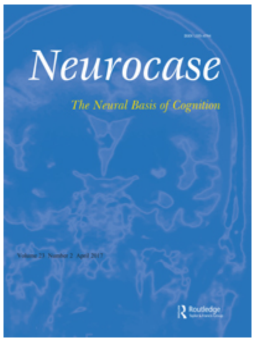

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REPORT

Modulation of somatoparaphrenia following left-hemisphere damage

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ABSTRACT

Somatoparaphrenic symptoms after left-hemisphere damage are rare. To verify the potential role of body-related sensory (proprioceptive, visual, and somatosensory) manipulation in patients experiencing sensations of hand disownership, the symptoms of a patient suffering from right-hand somatoparaphrenia were monitored and clinical and neuropsychological variables were controlled. Four types of manipulation were administered: changes in spatial position of the hand, multisensory stimulation, and self-observation using video or mirrors. Multisensory visuo-tactile stimulation was efficacious in terms of reducing somatoparaphrenia, and changes in the position of the hand produced some positive effects. Third-person perspective self-observation did not, however, result in any changes.

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Disturbed sensation of limb ownership; body awareness; Gertmann's syndrome; rehabilitation; somatoparaphrenia after a left-hemisphere lesion

Introduction

Disorders in body representations following brain damage have been reported since the first half of the twentieth century (Head & Holmes, 1911). Gerstmann (1942) described body ownership disturbances citing patients who were unable to recognize contralesional body parts as belonging to their own body. Later, various classifications were suggested (e.g., Critchley, 1953; Hécaen, 1972) and a distinction was made between patients showing a lack of recognition of the existence or ownership of their limbs (asomatognosia/disownership) and the condition where this is accompanied by delusions regarding the affected limbs, such as the belief that the affected limb belongs to another person (somatoparaphrenia).

Somatoparaphrenia may in fact take several clinical forms (Vallar & Ronchi, 2009) and in order to classify all abnormal feelings and beliefs regarding paralyzed limbs, a definition entitled "the disturbed sensation of limb ownership" (DSO) was proposed (Baier & Karnath, 2008; Moro et al., 2016).

The specificity of the syndrome and the contribution of other functions in its onset (in particular, somatosensory information and neglect) is still being debated (Vallar & Ronchi, 2009). Nevertheless, in accordance with previous classifications (Schwoebel & Coslett, 2005), DSO is considered as a disorder in body schema (i.e., the online representation of one's own body) which is strictly dependent on ongoing sensory and motor information (Sirigu, Grafman, Bressler, & Sunderland, 1991). Furthermore, DSO is usually associated with anosognosia for hemiplegia (AHP), although clinical and anatomic dissociations have been found. While AHP occurs after damage to the right insula, rolandic operculum, and superior temporal gyrus, a shift in the latero-medial direction (involving the basal ganglia) emerges when DSO co-occurs with AHP (Moro et al., 2016).

Only a few cases of DSO after left-hemisphere lesions have been reported (Beato et al., 2010; Cogliano, Crisci, Conson, Grossi, & Trojano, 2012; Cohen, Rémy, Leroy, Gény, & Degos, 1991; Miura et al., 1996; Nielsen, 1938; Perren, Heydrich, Blanke, & Landis, 2015; Schiff & Pulver, 1999; Schilder, 1935; Vallar & Ronchi, 2009) but even though the incidence of this pathology is rare, these cases may help us to understand the theories underlying neuro-cognitive mechanisms of body-ownership better.

It has been proposed that crossed somatoparaphrenia is less strongly associated with AHP and personal neglect than somatoparaphrenia after right brain damage, although from a clinical point of view, the two conditions appear very similar. In contrast, right-hand DSO seems rather to depend upon a combination of extra-personal neglect and sensory–motor deficits, with concomitant verbal capacities which allow the patient to express delusional ideas (Perren et al., 2015). In this way, awareness of body space (personal neglect) is preserved, while sensory–motor disorders are the principal cause of the symptoms. For this reason, we formulated the hypothesis that the manipulation of sensory–motor information would help these patients to improve and reconstruct their body representation. In addition, we tested the effects of spatial manipulation.

