Beyond the window: multisensory representation of peripersonal space across a transparent barrier

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Abstract

A large body of neuropsychological evidence has been recently provided showing that humans can code visual objects in nearby space through multisensory visuo–tactile integrative processes, which share several similarities with the functional properties of bimodal neurons documented in neurophysiological studies. In particular, the phenomenon of visuo–tactile extinction reveals that crossmodal integration may take place in a privileged manner within a limited sector of space closely surrounding the body surface, i.e. in the near peripersonal space. Here we report that visuo–tactile extinction can seemingly be obtained when a physical, transparent barrier is interposed between the patients’ hand and a proximal visual stimulus. These findings show that visuo–tactile representation of peripersonal space can be formed despite the subject’s explicit awareness concerning the physical impossibility for the hand to be touched. This phenomenon indicates that multisensory integrative processing can occur in a bottom-up fashion without necessarily being modulated by more ‘cognitive’ processes. Such integration may be functionally important for automatic reactions such as head turning or hand withdrawal.

Keywords: Multisensory; Peripersonal space; Tactile extinction; Crossmodal

1. Introduction

Imagine you are quietly observing the sunset, looking out of a window in the countryside. Suddenly, a bee flies towards your hand from outside. After a few milliseconds, you might be quite disappointed and wonder why you flinched and withdrew your hand, since you knew perfectly well that the bee had no chance of stinging your hand because a solid barrier, the window pane, was there to protect it. In several species including humans, avoidance reactions such as hand withdrawal or head turning are triggered by images of objects that grow in size and are present in infants as young as 1 week (Ball et al., 1983; Dunkeld and Bower, 1980). Escaping behaviour can be evoked in humans even if the object is projected on a screen, thus having no chances of touching the subject (King et al., 1992).

In evolutionary terms, visually based detection of nearby objects would be very useful to prepare...
appropriate motor reactions. Cues about direction of motion in depth and time to collision can be used to successfully avoid or achieve collision (Regan and Gray, 2000), and collision-sensitive neurons triggering avoidance movements have been reported in the pigeon and locust (Rind and Simmons, 1999). In higher vertebrates, detection of nearby objects can be derived by integrating multiple sources of sensory information (Spence and Driver, 2002). An ever-growing body of evidence supports the notion that visual space surrounding the body (peripersonal space) in the monkey is coded through multisensory integration at the single-neuron level (Duhamel et al., 1991, 1998; Graziano and Gross, 1995, 1998; Rizzolatti et al., 1981, 1998). The putamen, some parietal and premotor areas contain multisensory neurons with tactile and visual receptive fields (RF) whose locations are roughly matched in space. These neurons respond both to cutaneous and visual stimuli presented close to a given body part (e.g., the head or the hand) where the tactile RF is located, and their visual responses decrease at greater distances. In addition, bimodal neurons operate to some degree in body part centred co-ordinates, in that the visual RF remains spatially anchored to the tactile RF when this is moved. Owing to these functional properties, it has been suggested that premotor cortex, parietal areas and putamen form an interconnected system for multisensory coding of near peripersonal space centred on body parts (Colby et al., 1993; Duhamel et al., 1998; Fogassi et al., 1996, 1999; Graziano et al., 1997).

1.1. Visuo–tactile multisensory coding of peripersonal space in humans

By investigating patients with tactile extinction, we provided the first evidence that the human brain integrates visual–tactile information for representing the peripersonal space. Extinction patients (Loeb, 1885; Oppenheim, 1885) usually fail to report a contralesional stimulus when a concurrent stimulus is presented ipsilesionally and typically within the same sensory modality. Beyond the presence of some sensory deficits (Eimer et al., 2002; Lâdavas, 1990), the phenomenon of extinction results from uneven competition between spared and affected spatial representations, which benefit from stronger and weaker competitive weights, respectively (di Pellegrino and De Renzi, 1995; di Pellegrino et al., 1997a; Driver et al., 1997; Duncan, 1980, 1996; Ward et al., 1994). In the domain of visual–tactile extinction (Bender, 1952; Mattingley et al., 1997), we revealed the spatial specificity of crossmodal effects (di Pellegrino et al., 1997b; Lâdavas et al., 1998a,b) by showing that a visual stimulus presented near the patient’s ipsilesional hand or face (i.e. near peripersonal space) strongly inhibited the awareness of a tactile stimulus delivered on the contralesional hand or side of the face (crossmodal extinction). Crucially, less inhibition was produced by a visual stimulus presented far from the patient’s hand or face (i.e. far peripersonal space). As we reasoned elsewhere (for an authoritative review see Lâdavas, 2002) this pattern of results is consistent with the existence, in humans, of an integrated visual–tactile system coding near peripersonal space similar to that described in monkeys. Owing to this sensory integration, a visual stimulus could strongly activate the somatosensory representation of a body part when presented close to it, whereas weaker activation would be produced by stimuli presented at farther distances. Thus, the strongest crossmodal extinction will emerge from the simultaneous activation of somatosensory representation of the left hand by a tactile stimulus, and of the right hand by a proximal visual stimulus.

