Differences in finger localisation performance of patients with finger agnosia

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Several neuropsychological studies have suggested parallel processing of somatosensory input when localising a tactile stimulus on one's own by pointing towards it (body schema) and when localising this touched location by pointing to it on a map of a hand (body image). Usually these reports describe patients with impaired detection, but intact sensorimotor localisation. This study examined three patients with a lesion of the angular gyrus with intact somatosensory processing, but with selectively disturbed finger identification (finger agnosia). These patients performed normally when pointing towards the touched finger on their own hand but failed to indicate this finger on a drawing of a hand or to name it. Similar defects in the perception of other body parts were not observed. The findings provide converging evidence for the dissociation between body image and body schema and, more importantly, reveal for the first time that this distinction is also present in higher-order cognitive processes selectively for the fingers. *NeuroReport* 19:1429–1433 © 2008 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

A long-standing division in body representations is the distinction between body image and body schema [1–3]. Although different definitions have been used, the body schema is generally considered to be a representation essential for the guidance of body movements that is not accessible to consciousness. As such, it continuously receives input about the position and the changes in the current position of the body parts. In contrast, the body image is a consciously accessible representation that is used for a perceptual experience of the body. It contains knowledge about bodily features such as size, and the normal configuration of the body parts [3,4]. In a recent model of cortical somatosensory processing [5], it has been proposed that the inferior posterior parietal cortex is mainly involved in the body-image representation, whereas sensorimotor guidance (body schema) relies on subcortical and superior parietal processing. These ideas are supported by a double dissociation between certain neurological patients with impaired perceptual detection, but intact sensorimotor guidance towards a tactually stimulated location (i.e. 'numbsense') and vice versa [3].

Several studies have suggested that the representation of fingers may be separate from representations of the rest of the body [6–8]. This idea is supported by the occurrence of specific impairments in identifying the fingers (e.g. finger agnosia) in patients with lesions to the angular gyrus. The distinction between body image and body schema therefore provides us with a framework in which impairments in finger representations and identification, that is, finger agnosia, can be examined in more detail. We can test whether a dissociation is present between body image and body schema impairments even when impaired function is restricted to the fingers. In contrast to other studies that have investigated dissociations in body representations in patients with 'numbsense' [3,9,10], basic tactile perception (e.g. pressure sensitivity and spatial acuity) in finger agnosia patients is generally intact. Awareness of this tactile stimulus in terms of relating it to the finger that has been touched is, however, suggested to be lost [7], which is most commonly observed for the fingers of both hands [6]. Together, this provides us with a unique opportunity to investigate dissociations in body representations on a higher-order cognitive level in patients with intact somatosensory processing.

We investigated finger gnosis in three patients with lesions affecting the angular gyrus by asking them to localise a touched finger using three different response modes. They were required to either point towards the touched finger on their own hand, on a drawn map of a hand, or by means of naming the targeted finger. We compared the results with the findings in five healthy

controls. On the basis of earlier findings [3,9,10] we expected to observe intact localisation of a stimulated finger when immediately pointing (with the other hand) towards the touched finger, which presumably involves the body schema. In contrast, localisation of the tactually stimulated finger on a line drawing of the hand is expected to be impaired, because tactile information about the targeted finger has to be transferred to an abstract hand representation based on the body image [3,4]. In addition, performance is expected to be impaired for the fingers of both hands. Further, information about lesion site may provide further converging evidence that the body-image representation is dependent on inferior parietal areas and more specifically, the angular gyrus [11,12].

Methods

Participants

Patient 1

G.O. is a 52-year-old right-handed woman who had suffered bilateral watershed infarctions in the parietooccipital region at the boundary between the supply area of the middle cerebral artery and the posterior cerebral artery including the angular gyrus. No signs of additional subcortical damage were observed (Fig. 1a). As a result, the patient presented with a transient left-sided hemiparesis and a permanent right-sided hemiparesis, but there were no signs of profound somatosensory loss. Neuropsychological assessment revealed impairments in writing, mental arithmetic and spatial orientation (left/right dissociation, mental rotation, and visual construction). No impairments in memory, executive function or language were found. As she exhibited several symptoms of Gerstmann's syndrome (acalculia, agraphia and left/right disorientation), G.O. was subsequently tested on finger gnosis, which indeed was impaired. G.O. scored 8 out of 10 correct when naming fingers of a drawn hand, 6 out of 10 when her own fingers had to be named and 5 out of 10 when the fingers were to be named in response to an unseen touch. The visual fields were intact. Two years later, when the experimental data were collected, she still experienced minor residual problems in writing and calculation, although these could no longer be confirmed in formal testing. Both proprioception and tactile pressure sensitivity were intact when tested at the distal phalanx of the right index finger.

