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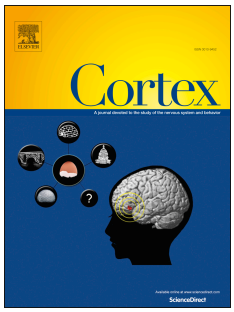

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Space-related confabulations after right hemisphere damage

Paolo Bartolomeo[1-4], Stefania de Vito[5] and Tal Seidel Malkinson[1-4]

1. Inserm U 1127, F-75013, Paris, France

2. Sorbonne Universités, UPMC Univ Paris 06, UMR S 1127, F-75013, Paris, France

3. CNRS, UMR 7225, F-75013, Paris, France

4. Institut du Cerveau et de la Moelle épinière, ICM, F-75013, Paris, France

5. School of Psychology, University of East London, E15 4LZ, London, UK

Corresponding author:

Paolo Bartolomeo

Inserm U1127; UPMC-Paris6; CNRS UMR 7225

Hôpital Pitié-Salpêtrière

Bâtiment ICM

75013 Paris

email paolo.bartolomeo@gmail.com

Abstract

Confabulations are usually referred to memory distortions, characterized by the production of verbal statements or actions that are inconsistent with the patient's history and present situation. However, behavioral patterns reminiscent of memory confabulations can also occur in patients with right hemisphere damage, in relation to their personal, peripersonal or extrapersonal space. Thus, such patients may be unaware of their left hemiplegia and confabulate about it (anosognosia), deny the ownership of their left limbs (somatoparaphrenia), insult and hit them (misoplegia), or experience a "third", supernumerary left limb. Right brain-damaged patients can also sometimes confabulate about the left, neglected part of images presented in their peripersonal space, or believe to be in another place (reduplicative paramnesia). We review here these instances of confabulation occurring after right hemisphere damage, and propose that they might reflect, at least partially, the attempts of the left hemisphere to make sense of inappropriate input received from the damaged right hemisphere.

Keywords. Anosognosia; somatoparaphrenia; implicit processing; visual neglect; brain damage

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1. Introduction

Traditionally, confabulations resulting from a brain lesion are defined as a form of memory distortion, "involving the production of statements or actions that are unintentionally incongruous to the subject's history, background, present, and future situation" (Dalla Barba & La Corte, 2013, p. 102). However, especially after right hemisphere lesions, incongruous verbal descriptions can also be produced outside the domain of temporal consciousness and memory, and can manifest some spatial aspects concerning the patient's own body or his/her extrapersonal space. These verbalizations often bear some resemblance to classic confabulations, at least in the key aspects of being incongruous with the patient's background and history, so that one may feel entitled to use the same term, at least in a broad sense. In the present review, we discuss clinically relevant examples of confabulations occurring after damage to the right hemisphere. At variance with classical confabulations, which can be conceived as distortions of temporal consciousness (Dalla Barba, 2002), confabulations in right brain-damaged patients appear to be broadly related to spatial processing. As noted by Bisiach (1997), these productive phenomena most often concern the patient's personal space, i.e. the left half of the patient's body, as in confabulations related to anosognosia, somatoparaphrenia and misoplegia (Critchley, 1953). Of these, confabulations related to left hemiplegia are probably the most common. More rarely, patients can confabulate on the left part of objects presented in the near extrapersonal space (peripersonal space, within reaching distance). Other right brain-damaged patients can confabulate about their far extrapersonal space, or their navigational space, and believe to be in another location (reduplicative paramnesia).

The next sections consider several types of neurological conditions typically resulting from right hemisphere damage that include confabulations as a part of their manifestation.

2. Anosognosia and anosodiaphoria

In 1914 Babinski coined the term anosognosia (lack of knowledge of the disease) to describe right brain-damaged patients who, despite normal intellectual and affective profile, did not perceive their hemiplegia (Babinski, 1914). This condition was not due to sensory problems, since passive motion of the left limbs and sensitivity to touch were preserved. Subsequently, the term anosognosia was extended to encompass unawareness of several neurological conditions, including somatosensory deficits such as hemianesthesia, visual field defects such as homonymous hemianopia or cerebral blindness (Anton's syndrome), memory deficits, and fluent aphasias resulting from post-Rolandic lesions of the left hemisphere. Still, anosognosia most frequently occurs in cases of hemiplegia (in 54% of patients after right hemisphere lesion and 9% of patients after left hemisphere damage) (Pia, Neppi-Modona, Ricci, & Berti, 2004), and is the most negative predictor for motor and functional recovery (Gialanella & Mattioli, 1992), as well as of impaired performance in daily activities (Vossel, Weiss, Eschenbeck, & Fink, 2013). In another study, anosognosia for hemiplegia was found to be frequent three days after the stroke (32% in the hyperacute phase), to substantially decrease after one week (18%) and to become sporadic at six months (5%) (Vocat, Staub, Stroppini, & Vuilleumier, 2010).

Characteristically, anosognosic patients display confabulations when confronted with their ailment. Josef Gerstmann (1942, p. 891) provided a vivid description of this condition and its confabulatory aspects: "The patient behaves as though he knew nothing about his hemiplegia, as though it had not existed, as though his paralyzed limbs were normal, and he insists that he can move them and can walk as well as he did before. Asked to lift up both arms, he naturally moves the healthy one only, but maintains that he has raised the disabled one also. Requests for movements with the paralyzed left arm or leg are performed by him merely with the healthy one, or not at all, but at the same time he is convinced that he has

carried out the task. […] Various illusions, distortions, confabulations and hallucinatory or delusional ideas may be produced in this connection". Feinberg and Roane (2003) suggested the term "illusory limb movement" to describe this phenomenon. Feinberg et al. (2000) evaluated eleven patients with acute right cerebral infarctions and left upper limb hemiparesis. Five of them produced this form of confabulation when asked to raise the left arm alone and when asked to raise both arms. Two patients showed a partial form of illusory limb movement, reporting movement of the left arm only when instructed to raise both arms. Feinberg et al. (1994) also reported on patients with anosognosia for hemiplegia and hemianopia, who were prone to confabulate about visual stimuli in the neglected hemifield.