To date, experimental results are not exhaustive and almost exclusively refer to DSO after right-hemisphere lesion (but see Spitoni et al., 2016). Thus, any efforts to investigate in depth these rare cases of crossed DSO would constitute a contribution toward a better understanding of the syndrome.

With the aim of investigating the potential role of body-related sensory information in modulating DSO after left-hemisphere damage, we compared the effects of four different types of manipulation in one individual patient (AS). Changes to the spatial position of the contralesional upper limb (UL) were made in order

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to evaluate proprioceptive and spatial components. Multisensory visuo-tactile stimulation served to investigate the role of sensory integration in the syndrome, while self-observation of the hand in a video clip or a mirror allowed us to assess the effects on the patient of changes in perspective.

All these procedures have been recently demonstrated to be efficacious in reducing DSO following right-hemisphere lesion. In particular, it has been suggested that there is a visuo-spatial component of the syndrome as changes in the observation perspective induce a modulation of the symptoms. In effect, it is considered that changing the visual perspective of a patient (from the first to the third person) will influence his/her visual-spatial frames of bodily reference and integrate multiple body representations (Fotopoulou et al., 2011; Jenkinson, Haggard, Ferreira, & Fotopoulou, 2013). The position of the examiner can also impact patients' responses (Salvato et al., 2015). Moreover, the importance of the role of sensory information has been demonstrated by means of a study involving multisensory visuo-tactile stimulation (Bolognini, Ronchi, Casati, Fortis, & Vallar, 2014). In fact, when visual information indicates that the plegic hand is being touched and this is in synchrony with the real sensation relating to the healthy hand which is being touched, this integration of different sensory afferences impacts the body higher order representations, improving the patients' awareness of their disowned hand.

To the best of our knowledge, these manipulations have not been applied to patients with right-hand DSO and there have been no comparisons of the effects on an individual patient. We expected that the spatial changes in the position of our patient's hand would have minimal effects in line with previous results (Moro, Zampini, & Aglioti, 2004), as a result also of the lesion in the left hemisphere. In contrast, it was anticipated that visuo-tactile stimulation would impact the symptoms as sensory–motor components seem to have a crucial role in right-hand DSO. Lastly, there were no specific predictions regarding any changes in the visual observation perspective as these tasks involved not only visuo-spatial but also motor components and high-order representations of the body.

Methods

Case report

AS is a 78-year-old, right-handed woman with 13 years of education. She suffered a hemorrhagic left-hemisphere stroke involving the fronto-temporal-insular cortex, the underlying white matter and basal ganglia (Figure 1). She was examined 3 days after the lesion onset and then daily for 3 months. During this period, she remained unable to move her right limbs due to the presence of hemiplegia (Medical Research Council – MRC – Scale for Muscle Strength test, Florence et al., 1992). She showed disorders in tactile perception and her sense of position. These were tested by means of touching and moving three different parts of the UL (index finger, wrist, and elbow) and asking the patient whether she had been touched or moved. Each trial was repeated three times (Vocat, Staub, Stroppini, & Vuilleumier, 2010, adapted for tactile perception). There were signs of right side personal and

(c)

Brain regions	% Voxels	N. Voxels
Temporal Middle L	87.56	34458
Temporal Inferior L	85.62	21958
Putamen L	84.88	6741
Insula L	84.43	12686
Heschl L	83.54	1507
Temporal Superior L	77.89	14259
Temporal Pole Middle L	76.50	4578
Temporal Pole Superior L	62.56	6399

Brain regions	% Voxels	N. Voxels
Rolandic Oper L	58.40	4636
Amygdala L	53.95	935
Pallidum L	48.88	1117
Frontal Inferior Oper L	26.91	2226
Caudate L	25.18	1934
Fusiform L	23.53	4313
Hippocampus L	18.53	1384
ParaHippocampal L	15.17	1197

(d)

Brain regions	% Voxels	N. Voxels
Sagittal Stratum	100	2228
Superior Fronto-occipital	100	507
Uncinate Fasciculus	100	380
External Capsule R	95.65	5367
Retrolenticular Part of Internal Capsule	95.51	2402
Posterior Limb of Internal Capsule	72.80	2733
Posterior Thalamic Radiation	60.22	2392
Anterior Limb of Internal Capsule	50.30	1861

