Research Article

VISUAL CAPTURE OF TOUCH: Out-of-the-Body Experiences With Rubber Gloves

Francesco Pavani,[1,2] Charles Spence,[3] and Jon Driver[2]

[1]*Dipartimento di Psicologia, Università degli Studi di Bologna, Bologna, Italy;* [2]*Institute of Cognitive Neuroscience, University College London, London, United Kingdom; and* [3]*Department of Psychology, University of Oxford, Oxford, United Kingdom*

Abstract—*When the apparent visual location of a body part conflicts with its veridical location, vision can dominate proprioception and kinesthesia. In this article, we show that vision can capture tactile localization. Participants discriminated the location of vibrotactile stimuli (upper, at the index finger, vs. lower, at the thumb), while ignoring distractor lights that could independently be upper or lower. Such tactile discriminations were slowed when the distractor light was incongruent with the tactile target (e.g., an upper light during lower touch) rather than congruent, especially when the lights appeared near the stimulated hand. The hands were occluded under a table, with all distractor lights above the table. The effect of the distractor lights increased when rubber hands were placed on the table, "holding" the distractor lights, but only when the rubber hands were spatially aligned with the participant's own hands. In this aligned situation, participants were more likely to report the illusion of feeling touch at the rubber hands. Such visual capture of touch appears cognitively impenetrable.*

How do people locate tactile stimuli? One might suppose that this merely depends on which region of the body surface is stimulated. However, when touched, people feel not only where the event is upon their skin, but also where it lies in space. For instance, a person who is suddenly touched on his or her hand will orient in different directions depending on where that hand is currently located (Driver & Spence, 1998; Groh & Sparks, 1996). Localization of tactile events may depend not only on somatotopic information within the tactile modality, but also on information about the current disposition of stimulated body parts, as given by other modalities (e.g., vision of the hand's location, proprioceptive signals about its posture). The brain must constantly merge information from different senses to derive useful representations of external space (Andersen, Snyder, Bradley, & Xing, 1997; Driver & Spence, 1998). Such cross-modal integration is required because a single modality can specify only the locations of events across its receptor surface, and locations in receptor space do not directly reveal location in external space, because posture changes continuously.

One approach to understanding how different sensory modalities are combined in spatial perception examines situations of multimodal spatial conflict (Gibson, 1943). A well-known example is the *ventriloquist effect,* in which sounds are mislocated toward their apparent visual source in situations of audiovisual spatial discrepancy (see Bertelson, 1998, for review). There have been reports that vision may similarly dominate the perception of body-part location. For instance, Tastevin (1937), who introduced the term visual capture, reported that people mistake a plastic finger protruding from a cloth as their own when the latter is concealed several centimeters away. Other examples of visual capture of limb localization arise when vision of the hand is displaced laterally by prisms (e.g., Hay, Pick, & Ikeda, 1965; Mon-Williams, Wann, Jenkinson, & Rushton, 1997; Rossetti, Desmurget, & Prablanc, 1995; Shimoio, 1987), or when people see the experimenter's hand instead of their own (Nielsen, 1963; Welch, 1972). But some of this classic evidence was based only on subjective reports (e.g., Tastevin, 1937). Moreover, none of it addresses the question of whether tactile percepts can be mislocated due to vision.

We addressed this question experimentally by exploiting a cross-modal effect of visual distractors on tactile judgments. Previously (Spence, Pavani, & Driver, 1998), we reported that speeded tactile discriminations (specifically, deciding whether a touch was *above,* at the index finger, or *below,* at the thumb) can be substantially delayed by a distracting flash that is incongruent with the above/below response (e.g., an upper light flashes while the tactile stimulation is lower, at the thumb). This cross-modal effect depends on the irrelevant light appearing close to the stimulated hand; it is reduced if the visual distractors are presented further away from that hand. This effect can therefore be used to provide a marker for where people locate a particular tactile event in space, because a visual distractor closer to that location should produce a larger effect.