Patient 2

B.U. is a 59-year-old man who suffered from a right occipital ischaemic stroke in the supply territory of the right posterior cerebral artery including the angular gyrus (Fig. 1b). Some minor white-matter lesions were visible on MRI, but no signs of profound subcortical damage were observed. He exhibited diminished visual capacities in the left visual field (left lower quadranopia), dysarthria and left-sided distal hemiparesis with intact coordination capacities. Both proprioception and tactile pressure sensitivity were intact when tested at the distal phalanx of the left index finger. Neuropsychological assessment revealed (mild) deficits in working memory, constructional praxis and finger gnosis. No executive or language impairments were found. B.U. scored 7 out of 10 correct when naming touched fingers (without vision), and 12 out of 20 when naming two simultaneously touched fingers. Experimental data were collected both 4 and 10 days poststroke.

Patient 3

M.A. is a 31-year-old woman who underwent a chronic subdural electrode investigation and surgery for intractable left temporal-lobe epilepsy by the removal of a circumscript epileptogenic focus caused by focal cortical dysplasia. The resection consisted of a superficial cortical ablation of about $5\,cm^2$ in the left posterior superior temporal gyrus and

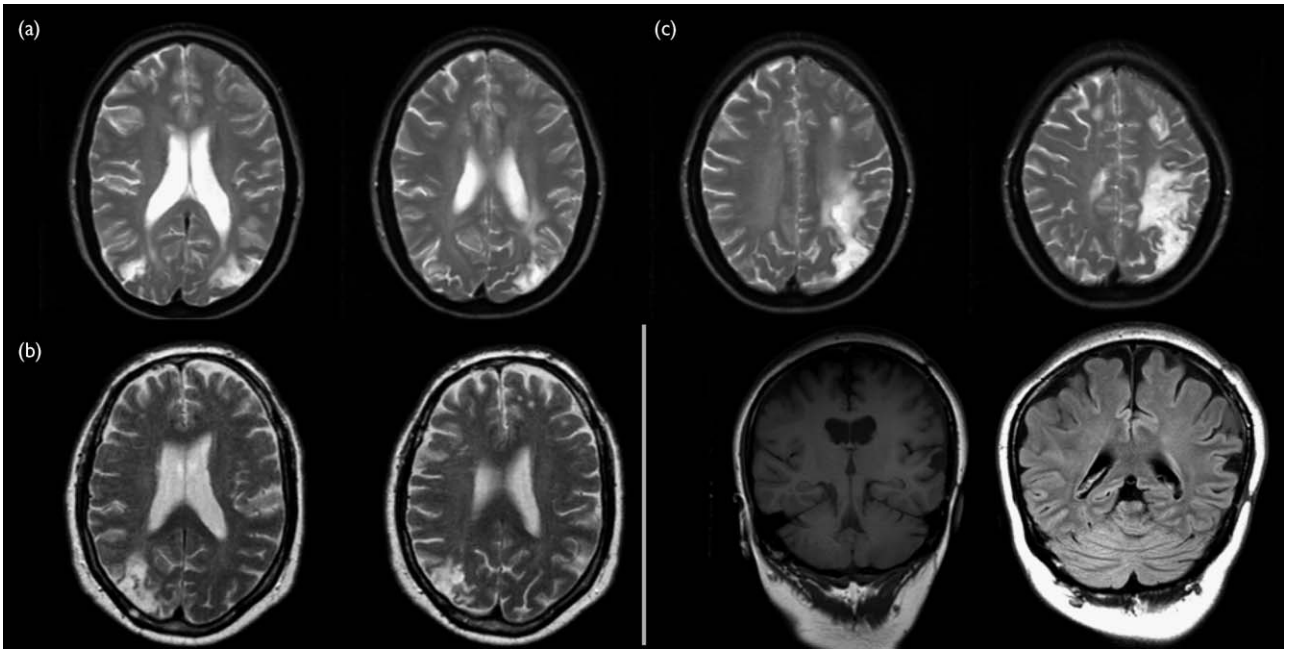

Fig. 1 Scans of patient 1 [(a) MRI T2/ FLAIR] patient 2 [(b) MRI T2/ FLAIR] and the postoperative scan of patient 3 [(c) MRI TI]. MRI, magnetic resonance imaging.

temporal part of the angular gyrus (Fig. 1c). A postoperative MRI scan did not show subcortical damage. Neurological examination was normal. Both proprioception and tactile pressure sensitivity were intact when tested at the distal phalanx of the right index finger. A short examination after the surgery did not show signs of finger agnosia (naming own fingers; 10/10 and fingers on a drawn map; 10/10 hand). Neuropsychological assessment revealed impairments in picture naming, a mild language-comprehension deficit and intact memory and executive functions. Experimental data were collected both 3 and 12 days postsurgery.