Brain regions	% Voxels	N. Voxels
Tapetum R	57.55	343
Superior Corona Radiata	57.39	4304
Superior Longitudinal Fasciculus	42.02	2776
Posterior Corona Radiata	31.30	1167
Anterior Corona Radiata	25.45	1743
Fornix	24.64	277

Figure 1. AS's lesion. (a) A representation of the traced lesion on a 3D brain, (b) real neurological CT in Axial view, (c) percentage and number of voxels damaged for each gray and (d) white matter divided according to brain region.

Table 1. Neuropsychological assessment.

	3 days			1 month			2 months		
Motricity	Right		Left	Right		Left	Right		Left
MRC[1]	0		5	0		5	0		5
Tactile perception (9)	**0**		9	**0**		9	**3**		9
Proprioception (9)[2]	**0**		9	**0**		9	**3**		9
Handedness									
Handedness questionnaire[3]	19		2						
Edinburgh inventory[4]	19		0						
Right spatial neglect									
Line crossing[5]	**0**		18	**0**		18	**0**		18
Star cancellation[6]		np			**8**			**6**	
Line bisection[6]		**9**			**9**			**9**	
Figure and shape copying[6]		**0**			**0**			**0**	
Representational drawing[6]		**0**			**0**			**0**	
Comb and razor test[7]		**0.78**						**0.28**	
Visual extinction of double stimulus %[8]	**0**		100	**0**		100	**0**		100
Body representation									
Anosognosia for hemiplegia (UL)[9]		**2**			**2**			**2**	
Anosognosia for hemiplegia (LL)[9]		**2**			**2**			**2**	
Somatoparaphrenia[10]		–			–			–	
Left–right disorientation (10)[11]		**6**			na			**6**	
Indication of body parts (verbal command)[12]									
One's own body with closed eyes(18)					17				
Examiner's Body open eyes (18)					17				
On a manikin (21)					*16*				
Spatial localization of body parts (13)					*10*				
Spatial localization of bicycle parts (13)					12				
Semantic Knowledge[12]									
Denomination of body parts (18)					***9***				
Definition of body part functions (10)					10				
Finger agnosia[12]									
Indication of her fingers (30)				**18**		np			
Indication on a drawing of a hand (30)				25		25			
Denomination of fingers (30)				**18**		**18**			
Definition of finger functions (10)					**2**				
General Functions (MMSE)[13]		*24*			na			na	
Language		+			+			+	
Memory[14]		np			+			+	
Praxic functions[15]		–			–			–	
Calculation[16]		np			–			–	
Frontal Functions (FAB)[17]		np			**7.5**			na	

The scores at the neuropsychological assessment at intervals of 3 days, 1 and 3 months from lesion onset are shown. Assessments in: motricity ([1]Florence et al., 1992), proprioception ([2]Vocat et al., 2010), handedness ([3]Briggs & Nebes, 1975; [4]Oldfield, 1971), and neglect ([5]Albert, 1973; [6]Wilson, Cockburn, & Halligan, 1987; [7]Beschin & Robertson, 1997; [8]Karnath, Baier, Nägele, 2005). Assessment of body representation: anosognosia for hemiplegia ([9]Berti et al., 1996); somatoparaphrenia ([10]Moro et al., 2004); left/right disorientation ([11]Benton, 1959); identification of body parts, semantic knowledge of body, and finger agnosia ([12]Moro et al., 2009). General functions ([13]Folstein, Folstein, & McHugh, 1975); language, memory ([14]Spinnler & Tognoni, 1987); Praxic functions ([15]De Renzi, Motti, Nichelli, 1980); calculation abilities ([16]Miceli & Capasso, 1991); frontal functions ([17]FAB – Frontal Assessment Battery, Apollonio, et al., 2005). UL: Upper limb; LL: lower limb. na: not available; np: not possible; +: not impaired; –: impaired. The number of total stimuli assessed is in parenthesis. Scores at cutoff are in italic. Pathological scores are in bold.

extra-personal neglect and deficits in calculation, praxic abilities and frontal functions, while language and memory were preserved (Table 1). AS was unaware of her hemiplegia (AHP) and showed signs of somatoparaphrenia (DSO): in a number of clinical interviews, she repeatedly denied that her right side was paralyzed and did not recognize her deficit even after her unsuccessful attempts to move (Berti, Làdavas, & Della Corte, 1996). When she looked at her right UL, she declared that it was not her hand and claimed that it belonged to the doctor or examiner.