Anosodiaphoria is a related condition, whose name was again introduced by Babinski (1914), in order to describe cases of patients' unconcern for their dramatic condition of being hemiplegic. These patients do acknowledge their paralysis but do not seem to care, and their confabulations may express this lack of concern. For instance, one patient with left hemiplegia "replied in an almost facetious manner to requests that he should try and move the limbs… 'I can almost do it, but it just won't come'. He showed no distress and expressed no anxiety or even interest as to the chances of a return of power. Throughout the consultation, he cheerily and light-heartedly bandied small talk with his doctors" (Critchley, 1953, p. 230f).

The case of A.M., a 75 year-old woman with right brain damage and left visual neglect suggests that confabulations related to anosognosia may also interact with temporal consciousness (Dalla Barba, 2002). A.M. was one of the patients described by de Vito et al. (2015), as showing a paradoxically more "veridical" visual perception than controls of a visual illusion on the left, neglected side of space. A.M. had suffered a hemorrhagic stroke implicating the right temporo-parietal junction (TPJ) and its white matter connections with the frontal lobe. Soon after the stroke, A.M. was anosognosic for her hemiplegia. Five years after onset, A.M. still had left hemiplegia and signs of visuo-spatial neglect. Although she was no

longer anosognosic, she could not imagine herself being hemiplegic in the future. In an episodic future thinking task (de Vito & Della Sala, 2011), when A.M. was asked to imagine detailed *realistic* episodes of her daily future life in two years' time, she reported seeing herself walking in a forest with her husband, although this had obviously been impossible in the five years since her stroke and would be objectively unachievable in the future, as doctors had repeatedly informed her. This phenomenon may reflect a confabulatory element of anosognosia solely restricted to future thinking, although an alternative explanation of a positive emotional bias for the future (Sharot, 2011) cannot be excluded.

The pattern of performance of another patient, examined by Laurent Cohen (personal communication, April 2004), suggests the possibility of "implicit" knowledge in anosognosia. When asked if she was capable of moving her left limbs, the patient said yes. However, when asked to actually move them, she burst in tears. The patient's verbal response might reflect the unawareness of her left hemisphere of the motor deficit; on the other hand, implicit, right-hemisphere based knowledge of her dramatic motor impairment could have prompted the negative emotional response to the examiner's request.

3. Asomatognosia and somatoparaphrenia

Other forms of confabulation often associated with lesions in the right hemisphere are of delusional misidentifications. Patients may produce delusional verbalizations concerning their left limbs, which are no longer perceived as part of their body, as in the case with asomatognosia (lack of knowledge of the body). Patients may not recognize the presence and ownership of their left limbs. Some patients produce confabulatory accounts of their left limbs. This variant of asomatognosia is known as somatoparaphrenia, where the experience of lack of a part of the body is associated with peculiar delusional or confabulatory ideas (Critchley, 1953; Gerstmann, 1942). The patients repeatedly report feelings of disownership. They are convinced that their left limbs do not belong to them. They may identify the

examiner as the actual owner of their left arm. However, they do not have generalized delirium or delusional beliefs, other than those related to the left side of their body.

Perhaps the first historically recorded case of asomatognosia/somatoparaphrenia was reported by Jean-Baptiste Bouillaud (1825), who observed a patient whose left side was so insensitive, that he "regarded it as if it were a stranger to him; it seemed to him that somebody else's body was lying on his side, or even a corpse. This peculiar sensitive illusion was the principal object of his daydreaming since his stroke. Requested to move his left limbs, he moved his right limbs instead" (p. 64). Hermann Zingerle (1913) described the case of a patient who persistently stated "that to the left of himself a woman was lying in the bed, and, in the meantime, he pointed to the left, and it was impossible to make him refrain from this, even by visual exploration [of the left side of space]. He often reported this impression combined with erotic joking, caressing his left arm. Yet, at the same time, he also complained about the inconvenience which it caused to him, particularly during the night hours; he was insensitive to passive movements. At this time, conversation with him on this topic took a very strange course. Whereas nothing unusual was noticed when talking to the patient about everyday matters or about his other physical conditions, and whereas he followed promptly and correctly commands regarding his right arm and leg, or to show his tongue, he suddenly failed and appeared grossly perplexed when one started to talk about the left side of his body, or asked questions concerning it. He appeared embarrassed, looked for an excuse, became mute and inattentive, and it was also impossible to evoke old memories of his left side. The same happened when the physician demonstrated the left side on his [the patient's] own body. He knew it: but this knowledge was irrelevant for his own person, and could clarify nothing. If one insisted, trying to make clear the discrepancies between his strange perceptions and reality by way of instruction, or guidance of his gaze, he became progressively agitated and absolutely unable to appreciate the situation. He was unaware of the oddity and absurdity of

having only a right half" (English translation by Benke, Luzzatti, & Vallar, 2004). After two weeks the patient recognized to have left limbs and that they were paralyzed. However, he still remembered that feeling of disownership.

Feinberg et al. (2010) reported several examples of right brain-damaged somatoparaphrenic patients with confabulations related to the left part of their body. One patient complained about "a hand that was left on the subway and they brought it here and they put it on me"; another patient noticed, "It's supposed to be my arm, but I think it's my brother's arm. I tell that to everyone but they don't believe me. My brother was on the wrong track for a while, and he got involved with some gangsters. They chopped off his arms and threw them in the river. I found this in my coffin. (Touching the left arm) Some people thought I was dead, and it was there. I don't know why I was in a coffin… after I was carried to the hospital… I was in a coffin… that's what I remember… I was lying next to this arm (pointing to left arm)... I was in a coffin... Yeah, that's how I found it. I was alive… I didn't die… I found the arm in the coffin".

