Alma Mater Studiorum – Università di Bologna

DOTTORATO DI RICERCA IN

SCIENZE PSICOLOGICHE

Ciclo XXVIII

**Settore Concorsuale di afferenza: 11/E1**

**Settore Scientifico disciplinare: M-PSI/02**

# THE CONTRIBUTION OF VISUAL AND ACOUSTIC INFORMATION TO BODILY SELF RECOGNITION

**Presentata da:**

**dr.ssa Michela Candini**

| | |
|---|---|
| **Coordinatore Dottorato** | **Relatore** |
| **Prof.ssa Monica Rubini** | **Prof.ssa Francesca Frassinetti** |

**Esame finale anno 2016**

## Table of Contents

## List of Figures

### Chapter 1

### Chapter 2

### Chapter 3

### Chapter 4

**Chapter 5**

**Chapter 6**

## List of Tables

### Chapter 3

### Chapter 4

### Chapter 6

## Abbreviations

ANOVA = analysis of variance

BOLD = blood oxygenation-level dependent

E- patients = patient without pathological embodiment

E+ patients = patient with pathological embodiment

EBA = extrastriate body area

EEG = electroencephalography

ERP = event-related potentials

FBA = fusiform body area

fMRI = functional magnetic resonance imaging

IFG = inferior frontal gyrus

LBD patient = left brain damaged patient

MEG = magnetoencephalography

MMN = mismatch negativity

PET = positron emission tomography

PIN = person identification node

RBD patient = right brain damaged patient

rCBF = regional cerebral blood flow

RT = response time

rTMS = repetitive transcranial magnetic stimulation

STS = superior temporal sulcus

TMS = transcranial magnetic stimulation

VLSM = voxel-based lesion-symptom mapping

vmPFC = ventromedial prefrontal cortex

vPMc = ventral premotor cortex

## Abstract

One of the most intriguing topic addressed by researchers across the cognitive sciences concerns the “self” and the self-other distinction. The present thesis adds to this debate by exploring the recognition of bodily self, based on visual and acoustical information. The first part of the present dissertation focuses on mechanisms and neural bases of bodily self, adopting a classical neuropsychological approach. Brain damaged patients were submitted to two different tasks designed for testing *implicit* and *explicit* self-body recognition using pictures depicting left and right hands as stimuli that belong to the participant or to other people.

In Study 1, right and left brain damaged patients’ performance was compared to verify whether implicit and explicit self-body recognition are mediated by different cerebral networks that can be selectively impaired after focal brain lesion. A Voxel-based lesion-symptom mapping analysis revealed that an integrated cortical–subcortical right frontal (motor) network is crucial for an implicit knowledge of one’s own body. Conversely, both hemispheres contribute to an explicit knowledge of our body. In addition, Study 2 demonstrates how the implicit and explicit bodily knowledge is selectively impaired in patients with and without pathological embodiment of others’ body.

The second part of the thesis explores the contribution of voice to self/other distinction. In Study 3, implicit and explicit self-voice recognition was investigated in healthy individuals. Interestingly, self-voice was better processed when an implicit rather than an explicit recognition was required. Finally, in Study 4, the anatomical basis of implicit and explicit self-voice recognition was investigated in neuropsychological patients. Behavioural and anatomical data demonstrates the

involvement of right hemisphere in implicit processing and the joint contribution of both hemispheres in explicit recognition of self-voice.

Overall, this thesis highlights the role played by visual and acoustic cues in building the sense of body-ownership.

## General introduction

One of the most intriguing issue discussed in neuroscience, psychology and philosophy is "*What is the self?*" (Gallagher, 2000; Gallagher & Frith, 2003; Metzinger & Gallese, 2003; Northoff, 2006). Traditionally, the self is considered a high-order function reflected in memory and other high-level judgements. However, other lines of research suggested a close and intimate relationship between the self and more low-level functions, such as self-consciousness, emotion and perception (Gallese & Sinigaglia, 2010; Northoff, 2016).

For instance, as Feinberg (2005) suggested, Self is a multilayered concept that involved at least three different aspects: a narrative, a relational and a bodily self. The narrative self is how one describes one's past and present circumstances and relates one's personal history; the relational self emerges in the interaction with others and it represents how the individual thinks about himself related to objects and to other persons in the world; last, the *bodily self* represents the most physical component.

Here, I will consider this last aspect, that is the bodily self, and the role that it plays in self-recognition and self-other discrimination. Thus, in the present thesis, with bodily self processing, I will refer to the multifaceted process through which we recognize, visual or acoustic stimuli as part of our corporeal appearance.