Due to the unusual side of the lesion, an extensive assessment of body representation was carried out 1 month after the onset of the lesion (Moro, Pernigo, Urgesi, Zapparoli, & Aglioti, 2009). This showed disorders in left–right orientation, the denomination of body parts and finger agnosia (Table 1). While the DSO resolved itself in 6 weeks, AHP was still present 6 months after the lesion onset.

AS gave written, informed consent to her participation in the study (CEP prot. No. 39216).

Lesion mapping

In order to ascertain the lesion in the patient's brain, AS's structural MRI scan was mapped using the MRIcron software (Rorden & Brett, 2000) and traced onto a standard T1-weighted MRI template (ICBM152) of the Montreal Neurology Institute coordinate system, approximately oriented to match the Talairach space (Talairach & Tournoux, 1988). The template was oriented on the mid-sagittal and mid-coronal axes to closely match the orientation of AS's original MRI scan. The lesion was then traced manually by an experienced clinician onto the rotated template. In this way, the outcome was a map of the damaged areas with each voxel labeled as 0 (intact) or 1 (lesioned). Finally, the lesion map was rotated back to the canonical orientation and was superimposed onto an Automatic Anatomical Label template (Tzourio-Mazoyer et al., 2002) and the Johns Hopkins University DTI-based white matter atlas (Mori, Wakana, Van Zijl, & Nagae-Poetscher, 2005) in order to analyze the damage to gray and white matter, respectively.

Procedure

To verify the role of visual and sensory components in the modulation of disownership, four experimental manipulations were repeatedly administered during the first 6 weeks. These included (1) changes in the spatial position of the patient's right hand; (2) multisensory stimulation; and changes in the patient's visual perspective of her hand by means of self-observation in (3) a video clip or (4) a mirror.

At least two different manipulations were carried out in each session in random order and with intervals of at least 45 min (see Table 2 for the sequence of the tasks and the time session-lesion onset intervals). In every session, there was only one trial for each manipulation, with the exception of the task involving spatial position changes which was repeated 5 times for each position within each session (see the Changes in spatial position section). The number of manipulations and the duration of each session depended on AS's conditions, in particular on her attention and fatigue. In fact, AS's cognitive functions fluctuated and were influenced by clinical variables (e.g., pain, quality of sleep) and manipulations were only administered when she felt well enough. A daily diary of symptoms potentially related to DSO was kept (Table 2).

AS was tested in a quiet room with the examiner standing on her right. She sat at a table, the position of her hands and the direction of her gaze were controlled. To assess any potential modulation in DSO due to experimental procedures, we recorded the patient's responses to two questions regarding DSO before and after each manipulation: "Is this hand your hand?" (response: Yes/No); and if the response was "No," "Whose is this hand?." All of the patient's responses were manually recorded. In the multisensory and mirror manipulations (see below), the questions were also asked during stimulation. The same questions were asked again 5 min later to check how long the modulation lasted and to avoid any carryover effects.

Whenever it was possible, any potential modulation in AHP and neglect was assessed before and after the experimental task (Table 2). Finally, the same experimental procedures were repeated once on the left hand as a control.

Changes in spatial position

While she was being distracted by general questions, AS's right hand was placed palm down, in one of four positions (counterbalanced order, Figure 2(b)): (a) raised in front of her eyes; resting on the table to her (b) left, (c) in the middle, and (d) to her right. When her hand was still, questions regarding its ownership were asked (25 assessments for each position).