1.2. Vision vs. proprioception in crossmodal modulation

Vision is more relevant than proprioception for the representation of near peripersonal space (Lâdavas et al., 2000), although they provide complementary information (Haggard et al., 2000; Rossetti et al., 1995; van Beers et al., 1999). Consistent with the fact that the proprioceptive response of monkey’s bimodal neurons is weaker than that evoked when vision of the arm is allowed (Graziano, 1999; Graziano et al., 2000; MacKay and Crammond, 1987; Obayashi et al., 2000), we showed that visual–tactile processing in periper-
sonal space may rely uniquely upon visual cues about hand position. In patients with tactile extinction (Farnè et al., 2000), we presented visual stimuli far from their ipsilesional hand, which was placed behind their back, but near a rubber hand that could be either visually aligned or misaligned with the patients’ ipsilesional shoulder. Unseen tactile stimuli were concurrently delivered on their contralesional hand. The results showed that the visual stimulus presented near the visible right rubber hand induced strong crossmodal visuo–tactile extinction, comparable to that obtained by proximal visual stimulation of the patients’ real hand. Critically, crossmodal extinction was reduced when the rubber hand could not be visually attributed to the patients’ body (being misaligned with respect to their shoulder). The vision of a fake hand deceived the multisensory system coding peripersonal space, such that a visual stimulus presented near a rubber hand was processed as if it were near the real hand (see also Pavani et al., 2000). However, this phenomenon can take place only if the fake hand looks plausible as a personal body part, showing that visual dominance is not complete. In most of everyday activities both the felt and seen positions of the hand are actually congruent. Thus, the deception operated by a rubber hand may reflect a sort of impenetrability of the integrated visual–tactile system to discrepant information provided by proprioception and vision. In addition, this impenetrability is present despite the subject’s conscious awareness concerning the actual discrepancy between the senses.

1.3. Is the coding of peripersonal space impeded by a transparent barrier?

Recent brain imaging studies revealed that activation of the primary and secondary somatosensory cortex, similar to that obtained following tactile stimulation, can be induced when no touch is actually delivered, but rather when the subject is waiting for it (Carlsson et al., 2000). The common pattern of cerebral activity during real somatosensory stimulation and anticipation supports the role of top-down mechanisms for the tuning of sensory processing (Carlsson et al., 2000; Drevets et al., 1995; Roland, 1981). Top-down modulations have been reported in motor, visual, as well as somatosensory imagery studies, whereby subjects are just imagining the skin sensation, without anticipation of any real stimulus (Hodge et al., 1998; Kosslyn et al., 1997; Roth et al., 1996).

These findings raise the question of whether multisensory processing of the space near the hand can be mediated by the expectancy of being touched. If this were true, crossmodal effects in the peripersonal space would be impeded when the hand and the proximal visual objects are physically separated, thereby preventing any top-down somatosensory expectancy. Thus, here we investigated whether strong crossmodal extinction can still be observed despite the subjects’ conscious awareness concerning the impossibility for their hand to be touched. Note that in the above reported rubber hand study (Farnè et al., 2000) patients knew that the experimenter’s finger would not touch their own right hand, since the former was located near the rubber hand, while the latter was behind their back. Nonetheless, strong crossmodal extinction was obtained through the illusory self-attribution of the rubber hand (see also Botvinick and Cohen, 1998; Pavani et al., 2000; Rorden et al., 1999). However, this implicit self-attribution leaves open the possibility that crossmodal extinction was due to visually induced tactile expectancy; that is, patients may have expected to feel a touch from the self-attributed rubber hand that was located close to, but not physically protected from, the visual stimulation. Therefore, in the present study we investigated directly whether crossmodal effects are dependent or not upon the situation-related expectancy of being touched. To this aim, the perceptual performances of nine right hemisphere brain-damaged patients with left tactile extinction were examined by using a crossmodal visuo–tactile stimulation paradigm. The experimenter’s hand was placed either near or far from the patient’s right hand, which could be screened or not by a transparent Plexiglas. On the basis of the above reported impenetrability of the multisensory system, we hypothesised that this system would process proximal visual stimuli as being near the body independent of their actual possibility of touching it,
thus being somewhat resistant to more cognitive, top-down processing. This, in turn, might be the basis of the representation of peripersonal space that allows the kind of ‘unmotivated’ avoidance reactions cited above.