In every present moment of our lives, we experience the feeling of having a body through our senses. We constantly receive proprioceptive, visual and somatosensory information, as well as visceral and motor signals through which we built a coherent sense of our body. Whether and to what extent, holding a coherent bodily self-representation is relevant in constructing and maintaining the basic awareness of ourselves as unitary, are examined here.

Even if, several attempts have been made in order to understand the different processes that are involved in the building up of normal body awareness, they are far from being clear. In the current work we sought to provide new insights on mechanisms underlying our sense of self by using a classical neuropsychological approach. Indeed, we focus on impaired mechanism in order to clarify the pathological and normal functioning.

## Chapter 1

# The bodily self-recognition

## 1.1 Bodies and body-parts perception

The appearance of the human body is an important component of our identity and one of the most distinctive physical feature. Accordingly, the human brain devotes considerably cortical resources to representing visual information about the human body (Berlucchi & Aglioti, 2010; Peelen & Downing, 2007; Schwoebel & Coslett, 2005). Accumulating evidence on the neural underpinnings of body perception in the human temporal lobes have converged around two body selective regions of the human brain, identified with functional magnetic resonance imaging (fMRI) and transcranial magnetic stimulation (TMS). These are the extrastriate body area (EBA) found in the posterior inferior temporal sulcus/middle temporal gyrus, and the fusiform body area (FBA) found ventrally on the fusiform gyrus (see Figure 1.1; Downing et al., 2001; Kaiser et al., 2014; Peelen & Downing 2005; Schwarzlose et al., 2005; Uddin et al., 2006; Urgesi et al., 2007). These areas constitute an occipitotemporal network specialized for bodily perception that jointly create a general visual representation of human body (Downing & Peelen, 2011).

However, this representation does not include high-level information about identity, action or emotional state, that probably results from the interaction among FBA and EBA with other interconnected areas, such as visual and motor regions. For example, the proximity of EBA to motion-selective regions, such as the visual area hMT+, suggests that it interacts with dynamic visual representations related to motor functions (Pitcher et al., 2009). Viewing another person to move their body while performing an action allows us to extract crucial social information related to the agent’s identity and the meaning of the actions.

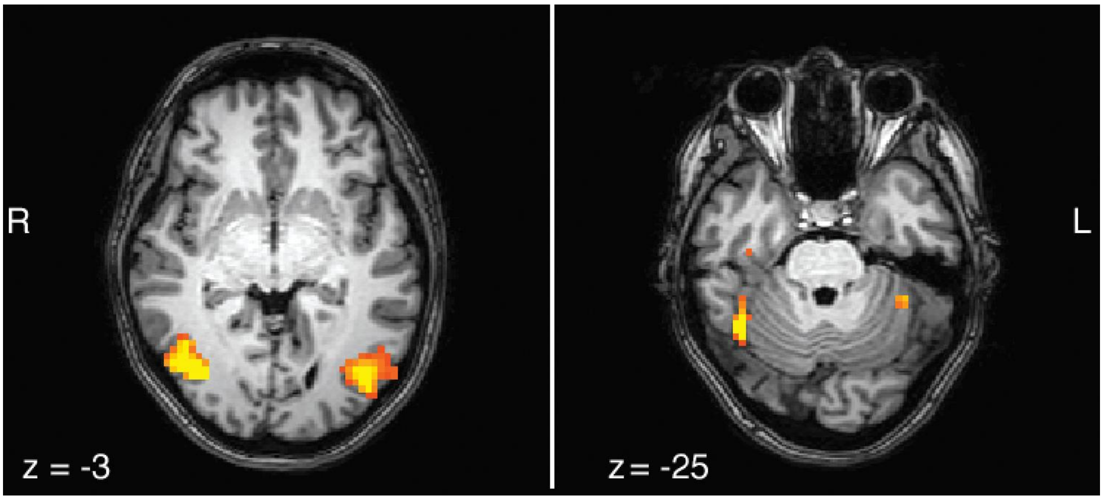

**Figure 1.1 - Location of occipitotemporal body-selective regions**

*From Downing and Peelen, (2011).*

An interesting contribution to understand the functional significance of EBA and FBA relies on testing the consequences of brain lesion in patients or in neurologically healthy individuals by using repetitive transcranial magnetic stimulation (rTMS). For instance, in order to investigate the causative role of EBA and ventral premotor cortex (vPMc) in the visual discrimination of bodily forms and bodily actions, Urgesi and colleagues (2007) create a “temporary lesion” applying the rTMS over EBA and vPMc in both hemispheres. Stimuli consisted of pictures depicting upper and lower body-parts paired as to depicted the same model performing two different actions (action discrimination task) or the same action performed by two different models (form discrimination task). Participants were required to decide which of two images matched a single sample previously seen. As a result, the temporary inactivation of EBA impaired the visual discrimination of body forms but not of body actions, in contrast when the rTMS was applied to vPMc impaired the discrimination of body actions but not of body forms (see Figure 1.2).

