The phenomenology of body image distortions induced by regional anaesthesia

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Summary
Patients with peripheral nerve or spinal cord lesions frequently report perceptual distortions related to position, shape, texture or temperature in the distribution of the affected areas. This study aimed to describe the phenomenology of such body image alterations during the course of upper limb, lower limb or spinal anaesthetic blocks in patients (n = 36) undergoing orthopaedic surgery. Multimodal sensory testing and assessment of motor function were performed at regular intervals, and the relationship between the reported body image distortions and the progression of sensory and motor impairment was analysed. We found that perceptual changes concerning the shape and size of the deafferented limb occurred in the great majority of patients. In all of them, illusions of swelling, elongation or shortening of the limb coincided with the impairment of warm, cold and/or pinprick sensations, suggesting that thin myelinated Aδ- and/or unmyelinated C-fibres may provide a source of tonic modulation to the limb’s cortical representation. Such perceptual alterations of shape and size of body parts differed clearly from postural illusions in terms of frequency, time course and influence of vision. In addition to perceptual changes in the deafferented area, almost half of the patients felt their unanaesthetized lips and/or mouth swelling during the course of upper limb block, suggesting the unmasking of dynamic interactions between somatotopically adjacent cortical representations. Conflicting sensations could co-exist in the patient’s body image, such as the illusion of swelling of a limb, which, at the same time, was felt to be missing. The sense of ownership of the deafferented limb was impaired in some cases. These observations show that the perception of body shape and the awareness of its postural variations are built from different plastic models. They also underline the contribution of peripheral afferent activity to the maintenance of a unified body image.

Keywords: body image; body shape; phantom limb; deafferentation; regional anaesthesia

Introduction
Patients with peripheral nerve lesions frequently describe perceptual distortions related to position, shape, texture or temperature in the distribution of the affected nerves. Illusory perceptions concerning limb position or movement have been studied extensively in amputees (see Melzack, 1990; Ramachandran and Hirstein, 1998), in patients with peripheral nerve (see Riddoch, 1941) or spinal cord lesions (Nathan et al., 1986), and during regional anaesthesia (Wallgren, 1954; Miles, 1956; Prevoznick and Eckenhoff, 1964; Melzack and Bromage, 1973; Isaacson et al., 2000; Gentili et al., 2002). In amputees, perceptual alterations of the shape of the removed limb, such as telescoping, have also been described, generally after a certain delay following amputation (see, for example, Riddoch, 1941; Ramachandran and Hirstein, 1998; André et al., 2001). However, illusions concerning the shape and size of body parts immediately after deafferentation have been assessed systematically only rarely. Recently, Gandevia and Phegan (1999) showed that subcutaneous infiltration of the thumb with lidocaine induced an increase in the perceived size of both the anaesthetized thumb and the unanaesthetized lips in normal subjects. This illusion may result from changes in neuronal activity and/or topographic reorganization within the somatosensory cortex, that occur immediately after deafferentation in both animals (for a review see Kaas, 2000) and human (Rossini et al., 1994; Buchner et al., 1995, 1999).

This study aimed to describe further the phenomenology of acute body image distortions induced by deafferentation and to address the following questions. Does the ‘enlargement’ illusion described above still occur when larger body areas are deafferented and how are the topographic features of such an illusion related to the extent of deafferentation? Which
type of nerve fibres may be involved in the alteration of body shape perception? At which level of the ‘neuromatrix’ of body image integration do the underlying mechanisms operate?

To address these questions, we examined prospectively the characteristics of body image alteration during regional anaesthesia in patients undergoing surgery of the upper or lower extremity. Regional blocks were performed at various sites with different local anaesthetics showing distinct pharmacokinetic profiles. Multimodal sensory testing and assessment of motor function were performed at regular intervals after the injection, and the temporal relationship between the subjective reports of the patients and the progression of sensory and motor impairment was analysed. In addition, we sought to determine whether misreferral of sensation during stimulation of regions somatotopically adjacent to the deafferented area, which has been observed in amputees and in patients with plexus or spinal cord lesions (see references in the Discussion), might also occur during the course of regional anaesthesia.

### Patients and methods

The patients gave their informed consent according to the principles of the Helsinki convention. This study was approved by the local institutional review board (CCPPRB Pitié-Salpêtrière). Thirty-six patients (24 male, 12 female, aged 18–92 years) undergoing orthopaedic surgery under regional anaesthesia were included in the study. Exclusion criteria were the presence of any neurological disease, diabetes mellitus, cutaneous infection at the site of needle insertion, a level of pain above 30 on a visual analogue scale ranging from zero (no pain) to 100 (maximal imaginable pain), and the absence of complete sensory and motor block 45 min after block placement. No patient received any sedative or anxiolytic drug during the study period.