Control participants

Five healthy right-handed female participants (mean age 58.8 years; range 56–62 years) of comparable age and educational background participated in this study as controls. Written informed consents were obtained from all participants according to the declaration of Helsinki and the study was approved by the medical ethics committee.

Procedure

Participants were seated at a table on which the forearms and hands (palm down) rested during testing. Tactile stimuli were applied by the experimenter for 1.5 s using Semmes–Weinstein monofilaments (North Coast Medical Inc., Morgan Hill, California, USA; no. 5.18/10 g target force). The participants' hands were placed underneath a wooden board to prevent them from relying on visual feedback.

First, body-schema representation was assessed by asking the participants to point towards the touched finger itself (further referred to as 'pointing own'). After tactile stimulation of the finger, participants were required to immediately point with the nonstimulated hand towards the stimulated finger and to subsequently return to the starting position. All 10 fingers were examined four times each in a random order, resulting in a total of eight trials per finger.

Second, the body-image representation was investigated using identical tactile stimuli. Pointing movements, however, aimed at a drawing of a hand mounted on top of the wooden board now. Both hands were represented on this drawing (further referred to as 'pointing map') and consisted of a simple scaled line drawing from a dorsal perspective including details such as nails and skin creases, but without objects, such as a watch or a ring. The number of trials was identical to that of the body-schema task.

To obtain a classic measure of finger agnosia, finger localisation was also tested by asking the participants to name the touched finger (further referred to as 'verbal'). The procedure of this task was similar to the one described above. Finally, to prevent the occurrence of order effects, the presentation of the three tasks was randomised across participants using a Latin Square. In a follow-up test session the three finger tasks were retested to confirm the observed results from the first test episode (G.O: after 2 months, B.U: after 6 days, M.A: after 8 days). The number of days between the first and second test was determined by logistics and was not part of the manipulation. To control gross localisation problems of body parts in general, we examined the localisation performance of other body parts separately in the first test episode. In this task patients were required to locate their own body parts (left and right knee, shoulder and ear) on verbal command under full vision. All side by body part conditions were tested twice, resulting in a total of 12 trials.

Data analyses

For each task percentages correct were calculated both for the patients and the control participants. The chance of randomly guessing a certain finger is one out of five (20%), when hand identification (left or right) is not impaired. Therefore, percentages were corrected by subtracting chance level from the percentages correct (resulting in a maximum percentage of 80). Next, performance of the patients was compared with that of the control subjects using Crawford and Garthwaite's test for the abnormality of test scores as ceiling effects were expected to be present in healthy controls [13]. In case of a perfect performance of the controls (SD=0) abnormality cut-off scores would be defined as 'less than 99% accuracy (79% when corrected for chance levels)'. Furthermore, to test for performance differences between left-hand and right-hand fingers, we performed a standard nonparametric test for frequencies of two related samples (McNemar test) for each task with the percentage correct as dependent variable.

Results

Figure 2a shows the corrected percentages correct for each task and participant. The healthy controls showed near-perfect performance in the finger gnosis tasks [pointing own: mean=80.0 (SD=0.0); pointing map: mean=79.0 (SD=2.2); verbal: mean=80.0 (SD=0.0)]. Visual inspection of the finger-gnosis data revealed that all patients showed a similar pattern of results (see Fig. 2a), that is, near-normal performance in the pointing-own task in combination with impaired performance in the pointing map and verbal task. The Crawford and Garthwaite test indeed confirmed the impaired performance in the pointing-map task for all three patients (significantly different from control group; all $P<0.001$). Overall performance of the three finger agnosia patients was, however, well above chance level, as is indicated by the 0% correct level. This clearly shows that at least some information about finger identity is preserved.

The pattern of performance is similar for right-hand and left-hand fingers. Indeed, no significant differences were observed between left and right hand performance as was revealed by the McNemar tests (all $P>0.2$; see Fig. 2b).