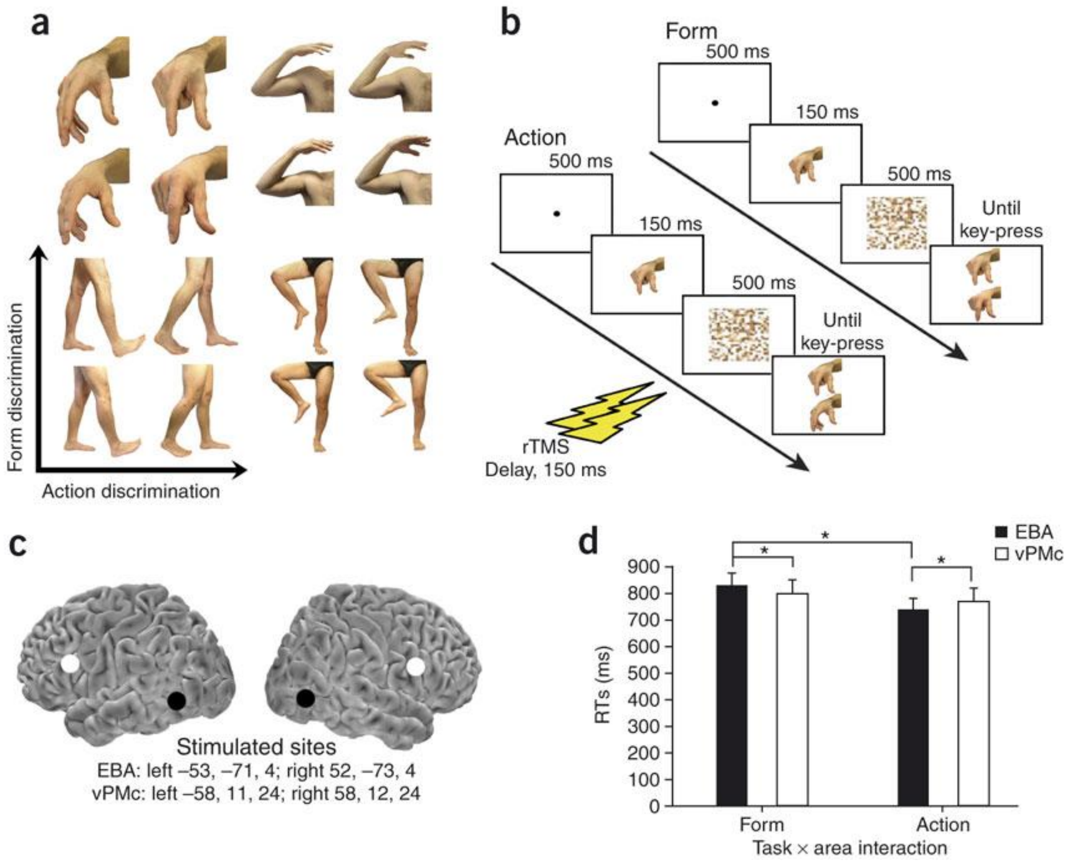

**Figure 1.2 - The experimental procedure adopted by Urgesi and colleagues**

Stimuli (A), experimental procedure (B), site of stimulation (C) and main results according with the stimulation site (D). *From Urgesi et al., (2007).*

Furthermore, this results is also supported by a neuropsychological investigation conducted by Moro and colleagues (2008) in which, using the same paradigm above described (Urgesi et al., 2007), the neural correlates of body action and body form discrimination were explored. To this aim, twenty-eight patients suffering from stroke were recruited. Patients were divided in two groups according with the lesion site: half of them were affected by lesion involving the prerolandic region (anterior group) and the other half were affected by temporo-parietal-occipital lesions (posterior group). Authors demonstrated a clear double dissociation since patients with anterior lesions were more impaired in the body action than in the body form discrimination task, and conversely patients with posterior lesions were more impaired in the body form than in the body action discrimination task. This behavioural evidence is further confirmed by the Voxel-Based Lesion-Symptom Mapping analysis (VLSM), a technique specifically developed for the purpose of identifying lesion–symptom relationships in stroke patients. The observed deficit in the action discrimination task were associated with lesions of ventral premotor cortex, whereas impaired performances in the body form discrimination task were associated with lesions of middle occipitotemporal cortex and inferior occipital cortex (see Figure 1.3).