### Nerve blocks

Thirteen patients received a brachial plexus peripheral nerve block, 10 patients received a combined sciatic and femoral or saphenous peripheral nerve block, and 13 patients received spinal anaesthesia at the L2–L3 interspace. The main characteristics of the patients and of the different blocks performed are listed in Table 1. All peripheral nerve blocks were performed with the aid of a peripheral nerve stimulator and a multiple stimulation technique with low stimulation intensity. Mepivacaine 1.5%, a mixture of equal volumes of lidocaine 2% and ropivacaine 0.75% (Lido 2/Ropi 0.75), plain ropivacaine 0.75% (Ropi 0.75) or plain mepivacaine 1.5% (Mepi 1.5). In the case of spinal anaesthesia, only plain hyperbaric bupivacaine 0.5% was used (Bupi 0.5). The different blocks used were interscalene block (ISB), infraclavicular block (ICB), midhumeral block (MHB) at the upper limb level, and sciatic nerve block at the buttock (postSB) or at the popliteal crease (poplSB) combined with a femoral (FB) or saphenous (SB) nerve block at the lower limb level. The assessment of the onset of block was always performed in the peripheral cutaneous nerve distribution corresponding to the last nerve blocked during the procedure or in the distribution of the peroneal nerve in the case of spinal anaesthesia.

| Table 1 Characteristics of the patients and description of the anaesthetic blocks       |
|-------------------------------------------------|-----------------|-----------------|
|                                                                                     | Upper (n = 13)  | Lower (n = 10)  | Spinal (n = 13) |
| Demographic variables                                                              |                |                |
| Age (years)                                                                        | 37 (26–57)     | 36 (31–50)     | 53 (35–66)     |
| Weight (kg)                                                                        | 70 (58–78)     | 74 (57–85)     | 72 (65–76)     |
| Height (cm)                                                                        | 170 (162–177)  | 174 (162–181)  | 171 (166–177)  |
| Male/female                                                                        | 9/4            | 5/5            | 10/3           |
| Local anaesthetics                                                                |                |                |
| Lido 2/Ropi 0.75                                                                  | 2              | 7              |               |
| Ropi 0.75                                                                         | 9              | 3              |               |
| Mepi 1.5                                                                         | 2              | 13             |               |
| Bupi 0.5                                                                         |                |                |               |
| Types of blocks                                                                  | ISB: 2         | PostSB + FB: 5  |
|                                                                                   | ICB: 1         | PoplSB + SB: 5 |
|                                                                                   | MHB: 10        |                |
| Nerve tested                                                                      | Axillar: 1     | Tibial: 4      | Peroneal: 13   |
|                                                                                   | Medial: 7      | Peroneal: 6    |                |
|                                                                                   | Radial: 3      |                |                |
|                                                                                   | Ulnar: 2       |                |                |

Values are median (95% confidence interval) or number. Patients received either an upper limb block, a lower limb block or a spinal anaesthesia. Local anaesthetics used were either a mixture of equal volumes of lidocaine 2% and ropivacaine 0.75% (Lido 2/Ropi 0.75), plain ropivacaine 0.75% (Ropi 0.75) or plain mepivacaine 1.5% (Mepi 1.5). In the case of spinal anaesthesia, only plain hyperbaric bupivacaine 0.5% was used (Bupi 0.5). The different blocks used were interscalene block (ISB), infraclavicular block (ICB), midhumeral block (MHB) at the upper limb level, and sciatic nerve block at the buttock (postSB) or at the popliteal crease (poplSB) combined with a femoral (FB) or saphenous (SB) nerve block at the lower limb level. The assessment of the onset of block was always performed in the peripheral cutaneous nerve distribution corresponding to the last nerve blocked during the procedure or in the distribution of the peroneal nerve in the case of spinal anaesthesia.
Assessment of sensory and motor functions
Immediately after the end of block placement, the anaesthetized limb(s) was hidden from the patient’s sight. The sensations elicited by pinprick, cold (compress soaked with alcohol at 16°C), warm (glass tube containing water at 42°C) and light rubbing stimuli, the accuracy of position sense and the strength of voluntary movement were assessed immediately after the end of block placement and then every 5 min for 45 min in the territory of the latest nerve blocked or, in the case of spinal anaesthesia, in the distribution of the peroneal nerve. Sensory and motor impairment were also assessed in all other territories of the anaesthetized limb 15 and 45 min after the end of block placement to evaluate the overall quality of the block before surgery began. Proprioception was assessed by displacing a limb segment from its original position and by asking the patient to show its new position with the use of the opposite joint or, in the case of spinal anaesthesia, with the use of his index finger. The interphalangeal joint of the big toe was not tested for position sense since its proprioceptive performances have been shown to be poorer than those of other joints (Refshauge et al., 1995). Sensory and motor functions were assessed on a 3-point scale, with 2 corresponding to a normal sensation or movement, 1 to a blunted sensation or movement, and 0 to an absence of sensation or movement.

