions, we next quantified the *presence or absence* of each component of experience in each condition. We therefore calculated component scores for each component in each condition by multiplying the orthogonal scoring coefficients for each item by each participant's response. The component scores effectively express the value of each latent variable as if they were being measured directly from each participant using the same Likert scale used to respond to individual items. An ANOVA was run on these component scores with condition (synchronous, asynchronous) and primary component (*embodiment of rubber hand*, *loss of own hand*, *movement*, *affect*) as within-subjects factors (see Fig. 1). There was a significant main effect of component, $F(3,390) = 107.41$, $p < .0001$, suggesting that these aspects of experience were differentially present. There was also a significant main effect of condition, $F(1,130) = 29.05$, $p < .0001$. More importantly, we found a significant interaction of the two factors, $F(3,390) = 69.24$, $p < .0001$, indicating that the effects of synchronous stroking did not influence all aspects of experience in the same way.

Inspection of the component scores showed that these were significantly higher following synchronous than asynchronous stroking for the *embodiment of rubber hand*, *loss of own hand*, and *affect* components. However, this relation was reversed for the *movement* component, with synchronous stroking showing a score significantly more negative than asynchronous (see Figure for stats).

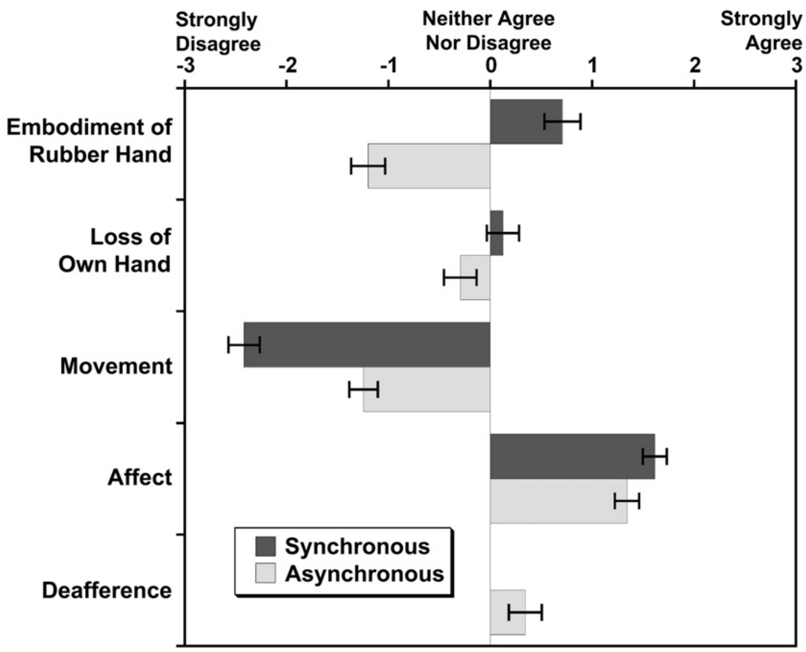

Fig. 1. Component scores for the primary PCA. Error bars are one *SEM*.

In the case of the *affect* and *movement* components, synchronous stroking simply exaggerated the effects of asynchronous stroking, whether they were positive or negative, respectively. That is, synchrony sharpened these aspects of experience, but did not qualitatively alter them. In contrast, component scores for *embodiment of rubber hand* were significantly positive following synchronous stroking, but significantly negative following asynchronous stroking. This suggests that the rubber hand illusion selectively inverts the sense of embodiment concerning the rubber hand. On average, participants had the sense that the rubber hand was part of their body in the synchronous – but not the asynchronous – condition.

We took the same approach to investigate the presence or absence of the three subcomponents of embodiment (*ownership*, *location*, *agency*; see Fig. 2). There was a significant main effect of component, $F(2, 260) = 11.26$, $p < .0001$, suggesting that these aspects of experience were differentially present. There was also a significant main effect of condition, $F(1, 130) = 110.69$, $p < .0001$, and a significant interaction of the two factors, $F(2, 260) = 3.60$, $p < .05$. This interaction suggests that multisensory synchrony differentially affected these three aspects of experience. Component scores for *ownership* and *location* were positive following synchronous stroking, but negative following asynchronous stroking. *Agency* scores were negative in both conditions, which were predicted since neither the participant's hand nor the rubber hand moved at any time. In summary, two specific aspects of

