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Visual enhancement of touch and the bodily self

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Abstract

We experience our own body through both touch and vision. We further see that others' bodies are similar to our own body, but we have no direct experience of touch on others' bodies. Therefore, relations between vision and touch are important for the sense of self and for mental representation of one's own body. For example, seeing the hand improves tactile acuity on the hand, compared to seeing a non-hand object. While several studies have demonstrated this *visual enhancement of touch* (VET) effect, its relation to the 'bodily self', or mental representation of one's own body remains unclear. We examined whether VET is an effect of seeing *a* hand, or of seeing *my* hand, using the rubber hand illusion. In this illusion, a prosthetic hand which is brushed synchronously—but not asynchronously—with one's own hand is felt to actually be one's hand. Thus, we manipulated whether or not participants felt like they were looking directly at their hand, while holding the actual stimulus they viewed constant. Tactile acuity was measured by having participants judge the orientation of square-wave gratings. Two characteristic effects of VET were observed: (1) cross-modal enhancement from seeing the hand was inversely related to overall tactile acuity, and (2) participants near sensory threshold showed significant improvement following synchronous stroking, compared to asynchronous stroking or no stroking at all. These results demonstrate a clear functional relation between the bodily self and basic tactile perception.

Keywords: Bodily self; Touch; Multisensory; Visual enhancement of touch; Rubber hand illusion; Inverse efficiency

The body is a unique multimodal object. In particular, we experience our bodies in two quite different ways, corresponding to different sensory channels: we see our body as a highly familiar, structured object; and we feel our bodies as locations of specific somatosensory experiences, such as touch and kinaesthesis. This distinction between sensory sources is maintained at higher, cognitive levels of representation. In particular, psychologists have traditionally distinguished between a *body image* and a *body schema* (Gallagher, 1986; Paillard, 2005). Body schema refers to a predominantly unconscious representation of the location of body parts in space, which is updated as the body moves. Body image refers to a conscious, essentially visual, representation

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of the body in its canonical position and, with the sort of structural and semantic detail that is familiar from seeing oneself in the mirror. The body image is often thought to have an enduring quality, which explains the traditional association with cognitive and affective attitudes to the body (Schilder, 1935), and the important role of body image in psychodynamic theory (e.g., Guimón, 1997).

Here, we focus on an important epistemic distinction between body image and body schema. Somatic information underlying the body schema is epistemically private, whereas visual information underlying the body image is not. For example, I can experience touch of an object on my own body, but I cannot have a *direct* experience of touch on someone else's body. My brain may *simulate* the experience of touch (Keysers et al., 2004; Thomas, Press, & Haggard, 2006), and, in the case of some individuals, the brain appears to actually produce a tactile experience when watching another person being touched (e.g., Blakemore, Bristow, Bird, Frith, & Ward, 2005). However, even this unusual vicarious experience appears to be clearly distinguishable from actual touch. In contrast, the *visual* experience of my own body can often be very similar to the experience of other bodies. Indeed, self-recognition experiments show that people may fail to recognise themselves when shown a screen that switches at random between a video image of their own hand moving, or the hand of an experimenter making a similar movement (Daprati et al., 1997; Tsakiris, Haggard, Franck, Mainy, & Sirigu, 2005). In many cases, of course, geometrical perspective, body morphology, or even clothing detail identifies the individual, but the point remains that visual body images are in principle ambiguous between self and other.

The interpersonal ambiguity of visual body images raises an important challenge for multisensory integration. For example, visual–tactile interactions play in important role in boosting both visual (e.g., Kennett, Eimer, Spence, & Driver, 2001) and tactile (e.g., Eimer & Driver, 2000) processing. While some visual–tactile interactions involve visual information about an external object, vision of the body also has important implications for touch. In particular, seeing your hand improves tactile acuity on that hand (Kennett, Taylor-Clarke, & Haggard, 2001; Taylor-Clarke, Kennett, & Haggard, 2002; Tipper et al., 1998), even when such vision is entirely non-informative regarding the tactile stimulus. This *visual enhancement of touch* (VET) effect suggests an important functional relationship between tactile perception and the mental representation of one's own body (cf. Haggard, Taylor-Clarke, & Kennett, 2003). Nevertheless, the relation between VET and the 'bodily self' remains unclear, because vision of the body is inherently ambiguous: existing studies have confounded potential effects of seeing *a* hand with the effect of seeing *my* hand. The present study addressed this confound by having participants view a single, common stimulus which they either did or did not attribute to their own body. We thereby aimed to isolate VET effects specifically related to the bodily self.