Assessment of body image distortions
Just after the end of block placement, patients were told that they might experience various alterations in the perception of their anaesthetized limb(s). Then, every 5 min, patients were encouraged to report their sensations during a two-step interview. During the first step, the investigator did not give any precise information about the type of sensation which might occur, while in the second step he would systematically ask the patient to focus on his perception of the shape, texture and position of specific body parts. The patient’s subjective report was fully transcribed. The perceptual alterations of shape and position of the limbs described by the patient were drawn on a schematic body template to fit his or her sensations best. Perceptual distortions of body shape were sought not only at the level of the deafferented limb(s), but also on the contralateral limb (in the case of unilateral block) and on somatotopically adjacent body regions (face and upper trunk in the case of upper limb block; buttock, penis and lower trunk in the case of lower limb block). Following the description of the changes in body image induced by the anaesthetic block, the influence of sight and of grasping the perceptually distorted body part(s) with an intact hand were investigated systematically. In addition, the affective colouring of these body image distortions was assessed by observing spontaneous emotional expressions and by asking the patients whether the perceptual changes were felt as unpleasant, worrying, distressing, indifferent, pleasant or amusing. Finally, mislocalization of touch stimuli applied to the face was sought during the course of upper limb block: a cotton swab was brushed rapidly at various selected points on the ipsilateral face, and the patient, whose eyes were shut, was asked to report the perceived location(s) of these stimuli.

Results
Perceptual distortions of shape and size of body parts
Perceptual changes concerning shape and size of the deafferented limb(s) occurred in all but six patients (30 out of 36). Such sensations were reported rarely at first and usually were acknowledged by the patients only after they had been asked to focus their attention on the perception of the shape of their limb(s). The patients could not ignore this perception anymore after they had acknowledged it for the first time, and giving details about its characteristics clearly did not require a great effort of introspection afterwards.

Characteristics of the perceptual alterations of body shape in the deafferented areas
Whatever the block localization, the perceived body shape alteration always included the sensation that the width of the anaesthetized limb(s) was increased, as if the limb(s) had swollen. In 11 out of 30 patients (four out of 10 with upper limb block, five out of 10 with lower limb block and two out of 10 with spinal anaesthesia), this sensation was associated with the feeling that the length of the limb was also modified. Six patients (two in each group) reported that they felt their anaesthetized limb(s) were longer, while five patients (two with upper limb block and three with lower limb block) had the opposite sensation of a shrunken arm or leg. These perceptual changes sometimes were very pronounced: some patients reported a 2- or 3-fold increase of their limb’s volume. One patient with spinal anaesthesia felt that his lower limbs had become ‘immense’. The anaesthetized limb was not always perceived uniformly swollen: in some patients, the sensation of increased width was more vivid in the distal part of the limb (foot or hand); one patient with a mid-humeral block reported, on the contrary, that he felt his arm and forearm to be enlarged, but not his hand. Interestingly, all the patients who received a sciatic nerve block followed by a femoral or saphenous block reported that at first the sensation of increased width included the whole lower limb below the knee with the exception of the medial part of the leg, which was felt as normal. Only after the second block had been performed did they feel their entire lower limb as swollen. Four male patients with spinal anaesthesia felt that their penis had increased in size.
Perceptual alterations of body shape in contralateral areas and in areas somatotopically adjacent to the deafferented limb

Patients with a unilateral block never reported any perceptual change in the contralateral limb. However, four out of 10 patients with an upper limb block reported a sensation of swelling of their lips and/or mouth in addition to the perceptual alterations of the shape of their anaesthetized limb. This sensation was ipsilateral to the block in one case and bilateral in three cases. In contrast, patients with lower limb block did not report any perceptual changes in the areas adjacent to their anaesthetized limb.