Somatoparaphrenia has been associated to lesions of a wide set of right hemisphere areas (see Feinberg & Venneri, 2014, for a recent review). For example, Vallar and Ronchi (2009) cited several cases with extensive fronto-temporo-parietal damage. Feinberg et al. (2010) stressed the possible effect of orbitofrontal damage, which was however absent in two cases described by Fotopoulou et al. (2011). Gandola et al. (2012) studied 11 somatoparaphrenic patients, who had the typical fronto-parietal network damage characteristic of left neglect (see Bartolomeo, Thiebaut de Schotten, & Doricchi, 2007), with a substantial involvement of white matter tracts, plus additional damage to the thalamus, basal ganglia and amygdala. Lesions to the right posterior insula were also reported in patients with asomatognosia and with somatoparaphrenia and in patients with "disturbed sensation of limb ownership" (Baier & Karnath, 2008; Feinberg et al., 2010). Overall, right brain lesions seem

to be larger in patients suffering from somatoparaphrenia than in patients with anosognosia only (Feinberg et al., 2010). Interestingly, the illusion of disonwership has been reversed by using vestibular stimulation (Rode et al., 1992), or by having patients look at their left arm in a mirror (Fotopoulou et al., 2011). Both maneuvers seem to activate the right TPJ (Bottini et al., 1994; Corradi-Dell'Acqua et al., 2008). TPJ activation might then trigger a better integration of bodily-related information for the left limbs.

4. Misoplegia, or the hatred for left limbs

Another, rare disorder related to bodily awareness was named *misoplegia* by Macdonald Critchley (1974). In this case, patients with right hemisphere damage dislike their left side or even show hostility towards it, often accompanied by confabulations. "Occasionally we find a patient displaying a veritable dislike of the paralyzed limbs which evoke feelings of disgust, dismay, and even horror. The paralyzed arm may be kept covered by the bedclothes or a shawl so as to conceal it. Or the patient may keep the gaze averted from the affected side…" (Critchley, 1955, p. 286). Patients can verbally insult their plegic limbs or hit them with the other hand. A patient with mild hemiparesis but severe loss of postural sensitivity and hemianopia referred to his arm, insulting it, "You bloody bastard! … It keeps following me around. It gets in my way when I read. I find my hand up by my face, waving about" (Critchley, 1979). By definition, confabulations related to anosognosia for hemiplegia are associated to a left-sided motor deficit. However, there is at least one published case of misoplegia, where the patient produced inappropriate verbalizations against her left leg, in the absence of any motor deficits (Loetscher, Regard, & Brugger, 2006). In other right brain-damaged patients, analogous forms of space-based dislike may rarely occur for left-sided objects in the peripersonal space ("levophobia", Bisiach, 1997)

5. Supernumerary phantom limbs

Right hemisphere damage may determine the feeling of a presence of one or more supernumerary limbs. This rare disturbance resembles the feeling of phantom limbs experienced by amputees. However, the two disorders differ in many regards. For instance, phantom limbs after amputation tend to become incomplete or compressed, whereas supernumerary limbs stay intact and healthy. Moreover, and most importantly for our purposes, patients with phantom limbs after amputation are well aware that the limb was removed and do not show delusional behavior, whereas right brain-damaged patients are sometimes (though not always) delusional about the nature of the supernumerary limb and they are often anosognosic (for an extensive review, see Feinberg & Roane, 2003). Halligan et al. (1993) reported a patient, who, after a large cerebral hematoma in the right basal ganglia region, showed left hemiplegia and sensory loss. On some occasions, he confabulated that his left arm and leg were amputated 23 years before, thus producing memory-related confabulations. On subsequent testing, the patient appeared to have recovered from this disturbance. However, he believed to have a third arm. This belief lasted several months, during which the patient felt uncomfortable about his belief ("I know it's a nonsense"). Sometimes the patient produced confabulations related to his supernumerary phantom limbs, as exemplified by the following exchange: Examiner, "What can you not do at the moment?" Patient, "I can't use my left hand or my left side... I can't do anything with them ... it's a terrible stroke condition... it's like a sack of coal ... I'm like an unguided missile... I fall all over the place". However, when asked specifically if there was something special about his hand, he answered: "Yes, I have a third one". Examiner, "A third one?" Patient, "Yes". Examiner, "Where is that?" Patient: "It is in the middle" (…) Examiner, "So tell me now at the moment, how many hands do you have?" Patient: "Three" (…). Examiner, "Count the number of hands you have for me". Patient (looking down and pointing): "… One… two…

three". Feinberg and Roane (2003) suggested that illusory limb movements and supernumerary limbs in anosognosic patients may be due to perceptual completion. This is a purely confabulatory phenomenon of completion of the left half of a visual stimulus, which may occur in the presence of right hemisphere damage and spatial neglect.

However, supernumerary phantom limbs do not necessarily give rise to confabulations. Cipriani et al. (2011) reported a patient with signs of left neglect and sensory loss in his left arm, probably due to a small low-density area in the right TPJ, who felt for two months he had a third arm, although he intellectually acknowledged the nonsensicality of his belief. The same illusion lasted for years in another patient, Madame S, observed by Bourlon et al. (2012). Consequent to an intracerebral hematoma in the right hemisphere, this 58-year-old woman presented with left hemiparesis, superficial and deep sensory deficits in the left upper limb, and mild signs of left visual neglect. She had the phantom impression of movement and warmth in an additional upper left limb. Also in this case, the patient recognized that this could not be possible, also because she could not see her "third" hand.