In prior VET studies, performance while viewing the hand has generally been compared with performance while viewing some other non-hand object. Tactile acuity across a range of dependent measures has been found to be higher when viewing the hand, than the object, demonstrating a clear visual enhancement effect. A major limitation of this manipulation, however, is that it confounds effects related to the stimulus per se (low-level or attentional differences between the participant's hand and the neutral object) with those related to the bodily self (the fact that the hand—but not the object—is part of the body). One recent study (Haggard, 2006) did compare the effects of seeing one's own hand and of seeing someone else's hand. That study found significant VET effects in both conditions, relative to a neutral object. This result might, at first sight, be taken to imply that VET is driven entirely by stimulus-related effects of seeing any hand, with no relation to the bodily self. There was, however, a (nonsignificant) trend for a larger VET effect when participants viewed their own hand, suggesting that the bodily self may, indeed, play a role. Even in Haggard's (2006) study, however, the experimenter's and the participant's hands were not visually identical. Therefore, while VET clearly involves an interaction between touch and visual body image, it remains unclear whether the interaction involves self-specific representation of one's own body, or generic representation of a body. What is wanted is a way to hold the actual visual stimulus at test constant, while manipulating whether or not it is interpreted as part of the body.

While it is not possible to manipulate whether a participant's own hand is or is not theirs, it is possible to manipulate the perceived ownership of an external object. In the *rubber hand illusion* (RHI), for example, a prosthetic hand which is stroked synchronously—but not asynchronously—with the participant's hand is perceived as being the participant's own hand (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). By using the RHI in the present study, we were able to manipulate whether or not participants felt like they were looking at their own hand, while holding constant the actual stimulus they viewed during test. This provides a degree of stimulus control lacking in previous VET studies, allowing us to dissociate effects related to the stimulus from those related to the bodily self. Specifically, by brushing the participants' hand and the rubber hand synchronously or asynchronously, we manipulated whether the rubber hand was, or was not, represented as part of the body. Additionally, we used a no brushing condition, to investigate whether any effects of multisensory stimulation involve positive effects of synchrony, or negative effects of asynchrony.

A general principle governing multisensory interactions is that maximal intersensory enhancement occurs when individual stimuli are near sensory threshold (Stein & Meredith, 1993), the principle of *inverse efficiency*. While this principle was originally derived to account for the responses of individual neurons, it appears similarly to govern high-level multisensory perception in humans (e.g., Bolognini, Rasi, Coccia, & Làdavas, 2005; Frassinetti, Bolognini, & Làdavas, 2002), and VET appears to be no exception to this pattern. Press, Taylor-Clarke, Kennett, and Haggard (2004) found a VET effect in a tactile location discrimination task only when the task was difficult. Interestingly, they found significant reversals of the VET effect when the tactile task was made easier. Serino and colleagues (Serino, Farnè, Rinaldesi, Haggard, & Làdavas, 2007) obtained a similar pattern examining between-participant variation in baseline acuity in a two-point discrimination task; a significant VET effect was obtained for the low-accuracy group, while no significant difference was observed between conditions in the high-accuracy group.

The present study used the RHI to investigate the relation between VET and the bodily self. If VET is driven purely by differences in the stimuli observed at test, no differences should be observed between any of the present experimental conditions, as all involve exactly the same stimuli at test. If, on the other hand, VET is specifically related to the bodily self, tactile acuity should be enhanced following synchronous as opposed to asynchronous stroking, at least in those participants operating close to threshold.

1. Method

1.1. Participants

Twenty-two volunteers (13 female) between 18 and 54 years of age participated. Participants were naïve to the experimental hypotheses, and the study was approved by the local ethical committee.

1.2. Apparatus and stimuli

Participants sat with their right hand resting palm up on a table. Their right index finger rested on a pedestal which kept it stationary so that stimuli could be applied consistently to the fingertip. Participants wore a black smock which covered their arms so they could not see them directly. They looked into a mirror aligned parallel to their sagittal plane which reflected the rubber hand such that it appeared to be located where their own right hand in fact was (see Fig. 1). The rubber hand was a life-sized prosthetic left hand, but appeared via the mirror to be a right hand. The rubber hand's index finger rested on a pedestal identical to that on which the participant's finger rested. Black cloth similar to the participant's smock covered the rubber hand up to the wrist. The rubber hand was occluded from direct view, and was only visible in the mirror.