Table 2 Time course of the impairment of the different sensory modalities among the three groups of patients

<table>
<thead>
<tr>
<th>Onset times (min)</th>
<th>Pinprick</th>
<th>Warm</th>
<th>Cold</th>
<th>Touch</th>
<th>Position</th>
<th>Motricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper limb block Ropi 0.75 (n = 7)</td>
<td>4.5 ± 3</td>
<td>5 ± 3</td>
<td>4.5 ± 3</td>
<td>18.5 ± 15.5</td>
<td>30 ± 15</td>
<td>8.5 ± 5</td>
</tr>
<tr>
<td>Lower limb block Lido2/Ropi0.75 (n = 7)</td>
<td>5 ± 0</td>
<td>9 ± 7.5</td>
<td>7.5 ± 8</td>
<td>17 ± 9.5</td>
<td>32 ± 13.5</td>
<td>14 ± 14</td>
</tr>
<tr>
<td>Spinal block Bupi 0.5 (n = 10)</td>
<td>5 ± 5.5</td>
<td>3 ± 2</td>
<td>3.5 ± 2.1</td>
<td>14 ± 8</td>
<td>20 ± 12</td>
<td>4 ± 2</td>
</tr>
</tbody>
</table>

The values (mean ±SD) correspond to the time elapsed (in minutes) between the injection and the onset of pinprick, cold, warm, touch, position sense and motor impairment among patients with upper limb, lower limb or spinal blocks. In each group, calculations were made with the most frequently employed local anaesthetic. Note that the sequence of sensory dysfunction is very similar among the three groups.

Fig. 1 Relationship between the course of sensory impairment and the occurrence of perceptual distortions of the shape of the deafferented areas among patients receiving an upper extremity block. Each graph represents the individual data regarding pinprick, warm, cold, touch and position sense, assessed immediately after block placement, and then every 5 min over a 45 min period. These sensory functions were scored on a 3-point scale, with 2 corresponding to a normal sensation, 1 to a blunted sensation, and 0 to an absence of sensation. Grey circles represent the first occurrence of a score of 1. Open circles represent the first occurrence of a score of 0. When a sensory modality was scored directly 0, score 1 was considered arbitrarily to have occurred 2.5 min before. The vertical bar represents the onset of perceptual distortions of the shape of the upper limb. Note that in almost all patients the perceptual distortions of the shape of the deafferented areas coincided with the impairment of warm, cold and/or pinprick sensations, but not with touch and position sense impairment. Similar results were observed in patients with lower limb or spinal blocks.

Perceptual alterations of body shape in contralateral areas and in areas somatotopically adjacent to the deafferented limb

Patients with a unilateral block never reported any perceptual change in the contralateral limb. However, four out of 10 patients with an upper limb block reported a sensation of swelling of their lips and/or mouth in addition to the perceptual alterations of the shape of their anaesthetized limb. This sensation was ipsilateral to the block in one case and bilateral in three cases. In contrast, patients with lower limb block did not report any perceptual changes in the areas adjacent to their anaesthetized limb.

Time course of perceived body shape distortions and relationship to motor and sensory dysfunction

Sensory impairment followed a very similar sequence, whatever the localization of the peripheral nerve block or the type of local anaesthetic used (Table 2). In all but two
patients, pinprick cold and warm sensations were altered first, while the sensation of touch and then eventually position sense became impaired later. Whatever the site of injection and the type of anaesthetic used, perceptual distortions of the shape of the deafferented areas coincided with the impairment of warm, cold and/or pinprick sensations (Fig. 1). Indeed, the sensation of alteration of the limb’s shape appeared during the interval between partial (score 1) and complete (score 0) impairment of warm, cold and pinprick sensations for 27, 29 and 30 out of 30 patients, respectively. In most patients, the feeling of body shape distortion appeared when pinprick, warm and cold sensations were only partially impaired, while in a few patients its onset coincided with the complete loss of these sensations. In contrast, perceptual distortion of the shape of the deafferented areas was not associated with touch and position sense impairment (Fig. 1), as it preceded the occurrence of touch and position sense impairment in 25 and 29 out of 30 patients, respectively. In the single case in which touch and position sense dysfunction occurred at first, the onset of the perceptual distortion of body shape still coincided with the impairment of pinprick, warm and cold sensations.

