NeuroReport 10, 135–138 (1999)

# When a rubber hand 'feels' what the real hand cannot

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**WE examined a patient who was clinically much better at reporting tactile stimulation when he could see his stimulated hand. Experimentally, we found that he had difficulty detecting taps accompanied by a salient (but not predictive) light located directly above his concealed hand. However, his performance was dramatically improved if the light was attached to a rubber hand situated in line with the patient's hidden hand. Previous studies have suggested that tactile sensitivity can be improved by nearby visual stimulation. However, our effect shows that crossmodal sensory facilitation does not only depend upon simple spatial proximity alone. Rather, a simultaneous visual event dramatically improves perception of touch specifically when it is attributed to the perceiver's stimulated limb. *NeuroReport* 10:135–138 © 1999 Lippincott Williams & Wilkins.**

**Key words**: Crossmodal integration; Left somatosensory impairment; Right hemisphere lesion

## Introduction

People who suffer cortical unilateral brain lesions frequently report loss of tactile sensation in the arm contralateral to their lesion. Halligan and colleagues [1] described a patient who reported feeling taps only when he could see the tapping device. This dramatic result appears to demonstrate that visual information can help 'recover' tactile sensation. This work emphasizes the interplay of crossmodal information in the human brain. However, there is a confounding factor in this study: when the patient can see the tapping device the visual information always perfectly predicts the tactile information. It is conceivable that the patient is simply reporting his visual experience. In other words, the patient may be shifting his criterion for reporting a tap based on the visual information. Therefore, it is important to replicate this finding using a paradigm where the visual stimuli do not predict the tactile stimuli. With such a design one could determine whether the visual information only changes the tactile criterion (reporting more touches regardless of whether or not a tap was applied) or actually changes tactile sensitivity (accurately reporting more tactile stimuli without raising more false alarms).

If the effect reported by Halligan and colleagues [1] is due to a change in tactile sensitivity, there are at least two plausible (though not mutually exclusive) explanations for their results. First, the proximity of the two simultaneous events in both the tactile and visual modalities may cause an enhanced perception of both modalities. Electrophysiologists have reported such 'enhancement' of multimodal information [2,3] from common locations. This explanation makes sense in Bayesian terms: a near threshold tactile stimulus which is accompanied by a temporally synchronous and spatially proximal visual event is unlikely to be the result of random noise compared with an equivalent tactile stimulus occurring in isolation. A second possible interpretation would be that the enhancement found by Halligan and colleagues [1] is not merely based on the spatial proximity between the visual and tactile information, but rather on the fact that both the sight and touch are being attributed to the same limb. We report a new paradigm that objectively distinguished between these explanations.

We present a paradigm that allows us to test objectively whether attribution of visual information improves tactile detection. In our design, a near threshold tap is applied in half the trials and the patient is asked to make an unspeeded judgement regarding whether he perceived a tap. This allows us to objectively assess both the sensitivity and the criterion with signal detection theory. During each trial a visual flash occurs, regardless of whether or not there is a tap during that trial. Therefore, the visual information is in no way predictive of the tactile stimulation. In order to test whether the attribution of the visual flash improves tactile stimulation the light is mounted either to the experimenter's right hand (misaligned with the patient's hand) or (in separate blocks, and at the same external positions) to a rubber hand mounted in line with the patient's own hand (appearing to be the patient's own hand). Crucially, in both conditions the light and the tap are presented at the same spatial positions. If enhancement is based simply on the spatial proximity between the visual and tactile stimuli there should be no difference between these two conditions. Alternatively, if attribution modulates tactile perception, performance should be better when the light appears to come from the patient's own hand rather than from the experimenter's hand.