Multisensory stimulation

AS's hands lay on the table in front of her, elbow bent, palm down, and in a symmetrical position (Figure 2(c)). Following Bolognini and colleagues' procedure (2014), we simultaneously stroked the dorsum of AS's right hand (which she could see) and left hand (hidden from view) with a soft cosmetic brush. Due to AS's limited attentional capacities, we reduced the stimulation time to 2 min (instead of 10 min, as in the original paradigm). Throughout the stimulation, we made sure that AS was looking at her right hand, recalling her attention whenever necessary. We asked questions relating to DSO before and during tactile stimulation (five measures). This allowed us to exclude the possibility that the mere sight of her right hand induced a modulation in DSO.

Video clip

A video (recorded during the first assessment of AHP and DSO) showed the patient while she was answering DSO-related questions (Besharati, Kopelman, Avesani, Moro, & Fotopoulou, 2015). In the video, a frontal view of the upper part of the patient's body was visible and the examiner was shown standing to the right of the patient holding her right arm. Over five sessions, the video clip was shown to AS and the DSO questions were asked.

Mirror

The procedure was similar to that used in the video clip experiment with the only difference being that AS responded to the DSO questions while she was sitting at a table looking at her right hand reflected in a mirror (online measure, five measures). The mirror was placed in front of AS and it showed her right hand from a third-person visual perceptive (Fotopoulou, Rudd, Holmes, & Kopelman, 2009).

Results

AS always recognized the left hand as her own during the control tasks.

In contrast, the sense of ownership of right hand was modulated to different degrees by the experimental manipulations. There were immediate strong effects resulting from the multisensory stimulation, minor benefits from the changes in the hand position, and no improvement from the changes in visual perspective. Since whenever the patient denied the ownership of her hand she was very consistent in attributing it to the doctor, we exclusively analyzed the Yes/No responses to the first question ("Is this hand your hand?").

Spatial position

Changing the position of AS's hand modulated her sense of disownership ($\chi^2_{(3)} = 12.438$, $p = 0.006$), with the central/raised position resulting in the worst performance. A progressive increase in accuracy was present in the positions with the hand lying on the table to the left, in the center, and to the right, although the only statistically significant comparison was that between the central-raised and right-side positions (Figure 2(b)).

Multisensory stimulation

There was an immediate, ameliorating effect on DSO during the multisensory stimulation sessions with the patient referring to the hand as her own in all five sessions (Figure 2(c)). Unfortunately, 5 min after manipulation, AS went back to

Table 2. Timetable of the experimental sessions and the evolution of the symptoms.

	Session number and interval from lesion																						
Task	1 3 d	2 4 d	3 5 d	4 6 d	5 7 d	6 10 d	7 11 d	8 12 d	9 13 d	10 14 d	11 18 d	12 19 d	13 20 d	14 22 d	15 27 d	16 31 d	17 33 d	18 35 d	19 37 d	20 38 d	21 45 d	22 75 d	23 105 d
	NT		NT	NT											NT						NP	NP	NP
Spatial position		x			x	x	x	x	x	x	x	x	x	x		x	x	x	x	x			
Multisensory								x		x				x				x	x				
Mirror					x		x				x		x					x					
Video									x			x		x		x	x						
Symptom	1 3 d	2 4 d	3 5 d	4 6 d	5 7 d	6 10 d	7 11 d	8 12 d	9 13 d	10 14 d	11 18 d	12 19 d	13 20 d	14 22 d	15 27 d	16 31 d	17 33 d	18 35 d	19 37 d	20 38 d	21 45 d	22 75 d	23 105 d
AHP (b/a)	+	+/+			+/+	+/+		+/+		/+	+/+		+/+		+	+		+/+	+/+	+/+	+	+	+
Neglect (b/a)	+	+/+			+/+	/+			/+		/+				+	+		+/+		+/+	+	+	+
Attention	1	2	1	1	2	2	1	3	4	3	5	4	5	4	4	4	4	4	4	4	4	4	4
Fluency	1	3	1	1	5	4	1	5	4	4	4	4	3	5	3	3	3	3	5	3	3	3	3
Confabulation	2	4	2	2	2	3	2	4	4	4	2	3	2	4	3	3	3	3	5	5	5	5	5
Avoidance	5	5	5	5	5	5	5	3	3	2	1	1	1	3	5	5	5	3	2	4	5	5	5
Referred pain	5	5	5	5	5	5	1	3	2	1	1	1	1	4	5	5	4	4	1	4	5	5	5
Fatigability	1	4	3	3	3	2	1	3	4	3	2	4	4	4	4	4	4	3	4	4	4	4	4
Gaze deviation	L	L	L	L	L	L	L	L	L	L													