In the present study, visual distractors were all presented well above the hands, which were occluded from view by a table (Fig. 1a). In half the experimental blocks, two rubber hands were placed in alignment with the real hands, but on top of the table (Fig. 1b), in view and apparently holding the visual distractors. In this situation, the visual information was as if the rubber hands were the participants' own. Hence, the distractor lights lay close to the position specified by vision for the tactile stimulation, even though they remained above the true location of the tactile stimulators and unseen real hands (as specified proprioceptively). We expected visual capture of tactile localization to lead to greater effects from the lights when the rubber hands were present versus absent, as the tactile stimuli would be felt close to the lights only in the former condition, if touch was mislocated to the seen rubber hands.

EXPERIMENT 1

Method

Ten participants (mean age of 25 years, range: 20–38) gave informed consent, but were naive as to the purpose of the experiment, which lasted 45 min. They rested their forearms on a bench, under a small table that prevented direct vision of their hands and forearms (Fig. 1a). They fixated an LED placed centrally on top of the table, situated 40 cm in front of their eyes, 27° below eye level. So that any visual differences between their own hands and the rubber hands

Address correspondence to Francesco Pavani, Institute of Cognitive Neuroscience, University College London, Alexandra House, 17 Queen Square, London WC1N 3AR, United Kingdom; e-mail: f.pavani@ucl.ac.uk.

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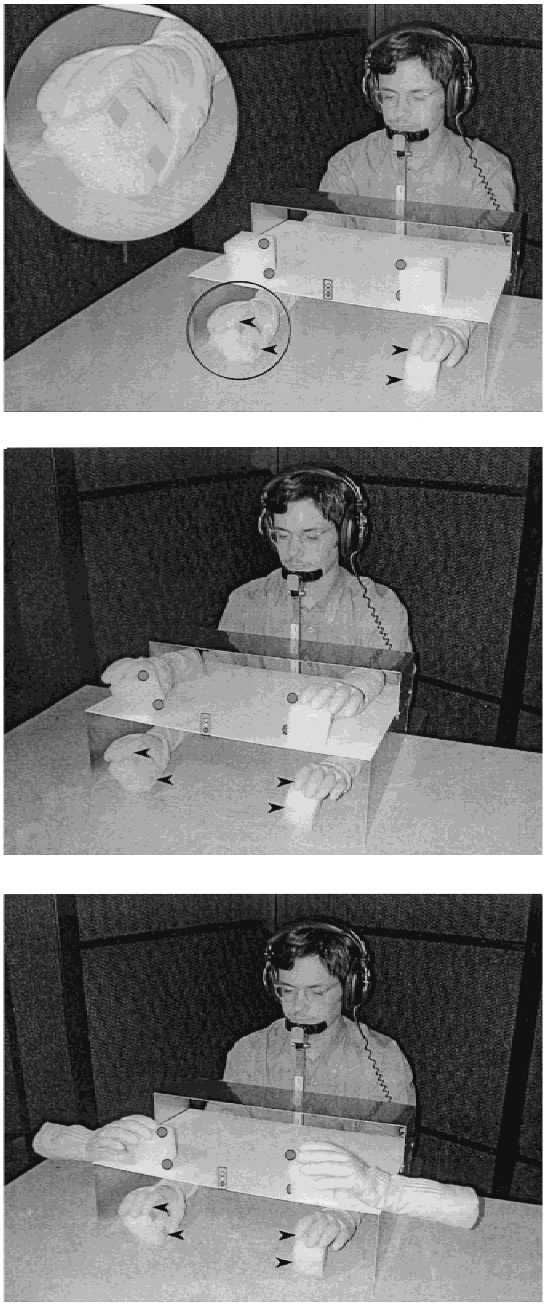

Fig. 1. Photographs showing the experimental setup, highlighting the location of the vibrotactile stimulators (indicated by arrows and visible in the blown-up circular panel at the top left), visual distractor lights (gray circles on the upper cubes), and fixation and feedback lights (circles in the small central column between the upper cubes). The layout is shown when (a) the rubber hands were absent, (b) the rubber hands were present and aligned with the participant's own hands (Experiment 1), and (c) the rubber hands were present and orthogonal to the participant's own hands (Experiment 2).

would be minimized, all participants wore a pair of blue kitchen gloves, and the rubber hands were constructed from an identical pair of gloves.