## Materials and Methods

*Patient details:* Patient GP is a right-handed 64-year-old man with a large right hemisphere fronto-temporal arachnoid cyst (Fig. 1). At the time of testing, GP was suffering from acute increased intracranial pressure due to the cyst's obstruction of the right ventricle. Due to the diffuse nature of the cortical compression we were unable to localize which regions were responsible for GP's lack of tactile sensitivity (or, indeed, which regions were still capable of improving tactile sensation when his hand was visible). We studied him immediately prior to an operation conducted in order to reduce the intracranial pressure. At this time, he suffered from severe left spatial neglect: for instance, eating food only from the right side of his plate, only shaving the right side of his face, as well as gazing predominantly to the right side. On a standard visual-search cancellation task [4] he correctly found the majority of targets on the right side of the field (9 of 10) while consistently neglecting the targets in the left half of the field (marking 0 out of 10). On clinical testing, GP acted in a similar fashion to the patient reported by Halligan *et al.*: he only reported feeling taps to his left hand when he could see the hand both when the taps were applied by hand, and with the solenoids described below. Following his operation, GP showed a remarkable recovery of his tactile sensitivity, accurately reporting taps regardless of whether his arm was visible, although he continued to suffer from hemispatial neglect.

*Procedure:* The patient was seated with arms positioned on arm rests underneath a table, to occlude view of his hands. A solenoid (RS 347-652) modified to deliver brief taps was attached to the index finger of his left (contralesional) hand, which had impaired sensitivity. In half the trials ('target'), a brief 30 ms tap was applied. These target trials were randomly intermingled with 'catch' trials, where no tactile stimulation was presented. In order to mask any possible auditory detection of the tap, a second solenoid mounted under the table was activated on every trial, at the same time as the tactile stimulus in the target trials, but also on catch trials. The target solenoid was virtually silent as hitting the finger cushioned its movement; the second solenoid always traveled to its endstop, making a considerably louder clicking sound. To ensure that the patient was not merely reporting his visual experience, we always presented a visual event near his occluded hand, regardless of whether a tap was applied. During each trial a yellow light (a small LED) was illuminated for 60 ms (the offset of this light coincided with the offset of the solenoid, with a computer controlling all stimuli to ensure precise timing). At the end of each trial, the patient was asked to make an unspeeded response as to whether or not his hand had been tapped. If the patient had been merely reporting his visual experience, he would not have been able to discriminate between the target trials and the catch trials, as the visible information was identical across these conditions.

In order to test the influence of attributing the visual events to the patient's limbs, we compared performance in trials in which the LED was mounted to the right index finger of the experimenter (who sat on the opposite side of the table) to trials in which the LED was mounted to the index finger of a rubber hand (positioned directly above the patient's own hand; Fig. 2). The alignment of the rubber hand gave the impression that the light was attached to the patient's own hand, while still concealing the motion of the tapping device from the patient's view. In both conditions, the light was mounted at exactly the same location on the table-

FIG. 1. MRI scans (T1 weighted) from patient GP at the time of testing. This scan was normalized using the linear-alignment function from SPM software <www.fil.ion.bpmf.ac.uk/spm/>. These six slices correspond to Talairach and Tournoux [22] planes of −14, −2, 10, 22, 34, 46 mm, respectively.

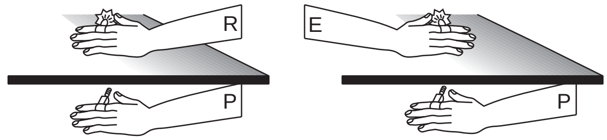


FIG. 2. Schematic illustration of the experiment. The patient's left hand (P) was hidden beneath a table, and a tapping solenoid was attached to his left index finger. A light was visible on top of the table, directly above the patient's hand. The left panel illustrates the condition where the light was mounted to a rubber hand (R), aligned with the patient's hand. The right panel illustrates the condition where the light was attached to the experimenter's hand (E), which was not aligned with the patient's hand. The patient was significantly better at detecting taps when the light was attached to the rubber hand (left panel) than when the light was attached to the experimenter's hand (right panel).

top covering the patient's hand. These two conditions were run in separate blocks of 50 trials (each with 25 target trials and 25 catch trials, where no target was presented). We counterbalanced the order of these blocks to control for practice and fatigue effects. In total, four blocks in each condition were run in two testing sessions.

## Results

When the light was fastened to the experimenter's hand, GP only reported 32 out of 100 targets. However, when the rubber hand was presented, he reported 51 out of 100 targets. This significant difference (two-tailed Fisher test, $p < 0.01$) confirms that performance was improved by the addition of the rubber hand. Importantly, this improved performance cannot be attributed simply to a greater willingness to report targets (i.e. a change in criteria) as GP was no more likely to report targets in catch trials when the light was affixed to the rubber hand (4/100) than when the light was mounted on the experimenter's hand (4/100).