6. Confabulations in peripersonal space: post-hoc accounts of "implicit" processing?

Geschwind (1965) suggested that some signs of neglect may reflect the activity of the left hemisphere when it does no longer receive information from his right counterpart. If the right visual and somesthetic cortex are isolated from the left hemisphere, "[t]he left side of the body and of space is…'lost'. The patient will then respond in many instances by using [a] technique of confabulatory completion" (p. 600). This may happen when the left hemisphere loses access to the left-sided information processed by the right hemisphere. The problem, according to Geschwind (1965), is due to the lack of communication between association areas such as right inferior parietal cortex and the speech area. When the association areas are disrupted, two scenarios may occur: either the speech area receives no messages, or it gets incomplete messages. In the former case, the errors are more bizarre because, in the total

absence of information, the speech area starts to respond to random messages coming over subcortical pathways or to react to its own spontaneous firing. Following Geschwind, Gazzaniga (1998) laid out the theory of an *interpreter* dwelling in the left hemisphere, responsible for decoding our behavior and our responses to environmental challenges. The interpreter can be "only as good as the information it receives'' (Gazzaniga, 1998, p. 136), and can thus make up imaginative stories, producing confabulations when it cannot access the essential knowledge processed by the right hemisphere. Gazzaniga (1998) applied this concept to reduplicative paramnesia (see section 7), and seems to imply that the interpeter has no capacity to evaluate its input (see Hirstein, 2005). The idea of a generally dominant left hemisphere is no longer accepted. Nonetheless, we can refer to other aspects of Geschwind's proposal when interpreting patterns of performance in split-brain patients and in neglect patients (Bartolomeo et al., 2007). Following surgical section of the corpus callosum, the left hemisphere may provide *post-hoc* confabulatory verbal explanations of actions performed by the right hemisphere (Gazzaniga & Baynes, 2000). For example, the case of a split-brain patient was observed, who was tachistoscopically presented with the pictures of a snow scene in the left visual field/right hemisphere and of a rooster claw in the right field/left hemisphere (see Gazzaniga & Baynes, 2000). When asked to choose using each hand, pictures matching the bilateral displays, the patient appropriately chose the picture of a rooster with his right hand; he also chose the image of a shovel as a match for the snow scene with his left hand. However, after the experiment, the patient, whose left hemisphere had not seen the snow scene, gave a confabulatory explanation of his choice, saying that the shovel served to clean out the chicken house.

Similarly, patients with right hemisphere lesions and consequent left-sided extinction or neglect may show a noticeable implicit processing of stimuli tachistoscopically presented in the left hemifield. When forced to guess the identity of a non-explicitly detected item in a

multiple choice task, patients' performance may be more accurate than chance (Volpe, Ledoux, & Gazzaniga, 1979) and they can also implicitly process the presented stimulus at a semantic level (Berti, Frassinetti, & Umiltà, 1994; McGlinchey-Berroth, Milberg, Verfaellie, Alexander, & Kiduff, 1993), although this seems only to hold true for a minority of neglect patients (D'Erme, Robertson, Bartolomeo, & Daniele, 1993).

The functional and anatomical bases of these different forms of dissociation between explicit and implicit processing are still far from being clear. However, Geschwind's proposal of confabulatory responses as a result of the isolation of the left hemisphere is worth to be further explored. Some cases suggest that inter-hemispheric disconnection factors may contribute to the implicit processing of the left, neglected side of a visual stimulus and to the confabulations referring to it. One example comes from the well-known case of patient P.S. (Marshall & Halligan, 1988), who could not tell the difference between a drawing of two houses, one of which was burning on the left side. However, when forced to choose one of the houses as a place where she would live, P.S. always chose the non-burning house. According to Geschwind, this behavior could be explained by the fact that: (1) the left hemisphere cannot access left-sided information and consequently P.S. cannot verbally recognize the difference between the two houses; (2) there is still some knowledge of this difference, perhaps based on the right hemisphere, which in this case may still result in the appropriate choice at a behavioral level, or may determine an erroneous interpretation of the difference and the consequent, inappropriate choice. If this hypothesis is valid, one could predict that, when required to explain their choice to live in the non-burning house, either patients would not know what to answer or they would confabulate. P.S. only commented on how "silly" it was to choose between two "identical" houses. Other patients, however, provided various comments at debriefing. Consistently with Geschwind's hypothesis, Manning and Kartsounis (1993) reported that a patient said to have chosen the non-burning house because of its extra

fireplace. Bisiach and Rusconi (1990) described a patient who repeatedly chose the burning house, because of the extra space (the profile of the flames may have increased the apparent size of the house). Doricchi et al. (1997) described neglect patients who, after choosing the non-burning house, stated either that they did not know why, since the houses were the same, or that the house they chose was 'better', 'bigger', or 'worked better'. The latter responses suggest a confabulatory explanation of implicit processing.

7. Confabulations in extrapersonal space: reduplicative paramnesia

Reduplicative paramnesia is the delusional belief of being in a different place (e.g. hospital room or town), which is sometimes believed to be identical to the original one, but displaced. At variance with the confabulations discussed in the previous sections, which concern the left part of the body or of the near extrapersonal space, reduplicative paramnesia does not refer to a particular side of space. This sets it apart from the other forms of confabulation discussed here. However, a relation with right hemisphere damage has repeatedly been suggested, which justifies its inclusion here. Arnold Pick (1903) introduced this term to describe the condition of a patient who, while being hospitalized, believed she had been moved to "the same clinic as the former one, but at a different place" (p. 263).