2. Methods

2.1. Subjects

A group of nine neurological patients gave their informed consent to participate in the study, which was approved by the local ethical committee. All patients were right-handed and suffered a right unilateral lesion due to a cerebro-vascular accident, as confirmed by CT or MRI scan. Table 1 illustrates the anatomical areas involved by the lesion from five patients, according to the methods of Damasio and Damasio (1989). The medical file of one patient (S.S.) was not available. For the three remaining patients, the lesion site was documented on the basis of the CT scan report. Patients P.G. and R.M.A. were affected by cortical lesions involving, respectively, the temporo-parietal and fronto-temporal region, whereas Z.G.’s lesion involved subcortical structures (basal ganglia, thalamus and internal capsule). Demographic and clinical details are also reported (Table 2).

Sensorimotor deficits were assessed through a neurological examination. Seven patients manifested hemiplegia on the left arm, while two patients (M.P. and L.E.) presented with milder contralateral motor deficits. On clinical examination, patients were alert and well oriented in time and space. All patients performed above cut-off level at the MMSE testing (Folstein et al., 1975). None had a history of previous head injury, left hemispheric stroke or other neurologic disorder. Since the presence of visuospatial neglect might obscure the spatial selectivity of crossmodal effects (Farnè and Ladavas, 2002), patients underwent a neuropsychological assessment aimed at evaluating the presence and severity of this deficit. The battery included three classical cancellation tests (Albert, letter and bell cancellation tasks) and a line bisection task. At the time of testing, only one of them (L.E.) showed signs of visual neglect (Table 2). Participants in the study were selected from a larger population of right brain-damaged patients according to the absence of obvious somatosensory loss. To this aim, tactile stimuli were manually delivered, prior to the experimental investigation, by using a set of probe fibres (analogous to Semmes–Weinstein probes) attached to a plastic rod handled by the experimenter. For each patient, the probe fibre that led to a minimum of 70% of left single detection was chosen. Most important, patients were selected according to the presence of left tactile extinction (left–right difference

Table 2
Demographic and clinical details of extinction patients

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex/age</th>
<th>Years of schooling</th>
<th>Months post-stroke</th>
<th>Visual neglect</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.V.</td>
<td>M/69</td>
<td>14</td>
<td>4</td>
<td>–</td>
</tr>
<tr>
<td>T.A.</td>
<td>M/65</td>
<td>5</td>
<td>9</td>
<td>–</td>
</tr>
<tr>
<td>M.P.</td>
<td>M/58</td>
<td>13</td>
<td>24</td>
<td>–</td>
</tr>
<tr>
<td>P.G.</td>
<td>M/62</td>
<td>5</td>
<td>13</td>
<td>–</td>
</tr>
<tr>
<td>R.M.A.</td>
<td>F/52</td>
<td>5</td>
<td>3</td>
<td>–</td>
</tr>
<tr>
<td>Z.G.</td>
<td>M/60</td>
<td>13</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td>S.S.</td>
<td>M/62</td>
<td>8</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td>P.A.</td>
<td>F/77</td>
<td>12</td>
<td>2</td>
<td>–</td>
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<tr>
<td>L.E.</td>
<td>M/68</td>
<td>13</td>
<td>2</td>
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</tr>
</tbody>
</table>

‘Visual neglect’ column reports whether patients were affected (+) or not (−) by left visual neglect, assessed as reported in the text.