**Positional and postural illusions of the deafferented limb(s)**

Fifteen patients developed an incorrect perception of the position of their anaesthetized limb(s) (10 out of 13 with upper limb block, one out of 10 with lower limb block and four out of 13 with spinal anaesthesia), 13 of whom also reported a perceptual alteration of the shape of the deafferented area. In most of these patients (nine out of 13), the perceptual illusions of limb position (‘phantom sensation’) appeared later than those concerning the limb shape (15 min later on average). The characteristics of these phantom sensations were very similar to those previously described (Melzack and Bromage, 1973). For example, most patients with upper limb block reported the illusion that their arm was at the side, their elbow flexed, their forearm above the abdomen and their fingers flexed.

**Influence of vision and of grasping the deafferented area**

Most patients became aware that their sensation of body shape alteration was an illusion only when they saw or grasped their anaesthetized limb. Before this, most of them thought that what they felt about the size of their limb(s) corresponded to reality: they believed their arm or leg(s) had swollen. Although the illusory nature of this feeling was revealed by seeing or grasping the anaesthetized limb, the sensation of body shape alteration itself was not modified by such information: all patients noted the existence of a persistent discrepancy between what they felt and what they saw, which was for them a cause of astonishment. One patient spontaneously described his sensation as ‘a feeling that persists, even though I am now conscious of its illusory nature’.

In contrast to the perceptual distortions of shape and size of the deafferented area, illusions of position and posture of the anaesthetized limb(s) generally were influenced by visual information. Indeed, for most patients, looking at their limb made the phantom limb position change and suddenly coincide with the real limb. This correction of the illusory perception of the limb’s position persisted as long as the patient looked at the real limb. Two patients, however, failed to recognize their real limb as they first saw it, and looked for it in an incorrect place that corresponded to their illusory perception. These patients said spontaneously ‘this is not my arm’ when they first looked at their real limb, and ultimately acknowledged the ownership of this limb only on the investigator’s insistence.

**Other sensations**

The vast majority of patients spontaneously reported sensations of tingling (32 out of 36), numbness (31 out of 36), heaviness (28 out of 36) and warmth (33 out of 36) in the anaesthetized area. These sensations occurred shortly after...
the local anaesthetic injection (mean delay: 5–7 min). The texture of the anaesthetized area was compared with plastic, wood, moss, wax or concrete. The anaesthetized limb was said to be ‘dead’ by 16 out of 36 patients. Seven patients described it as ‘absent’ and/or ‘cut’, of whom one patient had the sensation that his lower limbs were laying beside him on the bed, while another patient said that he felt his upper limb ‘going away’. When asked to focus on their ‘absent’ limb, all these patients reported that they felt it as swollen. Thus, paradoxically, both sensations of absence and swelling of the anaesthetized limb co-existed in their body image. Likewise, one patient reported that she felt her arm as ‘heavier when thinking of moving it’, and at the same time, as ‘becoming lighter and lighter’ in her mind. Some patients (five out of 36) reported that they felt that the anaesthetized limb did not belong to them anymore. All these five patients had a correct perception of their limb’s position (i.e. no phantom sensation) when they reported this sensation, and only two of them eventually developed a phantom sensation later. One patient with spinal anaesthesia suddenly exclaimed, ‘What is this thing?’ about his penis, which he felt enlarged and, at the same time, as if not belonging to him.

Affective colouring
Most patients (23 out of 30) claimed to be indifferent to the perceptual distortions of their anaesthetized limb(s). Six patients reported that such sensations were amusing, and three of them laughed during their report. Only one patient described the sensation of body shape alteration as distressing.

Search for mislocalization of tactile stimuli
Touch stimuli applied to the face were always localized correctly by patients during the course of upper limb block. The patients never reported any referred sensation in the deafferented area when stimulated on the ipsilateral face.

Discussion
Methodological limitations
The main limitation of our study is that it is based exclusively on the patient’s subjective reports. Moreover, as the sensations investigated usually were not reported spontaneously by the patients, but only when they were asked to direct their attention successively to different parts of their body, suggestions from the investigator may have interfered with the patients’ answers. This limitation cannot be overcome in studies on the awareness of one body part. As pointed out by Kinsbourne, ‘to contemplate the specific shape and disposition of one body part calls for focusing attention, which can be implemented only sequentially, one body part at a time.’ (...) Failing that, only some very general information is immediately available’ (Kinsbourne, 1995). Thus, the inquisitive character of our study was necessary to draw the patient’s perceptual experience of his body out of its ‘natural obscurity’ (O’Shaughnessy, 1995).

The qualitative nature of our multimodal sensory assessment represents another limitation, because the time course of sensory block is described less precisely by such a method than by threshold determinations (Brennum et al., 1994; Curatolo et al., 2000). However, the simplicity and rapidity of the qualitative assessment allowed a parallel measurement of both sensory impairment and body image distortions at close intervals, which was a main objective of this study.