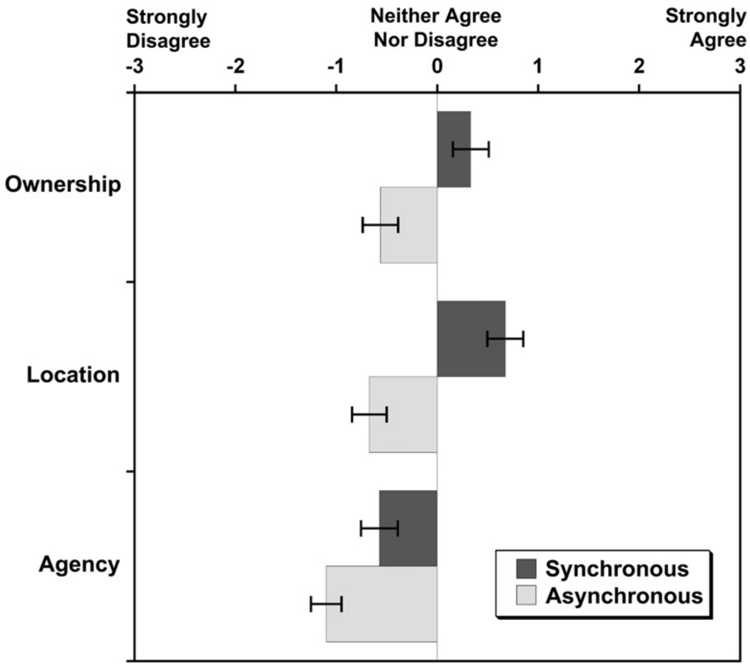

Fig. 2. Component scores for the secondary PCA unpacking the *embodiment of rubber hand* component. Error bars are one *SEM*.

embodiment are manipulated in the rubber hand illusion. These are the sense of ownership of the rubber hand and perceived location of the hand. The presence of ownership following synchronous stimulation does not necessarily cause a corresponding positive sense of agency, suggesting that these are dissociable aspects of experience (cf. Sato & Yasuda, 2005; Synofzik, Vosgerau, & Newen, in press; Tsakiris et al., 2006).

We ran an additional ANOVA on the top-level component structure including sex (female, male) and rubber hand laterality (left, right) as additional factors. There was a significant main effect of sex, $F(1, 127) = 4.06$, $p < .05$, with females showing significantly more agreement with questionnaire items generally ($-.055$), than males ($-.324$), consistent with findings that females are, on average, slightly more suggestible than males (e.g., Page & Green, 2007). This effect of sex did not interact, however, with component or synchrony, suggesting that it is not related to the rubber hand illusion, or to embodiment. There were no other main effects or interactions involving sex or rubber hand laterality, suggesting that these factors do not strongly influence the rubber hand illusion.

3.3. Proprioceptive judgments

Proprioceptive judgments from 11 participants were missing or unusable due to experimenter error or failure of participants to follow instructions. Judgments at pre-test showed a significant bias towards the body midline across conditions (0.58 cm), $t(119) = 2.43$, $p < .05$, (cf. Ghilardi, Gordon, & Ghez, 1995). A significant further displacement towards the rubber hand was observed at post-test following synchronous stroking (1.34 cm), $t(119) = 4.56$, $p < .0001$, but not asynchronous stroking (0.30 cm), $t(119) = 1.20$, n.s. The difference between conditions was also significant; $t(119) = 3.22$, $p < .005$.

3.4. Relations between objective and subjective measures

To investigate the relation between subjective experience and proprioceptive displacement we conducted a multiple linear regression on the difference in proprioceptive displacement between synchronous and asynchronous conditions, with the corresponding differences for each orthogonal component score as regressors. *Embodiment of rubber hand* significantly predicted the proprioceptive displacement, $\beta = 0.609$, $t(115) = 3.40$, $p < .001$, and *movement* had a marginal effect, $\beta = 0.290$, $t(115) = 1.68$, $p = .096$, but the *loss of own hand* and *affect* components did not significantly predict proprioceptive displacement, $\beta = -.128$, .087, $t(115) = -.76$, .32, respectively. As the *deafference* component appeared only in the asynchronous condition, an additional regression analysis was conducted on this component. *Deafference* was not a significant predictor of proprioceptive biases in the asynchronous condition, $\beta = -.034$, $t(118) = -.53$, $p > .20$.