The Grating Orientation Test (GOT; van Boven & Johnson, 1994), a well-established method in tactile psychophysics, was used to measure tactile acuity. Tactile stimuli were eight square-wave gratings with ridge widths of .75, 1, 1.25, and 1.5 mm. At each width, one grating was oriented such that it ran *along* the long axis of the finger, another such that it ran *across* this axis. Gratings were presented mechanically by a robot controlled by five servo motors (Milford Instruments Ltd., South Milford, England).

1.3. Procedure

Participants were instructed to look at the rubber hand in the mirror throughout the entire block, and the experimenter observed their gaze to check that they did so. In the *synchronous* condition, the experimenter brushed the index fingers of the rubber hand and of the participant's right hand in synchrony with two identical paintbrushes (Winsor & Newton, London). In the *asynchronous* condition the rubber hand and

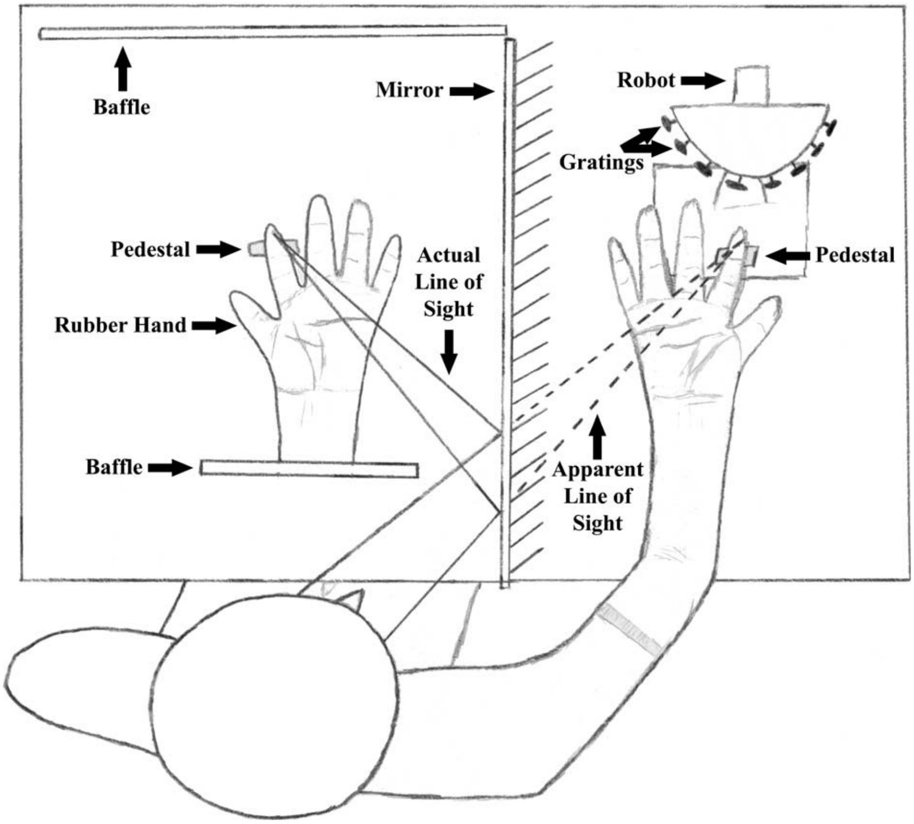

Fig. 1. Experimental setup. Participants looked into a mirror aligned parallel to their sagittal plane and saw the reflection of the rubber hand, which appeared to be a right hand located where their right hand was. The index fingers of both hands rested on pedestals which kept them still. Baffles prevented the participants seeing the experimenter or directly viewing the rubber hand. Tactile gratings were presented mechanically by a robot. Participants also wore a black cloth smock (not shown) which prevented any peripheral vision of their right arm. This figure is schematic and is not drawn precisely to scale.

the participant's fingers were stroked identically, but with a phase lag of approximately 0.5 s. Brush strokes were made at approximately 1 Hz. In the *no brushing* condition, neither finger was stroked, and the participant simply observed the rubber hand in the mirror. Blocks of the three viewing conditions were presented in ABCCBA order, counterbalanced between participants.