Illusions of shape and size of deafferented body parts
It is well known that dental anaesthesia induces a sensation of swelling of the lips and of other parts of the face. In addition, Gandevia and Phegan (1999) have shown that normal subjects report a sensation of an increase in the size of their thumb after it has been anaesthetized. However, whether a similar illusion can occur during regional anaesthesia, when a large surface of the body is deafferented, has been investigated only rarely. Wallgren (1954) observed that the distal parts and/or the joints of the lower limbs sometimes were felt enlarged after a lumbar spinal block. Some patients also had the illusion that their lower limbs were shortened or telescoped. In their study of the phantom limb phenomenon following an anaesthetic brachial plexus block, Melzack and Bromage (1973) stated that ‘the shape of the phantom limb was less vivid than its spatial position’ and reported a sensation of swelling of the fingers in most (nine out of 12) of the patients who were questioned specifically about this matter. The current study, which focused on a precise description of the perceived shape and size of the deafferented limb(s), yields additional information to these previous works, showing that the great majority of patients do have an illusion of swelling (i.e. increased width) of their entire upper or lower limb(s) following deafferentation. In a substantial number of cases, this illusion co-existed with perceptual alterations of the length of the limb. These observations contradict the prediction formulated by Gandevia and Phegan (1999) that ‘illusory increases in size may not occur when a large part of the body is anaesthetised or removed’. Such a prediction was based on the postulate that the illusion of enlargement of a body part may depend on the reorganization of overlapping sensory maps in the somatosensory cortex. Animal studies have shown that acute removal of the afferent inputs from one digit induces an immediate expansion of the receptive fields of cortical cells which represent skin areas adjacent to the site from which the input was removed (Calford and Tweedale, 1988, 1991a). However, the fact that the ‘enlargement’ sensation occurs when the entire limb is deafferented suggests that remapping within the somatosensory cortex actually may not be the cause of this illusion. Then, perceptual alterations of
body shape may be explained rather by a disinhibition of background activity within the deafferented cortex. In fact, neuronal recordings in the somatosensory cortex of rats and raccoons have shown increased levels of spontaneous activity following sciatic nerve section (Dykes and Lamour, 1988) or single digit amputation (Rasmussen et al., 1992). Interestingly, in this latter study, the topography of changes in spontaneous neuronal activity consisted of a radically affected core region and a slightly affected fringe adjacent to the intact representations. This inhomogeneity may explain why the anaesthetized limb was not perceived as uniformly modified in some of our patients.

The data obtained in patients with spinal anaesthesia show that the enlargement illusion might involve not only the limbs but also the penis. This observation contrasts with the absence of such a report in previous studies (Wallgren, 1954; Miles, 1956; Prevoznick and Eckenhoff, 1964). This discrepancy may reflect differences in the questioning method. For example, Miles (1956) noted that ‘leading questions were avoided’, meaning that in his study, patients were not asked to direct their attention specifically to this body part. Moreover, our data fit with the observations of a phantom penis associated with an illusion of erection after amputation of the penis and in patients with spinal cord injury (Mitchell, 1872; Bors, 1951; Sunderland, 1978), confirming that the body parts which perceptually tend to remain and to grow in size after amputation or deafferentation are ‘those which protrude or stand out from the general mass of the trunk and head (...), which anatomically are most heavily endowed with sensory end-organs and, physiologically, are most represented in the model of body shape’ (Riddoch, 1941).

**Perceptual alterations of body shape in contralateral areas and in areas somatotopically adjacent to the deafferented limb**

Almost half of the patients with an upper limb block who experienced perceptual alterations of the shape of their anaesthetized limb reported a sensation of swelling of their lips and/or mouth. This result is in agreement with the observations made by Gandevia and Phegan (1999) who used subject’s drawings to demonstrate an increase in the perceived size of the unanaesthetized lips following a digital block of the thumb. No obvious left–right asymmetry was found on these drawings. Likewise, the sensation of swelling of the lips and mouth was reported to be symmetrical by three of the four patients who reported such feelings during upper limb block. Several studies have shown that sensory input from the face may activate the hand territory of the primary somatosensory cortex following deafferentation of the upper limb (Ramachandran, 1993; Yang et al., 1994; Flor et al., 1995; Montoya et al., 1998). Immediate remapping, which has been shown to occur as soon as 24 h following amputation (Borsook et al., 1998), probably results from the unmasking of normally ineffective connections between hand and face representations. Accordingly, the perceptual distortions of the face during anaesthesia of the thumb or of the whole upper limb may depend on the release of an inhibitory input, leading to changes in the pattern of activity in the cortical representation of the face. The fact that inputs from the lips and mouth project bilaterally to somatosensory areas (Lin et al., 1994) may explain why a symmetrical sensation of swelling in these areas is reported by most patients with unilateral upper limb anaesthesia. Such a hypothesis is supported further by the occurrence of not only contralateral but also bilateral sensations in the mouth during unilateral electrical stimulation of the somatosensory cortex (Penfield and Boldrey, 1937).