Given that *embodiment of rubber hand* as a whole is significantly related to proprioceptive displacement, in the rubber hand illusion, we also investigated which of its subcomponents are driving this effect, again using multiple linear regression. Unsurprisingly, the *location* subcomponent was a significant predictor of proprioceptive displacement, $\beta = .485$, $t(116) = 3.02$, $p < .005$. More interestingly, the *ownership* subcomponent also independently predicted proprioceptive drift, $\beta = .425$, $t(116) = 2.85$, $p < .01$, whereas the *agency* subcomponent did not, $\beta = .110$, $t(116) = .75$, $p > .20$. Proprioceptive displacement therefore appears to be a genuine by-product of embodiment, but also related specifically to body ownership, but not agency.

4. Discussion

To our knowledge, the present findings represent the first systematic attempt to measure embodiment. By combining an experimental manipulation of the experience of one's own body, and a structured psychometric approach to measuring that experience, we were able to characterize what sort of experience embodiment is, and decompose it into sub-aspects. These results suggest that psychometric methods can be useful tools in elucidating structure underlying complex conscious experience. Specifically, we identified four components that emerged in both conditions: *embodiment of rubber hand* (which itself was composed of subcomponents relating to *ownership*, *location*, and *agency*), *loss of own hand*, *movement*, and *affect*. While each of these components was part of the structure of experience of both conditions, the conditions differed in terms of the extent to which each component was present or absent. Furthermore, an additional component, *deafference*, emerged only in the asynchronous condition. This pattern represents the characteristic structure of the rubber hand illusion, one of the few experimental models of embodiment.

While the analysis of embodiment we report here may be incomplete, and may not generalise to all 'embodied' experience, the structure we found is broadly consistent with results of previous experimental and conceptual work on embodiment. We provided the first direct empirical evidence confirming the intuition that body ownership and agency reflect dissociable components of embodiment (cf. Gallagher, 2000; Synofzik et al., in press; Tsakiris et al., 2006). Our results, furthermore, support the claim that affect associated with somatic sensations is separable from other forms of afferent input (cf. Rolls et al., 2003), as the pleasantness of touch loaded on the *affect* component, whereas the sense of causation associated with touch loaded on the *location* component. Additionally, however, our results also provide several novel insights. We particularly focus on three aspects of the substructure of the experience of the rubber hand illusion which were not predictable from previous experimental studies.

4.1. Displacement of participant's own hand by the rubber hand

First, while the focus of prior studies on the rubber hand illusion has been on feelings about the rubber hand, we identified important changes in feelings about the participant's *own* hand. Specifically, this component related to items reflecting paralysis of the hand, and its disappearance. This latent variable was significantly more present following synchronous than asynchronous stroking. This suggests that rather that simply being incorporated as part of the body, the rubber hand may in some sense displace the participant's actual hand. This overwriting of an existing body part by an incorporated object has important implications for plasticity of body representations. It confirms the intuition that the external object becomes a substitute for, and a part of, the functional self. But it also suggests that plasticity is constrained by a principle of body constancy: the novel rubber hand is incorporated by functionally suppressing the existing hand, rather than by adding an additional 'supernumerary' hand (McGonigle et al., 2002). Furthermore, the participant's own hand is felt to disappear. This suggests that the rubber hand actively displaces the actual hand, rather than merely being mistaken for it.

4.2. Dissociation of ownership and perceived location

Second, the experience of the location of one's own hand relative to the rubber hand was dissociable from the sense of ownership over the hand. This finding stands in contrast to theories which make location a constitutive component of selfhood. Jeannerod (2007), for example, argues that others are perceived as rotated-selves, such that the self's being 'here' and the other 'there' is the crucial distinction allowing them to be differentiated. The present dissociation of body ownership and location suggests that 'me-ness' is not reducible to 'here-ness'. Despite these components being dissociable, they are generally strongly linked in most experience. Indeed, ownership and location were merged in our primary PCA, and separated only at a secondary stage, suggesting that these components are highly correlated. Thus, even if the sense of self is not intrinsically reducible to perceived location, the correlation between these components of experience might normally be sufficient to differentiate self from other in practice (Jeannerod, 2007).