All the experimental and clinical sessions are reported with the session number and the session-lesion onset interval for each session indicated (d = days from lesion onset). In the upper section, the timing of the experimental tasks; NT: not testable for clinical reasons, NP: DSO no longer present; x indicates the experimental tasks administered in the session. In the lower section, the evolution of the clinical symptoms over time. AHP: Anosognosia for hemiplegia; b/a: assessment done before and after the experimental sessions; +: presence of deficits. Scores for clinical symptoms from 1 (severe deficit) to 5 (no deficit) are rated as follows: attention: scores from 1 (no attention) to 5 (complete attention), fluency: scores from 1 (mute) to 5 (loquacious); confabulation: scores from 1 (inconsistent language) to 5 (consistent language); avoidance: scores from 1 (very frequent) to 5 (not present at all); referred pain: scores from 1 (excessive complains) to 5 (not reported); fatigability: scores from 1 (high degree) to 5 (absent). L: Presence of gaze deviation toward the left side.

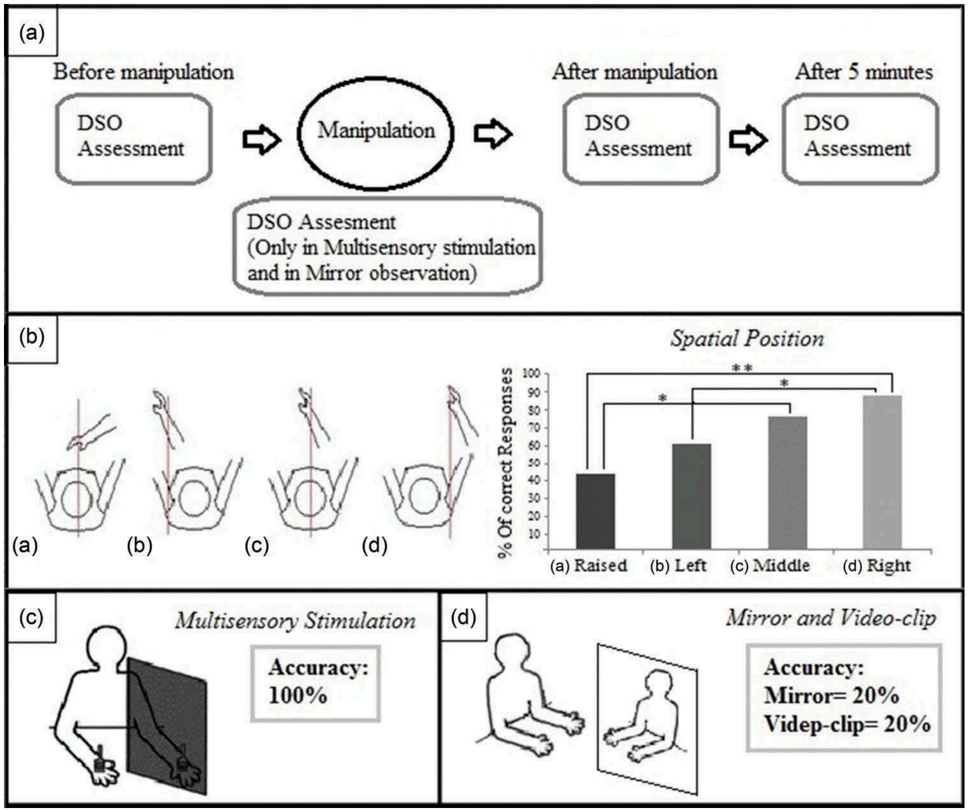

Figure 2. Experimental procedure: (a) The timeline for the experimental procedure for all tasks. (b) The positions of AS's right hand in spatial position manipulations: (a) raised; (b) to the left; (c) in the middle; (d) to the right. A graph with the percentage of correct responses is shown; **significant direct *post hoc* (χ^2, FDR corrected, Benjamini & Hochberg, 1995: raised vs. right: $\chi^2(1) = 8.912$, $p = 0.008$); *tendency to significant direct *post hoc* (raised vs. middle: $\chi^2(1) = 4.083$, $p = 0.053$ and left vs. right: $\chi^2(1) = 3.742$, $p = 0.053$). (c) AS position in the multisensory stimulation experiment and the percentage of correct responses. (d) AS position in the mirror (similar to video clip) stimulation and the percentage of correct responses for the mirror and video clip manipulations.

denying ownership of her hand. As her responses in this task were dichotomous and the frequency of correct responses ("Yes, this is my hand") was 0% before and after manipulation and 100% during tactile stimulation, we did not carry out any statistical analysis.

Video clip and mirror sessions

During both these procedures, only once (out of five trials) did AS declare that the hand was hers. Thus, this manipulation was not efficacious. In contrast, when AS was asked to look at her hand from a different perspective, she merely became confused. Due to the reduced number of trials administered, we did not perform any statistical analysis.

No changes in AHP and neglect were recorded either before or after experimental sessions.

Discussion

Somatoparaphrenia is a rare syndrome after right brain damage and it is almost unknown in left-side lesions. Only a few patients have been described (Perren et al., 2015) and for this reason, our patient is particularly interesting.