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Table 1
Lesion data of extinction patients

<table>
<thead>
<tr>
<th>Patient</th>
<th>F6</th>
<th>F7</th>
<th>F8</th>
<th>F9</th>
<th>F10</th>
<th>F14</th>
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<th>T3</th>
<th>T5</th>
<th>T6</th>
<th>T7</th>
<th>T8</th>
<th>T9</th>
<th>T12</th>
<th>P1</th>
<th>P2</th>
<th>P5</th>
<th>P6</th>
<th>O6</th>
<th>BG1,2</th>
<th>BG3,4</th>
<th>IC</th>
<th>Th</th>
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<tbody>
<tr>
<td>C.V.</td>
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<tr>
<td>L.E.</td>
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Affected areas (x) of the right hemisphere are reported according to Damasio and Damasio’s (1989) coding system. F: frontal; T: temporal; P: parietal; O: occipital; BG: basal ganglia; IC: internal capsule; Th: thalamus.
In the ‘far-aside’ condition, the visual stimulus was presented lateral to the patient’s hand (∼30 cm). As can be seen in Fig. 1, in the far-aside condition the visual stimulus’ location was the same as in the near condition, but the patient’s right hand was displaced laterally. With this posture, the far visual stimulus was presented at the same distance as in the near condition with respect to other body parts (e.g. the eye and the trunk). In both the unimodal tactile as well as the crossmodal near- and far-aside conditions, subjects fixated a red dot aligned with their mid-sagittal axis, marked on the table at a distance of 35 cm from its front edge. In the crossmodal far-above condition, subjects had to fixate the experimenter’s nose. Before starting a trial, the experimenter checked that the subject was keeping fixation (Fig. 1).

In each experimental condition, four types of stimulation were delivered: unilateral left or right stimulation, bilateral simultaneous stimulation or no stimulation at all (catch trials). For each type of stimulation, 10 trials were presented according to a fixed random sequence. Subjects were submitted to the following six crossmodal visuo-tactile (V-T) conditions, which were randomly run in separate blocks: (1) V-T Near No-Glass; (2) V-T Near Glass, (3) V-T Far Above No-Glass; (4) V-T Far Above Glass; (5) V-T Far Aside No-Glass; (6) V-T Far Aside Glass. All the subjects were tested twice, the order of conditions being reversed in the second session. Subjects were asked whether the experimenter’s finger could ever touch, in principle, their right hand. All subjects acknowledged their hand could have been touched only in the V-T Near No-Glass condition. They were required to respond verbally to what they felt or saw, by reporting the side of the stimulation with the words ‘left’, ‘right’, ‘both’ or ‘none’, regardless of the stimulus modality. To check for a possible confusion when using these verbal labels, they were also asked to accompany the verbal response by orienting their head towards the left, or right or both sides.

3. Results

3.1. Unimodal tactile extinction

Patients performed well on catch trials, producing very few false alarms (only two ‘left’ responses
Fig. 1. Schematic illustration of the crossmodal visuo–tactile conditions, and experimental setting with the patient (P) and examiner (E) relative positions, viewed from above. The visual stimulus (V) could be located near (first row), or far from the patient’s right (R) hand, which could be located either below (second row) or aside (third row) the visual stimulus. Tactile (T) stimuli were delivered to the patients’ left (L) hand. Note that in the first and latter case (first and third row) the position of the visual stimulus with respect to the patient’s body parts other than the hand (i.e. the eye, the head and the midline) is identical. Left column: No-Glass conditions; right column: Glass conditions.
were made by L.E.). The mean accuracy in reporting touches on the left hand, as a function of single and double simultaneous stimulation, was computed in percentage for all patients. A one-way ANOVA with stimulation (unilateral, bilateral) as within-subject factor was significant \( F(1, 8) = 137.29, P < 0.0001 \), confirming that patients were affected by a rather severe form of left tactile extinction. On average, they were able to detect 90% of left unilateral touches showing a quite preserved somatosensory sensitivity, whereas they reported only 21% of left touches in bilateral trials.

### 3.2. Visuo–tactile extinction

Also in case of visuo–tactile stimulation, patients’ performance on catch trials was almost errorless, false alarms being very rare (two ‘left’ responses overall, one by patient L.E. and one by M.P.). For each patient, the mean percentage of accuracy in reporting touches of the left hand as a function of single and double stimulation in all the crossmodal conditions was computed. To ascertain patients’ consistency in detecting touches singly delivered to the left hand across the different crossmodal conditions, a one-way ANOVA was performed with the mean accuracy obtained in left unilateral trials as within-subject factor (single left accuracy in the six crossmodal conditions). This analysis revealed no significant differences in patients’ tactile sensitivity across conditions, thus allowing for the successive calculation of a mean accuracy score (AS), computed for each patient and condition, which expressed the proportion of correct responses in bilateral trials as compared to left unilateral trials.