Having separated the *ownership* and *location* components, our analyses further showed that somatic sensory experiences are tied to *location*, not to *ownership*. Specifically, the feeling that the brushstrokes observed on the rubber hand had caused the feeling of being stroked loaded on *location*, rather than *ownership*. This suggests the possibility of sensory perception in a body part that is not perceived as being one's own. Indeed, this precise dissociation has been described in neurological cases, such as the somatoparaphrenic patient of Aglioti, Smania, Manfredi, and Berlucchi (1996). This patient denied ownership of her left hand in the acute phase following a right parietal stroke, but nevertheless reported feeling touches on the very hand that she claimed was not hers. Similar findings have been reported by Bottini, Bisiach, Sterzi, and Vallar (2002).[1] Our analysis supports the concept that tactile sensations can be dissociated from ownership of the limb on which they are felt to occur.

[1] The somatoparaphrenic patient studied by Rode et al. (1992) is perhaps also relevant in this light. She at one point claimed that her left arm was not hers "because it's too heavy".

4.3. Sensory conflict and deafference

Third, while the asynchronous stroking condition has generally been regarded as a control condition, we found an entirely new component of experience that emerged only in that condition. This latent variable related to afferent information from the participant's own hand, and recalls Jackson and Zangwill's (1952) finding that participants asked to move their fingers while looking at a mirrored reflection of their own hand often reported sensations that their hand was "isolated" or "detached from sensations of movement". Similarly, McCabe, Haigh, Halligan, and Blake (2005) reported that visuo-proprioceptive-motor conflict created with mirrors led participants to report several strange sensations, notably including numbness and pins-and-needles. We suggest that intersensory conflict in the asynchronous condition may create a form of deafferentation. For example, a visually driven gating mechanism might suppress transmission or interpretation of conflicting afferent information (cf. Press et al., 2008). Interestingly, the asynchronous condition can only be conceived of as involving conflict to the extent that some rudimentary form of ownership of the rubber hand is elicited merely from the visual perception of the rubber hand (at least when it is in plausible alignment with the participant's actual hand). Indeed, while some studies have found synchronous stimulation to be necessary to elicit the rubber hand illusion (e.g., Tsakiris & Haggard, 2005), others have found significant effects of the rubber hand in conditions where no brushing of either hand ever took place (e.g., Farnè et al., 2000; Pavani et al., 2000). This suggests that there are at least two types of cause of the rubber hand illusion: purely visual information from the perception of the hand in plausible configuration, and multisensory synchrony.

Previous psychological accounts of embodiment have accepted the concept of a bodily self as obvious and unproblematic (e.g., James, 1890), have linked it to a single somatic sensory system such as visceral interoception (e.g., Damasio, 1999), or have assumed a single innate capacity for self-representation (e.g., Meltzoff, 2007). Our study demonstrates for the first time that experience of one's own body is not a single dimension, but a composite of several different subjective components, organised with a characteristic structure. Thus, some aspects of embodiment clearly reflect bottom-up sensory factors (as captured by our *location* component), while others reflect top-down influences of an explicit model of the body as an object (such as our *loss of own hand* component). In general, the pattern of latent variables suggests at least two types of influences structuring embodiment: those associated with immediate sensations from the body and with stored representations of the body, respectively. This two-level view converges with studies which have manipulated independent variables providing information about the body, and measured a single behavioural and a single neural dependent variable (e.g., Tsakiris et al., 2007a). Both research approaches suggest that the experience of embodiment emerges from a complex interplay of bottom-up and top-down influences.

4.4. Implications for rubber hand illusion studies

While the rubber hand illusion is well accepted as an experimental model of embodiment, there has been less consensus on how to measure the illusion. Introspective reports have either been difficult to quantify (e.g., Peled, Ritsner, Hirschmann, Geva, & Modai, 2000), or confined to the mere occurrence of the illusion (e.g., Ehrsson et al., 2004). Proprioceptive biases that occur in the illusion provide a useful quantitative proxy, but miss the actual phenomenology entirely. This study makes a bridge between the two, uniting phenomenological richness with experimental rigour. This richer description confirmed significant embodiment of the rubber hand following synchronous – but not asynchronous – stroking. This validates use of the rubber hand illusion as an experimental manipulation of the normal sense of one's own body. Furthermore, we found that proprioceptive bias linked to the illusion was related specifically to the experience of ownership and of perceived location. Holmes et al. (2006) similarly found that proprioceptive biases correlated with questionnaire items relating to the rubber hand being the participant's hand, but not other types of items. They interpreted this restricted relation as evidence that proprioceptive biases are only *weakly* related to the experience of ownership. In contrast, we would argue that this is evidence of *selectivity* in this relation, rather than weakness.