Participants held a sponge cube between the forefinger and thumb of each hand. Two Oticon-A bone-conduction vibrators were attached to each cube, and used to present vibrotactile targets directly under the thumb or forefinger pad of each hand, at a lateral eccentricity of 24° from fixation. Suprathreshold vibrotactile targets were generated by presenting a 200-Hz sine-wave signal (for three successive 50-ms bursts separated by 50 ms) from any one of the four vibrators. White noise presented over headphones completely masked the sound of the vibrators.

Two additional sponge cubes were fixed in place on top of the table, aligned with the cubes held below by the participant. A pair of red LEDs (luminance of 64.3 cd/m^2) was located on each of these sponge cubes, one at the top and one at the bottom of the inner front edge from the participant's perspective. One of the four LEDs was illuminated on each trial to produce a visual distractor. Each visual distractor comprised three successive 50-ms flashes, separated by 50 ms, just as for the tactile targets.

Participants discriminated the vertical position of the vibrotactile target (i.e., whether it came from one of the upper locations on the cubes, at an index finger, or from one of the lower locations, at a thumb), regardless of its side. Speeded discrimination responses were made via two foot pedals, one beneath the toe and the other beneath the heel of the right foot. Raising the toe indicated upper targets, and raising the heel indicated lower targets. Participants were informed that a visual distractor would be presented at the same time as each tactile target, but was completely irrelevant to the tactile task. They were told to ignore these visual stimuli as much as possible, because the positions of the target and distractor on any trial were entirely independent. The foot response ended a trial, and feedback was presented for erroneous responses (via an LED below fixation).

On half the blocks, a pair of rubber gloves was present on top of the table (Fig. 1b), each filled with a wire frame and padded with cotton wool to produce a convincing visual impression of a hand inside the glove. When present, the gloves were aligned with the real hands but above them, "holding" the two cubes on top of the table, so that each visual distractor was close to the thumb or index finger of a glove. A shield prevented participants from seeing the open end of the rubber gloves nearest themselves. Participants saw the gloves being placed onto the table, or removed from it, between blocks, and thus always knew that the visible rubber hands were not their own hands. After each block with rubber hands present, participants completed a questionnaire to rate their subjective experience. This questionnaire and its results are discussed later, in the section on Experiment 2.

The design for the vibrotactile-discrimination task had three within-participants factors: *congruency* between the tactile target and position of the visual distractor (i.e., whether upper vibrations appeared together with upper lights, and lower vibrations with lower lights [congruent], or vice versa [incongruent]), visual *distractor side* with respect to the tactile target (i.e., same or opposite side), and *rubber hands* (present or absent). The latter factor only was blocked. Each of the four possible visual-distractor positions was equally likely to appear in combination with any of the four vibrators, in an unpredictable sequence. Each participant completed three blocks of 15 practice trials followed by four test blocks of 112 trials each. In the first practice block only, just tactile stimuli were presented to facilitate acquisition of the up/down vibrotactile task. Half the participants had rubber hands present in their first experimental block, and the rubber-hand factor alternated for successive blocks.

Results and Discussion

Trials with an incorrect response were discarded from reaction time (RT) analysis. The mean RTs and error rates are shown in Table 1. The critical observation is whether the congruency effect from a distracting light (i.e., incongruent minus congruent conditions) varied as a function of the presence of the rubber hands. Figure 2 plots this effect, as a function of the rubber hands' presence and of distractor side. Two influences are clear: The congruency effect was larger overall when the irrelevant light appeared on the same side as the tactile stimulation, rather than the opposite side (as previously found by Spence et al., 1998); more important, the effect was largest when the rubber hands were present in this condition.

The RT data were analyzed using a repeated measures analysis of variance (ANOVA) with three factors (Congruency × Distractor Side × Rubber Hands). This analysis revealed a main effect of congruency, $F(1, 9) = 38.7$, $p < .0005$, caused by faster RTs when tactile and visual stimuli were congruent (i.e., finger vibrations with upper LEDs, or thumb vibrations with lower LEDs) than incongruent (*M*s = 482 ms vs. 574 ms). This congruency effect was larger when the visual distractor appeared on the same side as the tactile target (117 ms) versus the opposite side (65 ms), resulting in an interaction between congruency and distractor side, $F(1, 9) = 11.2$, $p < .01$. The most important finding was an interaction between rubber hands, target-distractor congruency, and distractor side, $F(1, 9) = 5.9$, $p < .05$. This was caused by the congruency effect from visual distractors on the same side as tactile targets being significantly larger when the rubber hands were present (145 ms) versus absent (90 ms) $p < .005$. In contrast, the smaller congruency effect from visual distractors on the opposite side to tactile targets was not significantly affected by whether the rubber hands were present versus absent (71 vs. 59 ms).

