Can vision of the body ameliorate impaired somatosensory function?

Andrea Serino\textsuperscript{a,b,*}, Alessandro Farnè\textsuperscript{a,b,1}, Maria Luisa Rinaldesi\textsuperscript{c}, Patrick Haggard\textsuperscript{d,e}, Elisabetta LÀdavas\textsuperscript{a,b}

\textsuperscript{a} Dipartimento di Psicologia, Università degli Studi di Bologna, Italy
\textsuperscript{b} Centro Studi e Ricerche in Neuroscienze Cognitive, Cesena, Italy
\textsuperscript{c} Istituto di Riabilitazione Santo Stefano, Porto Potenza Picena, Macerata, Italy
\textsuperscript{d} Department of Psychology, University College London, United Kingdom
\textsuperscript{e} Institute of Cognitive Neuroscience, University College London, United Kingdom

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Abstract

Viewing the body is reported to improve tactile acuity [Kennett, S., Taylor-Clarke, M., & Haggard, P. (2001). Non-informative vision improves the spatial resolution of touch in humans. \textit{Current Biology}, 11, 1188–1191]. The aim of the present study was to investigate whether this effect might be useful in improving somatosensory deficits of brain damaged patients. To support this proposal, we firstly tested the hypothesis that vision might modulate tactile performance when tactile information is limited. Thirty-two healthy subjects performed a two points discrimination task (2PDT) in three conditions: looking at their stimulated forearm, at a neutral object or at a rubber foot. The results showed that the effectiveness of visual enhancement of touch varies as a function of subjects’ tactile acuity. Moreover, the accuracy in 2PDT was higher when viewing their arm only in subjects with lower tactile sensitivity. To directly demonstrate that viewing the body might ameliorate tactile deficits, the same experiment was conducted on 10 brain damaged patients suffering a reduced somatosensory sensitivity. An amelioration of the performance was found in viewing arm condition. These findings suggest that the interaction between different sensory modalities might be effective in ameliorating deficits in single modalities.

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1. Introduction

In 1997, Halligan and colleagues provocatively asked consultant neurologists why somatosensory assessment was conventionally performed with patients’ eyes closed. This question arose from the observation that, at least in some cases, patients’ performance was better if they could see the affected limb during the assessment (Halligan, Marshall, Hunt, & Wade, 1997). This observation has been supported by recent studies showing the relevance of visual information related to the body in tactile perception.

More specifically, it has been shown that healthy subjects are faster and/or more accurate in detecting \textit{invisible} tactile stimuli if they look at their stimulated body part (Kennett, Taylor-Clarke, & Haggard, 2001; Press, Taylor-Clarke, Kennett, & Haggard, 2004; Tipper et al., 1998, 2001; Whiteley, Kennett, Taylor-Clarke, & Haggard, 2004). For instance, Kennett and colleagues (2001) demonstrated that tactile thresholds on the forearm were significantly better when subjects looked at their arm, compared to looking at a neutral object presented at the same spatial location using a mirror. Crucially, vision of the stimulated body part was non-informative about tactile stimulation, but did provide a perceptual context which reliably facilitated tactile spatial acuity. We call this basic effect \textit{visual enhancement of touch}. Moreover, Press et al. (2004) showed that visual enhancement of touch occurs only in tasks requiring tactile spatial computation near to performance limits and not in easier tasks, or non-spatial tasks. These findings suggest that vision of the body facilitates tactile performance when it is close to threshold levels. There-
fore, visual enhancement of touch should occur specifically in subjects presenting lower somatosensory sensitivity. If this is the case, then it might be effective in ameliorating tactile perception in patients affected by somatosensory deficits due to brain damage.