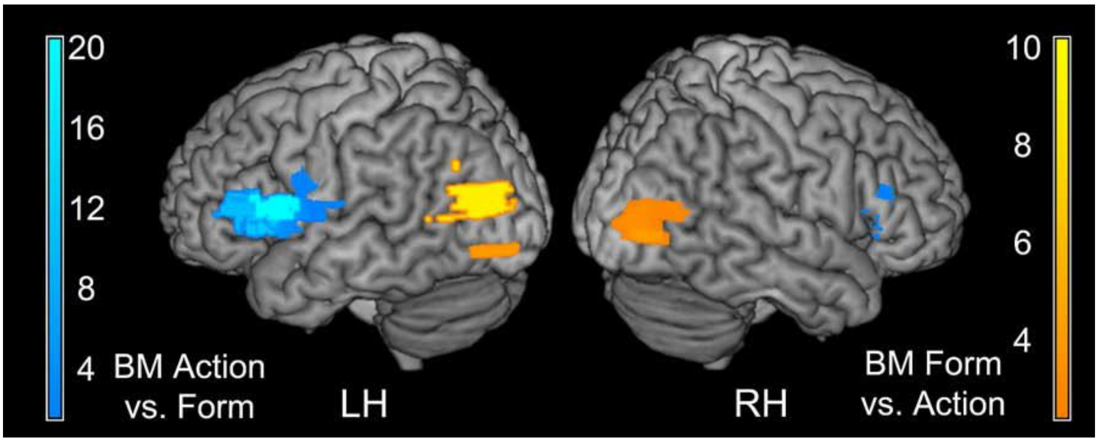

**Figure 1.3 - Brain lesions associated with deficit in body form and body action discrimination.**

Lesions were shown in yellow and blue color respectively. *Adapted from Moro et al., (2008).*

## 1.2 The recognition of the bodily self

We all constantly experience the boundaries between our body and the external world, a feeling that contribute to the common sense of having a body. However, within this experience several aspects can be identify. For instance, the feeling that allow us to perceive a body-part as part of our body and belonging to ourselves, that is defined “sense of body-ownership”. Moreover, our body may be consider as an interface between the environment and the phenomenal self (Merleau-Ponty, 1964). Indeed, we constantly act in the world, arising the feeling of being the one who generates an action using our own body. This feeling is defined “sense of agency”. Both these constructs, the body-ownership and the agency, jointly contributed to our ability of physically distinguish ourselves from others. Thus, in this chapter we will focus on bodily self-recognition, that’s how we recognize a body or a body-part as our own.

A first attempt in order to investigate the neuroanatomical locations underlying self-face and self-body recognition was carried out adopting the fMRI technique by Deveu and colleagues (2007). Pictures depicting face and whole-body belonged to the participants or to a friend (defined as familiar other) were adopted as stimuli. For each type of stimulus, two alterations were applied: the interocular distance and the waist-to-hip ratio was decreased or increased of 10%. Participants were presented with intact and altered pictures of faces and bodies. The cerebral activity was measured while they performed the experimental task: they had to indicate the real appearance of themselves and of a familiar other. Neuroimaging data revealed that *faces perception* was associated with a bilateral activity in the middle occipital gyrus, extending to the fusiform gyrus on the right and to the cerebellum on the left, as well as with activation of a large frontal area on the right side (middle and inferior frontal gyrus, and medial/superior frontal gyrus). By contrast, *body perception* was associated with activity in the fusiform and lateral occipital complex bilaterally, and with activity in the left middle occipital gyrus. More specifically, contrasting the cerebral activity found for *self vs. familiar body*, a greater activation was found in the superior frontal sulcus and in the cingulate cortex on the right, and in the inferior frontal gyrus on the left, and anterior insula bilaterally. Moreover, when contrasting the cerebral activity found for *self vs. familiar face*, activation was found in the right inferior frontal gyrus and in the insula. To summarize, these findings suggested that distinct brain networks underlie the one's own compared to others body and face perception.

Furthermore, recent evidence suggested that we are able to implicitly recognize the one's own body (Frassinetti et al., 2008, 2009). Indeed, when performing a visual matching task with picture of body-parts (e.g. hands, limbs, legs, feet) belonged to the participant or to other people, neurologically healthy individuals showed the so-called self-advantage effect. Namely, participants exhibit a better performance when self than others stimuli were presented.

In a subsequent work, Frassinetti and colleagues (2011) investigated whether the body self-advantage emerged also when participants are explicitly required to recognize their own body. In this study, body effectors (hands and feet) and inanimate object (shoes and phone) were adopted as experimental stimuli. Each of them could belong to the participant (self stimuli) or to others people (other stimuli). The visual matching task was adopted as an Implicit task. Three stimuli depicting the same body effector, or the same type of inanimate-object, were simultaneously presented in each trial, aligned along the vertical meridian of the computer screen. The central stimulus corresponded to the target stimulus and participants were required to press, as soon as they decided whether the upper or the lower stimulus matched the central one. In the Explicit task, the same stimuli were adopted and participants were requested to indicate whether the upper or the lower image, or none of these, corresponded to their own body-effector or object (see Figure 1.4).