Analysis of the error data revealed a similar pattern. There was a main effect of target-distractor congruency, $F(1, 9) = 16.4$, $p < .005$, caused by more errors on incongruent trials ($M = 11.3\%$) than congruent trials ($M = 1.8\%$) overall. There was also an interaction between target-distractor congruency and distractor side, $F(1, 9) = 5.1$, $p < .05$, with more interference when the visual distractors appeared on the same side as the tactile target (mean incongruent minus congruent difference of 13.6%) than when they appeared on opposite sides (interference of 5.4%). None of the other terms in this analysis reached significance, but note that the trends support the RT pattern (see Fig. 2).

Table 1. *Mean reaction time and percentage of errors for tactile targets in Experiment 1 as a function of the visual distractor's side with respect to the target, the distractor's congruence with the target, and presence of the rubber hands*

Target-distractor congruence (upper vs. lower position)	Position of distractor	Reaction time (ms)[a]	Error (%)
	Rubber hands absent		
Congruent	Same side	462 (16)	1.6
	Opposite side	477 (19)	2.5
Incongruent	Same side	552 (25)	12.2
	Opposite side	536 (24)	7.3
	Rubber hands present (aligned)		
Congruent	Same side	488 (20)	1.2
	Opposite side	503 (26)	1.8
Incongruent	Same side	633 (47)	17.9
	Opposite side	574 (35)	7.8

[a]Standard errors are given in parentheses.

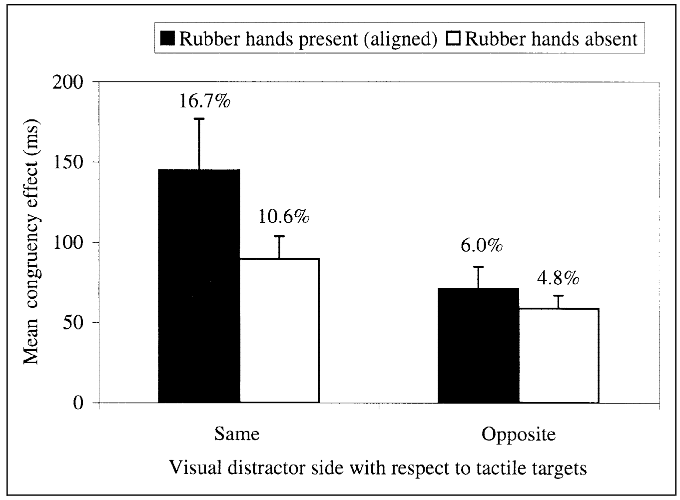

Fig. 2. Mean congruency effects in reaction time (i.e., difference between incongruent and congruent conditions) in Experiment 1, as a function of distractor side and presence of the rubber hands. Standard errors are also indicated. The mean congruency effect in error rate is given as a percentage above each bar in the histogram.

The results show a cross-modal congruency effect from an irrelevant visual stimulus on vibrotactile discriminations—specifically, increased RTs and errors when the light was incongruent (in the upper vs. lower dimension) with respect to the vibration. This effect was modulated by the distance between distracting lights and tactile targets, being greater for targets on the same side of space as the distractor, as we reported previously (Spence et al., 1998). The critical new result is that this cross-modal congruency effect was affected by the presence or absence of the rubber hands, provided visual distractors were on the same side as the tactile target. This is just as predicted, given our hypothesis that participants would feel the vibration to be coming from the location of the seen rubber hand on the side of the vibration, and thus from very close to a visual distractor on that side.

However, two alternative explanations must be considered. First, the rubber hands may simply have acted as an intriguing visual stimulus that attracted attention. This alone might have made the distracting visual lights harder to ignore when near the rubber hands (though it is unclear why this would have affected interference only from lights on the same side as the target vibration, as found). Second, it may be that the lights evoked some abstract code for the corresponding digit (e.g., "finger" vs. "thumb"; or "top" vs. "bottom") more effectively when flashed close to the rubber fingers than when flashed in the absence of the rubber hands. This alone might have produced a stronger congruency effect in the presence of the rubber hands, at the level of competing internal codes.