As a further example, after a vascular stroke in the right hemisphere, the novelist Henry James developed a striking identity delusion, and dictated two letters to his secretary, as if they were written by Napoleon Bonaparte. He also showed signs suggestive of reduplicative paramnesia, and said he was in California or in Cork and complained of being told he was actually in London, or erroneously believed he was in his mansion in Rye. Once he said: "This place I find myself is the strangest mixture of Edinburgh and Dublin and New York and some other place that I don't know" (Bartolomeo, 2013).

Another patient tried repeatedly to leave his room and the department because he "wanted to find his room", which he believed was situated in front of the department. As he

said, “There are the same doctors, same beds, but this is not my room; I need to leave this room to find my clothes and belongings” (Gerace & Blundo, 2013).

In these patients, lesions are often located in the right hemisphere (Hakim, Verma, & Greiffenstein, 1988; Murai, Toichi, Sengoku, Miyoshi, & Morimune, 1997), and typically encroach upon the frontal lobe (Lee, Shinbo, Kanai, & Nagumo, 2011).

8. Discussion

We have reviewed here some clinical examples of confabulations occurring as a consequence of right hemisphere damage. Unduly deemed for decades to be the “minor” hemisphere because of the language dominance of its left counterpart (Hervé, Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013), the right hemisphere is now known to have crucial functions, for instance in attention processes (Bartolomeo, 2006, 2014), emotional behavior (Gainotti, 1972), and social cognition (Adolphs, 2001).

Space-related confabulations may occur in relation to the patient’s personal, peripersonal or extrapersonal space. Among these, bodily-related confabulations are the most frequently observed (Bisiach, 1997). Also left hemisphere lesions can have consequences on bodily awareness, but of a completely different nature. For example, patients with damage to the language-dominant hemisphere may be unable to indicate body parts on themselves (autotopoagnosia, Denes, Cappelletti, Zilli, Dalla Porta, & Gallana, 2000) or other people (heterotopoagnosia, Degos, Bachoud-Levi, Ergis, Petrissans, & Cesaro, 1997). However, these disorders are not usually accompanied by confabulations. Unfortunately, knowledge in the field of bodily-related cognitive and emotional functions still lacks a systematic theoretical framework. Several models have been proposed, but none satisfactorily accounts for the available evidence from normal participants and brain-damaged patients (review in Berlucchi & Aglioti, 2010). Moreover, the suggested frameworks seem to be insufficient to

account for the dramatic hemispheric differences which are so evident in the clinical consequences of unilateral brain damage.

Here, we selectively reviewed confabulations arising as a consequence of right hemisphere damage. Because of this anatomo-clinical criterion, there is a frequent association with visual neglect, which often follows right hemisphere lesions (Bartolomeo, 2014). The relationship of confabulations with neglect is indeed an important issue. Both visual neglect and space-related confabulations tend to preferentially occur as a consequence of right hemisphere damage and can be associated in some patients. However, it is important to stress that space-related confabulations are not invariably associated with spatial neglect, although they might share some causal mechanism, such as the activity of an isolated left hemisphere (Bartolomeo et al., 2007, see below for further discussion).

It is difficult to pinpoint the exact mechanisms at the basis of the patterns of space-related confabulation reviewed here. Lesions in the right hemisphere, particularly in the frontal lobe, can also be associated with delusional misidentifications of others' identity, as it happens in the Capgras and Fregoli syndromes (Feinberg & Keenan, 2005). Thus, the right hemisphere appears to contribute in important ways not only to the individual's relation to the external environment (through attention processes), but also to the processing of one's own identity and place in the world (Bartolomeo, 2013). It has been suggested that right hemisphere damage may blur the ego boundaries, compromise self-monitoring and generate unfitting emotional response to external stimuli (such as erroneous familiarity or feelings of estrangement) (Devinsky, 2009), thus creating aberrant self-related experience. In this sense, damage to the right hemisphere may undermine what William James deemed as the grounds of personal identity, such as the feelings of "warmth and intimacy and immediacy" (James, 1890, p. 239) and the "resemblance among the parts of a continuum of feelings (especially bodily feelings)" (James, 1890, p. 336).

Also motivational factors have been suggested to play a role. Weinstein and Kahn (1955) proposed that motivation to deny illness provided a unifying concept to cover various patterns of behavior occurring after brain damage, including bodily-related confabulations and reduplicative paramnesia. They also stated that the presence or absence of such confabulations in different patients did not depend on lesion location, but on features in the patient's premorbid personality (a claim difficult to assess empirically). Bisiach and Geminiani (1991) provided an articulated critique of the motivational account of anosognosia, which has difficulties explaining, for example, why anosognosia is mainly observed in the acute phase of the stroke and tends to recede afterwards, and why it is predominantly observed after right hemisphere damage.

While not arguing that anosognosia for hemiplegia is psychogenic, Turnbull et al. (2014) have recently revived the motivational account. They took issue with the Bisiach and Geminani's critique and proposed that anosognosia involves a process of psychological defence resulting from impaired cognitive regulation of emotion. According to Turnbull et al. (2014), anosognosic patients would misconstrue emotionally charged spatial facts (e.g., "this arm is paralyzed and it belongs to me"), in accordance with their wishes. It remains to be seen what specific and testable predictions can be generated by the cognitive-emotional hypothesis, and how it can account for the fact that some anosognosic patients produce florid confabulations, while others do not.