To verify whether crossmodal extinction was modulated by the presence of the transparent barrier, the mean bilateral AS of crossmodal conditions was submitted to a two-way ANOVA with Glass (absent, present) and Distance of the visual stimulus (near, far-above, far-aside) as within-subject factors. Neither the main factor Glass nor the interaction Glass X Distance were significant (both \( P_s > 0.6 \)). The only significant source of variance turned out to be the factor Distance \( F(2, 16) = 6.32, P < 0.01 \), which was further explored with Newman–Keuls post hoc test. Regardless of the presence of the glass, the amount of crossmodal extinction varied according to the distance of the visual stimulus from the patient’s hand. Crossmodal extinction was more pronounced in the near (37% AS) with respect to both the far-above condition (51% AS, \( P < 0.01 \)) and the far-aside condition (48% AS, \( P < 0.02 \)). As can be seen in Fig. 2, which fully discloses patients’ performance as a function of all the experimental conditions, a comparable near–far difference was present in both the No-Glass and Glass conditions. Finally, the visuo–tactile far-above and far-aside conditions did not significantly differ from each other (51 vs. 48% AS), thus showing that crossmodal extinction may be weakened by a comparable proportion either by driving the visual stimulus away from the patient’s hand or vice versa.

### 4. Discussion

The study asked whether visuo–tactile extinction is affected by the patients’ top-down knowledge of the possibility for the visual stimulus to reach their own hand. To this aim, the performance of left tactile extinction patients was investigated when their right hand was either covered or not by a transparent Plexiglas. Three main findings were obtained. First, visual stimuli presented near the ipsilesional hand induced strong crossmodal
extinction of contralesional tactile stimuli. Crucially, the amount of crossmodal extinction was comparable whether the patients’ hand was physically protected or not against the approaching visual stimulus. A solid, transparent protection did not prevent the multisensory coding of nearby visual stimuli, thus allowing activation of the somatotopic representation of the right hand by a visual stimulus presented close to it. When spatial competition is biased ipsilaterally as in left tactile extinction patients, the somatosensory representation of either hand (activated by a left tactile stimulus and a right proximal visual stimulus) results in consistent extinction of contralesional touch.

Second, visuo–tactile extinction was significantly reduced when the same visual stimulus was presented farther away from the patients’ right hand. Such a reduction was not complete, as patients’ accuracy was relatively low in both ‘far’ crossmodal conditions compared to the unimodal condition. By systematically increasing the visual stimulus’ distance, future studies will clarify whether crossmodal extinction would decrease and eventually disappear or reach a plateau level that could be independent of multisensory integrative processes. Importantly, the transparent barrier did not alter the spatial modulation of crossmodal extinction. Thus, multisensory coding of nearby visual objects in humans can occur obligatorily, whether or not the objects can physically reach the body. As a corollary, multisensory coding of nearby space may occur whether or not the objects are physically reachable.

Third, crossmodal extinction was similarly reduced when the visual stimulus was moved away from the patient’s ipsilesional hand, or the hand was displaced laterally with respect to the visual stimulus. In the latter condition, we observed weaker crossmodal extinction despite the fact that the patients’ eyes, head and trunk were at the same distance from the visual stimulus. Again, this was true independent of the presence of the glass. These results further support the notion that multisensory representation of peripersonal space can operate in hand-centred co-ordinates. This issue has been previously addressed by asking a patient with tactile extinction to cross the hands across the body midline (di Pellegrino et al., 1997b). A visual stimulus presented near the right hand (on the left) strongly extinguished tactile stimuli applied to the left hand (on the right), revealing that crossmodal extinction was not modulated by the relative position of the hands in space. By showing weaker crossmodal effects when the hand is moved away relative to the visual stimulus, the present study brings new evidence that the visual peripersonal space is anchored to the hand.

Overall, these findings suggest that visuo–tactile integrative processes can occur automatically, along a bottom-up flow of information that is not necessarily affected by top-down regulation of sensory processing. Indeed, patients were explicitly aware that the transparent barrier would prevent any possibility for the visual stimulus to get into physical contact with their own right hand. In contrast, the Plexiglas did not block either visual or proprioceptive cues, which provided congruent inputs relative to the spatial proximity of the hand and visual stimulus. Finally, the present study also rules out possible interpretations of crossmodal extinction in peripersonal space as resulting from tactile expectancy induced by visual stimulation of either a real or a rubber hand (Farnè et al., 2000).