To discriminate between these possible explanations, we conducted a further study in which rubber hands were again present on half the blocks, but were not aligned with the participants' hands;

instead, they were placed orthogonally (Fig. 1c). With this setup, the rubber hands still provided intriguing visual stimulation, and a visual distractor flashed in their vicinity should still have been able to activate any abstract code representing the adjacent rubber digit (which was clearly visible). However, because the rubber hands were in an entirely different posture with regard to the real hands, they should not have given rise to the illusion of being the participant's own hands, and hence would fail to capture tactile localization if our account were correct.

EXPERIMENT 2

Method

Ten new participants (mean age of 24 years, range: 17–31) were recruited. The method was the same as in Experiment 1, except that when present, the rubber hands were not aligned with the participant's own hands (see Fig. 1c).

Results and Discussion

The mean RTs and error rates are shown in Table 2. Figure 3 plots the critical congruency effects on RT. The results differ from those of Experiment 1 in only one respect: The rubber hands no longer had any influence on performance. Analysis of RTs revealed a main effect of congruency, $F(1, 9) = 54.9$, $p < .0001$, caused by faster responses when distractors were congruent ($M = 477$ ms) versus incongruent ($M = 544$ ms). As before, congruency effects were larger when the visual distractor appeared on the same side as the tactile target (mean interference effect of 83 ms) versus the opposite side (mean effect of 51 ms), resulting in an interaction between congruency and distractor side, $F(1, 9) = 17.0$, $p < .005$. None of the other terms in the RT analysis reached significance. There was no significant term involving presence of the rubber hands (all Fs < 1), unlike in Experiment 1.

Table 2. *Mean reaction time and percentage of errors for tactile targets in Experiment 2 as a function of the visual distractor's side with respect to the target, the distractor's congruence with the target, and presence of the rubber hands*

Target-distractor congruence (upper vs. lower position)	Position of distractor	Reaction time (ms)[a]	Error (%)
	Rubber hands absent		
Congruent	Same side	468 (29)	3.1
	Opposite side	484 (28)	1.3
Incongruent	Same side	550 (32)	9
	Opposite side	533 (26)	7.6
	Rubber hands present (misaligned)		
Congruent	Same side	472 (27)	2.1
	Opposite side	485 (27)	2.2
Incongruent	Same side	557 (29)	8.8
	Opposite side	538 (25)	6.9

[a]Standard errors are given in parentheses.

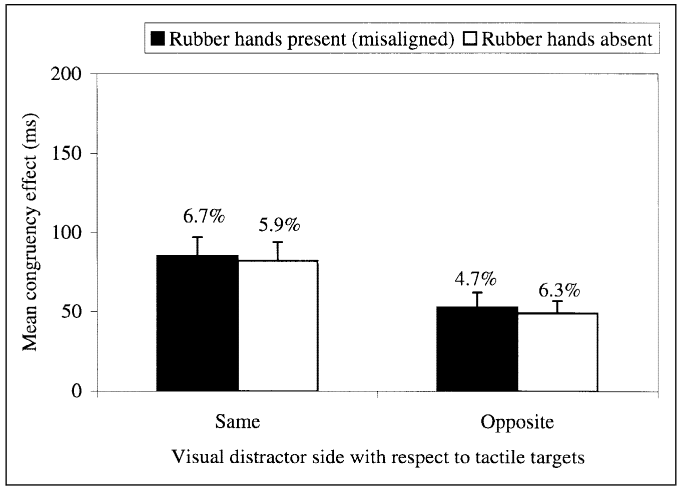

Fig. 3. Mean congruency effects in reaction time (i.e., difference between incongruent and congruent conditions) in Experiment 2, as a function of distractor side and presence of the rubber hands. Standard errors are also indicated. The mean congruency effect in error rate is given as a percentage above each bar in the histogram.