As mentioned in section 6, it has also being hypothesized that inadequate input from the damaged right hemisphere may drive the left hemisphere to produce "positive" symptoms such as delusional, confabulatory narratives (Devinsky, 2009), trying to verbally "explain away" these aberrant experiences, or to make sense of inappropriate information coming from the damaged left hemisphere. Thus, a perturbed interplay between the damaged right hemisphere and the intact left one might play an important role in space-related

confabulations, consistent with other examples of "wrong decisions" made by the left hemisphere after damage to the right hemisphere (Bartolomeo, 2015; Lunven et al., 2015). More generally, a left hemisphere receiving degraded information from the right hemisphere might also be prone to orient attention towards right-sided objects, thus provoking signs of left visual neglect (Bartolomeo, 2015). Not surprisingly, in many (though not all) of the reported cases of space-related confabulations, signs of visual neglect also occurred.

The left hemisphere hypothesis makes the prediction that there should be a better inter-hemispheric integration of information in non-confabulators than in confabulators, thus potentially explaining why not all right-brain damaged patients confabulate. The left hemisphere hypothesis, although surely in need of further specification, is consistent with (1) clinical evidence that space-related confabulations are much more frequent after right brain damage than after left brain damage; (2) clinical observations of confabulating patients whose non-linguistic behavior is instead consistent with the objective reality of their impairments (such as the hemiplegic patient mentioned in section 2, who cried while saying that she could move normally); (3) the evidence, discussed in section 6, of confabulatory behavior in split-brain patients only for items presented in the left visual hemifield and processed by the right hemisphere (Gazzaniga & Baynes, 2000).

We conclude by briefly outlining two empirically testable predictions stemming from the left hemisphere hypothesis. In transversal studies, confabulating patients should demonstrate worse inter-hemispheric integration of information than non-confabulators. Such a finding would explain why confabulations are not present in all right-brain damaged patients. This prediction might be assessed by using measures of the quality of inter-hemispheric communication. Potentially relevant new concepts and tools are now being developed to assess the unfolding of large-scale distant communication in the whole brain (see, e.g., Deco & Kringelbach, 2016). In longitudinal studies, the left hemisphere hypothesis

would predict that confabulations should remit in parallel with improvements in inter-hemispheric information transfer, resulting from resolution of diaschisis (Bartolomeo & Thiebaut de Schotten, 2016).

Thus, the study of space-related confabulations using the methods of cognitive neuroscience might ultimately provide substantial advances in our general knowledge on fundamental issues at the basis of information processing in the dual brain.

References

Adolphs, R. (2001). The neurobiology of social cognition. *Current opinion in neurobiology, 11*(2), 231-239.

Babinski, J. (1914). Contribution à l'étude des troubles mentaux dans l'hémiplégie organique (anosognosie). *Revue Neurologique, 27*, 845-848.

Baier, B., & Karnath, H.-O. (2008). Tight link between our sense of limb ownership and self-awareness of actions. *Stroke, 39*(2), 486-488.

Bartolomeo, P. (2006). A parieto-frontal network for spatial awareness in the right hemisphere of the human brain. *Archives of Neurology, 63*, 1238-1241.

Bartolomeo, P. (2013). The delusion of the Master: the last days of Henry James. *Neurol Sci, 34*(11), 2031-2034. doi: 10.1007/s10072-013-1546-y

Bartolomeo, P. (2014). *Attention disorders after right brain damage: Living in halved worlds*. London: Springer-Verlag.

Bartolomeo, P. (2015). Spatially biased decisions: Toward a dynamic interactive model of visual neglect. In J. I. Tracy, B. Hampstead, & K. Sathian (Eds.), *Plasticity of Cognition in Neurologic Disorders* (pp. 299-322). Oxford: Oxford University Press.

Bartolomeo, P., & Thiebaut de Schotten, M. (2016). Let thy left brain know what thy right brain doeth: inter-hemispheric compensation of functional deficits after brain damage. *Neuropsychologia*.

Bartolomeo, P., Thiebaut de Schotten, M., & Doricchi, F. (2007). Left unilateral neglect as a disconnection syndrome. *Cerebral Cortex, 45*(14), 3127-3148.

Benke, T., Luzzatti, C., & Vallar, G. (2004). Hermann Zingerle's "Impaired perception of the own body due to organic brain disorders". 1913. An introductory comment, and an abridged translation. *Cortex, 40*(2), 265-274.

Berlucchi, G., & Aglioti, S. M. (2010). The body in the brain revisited. *Experimental Brain Research, 200*(1), 25-35. doi: 10.1007/s00221-009-1970-7 [doi]

Berti, A., Frassinetti, F., & Umiltà, C. (1994). Nonconscious reading? Evidence from neglect dyslexia. *Cortex, 30*, 181-197.

Bisiach, E. (1997). Understanding Consciousness: Clues from Unilateral Neglect and Related Disorders. In N. Block, O. Flanagan, & G. Güzeldere (Eds.), *The Nature of Consciousness: Philosophical Debates* (pp. 237-253). Cambridge, MA: The MIT press.

Bisiach, E., & Geminiani, G. (1991). Anosognosia related to hemiplegia and hemianopia. In G. P. Prigatano & D. L. Schacter (Eds.), *Awareness of deficit after brain injury: Clinical and theoretical issues* (pp. 17-39). New York, NY: Oxford University Press.

Bisiach, E., & Rusconi, M. L. (1990). Break-down of perceptual awareness in unilateral neglect. *Cortex, 26*(4), 643-649.

Bottini, G., Sterzi, R., Paulesu, E., Vallar, G., Cappa, S. F., Erminio, F., . . . Frackowiak, R. S. (1994). Identification of the central vestibular projections in man: a positron emission tomography activation study. *Experimental Brain Research, 99*(1), 164-169.

Bouillaud, J.-B. (1825). *Traité clinique et physiologique de l'encéphalite, ou inflammation du cerveau, et de ses suites.* Paris: Chez J.-B. Baillière.