Each block began with a 90 s induction period in which the rubber hand was viewed in the mirror and the brushing (or lack thereof) occurred. At the end of this period the gratings were administered. Each grating was presented five times per block, for a total of 40 trials. Order of trials was randomized within block. Participants made unspeeded verbal two-alternative forced-choice (2AFT) judgments regarding the orientation ("along"/"across") of the gratings. The grating remained in contact will the participant's finger until their response had been entered.

Following each block, participants were asked to rate their agreement with several statements relating to their subjective experience during the block (see Fig. 4). The statements were read aloud by the experimenter and participants responded verbally using a seven-point Likert scale with a score of 3 indicating that they "strongly agreed", −3 indicating that they "strongly disagreed", and 0 that they "neither agreed nor disagreed" with the statement.

Before the experiment, half the participants completed a brief training session consisting of 40 GOT trials in which they were given feedback about their performance after each trial, followed by another 40 trials in which no feedback was given. Each of these blocks of 40 trials consisted of five trials each of the eight gratings, in random order. Overall experimental performance did not differ significantly between the training (64.0%

correct) and no-training (61.0% correct) groups, $F(1, 20) = 0.42$, $MSE = .142$, and this factor was collapsed for subsequent analyses.

2. Results

2.1. Visual enhancement effects

The inverse efficiency principle suggests that multisensory integration effects are strongest when individual sensory channels are weakest. Thus, we would expect that VET effects should be largest for participants performing close to chance. VET effects were computed by taking the difference in performance following synchronous stroking and both asynchronous stroking and no brushing; overall acuity was computed by taking the overall average performance, across conditions. There was a significant negative correlation between overall acuity and VET effects, both comparing the synchronous and asynchronous conditions, $r(21) = -.517$, $p < .01$ (one-tailed, see Fig. 2, top panel), and the synchronous and no brushing conditions,

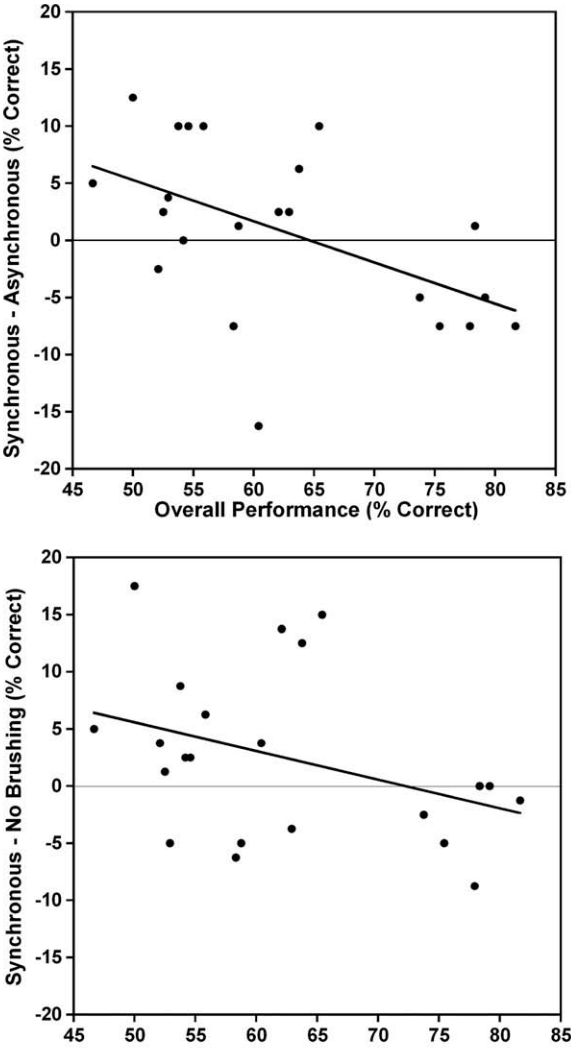

Fig. 2. Scatterplots showing inverse relation between overall acuity (x-axes) and VET (y-axes) comparing performance following synchronous and asynchronous stroking (top panel) and comparing performance following synchronous stroking and no brushing (bottom panel). The inverse efficiency relation characteristic of multisensory integration is apparent in both cases.