This effect might have important clinical applications, since loss of body sensation occurs in about 50% of stroke patients (Feigenson, McCarthy, Greenberg, & Feigenson, 1977; Feigenson, McDowell, Meese, McCarthy, & Greenberg, 1977) and these deficits impair patients’ ability to manipulate and use objects, to feel noxious stimuli, to control movements. In the most severe cases, sensory deficits can lead to a complete non-use of an upper limb which nevertheless shows normal motor function. For these reasons, somatosensory impairments can limit patients’ functional recovery after stroke in everyday life (Carey, 1995; Van Buskirk & Webster, 1995). Partial spontaneous recovery of somatosensation may occur, mainly within 3 months post-stroke, however, many deficits persist in the chronic phase and require specific intervention (Julkunen, Tenovuo, Jaaskelainen, & Hamalainen, 2005; Stern, McDowell, Miller, & Robinson, 1971). Prolonged training, consisting of tactile discrimination exercises, object recognition or joint position sense, can induce a moderate improvement in somatosensory performance (Carey, Matyas, & Oke, 1993; Smania, Montagnana, Faccioli, Fiaschi, & Aglioti, 2003; Yekutieli & Gutman, 1993). However, in those studies the stimuli (Carey et al., 1993) or the tasks (Smania et al., 2003; Yekutieli & Gutman, 1993) used in the rehabilitation were quite similar to those used in the testing phase. Thus, the generalisation of the acquired abilities remains uncertain (Carey & Matyas, 2005).

In the present study we verified whether a new approach, based on multisensory interaction between touch and vision, can be effective in ameliorating tactile perception in patients affected by somatosensory deficits due to brain damage. In particular, the hypothesis that viewing the body might improve tactile sensitivity was investigated both indirectly and directly in two experiments conducted on healthy subjects and on patients suffering somatosensory deficits.

First, previous studies already demonstrated a basic visual enhancement of touch (Kennett et al., 2001; Press et al., 2004; Whiteley et al., 2004). However, there are large individual differences between subjects in the effectiveness of visual enhancement (Fiorio & Haggard, 2005). Moreover, the effect was found in a difficult spatial discrimination task, but not in easier tasks (Press et al., 2004). Combining these two findings, we hypothesized that visual enhancement of touch varies as a function of subjects’ tactile acuity, being greatest for subjects with poor acuity and poor tactile performance. This hypothesis was studied by assessing 32 healthy subjects’ tactile acuity with the traditional two point discrimination task (2PDT; Weinstein, 1968). Subjects could be touched on their forearm either by one or two stimulators, separated by different distances. They were asked to verbally respond only when they felt two taps. The task was administered under three visual context conditions, i.e. while subjects were looking at their stimulated forearm (arm condition), at a neutral object (neutral condition) or at a rubber foot (foot condition). Tactile stimuli were always invisible. Subjects always gazed at the same spatial position, i.e. where the subject’s arm was touched, by means of a semi-silvered mirror. Two related predictions were tested. First, if the effectiveness of visual enhancement of touch is specific to poor tactile performance, then the difference between arm and neutral conditions should be negatively correlated with the level of performance in the neutral condition. Second, if the previous hypothesis would be confirmed, then an improvement of tactile acuity should be expected in the arm condition compared to neutral condition only in subjects presenting low tactile acuity. Finally, we added a new control, the foot condition. In previous studies (Kennett et al., 2001; Press et al., 2004; Whiteley et al., 2004), visual enhancement of touch was always demonstrated by comparing viewing the body with viewing a neutral object, usually a wooden box of various dimensions. However, a neutral object is much less salient and less arousing than a part of the human body. Thus, to control for any effect due to complexity of visual stimulation, we also presented subjects with a stimulus matched for shape, colour and dimension to the stimulated body part, as a realistic copy of another body part.