**Figure 1.4 - An example of a single trial adopted by Frassinetti et al., (2011)**

Single trial for the Implicit and Explicit task were shown on left and right side, respectively.

*Adapted from Frassinetti et al., (2011).*

As a result, in the Implicit task participants were more accurate with self- compared to other body-parts, whereas this effect was not present for object stimuli. Moreover, a lack of this facilitation was found in the Explicit task in which a self-disadvantage emerged. Indeed, participants performed substantially worse with their own than with other body-parts. Thus, the main result of this study is that the self-advantage for body-effectors emerged only when an explicit recognition of them was not required. These results suggest that implicit recognition and explicit recognition of the body self are based on different mechanisms and probably they constitute distinct ways to access to body self-representation.

Looking more deeply at the mechanism underlying the self-advantage effect, the authors suggested that bodily self-recognition is based upon a sensorimotor, rather than a mere visual representation of one's own body. This hypothesis was further confirmed by a subsequent study in which a laterality judgment task was adopted. Ferri and colleagues (2011) submitted a group of healthy participants to two different tasks designed to test Implicit and Explicit bodily self-recognition. Pictures depicting left and right hands, rotated at different angle, were used as experimental stimuli. According with previous studies, picture belonged to the participant or to other people in order to constitute the self and other's stimuli. In the Implicit task participants had to judge the laterality of the stimuli, while in the Explicit task participants were required to explicitly judge whether the displayed hand corresponded or not to their own hand.

Authors adopted the laterality judgment task because it is well known that in order to perform it, participants simulate a motor rotation of their own hand so as to match the observed stimulus (Ionta et al., 2007; Parson, 1994). Accordingly, the laterality judgement task should be easier when the displayed stimulus is the participant's hand. Indeed, only in this case, the displayed stimulus matches with the mentally rotated, and the self-advantage should emerge. Results showed a facilitation, that's means faster response time when judging one's own right compared to others' hands. By contrast, such an advantage was not found in the

Explicit task, where bodily self-recognition was explicitly investigated. Indeed, a worse performance with self-related stimuli compared to other-related stimuli was observed (see Figure 1.5).