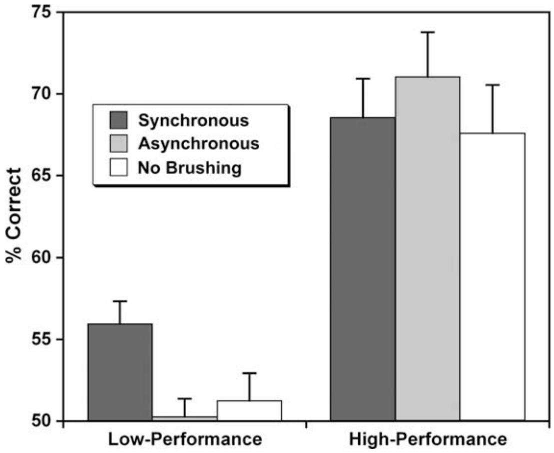

Fig. 3. Performance across conditions for the low- and high-performance groups. Error bars represent one SEM.

$r(21) = -.368$, $p < .05$ (one-tailed, see Fig. 2, bottom panel). This recalls the characteristic inverse efficiency effect previously reported by Serino et al. (2007). In order to make sure that these correlations were not driven by a few outlying participants, we also used one-way robust regression with least trimmed squares (LTS) estimation to examine how strongly overall performance predicted the magnitude of the enhancement effect. Overall performance was a significant negative predictor both of the difference between synchronous and asynchronous, $\beta = -.376$, $R^2 = .552$, $\chi^2(1) = 12.08$, $p < .001$ (one-tailed), and synchronous and no brushing conditions, $\beta = -.251$, $R^2 = .203$, $\chi^2(1) = 3.11$, $p < .05$ (one-tailed).

To examine these differences in greater detail, participants were divided into low- and high-accuracy groups.[1] Participants with overall performance below the lower bound of the 95% confidence interval for the population mean (in this study, 57.5% correct) were classed as low-accuracy ($n = 9$), while the remaining participants were classed as high-accuracy ($n = 13$). The proportion of participants classed as low-accuracy in this study (40.9%) is comparable to that in the study of Serino et al. (13 of 32 = 40.6%).

A 2 × 3 ANOVA was conducted on accuracy with performance (low-, high-accuracy) as a between-participants factor; and condition (synchronous, asynchronous, no brushing) as a within-participant factor. There was a significant interaction between performance group and condition, $F(2, 40) = 3.99$, $p < .05$, $MSE = .009$. Performance in the low-accuracy group was significantly above chance following synchronous stimulation (56.0% correct), $t(8) = 4.38$, $p < .005$, but not following asynchronous stimulation (50.3% correct), $t(8) = 0.25$, or no brushing (51.3% correct), $t(8) = 0.74$. In the low-accuracy group, accuracy was significantly greater following synchronous stroking than following asynchronous stroking, $t(8) = 3.29$, $p < .02$, or no brushing, $t(8) = 2.32$, $p < .05$. No such differences were observed in the high-accuracy group, all $p > .20$. Indeed, performance in the high-accuracy group was numerically worse in the synchronous than in the asynchronous condition (See Fig. 3).

2.2. *Subjective reports of rubber hand illusion*

Results of the subjective ratings questionnaires are shown in Fig. 4. One-way ANOVAs examining the effect of condition were performed separately on each questionnaire item. These statistics are presented in Fig. 4. Significant effects of condition were observed for all items, except items (4) and (5), which concern the transfer of structural properties from the real to the rubber hand and vice versa. This pattern is similar to that obtained

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[1] Serino et al. (2007) divided their participants into high- and low-performance groups on the basis of performance in the baseline condition only. In the present study, participants were divided on the basis of overall performance across all experimental conditions. This eliminates the possibility that differences between groups could be a statistical artifact of regression to the mean (cf. Holmes, 2007).