The second experiment was conducted to directly test whether visual enhancement of touch might be effective in ameliorating somatosensory deficits in brain damaged patients. To this aim, we studied 10 patients affected by cerebrovascular disease, selected for the presence of reduced – but not completely absent – somatosensation in the upper limb, as assessed by a standardized clinical test (Winward, Halligan, & Wade, 2002). We hypothesized that, where some residual tactile function is present, vision might enhance its spatial resolution, and thus make it more functionally useful. Patients showing hemianopia and hemispatial neglect were excluded from the study, because these deficits may affect their perception of the different visual contexts. The experimental conditions were the same as in the first experiment.

2. Methods

2.1. Subjects

Thirty-two right-handed healthy participants (aged 20–30 years, 20 females) reporting normal or corrected-to-normal vision and normal touch, took part in the first experiment. Ten patients with radiological and clinical evidence of unilateral cerebrovascular lesions, occurred at least 1 month before assessment, participated in the second experiment. Five patients showing right and five left brain damage (RDB and LBD, respectively) were studied. Patients were recruited in Santo Stefano Hospital, Porto Potenza Picena, Italy, where they were undergoing traditional physiotherapy and motor treatments at the time of testing. Inclusion criteria were the presence of a somatosensory deficit, and in particular a loss of tactile acuity, as documented by a pathological performance in a standardized clinical test: two point discrimination subtest from the Rivermead Assessment of Somatosensory Performance (RASP; Winward et al., 2002, see below) was administered. This test requires patients to discriminate between single or two tactile stimuli, separated by 3–5 mm. Patients unable to perform the task at any distance were considered to show impairment on this test, as recommended by test’s normative data (see Table 1). Exclusion criteria were: complete absence of tactile sensitivity; presence of widespread mental deterioration (Mini-Mental State Examination: cut off score 24) or psychiatric disorders; arousal or behavioural control inadequate for a 60-min experimental session; hemispatial neglect and hemianopia; comprehension deficits. Patients’ demographic and clinical details are presented in Table 1. All the subjects gave their informed consent to participate to the experiment, which was approved by
2.2. Materials and procedure

During the experiment, eight miniature solenoid tappers were attached to the healthy participant’s (Experiment 1) or patient’s (Experiment 2) ventral forearm, 50 mm proximal to the wrist. For healthy subjects, the right forearm was stimulated, whereas patients were assessed on their contralesional affected limb. The solenoids were aligned longitudinally with the subject’s forearm and were separated one from each other by 15 mm. The solenoids were invisible to the subject, since they were held within and covered by a small wooden box (12 cm × 2 cm), whose lower surface was open and placed on the subject’s skin.1 The solenoids produced a supra-threshold vibrotactile stimulus oscillating at 100 Hz for a total duration of 500 ms. Either one or two solenoids could be activated in each trial. Subjects were asked to verbally respond “two” only when they perceived two taps. Subjects’ responses were logged manually via computer keyboard by the experimenter and performance was automatically scored by computer software at the end of the session. Twenty-four single taps, randomly provided by one of the 8 solenoids, and 24 simultaneous double stimuli, with 3 different separations (i.e. 30, 60 and 90 mm) were randomly given.

The task was performed in three visual context conditions, viewing the arm (arm condition), viewing a neutral object (neutral condition), and viewing a rubber foot (foot condition). The conditions were tested in counterbalanced blocks. During each condition, the subjects’ arm was placed in a box, beneath a semi-silvered mirror (see Fig. 1A). When the box was illuminated, subjects saw their arm through the mirror (arm condition, see Fig. 1B), whereas when the light was off they saw either a 30 cm × 20 cm wooden rectangle (neutral object, see Fig. 1C) or a rubber foot (foot condition, see Fig. 1D), which were suspended above and reflected by the mirror (see Fig. 1). The rubber foot was a prosthetic reproduction of a human foot. A rubber foot, instead of subjects’ real foot, was chosen as a control condition to keep external spatial location at which subjects gazed constant across conditions. Holding their real foot in the location of the arm was too uncomfortable, especially for patients. On the top of both the neutral object and the rubber foot, a box of the same dimension and material was placed to resemble the small wooden box containing the solenoid array. Identical visual markers were placed on the upper surface of the solenoids box and of its reproductions. Prior to the each experimental condition, the visual marker on the solenoids box was aligned with that on the object or on the rubber foot. During testing, an experimenter controlled that subjects maintained their gaze on the visual marker. Headphones providing white noise masked any auditory cues generated by the stimulators.