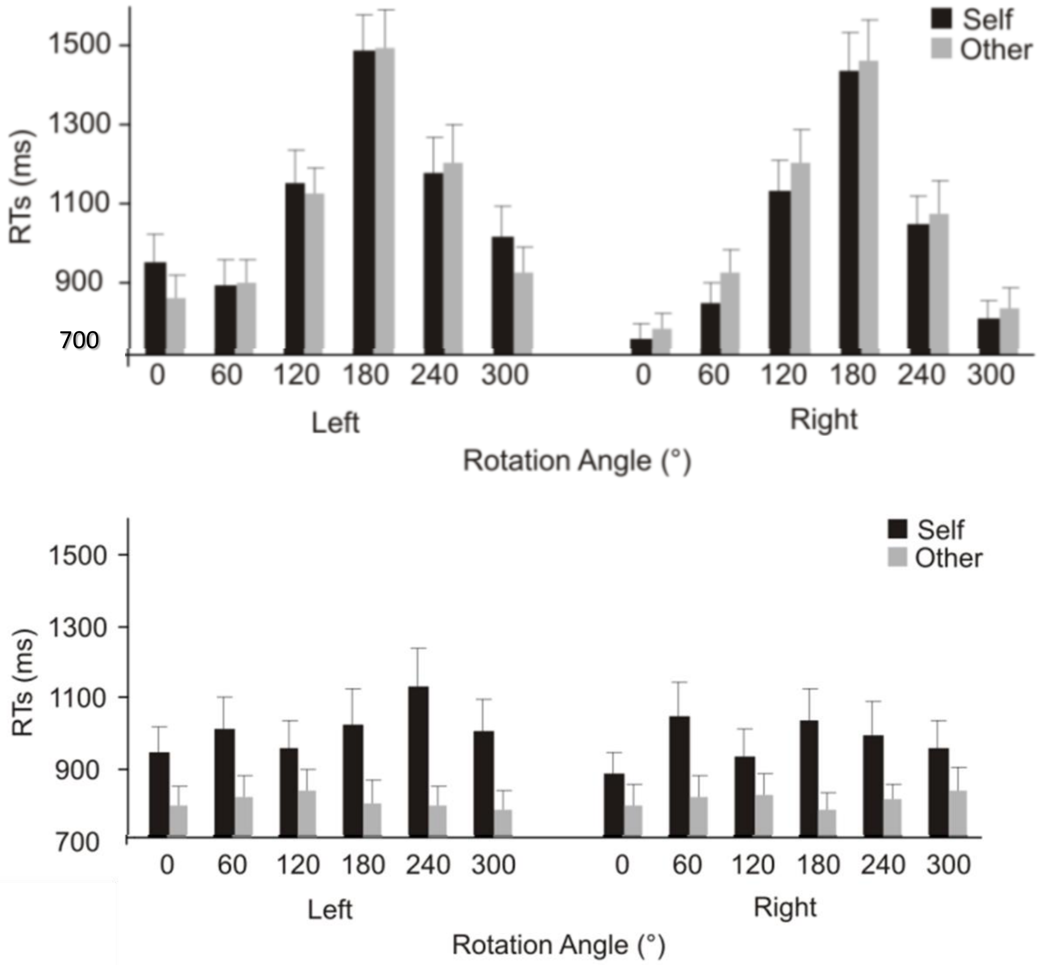

**Figure 1.5 – The mean of RT in the Implicit and Explicit task.**

The mean of RTs as a function of Ownership (Self, Other) and Laterality (left and right hand) in the Implicit (upper panel) and Explicit Task (lower panel). Error bars depict the standard error of the mean.

*Adapted from Ferri et al., (2011).*

Finally, the presence of the self-advantage only for participants' right hand is likely to be a further argument in favour of the motor hypothesis of the self-advantage. Indeed, the presence of the "self-advantage" only for the right hand can be explained by the greater lateralization in hand motor skills observed in right-handers compared to left-handers (Gentilucci et al., 1998).

This latter hypothesis is also supported by a recent fMRI study (Ferri et al., 2012) in which a group of healthy participants were scanned while they performed the laterality judgment task previously described. fMRI data revealed a neural network for the representation of the bodily self involving motor areas, such as the supplemental motor area (SMA) and pre-SMA, the anterior insula and the occipital cortex. Critically, the representation of the one’s own right hand was confined to the left premotor cortex supporting the existence of a sense of bodily self embedded within the sensorimotor system.

## 1.3 Disorders related to bodily self-representation: evidence from brain damaged patients.

In this section we will focus on neuropsychological investigations which revealed how the bodily self-knowledge may be lost following a brain lesion. Indeed, neurological patients are frequently affected by a sensorimotor hemisyndrome to the contralesional side of the body. Thus, is very common that a pathological bodily self-representation involves the affected hemisoma.

One of the most studied clinical conditions, is the *somatoparaphrenia* (Gertsmann, 1942; Invernizzi et al., 2013; Vallar & Ronchi, 2009). Somatoparaphrenia is defined as the acquired delusion and confabulation about the contralesional side of the body. It is a neuropsychological disorder in which patients typically deny the ownership of their contralesional limbs, which they attribute to others. This condition is typically found in the acute post-ictal phase and it is often associated with right brain lesions (Gandola et al., 2012).

Furthermore, when patients deny the contralesional motor and/or sensory deficit affecting their hemisoma, we refer to the *anosognosia for hemiplegia and hemianestesia*, respectively. The *anosognosia for hemiplegia* is frequently associated with right brain lesion involving areas related to the programming of motor acts, particularly Brodmann’s premotor areas 6 and 44, motor area 4, and the somatosensory cortex (Berti et al., 2005). Concerning *anosognosia for hemianestesia*, in order to identify the lesion responsible for, in a recent study a voxelwise statistical analysis was conducted. The critical lesion was found confined to the anterior part of the putamen (Pia et al., 2014). The authors suggested that anosognosia for hemianaesthesia is mainly due to a failure in detecting the mismatch between expected and actual tactile stimulation.

As far as the facilitation observed for self- compared to other body-parts (Frassinetti et al., 2008, 2011) described in the previous section, further neuropsychological investigations have explored its neural correlates recruiting left (LBD) and right brain damage (RBD) patients (Frassinetti et al., 2008). A group of healthy participants and brain damage patients were submitted to a visual matching to sample task designed to implicitly assess the self-body recognition. In a first experiment, body-parts belonged to the participant or to other people were adopted as stimuli. Aim of this experiment was to verify whether the right hemisphere was specialized for self body-parts processing. As predicted, RBD patients were more impaired than LBD patients in self body-parts recognition, whereas no difference was found between RBD and LBD patients when judging other people’s body-parts. Crucially, the self-advantage effect was present both in controls and LBD patients but not in RBD patients, who did not show any facilitation with self- compared to other body-parts.