Bourlon, C., Bourgeois, A., Vandier, J., Bordier, A., Baradji, M., Bartolomeo, P., & Duret, C. (2012). Membre fantôme surnuméraire : le cas de Madame S. *Revue Neurologique, 168*, A21-A22. doi: 10.1016/j.neurol.2012.01.050

Cipriani, G., Picchi, L., Vedovello, M., Nuti, A., & Fiorino, M. D. (2011). The phantom and the supernumerary phantom limb: historical review and new case. *Neuroscience bulletin, 27*(6), 359-365. doi: 10.1007/s12264-011

Corradi-Dell'Acqua, C., Ueno, K., Ogawa, A., Cheng, K., Rumiati, R. I., & Iriki, A. (2008). Effects of shifting perspective of the self: an fMRI study. *Neuroimage, 40*(4), 1902-1911.

Critchley, M. (1953). *The Parietal Lobes*. New York: Hafner.

Critchley, M. (1955). Personification of paralysed limbs in hemiplegics. *Br Med J, 2*(4934), 284-286.

Critchley, M. (1974). Misoplegia, or hatred of hemiplegia. *Mount Sinai Journal of Medicine, 41*(1), 82-87.

Critchley, M. (1979). Misoplegia, or Hatred of Hemiplegia *The Divine Banquet of the Brain* (pp. 115-120). New York: Raven Press.

D'Erme, P., Robertson, I. H., Bartolomeo, P., & Daniele, A. (1993). Unilateral neglect: The fate of the extinguished visual stimuli. *Behavioural Neurology, 6*, 143-150.

Dalla Barba, G. (2002). *Memory, Consciousness and Temporality*. Boston: Kluver Academic Publishers.

Dalla Barba, G., & La Corte, V. (2013). The hippocampus, a time machine that makes errors. *Trends Cogn Sci, 17*(3), 102-104. doi: 10.1016/j.tics.2013.01.005

de Vito, S., & Della Sala, S. (2011). Predicting the future. *Cortex, 47*(8), 1018-1022.

de Vito, S., Lunven, M., Bourlon, C., Duret, C., Cavanagh, P., & Bartolomeo, P. (2015). When brain damage "improves" perception: neglect patients can localize motion-shifted probes better than controls. *J Neurophysiol, 114*(6), 3351-3358. doi: 10.1152/jn.00757.2015

Deco, G., & Kringelbach, M. L. (2016). Metastability and Coherence: Extending the Communication through Coherence Hypothesis Using A Whole-Brain Computational Perspective. *Trends in Neurosciences, 39*(3), 125-135. doi: http://dx.doi.org/10.1016/j.tins.2016.01.001

Degos, J. D., Bachoud-Levi, A. C., Ergis, A. M., Petrissans, J. L., & Cesaro, P. (1997). Selective inability to point to extrapersonal targets after left posterior parietal lesions: An 0bjectivization disorder? *Neurocase, 3*(1), 31-39. doi: 10.1080/13554799708404032

Denes, G., Cappelletti, J. Y., Zilli, T., Dalla Porta, F., & Gallana, A. (2000). A category-specific deficit of spatial representation: The case of autotopagnosia. *Neuropsychologia, 38*(4), 345-350.

Devinsky, O. (2009). Delusional misidentifications and duplications: right brain lesions, left brain delusions. *Neurology, 72*(1), 80-87. doi: 10.1212/01.wnl.0000338625.47892.74

Doricchi, F., Incoccia, C., & Galati, G. (1997). Influence of figure–ground contrast on the implicit and explicit processing of line drawings in patients with left unilateral neglect. *Cognitive Neuropsychology, 14*, 573-594.

Feinberg, T. E., & Keenan, J. P. (2005). Where in the brain is the self? *Consciousness and Cognition, 14*(4), 661-678.

Feinberg, T. E., & Roane, D. M. (2003). Anosognosia. In T. E. Feinberg & M. J. Farah (Eds.), *Behavioral neurology and neuropsychology*: McGraw-Hill Professional.

Feinberg, T. E., Roane, D. M., & Ali, J. (2000). Illusory limb movements in anosognosia for hemiplegia. *Journal of Neurology, Neurosurgery & Psychiatry, 68*(4), 511-513.

Feinberg, T. E., Roane, D. M., Kwan, P. C., Schindler, R. J., & Haber, L. D. (1994). Anosognosia and visuoverbal confabulation. *Archives of Neurology, 51*(5), 468-473.

Feinberg, T. E., & Venneri, A. (2014). Somatoparaphrenia: Evolving theories and concepts. *Cortex, 61*, 74-80.

Feinberg, T. E., Venneri, A., Simone, A. M., Fan, Y., & Northoff, G. (2010). The neuroanatomy of asomatognosia and somatoparaphrenia. *Journal of Neurology, Neurosurgery & Psychiatry, 81*(3), 276-281. doi: 10.1136/jnnp.2009.188946

Fotopoulou, A., Jenkinson, P. M., Tsakiris, M., Haggard, P., Rudd, A., & Kopelman, M. D. (2011). Mirror-view reverses somatoparaphrenia: dissociation between first-and third-person perspectives on body ownership. *Neuropsychologia, 49*(14), 3946-3955.

Gainotti, G. (1972). Emotional behavior and hemispheric side of the lesion. *Cortex, 8*(1), 41-55.

Gandola, M., Invernizzi, P., Sedda, A., Ferre, E. R., Sterzi, R., Sberna, M., . . . Bottini, G. (2012). An anatomical account of somatoparaphrenia. *Cortex, 48*(9), 1165-1178. doi: S0010-9452(11)00200-0 [pii] 10.1016/j.cortex.2011.06.012

Gazzaniga, M. S. (1998). *The mind's past*: Univ of California Press.

Gazzaniga, M. S., & Baynes, K. (2000). Consciousness, introspection, and the split-brain: The two minds/one body problem. In M. S. Gazzaniga (Ed.), *The New Cognitive Neurosciences* (pp. 1355-1363). Cambridge, Mass.: MIT Press.