Neuropsychological research indicates that various different kinds of information (semantic, somatosensory, visuo-spatial, and motor knowledge; Sirigu et al., 1991) contribute to body representation. Three distinct types of body-related constructs have been postulated (Schwoebel & Coslett, 2005): (1) *body image* – which refers to the semantic representation of the body, such as knowing the names of body parts, their functions, and their relationships to objects; (2) *body schema* – which refers to the dynamic representation of the relative position of body parts which depends on multiple sensory and motor inputs and their interaction with the planning and execution of actions; and (3) *body structural description* – which is a topological map of body locations which primarily depends on visual inputs and defines body part boundaries and proximity relationships. While body image and body structural representations seem to rely on the left hemisphere, the body schema seems to be linked to the right hemisphere (Buxbaum & Coslett, 2001; Schwoebel & Coslett, 2005).

Our neuropsychological assessment excluded the possibility that AS presented with reversed hemispheric lateralization and thus, her case is even rarer. Indeed, she showed symptoms typically associated with both left (calculation disorders, left/right confusion, finger agnosia, apraxia) and right-hemisphere lesions (neglect, AHP, DSO). For this reason, we consider that her case involves a co-occurrence of Gerstmann's syndrome (Mayer et al., 1999). A similar combination of symptoms traditionally related to body schema (right-hemisphere lesions) and body image (left-hemisphere lesions) was previously reported in a patient suffering from Gerstmann's Syndrome following right lesion (Moro et al., 2009). Although rare these cases lead us to consider that a definitive version of the distinction between body schema and body image, normally connected with right or left hemispheric lesions, respectively, is not totally adequate in terms of describing the neural correlates of body representation.

Although AS had suffered damage to the left hemisphere, the lesion was very similar to those reported for DSO following right-hemisphere damage involving the temporo-insular cortex, basal ganglia (mainly the putamen and amygdale), and the subcortical white matter around these (Moro et al., 2016; Perren et al., 2015).

AS was in the acute phase of the illness and her attention fluctuated. This precluded the possibility of devising complex experimental paradigms, which are generally very demanding in terms of attention. Nevertheless, the continuous, daily monitoring of her clinical and neuropsychological symptoms (in particular, neglect and AHP) enabled us to exclude the possibility that the modulation of DSO was mediated by factors other than those relating to our experimental procedure. Indeed, we noted a progressive increase in attention over time, but this did not correspond to any change in DSO. In contrast, this increase in her attention capacity appeared to be associated with a temporary aggravation of other symptoms such as fatigue and avoidance (Fotopoulou, Pfaff, & Conway, 2012). Confabulations did not change over time. Thus, as symptoms of DSO were present during the whole period of the examination and clinical evaluations (until session number 20, see Table 2), we can conclude that it was not influenced by fluctuations in attention, confabulations, or avoidance behaviors.