In a second experiment, authors aimed at verify whether the observed deficit in RBD damaged patients was selective for self body-parts processing or merely due to a general deficit in body-parts processing. Thus, body-, face and object parts were adopted as stimuli. The results demonstrated that RBD patients’ deficit was comparable across stimulus categories (face, body, object), thus excluding the presence of any selective deficit in the visual processing of body-parts. These findings supported the idea that RBD, but not LBD patients are selective impaired in “self body-parts” recognition. The patients’ lesions analysis indicates that the “self body-parts” processing seems to be subtended by a specific network within the right hemisphere, which mainly involves frontal and parietal areas (see Figure 1.6).

**Figure 1.6 - The brain lesion associated with self body-parts recognition impairment.**

Illustration shows the graphical subtraction of areas damaged in RBD patients without “self body-parts” recognition impairment and in RBD patients with “self body-parts” recognition impairment.

*Adapted from Frassinetti et al., (2008).*

In a subsequent study, Frassinetti and colleagues (2010) provide further support to the right lateralization of bodily self-processing. Indeed, they compared a group of RBD patients with a group of neurologically healthy individuals in a visual matching to sample task in which body- and face-parts were adopted as stimuli. Healthy participants showed the so-called self-advantage, since they were more accurate in processing pictures representing their own as compared to other people’s body- and face-parts. Concerning RBD patients, the authors demonstrated that a subgroup of RBD patients (G1) was selectively impaired in self body-parts processing. By contrast, other RBD patients were not impaired neither in self body- or self face-parts processing, since they exhibit a self-advantage effect for both stimuli categories. To sum up, the authors sought experimental evidence on the neural correlates underlying the processing of self body- and face-parts, demonstrating that these functions can be selectively impaired following a brain lesion.

Overall, evidence here reported demonstrate that RBD but not LBD patients were impaired in implicit self-body processing. However, less is known concerning the explicit processing of the one’s own body. The study presented in Chapter 3  is designed to address this unanswered question.

Very recently, an interesting phenomena concerning the bodily self-representation has been described in neuropsychological patients affected by an atypical form of hemisomatognosia (Garbarini et al., 2013). Hemisomatognosia is a clinical condition commonly observed in right-brain damaged patients with a paralysis of the contralateral limbs. In this syndrome, patients typically deny the ownership of a part of their body, they show hemispatial neglect, and they are anosognosic for their condition (Zeller et al., 2011). By contrast, patients described by Garbarini and colleagues (2013), didn’t show the classical and well known form of hemisomatognosia. Indeed, they didn’t explicitly disowner their contralesional limbs but they claimed that the examiner’s left hand was their own hand, whenever it was positioned in egocentric coordinates, on the table near their real hand. Moreover, when the examiner moved his/her left hand, patients claimed that they were moving their own (paralysed) hand. Authors’ hypothesis is that this delusion of ownership was not the result of a mere verbal confabulation but the result of a physical “embodiment” that alters patient’s motor behavior. To test this hypothesis, a group of neurologically healthy participants and a group of hemiplegic patients, with (E+) and without (E-) alien-limb embodiment were submitted to a bimanual coupling task. Basically, participants were asked to simultaneously draw lines with one hand and circles with the other. When healthy participants performed the task, both trajectories assume oval shapes, indicating that the motor programs of one hand affects the motor programs of the other hand (coupling effect; see Figure 1.7).

Hemiplegic patients were asked to draw lines with their right (healthy) hand and to 'try' to draw circles with the left (paralyzed) hand in different conditions:

- when an alien left hand simultaneously drew circles
- when only the patient's hands were presented

**Figure 1.7 - Circle-Lines bimanual motor task.**
The illustration shows the participant while simultaneously performing lines with the right and circles with the left hand. *Adapted from Garbarini et al., (2012).*

The baseline condition is considered when only the right hand drew lines.

Results showed that, when only the patients' hands were present, neither E+ nor E– patients showed a significant coupling effect. This confirmed that, although requested 'to try' to move their left hand, hemiplegic patients, didn't produce any effective motor programming. Crucially in the alien hand condition, E+ patients, but not E- patients, showed a significant coupling effect. The coupling effect found in the alien condition clearly shows that E+ patients' altered sense of body ownership affects both their motor awareness and their sense of agency.

This result suggested that our body representation is dynamic. In addition, based on these evidence, it could be hypothesized that self-body awareness is not a unique knowledge, but it is characterized by multiple levels, and only their integration makes what we commonly refer to self-body awareness. Indeed, these patients didn't show any relevant symptoms that can be clearly referred to an impairment of body awareness before participating in the study. However, during the alien hand condition, when asked to reach their hand, patients identified as own hand the alien hand, thus showing a kind of implicit sense of disownership. Regarding this last point, we may speculate that the construction of body awareness is a multifaceted process resulting from the integration of different aspects. In this respect, the ability to correctly recognize the one's own body-parts is likely to be crucial. As we have already described in this section, previous studies (Frassinetti et al, 2008, 2010) reported a deficit in implicit self-body recognition in right brain damaged patients. At this point, an interesting question arises spontaneously: should patients, who showed an altered sense of body-ownership, as well as E+ patients, be impaired also in self-body recognition processing?