A similar analysis on errors revealed a main effect of congruency, $F(1, 9) = 9.9$, $p < .01$, with more errors on incongruent ($M = 8.0\%$) than congruent trials ($M = 2.2\%$) overall. Participants also made more errors when visual distractors appeared on the same side as the tactile target ($M = 5.8\%$) than on the opposite side ($M = 4.5\%$), resulting in a marginal effect of distractor side, $F(1, 9) = 4.6$, $p = .06$. None of the other terms in the error analysis approached significance (all Fs < 1).

When the rubber hands were substantially misaligned with the participants' real hands (see Fig. 1c), they no longer modulated the cross-modal congruency effect, even though the rubber digits were still located by the same distractor lights, and were clearly visible. To confirm this difference between Experiments 1 and 2, we conducted an analysis on the congruency effects from both experiments, with one between-participants factor, experiment (1 vs. 2), and two within-participants factors, distractor side (same vs. opposite) and rubber hands (present vs. absent). The increased congruency effect for visual distractors on the same side as tactile targets when the rubber hands were present and aligned (Experiment 1 only) should be apparent as a three-way interaction. This term was significant for RTs, $F(1, 18) = 4.5$, $p < .05$ (compare Figs. 2 and 3), with no opposing trends in the errors. This result confirms that the increased congruency effect from same-side distractors with a rubber hand present is specific to the case in which the rubber hand is aligned so as to look plausibly like the participant's own hand (Experiment 1). This fits our hypothesis concerning visual capture of tactile location, but is inconsistent with the alternative accounts described earlier.

Further evidence consistent with our interpretation of the objective performance data comes from the subjective impressions revealed by the questionnaire data. After each block with the rubber hands present, subjects gave ratings in response to five printed statements (modeled on a study by Botvinick & Cohen, 1998; see Fig. 4). Statements 1 and 2 relate to our claims concerning visual capture of tactile location (Statement 3 may be relevant also, but is more ambiguous because the term “real” within it may have biased subjects to refer to objective rather than subjective reality). We predicted in particular that participants would be more likely to agree with Statement 2 (feeling the vibration in the location of the rubber hands) when the rubber hands were aligned (Experiment 1) versus misaligned (Experiment 2); Statements 4 and 5 were included to control for demand characteristics.

As can be seen in Figure 4, participants in Experiment 1 (rubber hands aligned) responded more positively than participants in Experiment 2 (rubber hands misaligned) to Statements 1 and 2 ($p < .01$ and .04, respectively, by t test), and showed a similar trend for Statement 3. By contrast, there was no such difference between experiments for Statements 4 and 5, confirming the specificity of the subjective impressions induced by aligned rubber hands. We believe that these subjective impressions relate to the visual capture of touch documented by the objective performance measure (i.e., the congruency effects). Consistent with this interpretation, the increase in congruency effects when the rubber hands were present (i.e., the difference between same-side congruency effects with rubber hands present vs. absent) correlated with the ratings produced in response to Statements 1 and 2, $r(19) = .58$, $p < .01$, and $r(19) = .50$, $p < .05$, respectively. That is, those participants who indicated a stronger impression of feeling vibrations where the rubber hands were seen, and of feeling that the rubber hands were their hands, showed a larger increase in cross-modal congruency when the rubber hands were present, as we would expect.

CONCLUSIONS

The objective performance data are consistent with the vibrotactile stimuli being mislocalized toward the rubber hand on the same side, and hence toward the lights “held” by this rubber hand, provided it was aligned with the real hand. Visual distractors produce larger congruency effects when close to the tactually stimulated hand (as shown by Spence et al., 1998, and as confirmed here by the larger congruency effects for same-side distractors). This pattern of effects is consistent with a general principle from many experiments on selective attention within a single modality: larger effects from distractors when placed closer to targets (e.g., Eriksen & Eriksen, 1974). A similar spatial principle evidently applies for targets and distractors in separate modalities also. The increased congruency effect with aligned rubber hands follows from this principle if the vibrotactile stimuli were mislocated toward these rubber hands, and thus closer to the distracting lights. Moreover, the subjective ratings of such tactile mislocations correlated with the objective impact on performance. These results thus suggest visual capture of specifically tactile localization, toward the location of a seen hand.