4.5. Psychometrics as a tool for studying complex phenomenology

The experience of embodiment may seem to be a prototypical instance of an inherently private experience, with a first-person ontology. In contrast, the public data required for rigorous science may seem to involve a third-person ontology (cf. Searle, 1994). Understanding experiences such as embodiment by introspection alone is problematic, because of the complexity of the experience itself, and because introspectionism cannot provide a clear way to deal with differences in reports between participants (e.g., the infamous disagreement regarding imageless thought, see Boring, 1953). Nevertheless, we suggest there is no need to be solipsistic about complex experience. Our psychometric approach works by analyzing correlations between items across participants. To the extent that participants do not agree, no structure should emerge. Conversely, to the extent that structure does emerge – as in the present study – it demonstrates agreement (however implicit) across participants regarding the structure of their experience.

Psychometric approaches have been used for at least 100 years to study phenomena as diverse as intelligence, attitudes, and consumer preferences, including basic conscious sensations such as tastes (e.g., Stevens, Smith, & Lawless, 2006). Some recent studies have even used psychometrics to investigate complex conscious experiences such as the feeling of presence in virtual environments (e.g., Witmer, Jerome, & Singer, 2005), and anomalous sensations associated with schizophrenia (Bell, Halligan, & Ellis, 2006) and depersonalization (Sierra, Baker, Medford, & David, 2005). To our knowledge, however, this study represents the first systematic application of psychometric methods to investigate complex conscious experience elicited under controlled, experimental conditions, and to identify subcomponents of that experience by systematic questioning. We validated the use of structured introspective reports as a rigorous tool for the study of bodily self-consciousness in two ways: first, by showing that systematic structure emerges in the pattern of responses across participants, and that such structure is similar across experimental conditions, and second, by showing that individual differences between participants were nevertheless related to an objective behavioural measure (proprioceptive displacement). Thus, both similarities across, and differences between participants are theoretically meaningful, and show measurable structure. That comparable structure emerged in both the synchronous and asynchronous conditions speaks to the reliability of our method; that components of experiences are selectively related to proprioceptive biases attests to its validity.

Several limitations of our method and results should be kept in mind. The selection of questionnaire items always restricts the potential structure that can emerge from psychometric studies. If a potential component of the experience of embodiment was not reflected by any of the items we used, it could not have emerged in our analysis. We designed the questionnaire to include items relating to a broad range of potential experiences, motivated both theoretically and by prior qualitative research. However, there are no doubt additional components of embodiment which were not covered by our questionnaire. Second, we have focussed on the rubber hand illusion as an initial model for embodiment, because it is subjectively compelling for many people, and can elicited under systematically controlled experimental conditions. However, the term ‘embodiment’ is used in widely used in modern cognitive science, with a range of different connotations, often with emphases on affect, sublinguistic thought, or social interaction. The psychometric structure found here may or may not generalise to such other instances of embodiment. Indeed, a fruitful focus for future research might be to use psychometrics to identify whether instances of embodied cognition do or do not share common structure.

To conclude, our results suggest that embodiment, at least in the model instance of the rubber hand illusion studied here, is a genuine but complex experience with a common structure, and identifiable subcomponents. For example, we clearly dissociated “what” and “where” aspects of embodiment by identifying dissociable components of *ownership* and perceived *location* of the rubber hand. Nevertheless, *ownership* and *location* along with the sense of *agency* grouped together in the omnibus PCA, suggesting that these three components of embodiment, while dissociable in a focused analysis, form a coherent cluster of experience. This experiential link between the senses of ownership and agency belies the traditional view that these are distinct (Gallagher, 2000; Sato & Yasuda, 2005; Tsakiris, Schütz-Bosbach, & Gallagher, 2007b). Most psychological models of conscious experience focus on simple qualia. These models, however, are not appropriate for composite, background states of experience such as embodiment. By decomposing such experiences psychometrically, we have made it possible to search for the neural correlates of specific subcomponents of bodily self-consciousness, and made an initial step towards uniting experimental and phenomenological research (cf. Gallagher & Brøsted Sørensen, 2006).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.cognition.2007.12.004.

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