In contrast to these observations concerning the face, perceptual distortions were never reported in other anaesthetized body parts. For example, all the patients with a sciatic nerve block noted that the illusion of swelling was confined to the anaesthetized part of their lower limb and did not include the medial part of the leg until the femoral or saphenous nerve was blocked. Moreover, no perceptual alteration of shape of the unanaesthetized contralateral limb was observed in our study. Likewise, Gandevia and Phegan (1999) found that complete anaesthesia of the thumb failed to alter significantly the perceived size of the adjacent index finger and of the contralateral thumb in healthy volunteers.

Overall, these observations show that the dynamic interactions between two somatotopically adjacent representations may or may not have functional consequences on body image, depending on the deafferented body part and, presumably, on the degree of its cortical magnification. Calford and Tweedale (1990) demonstrated that plastic changes in the primary somatosensory cortex opposite to a peripheral denervation are mirrored immediately by corresponding changes in the opposite hemisphere. However, we found no body image correlate of such interhemispheric transfer of plasticity during upper or lower limb block.

**Search for mislocalization of tactile stimuli**

Studies in amputees and in patients with peripheral nerve or spinal cord lesions have shown that a stimulus may be referred to the deafferented area when applied to a somatotopically adjacent region (Cronholm, 1951; Melzack, 1990; Ramachandran et al., 1992; Aglioti et al., 1994; Halligan et al., 1994; Clarke, 1996; Kew et al., 1997; Borsook et al., 1998). For example, in upper limb amputees, stimulation of discrete areas of the face may be felt simultaneously at the stimulated site and in the phantom hand. Such mislocalization, which may appear as soon as 24 h after the deafferentation (Doetsch, 1997; Borsook et al., 1998), is considered as a perceptual manifestation of cortical reorganization, although the precise mechanisms and cortical regions involved are still a matter of debate (Ramachandran, 1993; Knecht et al., 1996; Ramachandran and Hirstein, 1998; Flor et al., 2000). The fact that we did not observe any referred sensation in the deafferented upper limb
during tactile stimulation of the ipsilateral face may be explained by the very short duration of the deafferentation and/or by the small number of patients examined. In all but one of our patients, the distribution of the C5 sensory root was not involved in the upper limb block. Thus, we cannot exclude that referred sensations could have been elicited by tactile stimulation of the ipsilateral shoulder, as occurs in some upper limb amputees (Ramachandran and Hirstein, 1998).

Peripheral mechanisms subserving body shape distortions

Our study showed that the occurrence of perceptual distortions of body shape is associated specifically with the impairment of thermal and pinprick sensations, known to depend on thin myelinated Aδ- and unmyelinated C-fibres (Yarnitsky and Ochoa, 1990, 1991; Fowler et al., 1988). This relationship between dysfunction of thin fibres and body shape alteration was found in almost all the patients, whatever the site of injection, the type of anaesthetic used and the sequence of sensory impairment. Interestingly, animal studies suggest that peripheral C-fibres provide a somatotopically specific source of tonic inhibition to the primary sensory cortex (Calford and Tweedale, 1991b). Accordingly, the suppression of such an inhibitory influence could contribute to the enlargement illusion reported by the patients during the course of deafferentation. Conversely, tonic pain elicited by nociceptive stimuli activating C-nociceptors, such as capsaicin, may also be associated with a perceptual enlargement of the painful area (N. Danziger and J. C. Willer, personal communication). This observation further emphasizes the modulatory role of thin fibres on the perception of shape and size of body parts. In contrast, our findings suggest that large myelinated Aβ fibres, which mediate touch sensation and position sense, are not involved in the perception of shape and size of body parts. This is in agreement with the observations made in two patients with a severe sensory polyneuropathy involving specifically large myelinated fibres, who completely lost the sensations of touch and position sense without any significant perceptual change of body shape (Gallagher and Cole, 1995).