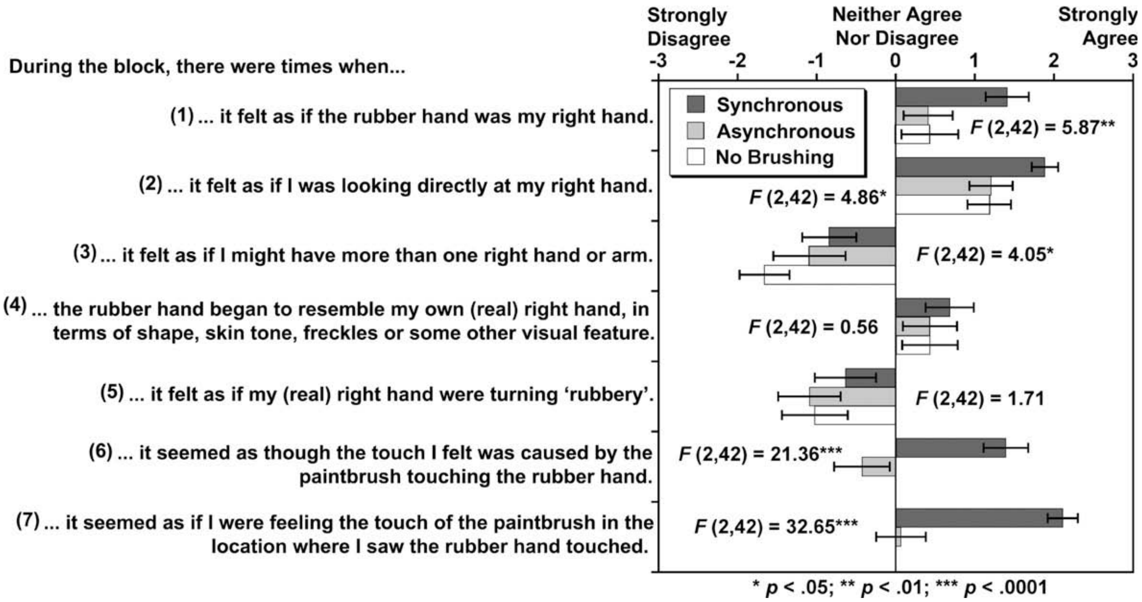

Fig. 4. Responses to questionnaire items across conditions. Error bars represent one SEM. *F*-statistics represent main effects of condition for ANOVAs performed separately for each questionnaire item.

Table 1
Component loadings for PCA on Synchronous—Asynchronous

During the block...	Component		Communalities
	High-Level/Embodiment	*Low-Level/Touch*	
(1) ...it felt as if the rubber hand was my hand.	.738	.435	.738
(2) ...it felt as if I was looking directly at my right hand.	.832	.161	.809
(3) ...it felt as if I might have more than one right hand or arm.	.770	−.244	.698
(4) ...the rubber hand began to resemble my (real) right hand...	.787	.196	.754
(5) ...it felt as if my (real) right hand were turning 'rubbery'.	.090	.122	.925
(6) ...it seemed as though the touch I felt was caused by the paintbrush touching the rubber hand.	.059	.971	.947
(7) ...it seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched.	.148	.894	.881
Eigenvalue:	3.124	1.652	
Variance Explained:	2.483	2.070	

in other RHI studies (e.g., Botvinick & Cohen, 1998; Longo, Schüür, Kammers, Tsakiris, & Haggard, in press).

We next investigated how these phenomenal experiences of the RHI relate to the VET effect. Because the different questionnaire items are intercorrelated, simply including individual item responses as regressors (Holmes, Snijders, & Spence, 2006) could be misleading. We therefore reduced the multiple questionnaire items to a smaller set of orthogonal dimensions, using principal components analysis (PCA). PCA with orthogonal varimax rotation was performed on difference scores between synchronous and asynchronous stroking, and two orthogonal components of experience sensitive to this difference were extracted (see Table 1). Component 1, which we termed *High-Level/Embodiment*, reflects the feeling of ownership and the rubber hand becoming like the real hand. Component 2, which we termed *Low-Level/Touch*, appears to reflect bottom–up sensations relating to brushing stimulation, but was also related to the feeling of ownership. Thus, body ownership is simultaneously related to both high- and low-level influences (cf. Tsakiris & Haggard, 2005). A third component had an eigenvalue less than 1, and moreover loaded only on the single item addressing similarity between the participant's own hand and the rubber hand. It was therefore judged as not theoretically meaningful. While the sample size in this study is smaller than is ideally recommended for PCA (Tabachnick & Fidell, 2001), the analysis does identify independent aspects of experience in the RHI that make theoretical sense, and appropriate for predicting VET.