In these experiments, the visual locations of the rubber hands differed from the true locations of the participants’ real hands, for which proprioception should have provided some information. However, proprioception has less spatial acuity than vision, with particularly high variance when body parts are supported passively in a constant position (Wann & Ibrahim, 1992), as here. Therefore, it

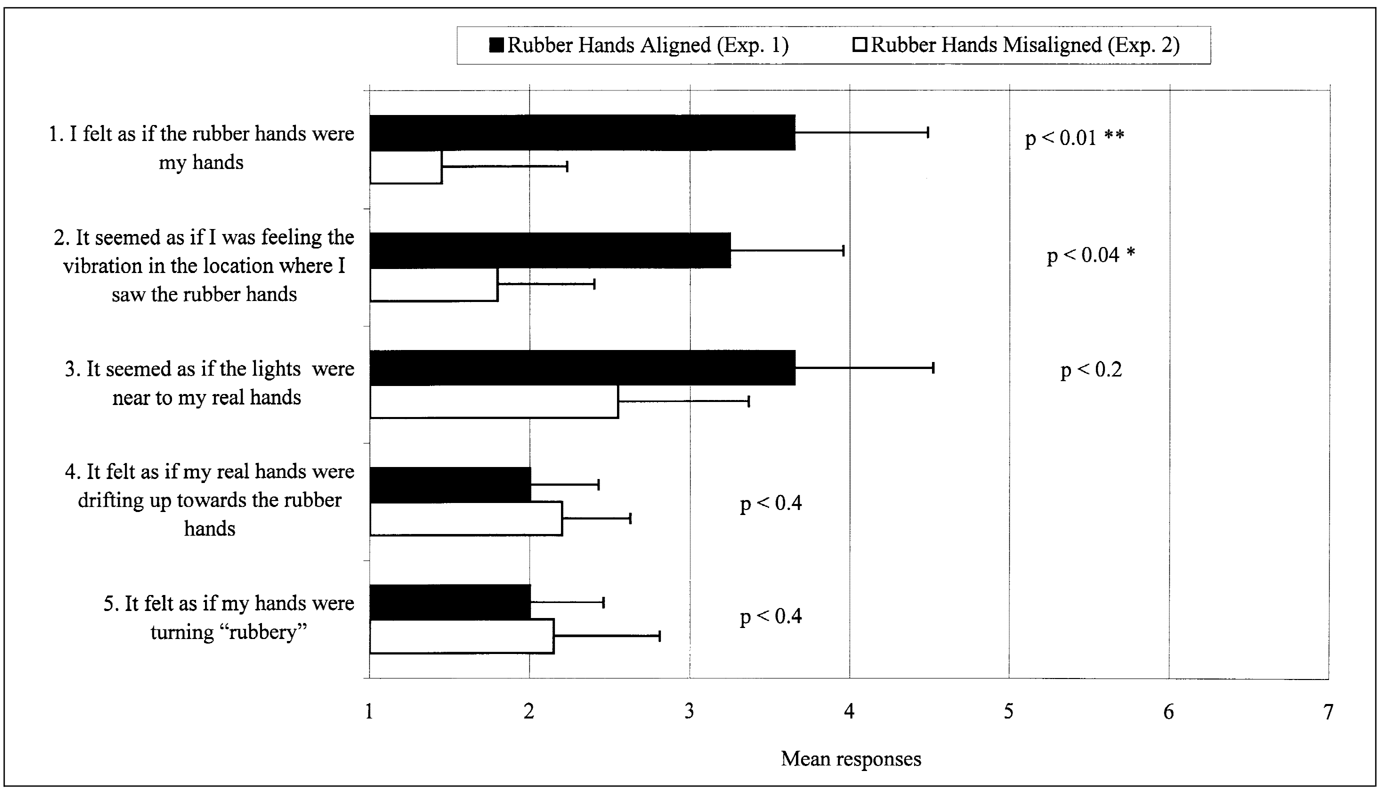

Fig. 4. Mean rating scores, with standard errors, for the five statements from the questionnaire in Experiments 1 (solid bars) and 2 (empty bars). Mean rating score refers to participants’ agreement with each sentence on a 7-point scale, ranging from *totally disagree* (score = 1) to *totally agree* (score = 7). Significance values are indicated with asterisks (*$p < .05$; **$p < .01$) and refer to one-tailed t tests between experiments for each statement.

makes good sense for the brain to weight visual information about posture strongly, especially when the indicated visible location falls within the possible range indicated proprioceptively. We suggest that the reason for visual capture of touch in Experiment 1, but not in Experiment 2, is that the seen posture was proprioceptively possible in the former but not the latter case. Similar principles are thought to apply for audiovisual ventriloquism (Bertelson, 1998). That is, auditory events may be mislocalized toward their apparent visual source only when the location of the visual event (perceived with high acuity) falls within the possible range for the sound location (perceived with less precision).