3. Results

3.1. Experiment 1

Healthy subjects almost never produced false alarms (i.e. ‘two’ responses to a single tap were less than 5%). Percentage of correct responses to double taps was therefore taken as a measure of 2PDT accuracy. Response to double taps at the three different distances were collapsed in order to get a sufficient set of data for analysis (i.e. 24 double trials).2

To test whether the amount of visual enhancement of touch varies as a function of subjects’ tactile acuity, an index of effectiveness was calculated as the difference between-subjects’ performance when viewing the arm and the neutral condition, the latter being a baseline condition for tactile sensitivity, controlling for spatial attention orienting. A linear regression analysis was performed to relate the enhancement to accuracy in the neutral condition. The results showed a negative relationship ($R^2 = .24; \beta = -.49; p < .005$): subjects with a lower performance when viewing the neutral object, showed a greater improvement when viewing their arm. On the contrary the performance in neutral condition was not related to any change of the performance between foot and neutral condition ($R^2 = .003; \beta = -.047; p = .78$).

Second, to demonstrate that viewing the arm can significantly influence touch specifically in subjects with poor tactile performance, the total sample of participants was divided in two groups according to their performance in the neutral condition. Subjects

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1 Results from a control experiment assured that subjects could not actually see the stimuli. Ten healthy subjects were asked to distinguish between one or two taps only by looking at the solenoids wooden box placed on the experimenter’s forearm. Twenty stimuli (10 single and 10 double taps) were delivered. Average accuracy was 54%, and did not differ significantly from chance ($\chi^2 = 10, p = .75$).

2 To test whether spatial separations between stimuli was relevant for the effect, an ANOVA was also performed with group as between-subjects factor and condition (arm, neutral and foot) and separation (30, 60 and 90 cm) as within-subjects factor. The three-way interaction was not significant.
performing below the 95% confidence interval for the population mean, which fell at 67% accuracy, were classed as low accuracy (LA group, n = 13), whereas the remaining subjects were included in the high accuracy group (HA, n = 19). A 2 × 3 ANOVA was then conducted on accuracy scores with group (LA and HA) as between-subjects factor and condition (arm, neutral and foot condition) as within-subjects factor. The interaction group × condition was significant \( F(60, 2) = 3.46; p < .04 \). Post hoc comparisons were conducted with Newman–Keuls test and showed a significant improvement of the performance in the arm
condition (mean accuracy = 64%) compared to the neutral condition (55%; \( p < .03 \)) only in the LA group, this showing visual enhancement of touch. Moreover, viewing the rubber foot had no effect on the performance, since in LA group the accuracy in the foot condition (56%) was lower than in the arm (\( p < .04 \)) and equal to the neutral condition (\( p > .9 \)). Finally, no significant modulation of the performance among the conditions was found in the HA group (79%, 83% and 83% in arm, neutral and foot conditions, respectively, \( p > .3 \) in all comparisons) (see Fig. 2).

3.2. Experiment 2

In contrast to healthy subjects, patients made many false alarms (more than 25%), responding “two” to single-tap stimuli. Therefore, the \( d' \) index was used as a more appropriate measure of perceptual sensitivity. \( C \) scores were also calculated as a measure of response bias in subjects’ post-perceptive decision criterion (Krantz, 1969).