Individual scores for each participant were computed for each of the components 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. These were then entered as regressors in a multiple linear regression to predict the difference between performance on the GOT task following synchronous and asynchronous stroking (i.e., the self-related VET effect). *High-Level/Embodiment* did not significantly predict the enhancement effect ($\beta = -.008$), $t(18) = -.06$, but *Low-Level/Touch* was a significant predictor ($\beta = .015$), $t(18) = 2.51$, $p < .05$. To examine whether this effect was independent of the inverse efficiency effect described above, the same multiple linear regression was run but with overall performance added as an additional predictor. Consistent with the above results, overall performance was a significantly negative predictor of VET ($\beta = -.305$), $t(17) = -2.25$, $p < .05$, while *Low-Level/Touch* was a significantly positive predictor ($\beta = .012$), $t(17) = 2.09$, $p = .05$, but *High-Level/Embodiment* was not ($\beta = -.001$), $t(17) = -.05$.[2]

3. Discussion

Two principal effects were observed in the present study. First, the characteristic inverse efficiency pattern for VET was observed even when stimuli were held constant at test; performance overall was negatively related to the difference in performance following synchronous stroking and both asynchronous stroking and no brushing. This confirms the similarity between VET and other forms of multisensory interaction (Stein & Meredith, 1993). It also points to a possible functional role of VET, in boosting tactile performance close to threshold. Second, among participants who performed close to threshold, significant VET effects were observed comparing performance following synchronous stroking to performance following either asynchronous stroking or no brushing. These results demonstrate that the VET effect is not driven by the visual stimulus of a hand, per se, but relates specifically to the representation of the hand as part of the body. It is not just an effect of seeing *a* hand, but (at least partly) of seeing *my* hand. Thus, this study provides the first direct relation between VET and the bodily self. The VET involves, at least in part, an interaction between touch and a self-specific visual body image, rather than a generic visual image of a body.

Several pieces of evidence suggest that the VET effect is caused specifically by a top–down modulation of tactile processing in primary somatosensory cortex (SI): first, viewing the hand leads to an increase in early somatosensory ERPs (Taylor-Clarke et al., 2002); second, transcranial magnetic stimulation (TMS) applied to SI—but not SII—disrupts VET (Fiorio & Haggard, 2005); third, viewing the hand leads to a sharpening of tactile receptive fields (Haggard, Christakou, & Serino, 2007). Given such findings, the present results indirectly suggest that the bodily self influences basic somatosensory processing. Certainly, the present results demonstrate a clear effect of the bodily self on one of the most basic properties of touch, i.e., tactile acuity. While several studies have demonstrated effects of the bodily self on higher-level perception (e.g., Longo & Lourenco, 2007; Warren & Whang, 1987), to our knowledge the present results constitute the first evidence of such effects at the level of basic sensory processing.

Results in the no brushing condition were quite similar to those in the asynchronous condition, both of which differed from the synchronous condition. This pattern suggests that the effects observed reflect a positive effect of synchronous stroking, rather than a negative effect of asynchronous stroking. This is consistent with the claim of Tsakiris and Haggard (2005) that synchronous stroking is a necessary prerequisite of the RHI. This hypothesis is at odds, however, with the findings of at least two studies that have reported significant

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[2] For completeness, a similar analysis was conducted comparing the synchronous and no brushing conditions, though, as questionnaire items (6) and (7) were not given in the no brushing condition, only items (1–5) were used. Analysis of the screen plot led to extraction of only a single component loading on all five items. This is not surprising given that the strongest loadings on component 2 in the above analysis were on questions (6) and (7), which were absent in this analysis. The single factor was not a significant predictor of VET, ($\beta = .014$), $t(20) = 1.27$.

effects of seeing a rubber hand without any stroking whatsoever (Farnè, Pavani, Meneghello, & Làdavas, 2000; Pavani, Spence, & Driver, 2000). We suggest that there may be (at least) two independent causes of the RHI: one driven purely by visual perception of the rubber hand in the proper position and orientation, another driven by the synchronous stroking of the participants' and the rubber hand. The studies of Farnè et al. and of Pavani et al., then, would have manipulated only the former effect. The key contrasts in the present study depend only on the latter effect of multisensory synchrony, since the effects of merely seeing a hand were constant across conditions. The multisensory synchronicity effect revealed VET only in low-performing participants. Previous reports of effects of merely seeing a rubber hand (Farnè et al.; Pavani et al.) showed significant differences across the whole sample (albeit with different dependent measures). We speculate that the multisensory synchrony effect, like other cross-modal enhancement effects, obeys the inverse efficiency law. In contrast, the visual recognition of a hand might simply reflect visual dominance of perception (Ernst & Banks, 2002) rather than a true cross-modal *interaction*, and would therefore not obey the inverse efficiency law.