## Discussion

Halligan *et al.* [1] previously observed a patient who only reported tactile sensations when he could see the stimulating device. By using a rubber hand and an objective threshold, our study greatly extends these findings, to rule out the possibility that the patient might simply be reporting his visual experience. In our study, the tactile, auditory and target-related visual (LED) stimulation were identical across conditions, the only difference being whether the LED flash was attributed to the experimenter's hand or to the dummy hand which the patient felt to be his own.

Recent research [6] has indicated that, under appropriate conditions, healthy individuals can experience the subjective illusion that a rubber hand is their own. Our study demonstrates that this illusion can lead to objectively improved tactile sensation in an individual who has impaired tactile awareness due to brain damage. Work by Ramachandran and colleagues [7] on the phantom limbs experienced by some amputees has revealed the dramatic effect that visual inputs can have on subjective feelings concerning body parts. The authors speculated that the amputees' subjective reports demonstrated the depth of interaction between touch and vision, in contrast with the 'strictly modular, hierarchical model of the brain currently in vogue' ([7], p. 490). Our own empirical findings strongly support this view, the visual illusion caused by the rubber hand dramatically improved GP's ability to feel tactile stimuli.

Electrophysiologists have described bimodal neurons, which respond to either tactile or visual stimuli, in premotor area 6 [2,8,9], parietal areas 7b [5,10–14] and VIP [15], and the putamen [3]. These studies demonstrate the integration of visual and tactile information. Of particular interest, some of these bimodal cells in the monkey brain fire more vigorously in response to a visual stimulus when it is near the perceived location of the monkey's arm [2,3,10,16]. However, the properties of these cells have usually been described in terms of the simple spatial proximity between the limb and the visual event. For example, Graziano and Gross [16] note that the visual response of cells is modulated by arm position, regardless of whether the arm is visible or hidden from view. In contrast, the modulation we report can not be described in terms of proximity alone.

Analogous to the electrophysiological work in monkeys, recent studies with humans have demonstrated bimodal links between visual and tactile perception. This work, on healthy adults [17] and on a neurological patient [18], suggests that visual events near a hand can modulate discrimination of tactile events. Again, each of these studies stresses the importance of spatial proximity between visual events and hand position.

In contrast to these previous studies in monkeys and humans, proximity alone cannot account for our findings, since the distance between the light and the tactile event were the same regardless of whether the rubber hand was present. Our findings suggest instead greater tactile enhancement by visual information when it is attributed to the same limb as the tactile input (i.e. the patient felt the rubber hand to be his own, but this was not true for the experimenter's hand). This effect of enhanced tactile perception when visual events are attributed to the same limb has recently been replicated in neurologically healthy adults [19].

Indeed, our proposal that visual and tactile events interact more strongly when attributed to the same limb may resolve an apparent paradox in the current literature. Mattingley *et al.* [20] and Ládavas *et al.* [21] reported studies with patients who suffer from left tactile extinction (failing to report a tap to the left hand when presented with a simultaneous tap to the right hand). Mattingley et al. found that a visual event near the right hand generally did not extinguish detection of a tap on the left hand (64% of taps were reported). In contrast, patients described by Ladavas *et al.* were very poor at detecting taps (only 25.5% reported) to the left hand when presented in conjunction with a visual event near the right hand. Critically, in the Ládavas *et al.* study the right hand was visible (therefore the visual event may be attributed to the limb) whereas in the Mattingley *et al.* study the arms were occluded from view.

## Conclusion

This study demonstrates improved tactile sensitivity in a neurological patient when concurrent visual information is perceived to come from the same limb. Critically, this enhancement can not be attributed to the simple proximity between the visual and tactile stimuli. This suggests that tactile perception is modulated by high level visual information. The link between visual attribution and tactile perception has widespread implications including, for instance, in the field of ergonomic design. Furthermore, our paradigm could be adapted for single cell recording to identify the regions involved in this high level integration of crossmodal information.

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ACKNOWLEDGEMENTS: This research was supported by the Wellcome Trust.

**Received 30 September 1998; accepted 23 October 1998**