A 2 × 3 ANOVA was conducted on \( d' \) scores with group (LBD and RBD patients) as between-subjects factor and condition (arm, neutral and foot condition) as within-subjects factor. The effect of condition was significant \([F(2, 16) = 14.63; \ p < .0003] \). Newman–Keuls post hoc tests showed that patients’ performance was better in arm condition (mean \( d' = 1.8 \)) compared both to neutral (1.30; \( p < .03 \)) and foot condition (.72; \( p < .0004 \)). Moreover, in patients performance in the neutral condition was better than in the foot condition (\( p < .02 \)) (see Fig. 3).

Neither the effect of group nor the interaction group × condition were significant: RBD and LBD patients showed a similar performance in arm (1.96 and 1.64, respectively), neutral (1.54 and 1.06) and foot condition (1.14 and .29). It worth noting that 2 out of 10 patients did not show visual enhancement of touch, since their performance did not improve from neutral to arm condition. Both of them presented lesions in the right hemisphere, involving in one patient the internal capsula (patient R2) and in the other patient the parietal and temporal lobes (R5). However, from this evidence, it is not possible to make any inference about the role of these structures in modulating visual enhancement of touch, because other patients, affected by similar lesions (R3 and R4), showed the effect.

To demonstrate that vision of the arm altered only tactile acuity without also shifting the response criterion, \( C \) scores were compared across conditions. A 2 × 3 ANOVA with group and condition as main factors showed no significant effect: the response criterion did not vary between arm (mean \( C = .10 \)), neutral (.02) and foot condition (.09) (\( p > .36 \)).

4. Discussion

We investigated whether tactile perception could be improved in patients with somatosensory loss by viewing the stimulated body part. This hypothesis was confirmed both indirectly and directly by the results of the two experiments conducted on healthy subjects and on brain damaged patients.

The results of the first experiment showed that tactile sensitivity on the forearm improved in healthy participants when looking at their stimulated arm compared to a neutral object, presented in the same spatial location. This effect could not be due to spatial attention linked to gaze, because gaze direction and depth were constant across all visual context conditions. Moreover, touch improvement could not be either due to perceptive salience of visual information related to the body. Indeed, viewing a rubber foot, which is a rich and complex stimulus, with the same physical and spatial characteristics, and some bodily connotations, as the tactitley stimulated body part, did not enhance touch, since no amelioration of tactile acuity occurred compared to viewing a neutral object.

By studying a larger sample than previous studies (Kennett et al., 2001; Press et al., 2004; Whiteley et al., 2004) we investigated the distribution of the enhancement effect. We found visual enhancement was inversely related to a baseline measure of tactile acuity. In addition, significant enhancement was present only in subjects presenting poor tactile acuity. These findings suggest that visual enhancement of touch occurs specifically when tactile information alone is limited. The case of acquired somatosensory deficits due to brain lesions can be considered an extreme manifestation of this situation. Results from the second experiment showed that the tactile acuity of brain damaged patients, selected for presence of a somatosensory deficit, improved when they looked at their arm relative to viewing a neutral object and a
rubber foot. In addition, viewing a rubber foot in the spatial location normally occupied by the arm induced a further decrease of tactile performance in patients. This unexpected result might be due to an interfering effect produced by an incompatibility between body schema and body-related visual information (Farne, Pavani, Meneghello, & Ladavas, 2000; Pavani, Spence, & Driver, 2000).

Taken together the present findings suggest that multisensory integration might improve the sensitivity of unisensory modality in situations of low performance or deficit. This suggestion is compatible with a general principle of multisensory integration, the inverse effectiveness rule (Stanford, Quesy, & Stein, 2005; Stein, Jiang, & Stanford, 2004; Stein & Meredith, 1993). According to this principle, multisensory systems show an enhanced response when weakly effective unisensory stimuli are combined; conversely, the magnitude of multisensory enhancement is much reduced, or absent, when strongly effective unisensory stimuli are presented. This principle suggests a possible functional role of multisensory integration in ameliorating the performance of perceptive systems, when a poor information derives from unisensory channels.