A previous study (Haggard, 2006) reported similar VET effects when participants viewed the experimenter's arm as when they viewed their own, though the latter effect was numerically larger. Thus, while the present results suggest that attribution of a hand to oneself matters for VET, those of Haggard (2006) suggest that attribution is rather unimportant. Given that the present study isolated the effect of VET driven specifically by multisensory synchrony, the present study could be seen as focusing only the smaller difference between self and other found by Haggard, rather than the much larger difference between both those stimuli and a neutral object. This interpretation is consistent with the fact that while Haggard found an overall VET effect, VET in the present study was limited to participants near threshold. Additionally, viewing another person's hand may cause social effects that seeing a rubber hand would not. Recent studies, for example, have found that seeing someone else being touched activates primary and secondary somatosensory cortex in a manner comparable to actual tactile perception (Blakemore et al., 2005; Bufalari, Aprile, Avenanti, Di Russo, & Aglioti, 2007; Keysers et al., 2004), suggesting a tactile homolog of the human mirror system (cf. Rizzolatti & Craighero, 2004).

Johnson, Burton, and Ro (2006) recently argued that VET effects arise from response biases or changes in detection criteria introduced by seeing the hand, rather than changes in acuity, per se. Seeing a hand might indeed induce response bias, but such bias or changes in response criterion cannot account for differences between conditions with a two-alternative forced-choice paradigm, such as the grating-orientation discrimination task employed in the present study, and others (Fiorio & Haggard, 2005; Haggard, 2006; Taylor-Clarke, Kennett, & Haggard, 2004). Response bias in such a task would, on average, make performance closer to chance, and cannot account for the significant increases in performance observed in all these studies.

Our results, together with previous literature, suggest the existence of *two* varieties of body image, both of which enter into multisensory interactions with touch, and are both therefore functionally significant for perception. First, merely seeing a hand can influence the sense of touch, even when the hand belongs to another person (Haggard, 2006). This VET effect seems to be related to a generic visual body image, arising from recognition of the characteristic structural form of a hand. Second, an additional VET occurs when the viewed hand is linked to the self, rather than another person or object (this study). This second VET effect seems to be related to a self-specific body image, arising from recognition that a specific visual object is part of one's own body. Classical discussions of visual body image have often conflated the generic and self-specific aspects of viewing the body. On the one hand, the body image provides structural and semantic information about body composition (de Vignemont, Tsakiris, & Haggard, 2005; Gallagher, 2005; Sirigu, Grafman, Bressler, & Sunderland, 1991), which naturally generalizes across oneself and conspecifics. On the other hand, the body image is also an important component of selfhood, playing a key role in self-esteem and identity (Rumsey & Harcourt, 2005; Schilder, 1935). Studying the interaction of visual body image and touch has allowed us to isolate contributions of these two aspects, and to demonstrate that they have independent effects.

Up to now, we have used the admittedly rather vague and broad phrase 'bodily self' to refer to the representations underlying the RHI, driving the effects observed in this study. In part, this is due to existing controversy and confusion regarding how the self is constituted (cf. Gallagher, 2005). Various theoretical distinctions have been made, such as those between the *body image* and *body schema*, *minimal self* and *extended self*, or *sense of ownership* of the body and the *sense of agency* over it. Our PCA applied a data-driven approach to a series of introspective judgments, in order to investigate the structure underlying bodily self-consciousness. This approach suggested two major components underlying the difference in experience between the synchronous and asynchronous conditions, one reflecting multisensory integration of the correlated visual–tactile stimulation, the other reflecting more top–down experiences of ownership of the rubber hand and general feelings of strangeness. A similar dissociation has been suggested by Tsakiris and colleagues (2007).

The VET effect was related specifically to the former component reflecting multimodal integration of visual and tactile information. This suggests that VET might arise from a top–down modulation of SI from multisensory representations in the posterior parietal cortex (e.g., Graziano, Cooke, & Taylor, 2000; Làdavas & Farnè, 2004). This interpretation is consistent with findings that TMS applied either to SI (Fiorio & Haggard, 2005) or the posterior parietal cortex (Ro, Wallace, Hagerdorn, Farnè, & Pienkos, 2004) disrupts VET. This selective relation between the behavioral effect and a single component identified by the PCA provides convergent validity that the PCA did indeed divide the questionnaire items in a theoretically meaningful way. The combination of naïve introspection regarding conscious experiences and psychometric techniques is a promising technique for studying phenomenology in an empirically rigorous way (cf. Longo et al., in press).

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