Gerace, C., & Blundo, C. (2013). Reduplicative Paramnesia: Not Only One. *The Journal of neuropsychiatry and clinical neurosciences*.

Gerstmann, J. (1942). Problem of imperception of disease and of impaired body territories with organic lesions: Relation to body scheme and its disorders. *Archives of Neurology and Psychiatry, 48*(6), 890-913.

Geschwind, N. (1965). Disconnexion syndromes in animals and man - Part II. *Brain, 88*, 585-644.

Gialanella, B., & Mattioli, F. (1992). Anosognosia and extrapersonal neglect as predictors of functional recovery following right hemisphere stroke. *Neuropsychological Rehabilitation, 2*(3), 169-178. doi: 10.1080/09602019208401406

Hakim, H., Verma, N. P., & Greiffenstein, M. F. (1988). Pathogenesis of reduplicative paramnesia. *Journal of Neurology, Neurosurgery & Psychiatry, 51*(6), 839-841.

Halligan, P. W., Marshall, J. C., & Wade, D. T. (1993). Three arms: a case study of supernumerary phantom limb after right hemisphere stroke. *Journal of Neurology, Neurosurgery & Psychiatry, 56*(2), 159-166.

Hervé, P.-Y., Zago, L., Petit, L., Mazoyer, B., & Tzourio-Mazoyer, N. (2013). Revisiting human hemispheric specialization with neuroimaging. *Trends Cogn Sci, 17*(2), 69-80. doi: 10.1016/j.tics.2012.12.004

Hirstein, W. (2005). *Brain fiction: Self-deception and the riddle of confabulation*: Mit Press.

James, W. (1890). *The Principles of Psychology* (Vol. One). New York: Henry Holt.

Lee, K., Shinbo, M., Kanai, H., & Nagumo, Y. (2011). Reduplicative paramnesia after a right frontal lesion. *Cognitive and Behavioral Neurology, 24*(1), 35-39.

Loetscher, T., Regard, M., & Brugger, P. (2006). Misoplegia: a review of the literature and a case without hemiplegia. *Journal of Neurology, Neurosurgery and Psychiatry, 77*(9), 1099-1100.

Lunven, M., Thiebaut De Schotten, M., Bourlon, C., Duret, C., Migliaccio, R., Rode, G., & Bartolomeo, P. (2015). White matter lesional predictors of chronic visual neglect: a longitudinal study. *Brain, 138*(Pt 3), 746-760. doi: 10.1093/brain/awu389

Manning, L., & Kartsounis, L. D. (1993). Confabulations related to tacit awareness in visual neglect. *Behavioural Neurology, 6*, 211-213.

Marshall, J. C., & Halligan, P. W. (1988). Blindsight and insight into visuo-spatial neglect. *Nature, 336*, 766-767.

McGlinchey-Berroth, R., Milberg, W., Verfaellie, M., Alexander, M., & Kiduff, P. T. (1993). Semantic processing in the neglected visual field: Evidence from a lexical decision task. *Cognitive Neuropsychology, 10*, 79-108.

Murai, T., Toichi, M., Sengoku, A., Miyoshi, K., & Morimune, S. (1997). Reduplicative paramnesia in patients with focal brain damage. *Cognitive and Behavioral Neurology, 10*(3), 190-196.

Pia, L., Neppi-Modona, M., Ricci, R., & Berti, A. (2004). The anatomy of anosognosia for hemiplegia: A meta-analysis. *Cortex, 40*(2), 367-377.

Pick, A. (1903). Clinical studies on "dreamy mental states" as a permanent condition in epileptics. *Brain, 26*(2), 242-267.

Rode, G., Charles, N., Perenin, M. T., Vighetto, A., Trillet, M., & Aymard, G. (1992). Partial remission of hemiplegia and somatoparaphrenia through vestibular stimulation in a case of unilateral neglect. *Cortex, 28*, 203-208.

Sharot, T. (2011). The optimism bias. *Current Biology, 21*(23), R941-R945.

Turnbull, O. H., Fotopoulou, A., & Solms, M. (2014). Anosognosia as motivated unawareness: The 'defence' hypothesis revisited. *Cortex, 61*, 18-29. doi: http://dx.doi.org/10.1016/j.cortex.2014.10.008

Vallar, G., & Ronchi, R. (2009). Somatoparaphrenia: a body delusion. A review of the neuropsychological literature. *Experimental Brain Research, 192*(3), 533-551. doi: 10.1007/s00221-008-1562-y

Vocat, R., Staub, F., Stroppini, T., & Vuilleumier, P. (2010). Anosognosia for hemiplegia: a clinical-anatomical prospective study. *Brain, 133*(12), 3578-3597. doi: 10.1093/brain/awq297

Volpe, B. T., Ledoux, J. E., & Gazzaniga, M. S. (1979). Information processing of visual stimuli in an "extinguished" field. *Nature, 282*(5740), 722-724.

Vossel, S., Weiss, P. H., Eschenbeck, P., & Fink, G. R. (2013). Anosognosia, neglect, extinction and lesion site predict impairment of daily living after right-hemispheric stroke. *Cortex, 49*(7), 1782-1789. doi: http://dx.doi.org/10.1016/j.cortex.2012.12.011

Weinstein, E. A., & Kahn, R. L. (1955). *Denial of illness: Symbolic and physiological aspects*. Springfield, IL: Charles C Thomas Publisher.

Zingerle, H. (1913). Über Störungen der Wahrnehmung des eigenen Körpers bei organischen Gehirnerkrankungen. *Monatsschrift für Psychiatrie und Neurologie, 34*, 13–36.