Our results confirm that it is possible to modulate DSO symptoms by means of simple manipulation (Bolognini et al., 2014; Fotopoulou et al., 2009; Spitoni et al., 2016). Nevertheless, while in DSO after right brain damage, changes in the visual perspective relating to self-observation improve body representations, this was not efficacious with our patient, supporting the hypothesis that sensory–motor feedback has a main role in crossed DSO.

Due to the reduced and varying number of trials for each typology of manipulation, we could not directly compare the results of the four experimental procedures. Nevertheless, the only intervention which was able to induce consistent responses in AS in which she acknowledged ownership of her hand was multisensory stimulation. This procedure had immediate effects, although only temporary, on the patient's self-attribution of the disowned hand. As expected due to her sensory deficit, AS did not report any sensation of being touched when her hand was stroked. Thus, we consider that the combination of contralateral (left hand) tactile stimulation and visual input from the affected right hand provided an integration of the sensations from the unimpaired hand onto the disowned hand, with resulting increase in the sense of ownership (Bolognini et al., 2014).

Changes in spatial position also had some positive effects. That there is a spatial component to DSO is supported by the observation that vestibular stimulation ameliorates neglect (Peru, Moro, Sattibaldi, Morgant, Aglioti, 2006) and DSO (Rode et al., 1994).

However, our result is in this respect counterintuitive. In fact, one might expect that the sense of ownership would increase when the hand is placed in the non-neglected hemi-space. In contrast, AS identified the hand as her own more frequently when it was on her right, neglected side. This suggests that neglect and DSO are largely independent. Unfortunately, we could not directly investigate the potential effects of vestibular and attentional manipulation by means of experimental procedures. In effect, we had also planned to administer Caloric Vestibular Stimulation (Ronchi et al., 2013; Bottini & Gandola, 2015; Bottini, Gandola, Sedda, & Ferrè, 2013, for review;) but the patient was not willing to participate in this procedure.

A similar dissociation between DSO and neglect has been documented in other two somatoparaphrenic patients (Moro et al., 2004). In that study, moving the spatial position of the hand toward the non-neglected hemi-space induced a recovery in tactile extinction (symptom of neglect) but did not affect DSO.

We consider that in AS, it was the congruency between visual information and the position of the hand in the canonical representation of the body, rather than the spatial position itself, that facilitated the integration of her hand in her body, thereby increasing the sense of ownership. This is also consistent with the frequent clinical observation that somatoparaphrenic patients often look for "their" supernumerary hand in the canonical position (precisely on the neglected side of the space), where the hand is expected to be.

A limited impact of vision is confirmed by the absence of modulation found in visual perspective manipulation, both in the online (mirror) and off-line (video clip) conditions. This contrasts with previous results involving DSO and AHP after right lesion where these manipulations were efficacious in terms of reducing symptoms (Besharati et al., 2015; Fotopoulou et al., 2009; Moro, Scandola, Bulgarelli, Avesani, & Fotopoulou, 2015).

Thus, in the case of AS, stimulation of multisensory integration and top-down (canonical) representations of the body have ameliorative effects on DSO. In contrast, visuo-spatial components do not impact directly on the sense of ownership. We can thus conclude that although clinically similar, DSO after left-hemisphere damage differs from the more frequent ownership deficits following right lesions in terms of symptoms. The hypothesis of a main role of sensory–motor information is confirmed by our results. Furthermore, the results also support the idea that body schema and body images are not totally segregated in the right and left hemispheres, respectively.

Finally, we do not know whether our experimental manipulations impacted on AHP. Unfortunately, awareness was only checked before and after the sessions and we never asked specific questions regarding this issue during the manipulations, meaning that any potential changes went unrecorded.

All things considered, it is clear that these factors and the difference in sensitivity to experimental manipulations after right and left-hemisphere lesions deserve further investigation.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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