The distribution of incorrect responses (Fig. 2c) showed that across tasks and patients most errors were related to the middle three fingers, whereas the thumb and little finger were identified almost perfectly. Figure 2d shows the performance of each patient when ignoring the thumb and little finger. Performance in the pointing map and verbal tasks is reduced compared with all fingers when they were included, but still above chance level, which is indicated by the 0% level.

Finally, all patients showed a perfect performance of the body parts localisation task indicating that the localisation of other body parts is intact (G.O: 12/12, B.U: 12/12, M.A: 12/12). Normative scores of this task have been determined earlier in a separate age-matched healthy control group (n=20) and revealed a perfect score of 12 out of 12 in all participants.

Observation of the data of the second test episode revealed a consistent pattern, with normal performance on the pointing-own task and impaired performance on the

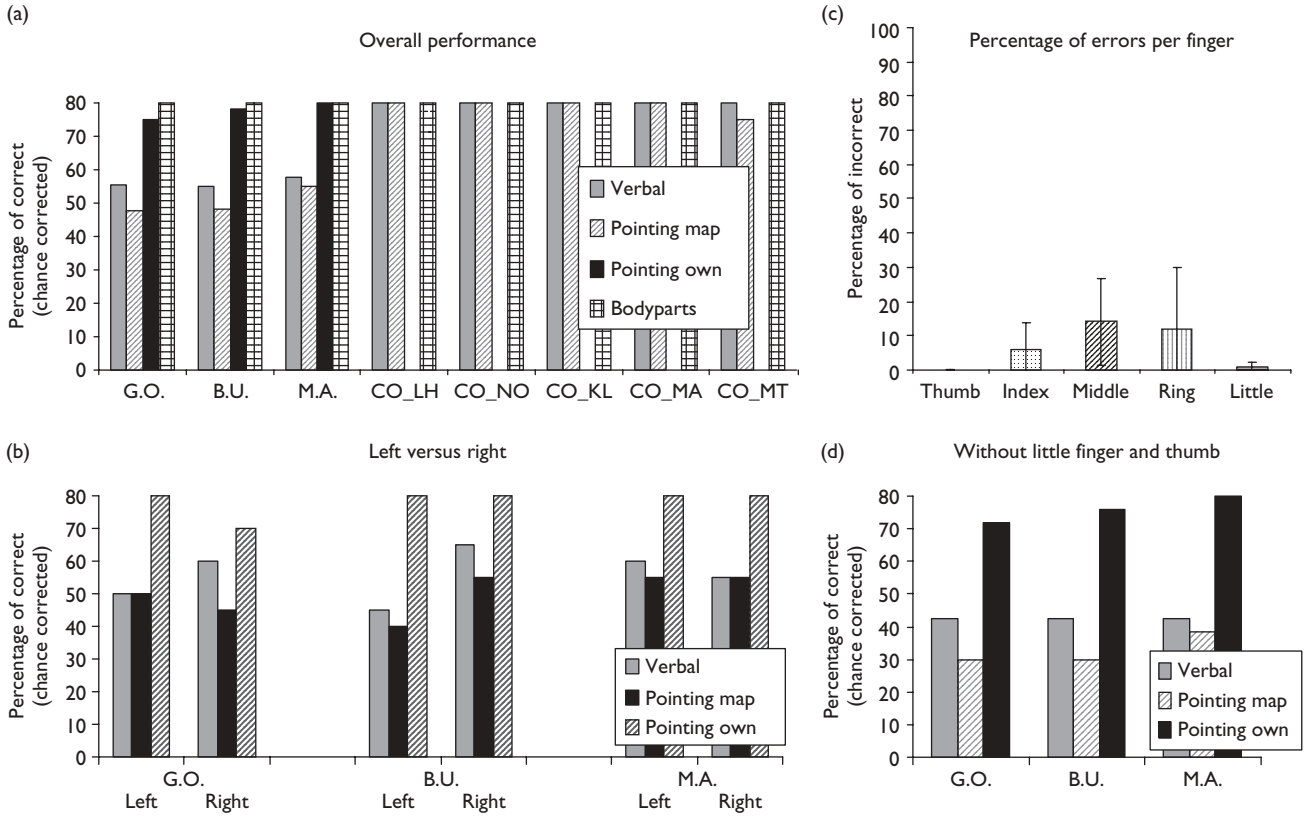

Fig. 2 (a) Accuracy results (% correct – 20% chance level) of the patients and the age-matched control participants on the pointing own, pointing map and verbal tasks. (b) Performance of left-hand and right-hand fingers for each task and patient separately (% correct – 20% chance level). (c) Distribution of errors over the different fingers, across hands, tasks and patients. The error bars represent +/− 1 standard error of the mean. (d) Performance for each patient per task calculated on the basis of ring, middle and index finger only (% correct – 20% chance level).