But why should our perception of nearby space resist to top-down influences, at least in the condition investigated here? This might relate to the way in which multisensory-motor systems encode the location of nearby stimuli to allow appropriate motor responses. Head and arm movements towards and away from the body are some of the actions partly mediated by these systems in the monkey. Multisensory neurons can control movements on the basis of both cutaneous and visual information, localising an object when the skin has not (yet) been stimulated. Such a multisensory-motor control can combine information concerning the position of a visual stimulus relative to the head, hand or both, which can in turn be used even for relatively simple actions, such as avoiding a stimulus coming towards the face or the hand, reaching to grasp an object or bringing food to the mouth. This information is likely to be provided by bimodal visuo–tactile neurons, as supported by the fact that the regions of the premotor cortex
coding head movements, mouth grasping and coordinated hand/mouth actions are reciprocally connected with area VIP (Matelli et al., 1994; Rizzolatti et al., 1998). Fogassi et al. (1996) have also found that visual RFs of visuo–tactile neurons in area F4 expand when the visual stimulus velocity increases while approaching the cutaneous RF, a property that could be relevant for the preparation of action towards nearby stimuli. The approaching or escaping nature of the action could be partly determined by the characteristics of the visual stimulus and the ongoing degree of voluntary motor control, as it is the case when tickling sensations are suppressed by self-generated movements (Blakemore et al., 1998, 1999; see also Iwamura et al., 1995). Recently, the idea that multisensory-motor interfaces might code defensive movements received some preliminary support. Electrical stimulation of precentral areas seems to evoke complex avoidance or defensive actions, such as withdrawal of the hand, turning of the head or lifting of the hand as if to defend the side of the head (Graziano et al., 2001). It would thus be adaptive that responses possibly evoked by multisensory neurons are fast and mainly outside the control of top-down mechanisms.

This conclusion is also supported by studies on humans, which indirectly speak to a bottom-up control of visually driven withdrawal reactions. Pathological escaping actions were first reported by Denny-Brown et al. (1952) (Mori and Yama-dori, 1989) in a patient with a right parietal lesion. When approached by the experimenter’s hand, the patient’s hand was involuntarily moved away, as if to avoid the examiner’s hand. The automatic nature of exaggerated withdrawal reactions is even clearer in a more recent report by Hoogenraad et al. (1994). They described a patient affected by a right parietal lobe infarction who presented with a dense hemianesthesia and hemiplegia of the left hand when vision was prevented. However, ‘with eyes open, visual stimuli induced withdrawal of the arm and burning pain in the numb side’. The brisk sideways movement of the arm, ‘as if it had been stung’, was evoked by the experimenter’s hand merely approaching the left hand for sensory testing. Embarrassed by the inability to avoid withdrawal movements of his left arm, the patient tied it to his belt. In contrast, when a contact was not visually anticipated, or when the patient himself approached his left arm with the right hand, there was neither pain nor withdrawal. While the authors themselves refer to the anticipatory activity of bimodal neurons (cf. MacKay and Crammond, 1987) as a possible neural basis for the pathological escaping behaviour, it is of interest to mention that some thermal nociceptive parietal neurons in the monkey display bimodal, visual–tactile properties. Dong et al. (1994) found multisensory neurons that responded with approximately equal maximum peak of discharge frequencies both to noxious thermal and threatening or novel visual stimuli, provided that they were approaching the most sensitive part of the tactile RF. It is tempting to speculate that both the pathological withdrawal reaction and the visually induced burning pain cited above could share a common multisensory physiological mechanism. Visually induced withdrawal could be mediated by anticipatory pain reaction.

In conclusion, here we reported neuropsychological findings that shed new light onto the properties of brain mechanisms coding near-peripersonal space in humans on the basis of multisensory fusion. The fact that nearby visual stimuli are coded as near even when a physical but transparent barrier would impede any contact between the body and the visual stimulus suggests that multisensory fusion may occur in a bottom-up fashion. A relatively encapsulated multisensory processing of nearby space might deserve important primitive preservative functions, and represent a clear evolutionary advantage.

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