Dissociation between shape distortions and postural illusions

Our results also suggest that the perceptual alterations of body shape are independent of phantom limb sensations during the course of an anaesthetic block. First, a majority of patients experienced an illusion of swelling, shortening or elongation of their anaesthetized limb during the block without any perceptual alteration of its posture and position. Secondly, the time course of these two phenomena was clearly different, the phantom sensation occurring after the body shape distortion in most cases. Furthermore, in patients who experienced both illusions successively, the occurrence of the phantom sensation did not modify the perceptual alteration of shape and size of the deafferented limb. Moreover, as discussed above, we found that perceptual alterations of body shape were associated specifically with partial impairment of thin myelinated and/or unmyelinated fibres. In contrast, anatomo-clinical correlations made in patients with spinal cord lesions suggest that postural hallucinations may occur as a result of the alteration of large myelinated fibres running in the posterior columns or as a result of the loss of massive input transmitted through other pathways (Nathan et al., 1986). Such dissociation between shape and postural illusions illustrates the view of Head and Holmes (1911) that the perception of the body outline and the awareness of its postural variations are constructed from different ‘schemas’ or ‘plastic models’, including a surface model and a postural model. These models normally act together and are linked by mutual interactions, as illustrated for example by the experiments of Lackner (1988) showing how proprioceptive misinformation about limb position can induce striking changes in the perceived shape of the body.

Visual information can also contribute to the construction of body image, although its role may be subsidiary in normal circumstances (Riddoch, 1941; Kinsbourne, 1995). The role of the visual image of the body is particularly well illustrated by the observation that mirrors can induce synaesthesia in a phantom limb (Ramachandran and Rogers-Ramachandran, 1996) and by the fact that illusions of ownership of a rubber hand can be elicited by synchronized visual and tactile stimuli in normal subjects (Botvinick and Cohen, 1998). Electrophysiological recordings in the monkey have shown that the position of a limb may be represented in the premotor cortex by means of a convergence of visual and proprioceptive cues onto the same neurons (Graziano, 1999). Such a combination of proprioceptive and visual information at the cortical level may explain why the view of the anaesthetized limb could abolish the phantom limb sensation induced by regional blocks, as described in the present work as well as in previous studies (Wallgren, 1954; Melzack and Bromage, 1973). In contrast, the lack of influence of vision on the perceptual distortions of body shape in the present study suggests that the neurophysiological mechanisms involved in this type of illusion take place at another, presumably less integrated, level of body image construction (see Crick and Koch, 1990).

Multiple levels of body image integration and the sense of ownership

Some patients reported a sensation of absence or cut of the deafferented limb. The absence of the limb was felt as a positive sensation of that limb being missing, but curiously this feeling of a missing limb co-existed with sensations such as tingling in or swelling of the absent limb. The co-existence of such contradictory sensations following deafferentation...
illustrates Schilder’s theory of body image as a synaesthetic construction depending on multiple levels of integration (Schilder, 1950). The living quality of the deafferented limb and the sense of its ownership were also questioned by a number of patients. Subjects who, while blinded, reported the feeling that the limb did not belong to them anymore had a correct perception of the limb’s position and posture. In other cases, denial of ownership occurred as the patient saw his real limb in a position which differed greatly from his illusory perception. These observations show that the sense of ownership of a body part may be influenced by peripheral afferent information through different mechanisms. One mechanism may consist of the alteration of the surface model of the body (Martin, 1995), while another may partly rely on the discrepancy between postural and visual models, i.e. between what the patient feels and what he sees.

For our patients, the feelings of a missing, dead or alien limb were never associated with fear or worry, probably because they could link these feelings to the transient effect of anaesthetics. In fact, most patients expressed their astonishment, curiosity or even amusement with regard to these sensations, as noted previously by other investigators (Miles, 1956). In contrast, clinical data show that patients with peripheral nerve or spinal cord lesions who experience such distortions of body image may be considerably distressed. Oliver Sacks described in an autobiographical ‘neurological novel’ the kind of subjective experience that may be associated with severe deafferentation in the context of peripheral nerve injury (Sacks, 1984). Body image alterations included the feeling of an ‘internal amputation’ and of the loss of the consistency, living quality and sense of ownership of the deafferented leg, as well as frightening illusions concerning its shape and size. Sacks showed how such body image distortions may constitute an ontological experience in which the patient’s sense of reality and sense of self may be threatened. His narrative, as well as the findings of the present work, invites us to pay attention to such peculiar feelings in patients with peripheral nerve or spinal cord lesions.

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