two body-image tasks (G.O: verbal=38%, pointing map=48%, pointing own=70%; B.U: verbal=65%, pointing map=63%, pointing own=80%; M.A: verbal=65%, pointing map=60%, pointing own=80%). In addition, an overall higher accuracy was observed for all patients in the second test episode (G.O. +2%; B.U. +9%; M.A. +4%). Paired samples *t*-tests comparing the first and second episode revealed that only the difference observed in B.U. reached statistical significance [$t(40)=2.56$, $P<0.05$].

Discussion

We examined different types of finger representations in three patients with lesions in the angular gyrus who were suspected of having finger agnosia. The results clearly showed a similar pattern in all three patients, despite differences in aetiology and lesion side. All patients exhibited impaired performance in the task that was hypothesised to activate the body image, that is, a perceptual or semantic representation of the fingers. This deficit was found in naming a touched finger or pointing towards this finger on a schematic drawing, and was not because of language problems or motor deficits. In contrast, the patients performed normally when asked to point directly to the touched finger without the aid of visual feedback. This latter task condition is considered to involve the body schema, a sensorimotor representation of the fingers that is not consciously accessible and is used for guiding motor action.

Together, the current findings demonstrate dissociation between perceptual and sensorimotor responses which is in line with studies reported earlier on body representations [3,9]. These earlier studies, however, have investigated 'numbsense' patients who have intact localisation abilities in the absence of conscious touch perception, but who performed at chance level when pointing towards the touched location on a map of the body. Extending these findings, we tested patients who were completely aware of the tactile stimulations on the fingers, but most remarkably remained unable to localise the tactile stimulation on drawing of hand. Thus, this is the first time that such a dissociation is reported in patients with specific higher-order impairments leading to impaired identification of the fingers. Furthermore, the intact performance when localising tactile stimuli in other body parts suggests that the impairment is indeed restricted to the fingers, confirming the notion of a separate finger representation [6,8].

We suggest that the specific location of the target finger in terms of its relative position within the other fingers is lost in our patients. This caused the impairments in localising touched fingers on drawing of the hand. To associate tactile information about the target finger with appropriate finger name, one must be aware of the specific location of the finger amongst the other fingers, hence the impaired performance in the verbal task. In contrast, the intact localisation abilities when pointing to tactile stimuli on one's own hand indicates that spatial information about the

relative position of the finger that had been touched is not crucial for programming a motor response targeted at the touched skin. This action is computed on the basis of the skin location, which can be classified as direct sensorimotor coupling and occurs without elaborate cognitive processing.

Finger agnosia is often reported after lesions of the angular as well as the supramarginal gyrus [11,12]. Neuroimaging data of our patients confirmed involvement of these regions. In line with the observed lesion data, Dijkerman and de Haan [5] have suggested that with respect to immediate guidance of action (pointing to self), somatosensory information is processed both by subcortical and cortical routes from the somatosensory cortex to the superior parietal lobule. In contrast, conscious perception and memory, which are required when pointing towards a touched location on a map of the hand, are mainly subserved by cortical routes to the posterior insula and posterior parietal cortex. The authors assigned the inferior parietal lobule, which includes the angular gyrus, to be involved in conscious perception and memory with respect to metric aspects of the body and its parts.

Finally, some aspects about this study require discussion. First, finger agnosia impairments are heterogeneous and finger identification involves many complex higher-order functions which can be impaired, such as executive functioning, spatial awareness, language or memory. The current findings are unlikely to be caused by impairments in these cognitive domains, because none of our patients presented with profound impairments in executive functioning, spatial awareness or memory. The second issue is the location of the lesion. The aetiologies (stroke) in two of the three patients were such that the lesion was unlikely to be restricted to only one cortical area. In the third patient, however, the lesion was made surgically and was mainly restricted to the cortex of the angular gyrus. Nevertheless, we were able to identify unique overlay of the lesions in this brain region. Finally, it must be noted that even in the absence of severe finger-gnosis deficits in a short clinical examination (M.A.), impaired finger identification performance can be demonstrated when tested more extensively.

Overall, this study further confirms the hypothesised dissociation between body image and body schema representations and most importantly suggest that such a dissociation applies even at the higher-order level of the fingers.

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