Our results extend previous findings of visual capture of felt position, in particular those from a related study by Botvinick and Cohen (1998), who were more concerned with adaptation processes in the coding of body posture. They showed that a rubber hand which was somewhat misaligned with the real hand (albeit in an anatomically possible posture, unlike in our Experiment 2) came to be perceived "as if" it was the real hand, following an adaptation phase. During this phase, the unseen real hand was stroked in temporal correlation with seen strokes on the rubber hand. Subjects were more likely to rate the rubber hand as appearing to be their own following adaptation than before adaptation, and their proprioceptive sense of hand location also drifted toward the rubber hand, as revealed by pointing measures. These results agree with ours in the general sense of showing that vision can affect the localization of bodily sensations. However, there are several important differences. In particular, our effects do not require adaptation via fine-grained temporal correlation (the visual capture here relied instead on the higher acuity of vision than proprioception, as explained earlier). Also, our data specifically refer to the localization of tactile events, rather than to proprioceptive drift with adaptation. Finally, our study demonstrates that subjective visual capture has objective performance consequences for tactile discrimination. It would be interesting to combine our method with Botvinick and Cohen's adaptation procedure, to test whether the present objective effect on tactile discriminations can also be modulated by adaptation.

The cross-modal interaction among vision, proprioception, and touch that we have described in this study on normal subjects may relate to some intriguing phenomena related to visual capture in neurological patients. Ramachandran and his colleagues (Ramachandran & Rogers-Ramachandran, 1996; Ramachandran, Rogers-Ramachandran, & Cobb, 1995) described amputees with phantom-limb sensations, who experienced a resurrection of their amputated arm when viewing the moving reflection of their intact arm in a mirror, arranged so that the reflection appeared where the missing limb would have been seen if present. These patients reported proprioceptive and kinesthetic sensations induced by the reflected visual information, and subjectively reported that they mislocalized seen touches on their intact arm toward the reflected visual image that was perceived as the missing limb. More direct evidence for an interaction between vision of the body part and tactile perception in patients has emerged from a recent neuropsychological study by Rorden, Heutink, Greenfield, and Robertson (1999). They described a patient who had partial tactile loss for the left hand after right-hemisphere damage centered on the parietal lobe and who reported stronger tactile sensations when he saw the affected hand being touched (see also Halligan, Hunt, Marshall, & Wade, 1996). If his left hand was placed beneath the table, his objective tactile sensitivity with this hand could be improved by illuminating a light above the table concurrently with the touch immediately below, but only if a rubber hand was placed on the table, in alignment with the real hand below. This neuropsychological result can be explained by the account advocated here—the tactile event should have been localized near to the light only in the presence of an aligned rubber hand (as for the present Experiments 1 vs. 2; see also Graziano, 1999, for related recent findings from monkey electrophysiology).

The conflict situation examined here demonstrates vision's role in determining tactile localization. Only real hands will typically be seen in everyday life, and so vision should usually provide veridical information about their posture, rather than a source of conflict. It therefore makes good functional sense that seeing should influence where people feel touch, as this influence will usually be beneficial, given the high acuity of vision. Because of this likely benefit, the visual contribution to tactile perception may arise automatically. Note that an influence from seeing the rubber hands was found in the present Experiment 1 even though the visual modality was entirely irrelevant to the prescribed vibrotactile task, and even though participants knew cognitively that the rubber hands were not their own (recall that they actually saw the rubber hands being placed on the table between blocks, so no attempt was made to trick them, unlike in most experiments in the tradition of Tastevin, 1937). The visual influence on tactile localization that we have documented thus appears to be cognitively impenetrable, reflecting perception rather than beliefs (Radeau, 1994).

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