Analogous propriety seems to reflect also at level of sensory detection in humans: converging evidence (Bolognini, Frassinetti, Serino, & Ladavas, 2005; Frassinetti, Bolognini, & Ladavas, 2002; McDonald, Teder-Salejarvi, & Ward, 2001) showed that the detection of visual stimuli was improved, by concurrent acoustical stimulation, only if visual stimuli were degraded rather than being presented clearly above thresholds. These results support the proposal that multisensory integration is highly effective when the information derived from unisensory channels is weak. This general principle was also demonstrated in the clinical field, in particular in patients with visual field and visuo-spatial deficits (Frassinetti, Bolognini, Bottari, Bonora, & Ladavas, 2005) and in rehabilitation of patients with hemianopia (Bolognini, Rasi, Coccia, & Ladavas, 2005). The present study shows that inverse effectiveness principle is valid also for the interaction between touch and vision of the body.

This finding might have important and new application for rehabilitation: multisensory stimulation may represent an alternative way to enhance somatosensory performance in case of brain damage. Most current treatments for rehabilitation of somatosensory deficits prevent the patient from seeing the relevant body part. For instance, usually patients lie supine during physiotherapy, with their eyes closed, or looking at the ceiling, while physiotherapists stimulate their affected limbs. On the contrary, our data suggest that looking at the stimulated body part might positively boost somatosensory recovery.

Performance enhancement due to vision of the body might involve two distinct processes. The first would be a short term functional improvement in itself, as measured here. This process could also serve to promote further long term recovery of somatosensation. Somatosensory deficits are commonly due to lesions involving the primary somatosensory cortex (SI) (Wikstrom et al., 2000). Neurophysiological studies on healthy subjects suggest that visual enhancement of touch involves changes in SI activity (Fiorio & Haggard, 2005; Taylor-Clarke, Kennett, & Haggard, 2002). Therefore, a short term modulation in the activity of SI, which is traditionally considered a totally unisensory brain area, occurs when concurrent visual information regarding the stimulated body part is provided (Haggard, Taylor-Clarke, & Kennett, 2003). The modulation of SI activity might be due to backward projections from multisensory brain areas (Bremmer et al., 2001; Macaluso & Driver, 2005; Macaluso, Frith, & Driver, 2000), probably located in parietal lobe (Duhamel, Colby, & Goldberg, 1998; Fogassi et al., 1996; Graziano, Yap, & Gross, 1994; Ro, Wallace, Hagedorn, Farne, & Pienkos, 2004). Moreover, an emerging body of evidence now shows the existence of direct projections between different primary sensory areas (see Ghazanfar & Schroeder, 2006; Schroeder & Foxe, 2005 for recent reviews). Therefore, feed-forward connections between visual and somatosensory areas might also contribute to the form of visuo-tactile interaction shown in the present study.

When brain lesions affect SI, continuously visual reinforcement of tactile experience might cause both short term modulation of surviving SI networks, and might also be effective in promoting a long term reorganization of affected areas. This process might contribute to the recovery of somatosensation after stroke, since a single case study recently showed that somatosensory recovery is strictly associated to the re-emergence of activation in somatosensory cortices (Carey et al., 2002).

Indeed, a very general principle of rehabilitation is that providing afferent information to an affected function is crucial to stimulate and promote its recovery (Wilson, 1998). Sensory experience due to incoming information to a partially deafferented neural circuit might promote experience-dependent changes in synaptic connectivity within that circuit. These changes could promote a plastic reorganization of damaged brain systems (Robertson & Murre, 1999; Taub, Uswatte, & Elbert, 2002).

In conclusion, the present results indicate that viewing the body can improve tactile sensation in patients with somatosensory deficits. This interaction between vision and touch is effective in an immediate enhancement of somatosensory function, and might also promote the recovery of somatosensation. In particular, descending modulatory inputs from visual body representation areas might provide important stimulation necessary to drive the reorganization of damaged brain areas after stroke.

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References