Starting from this question, in the Chapter 4 we investigate whether the E+ patients, who implicitly incorporate in their body schema the body parts of others, can be impaired in implicit and explicit self-body recognition processing.

## Chapter 2

# The recognition of one’s own voice

## 2.1 The voice as a special stimulus

Body, face and voice signals, despite the different nature of their physical structure, convey socially and personal relevant information, such as age, gender, emotional state and identity. Voice recognition is critical in several social contexts, for instance when we are at the phone or when someone talks from a different room and the visual stimuli that allow to recognize the other person are not available. The social relevance of voice recognition is reinforced by evidence of fetal recognition of mother's voice in utero (Kisilevsky et al., 2003) and by an increasing specialization of neural mechanisms for human voice over the first six months of development (Lloyd-Fox et al., 2012; Vouloumanos et al., 2010). Moreover, the existence of selective brain regions in the monkey (Petkov et al., 2008) and in human brain (Belin et al., 2000) suggested that our conspecifics' vocalizations may be considered as special stimuli. Indeed, we are constantly expose to social interactions and conversations in which reciprocal verbal exchanges are predominant.

Starting from this point of view, Belin and colleagues (2004) have recently updated a model on voice processing (for previous description see also Burton et al., 1990) in which the voice can be considered as an *auditory face.* They extended the Bruce and Young's seminal model of face processing (Bruce & Young, 1986; Young & Bruce, 2011) and hypothesized three different pathways involved in voice processing. Initially, a more general low-level analysis of voice occurs in the auditory cortex. After this preliminary stage, in order to develop a structural encoding of voice, three different types of information are extracted in three dissociable and interacting functional pathways:

1. A pathway for analysis of speech information involving STS and inferior prefrontal regions
2. A pathway for analysis of vocal affective information involving temporo-medial regions, anterior insula and amygdala
3. A pathway for analysis of vocal identity involving voice recognition units, each activated by one of the voices known to the person

Finally, the authors proposed that these three pathways interact each other and with homologous pathways in the face-processing (see Figure 2.1).

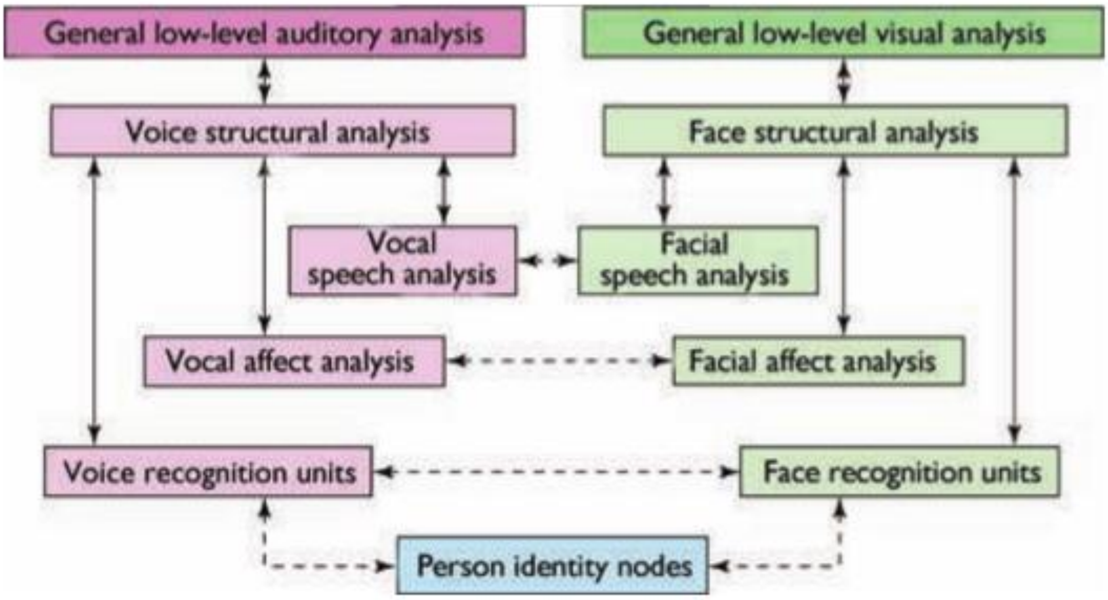

**Figure 2.1 – The Bruce and Young's model of voice perception.**

*From Belin et al., (2004).*

Thus, according with the above mentioned model, despite faces and voices are very different sensory input, one visual and the other one acoustic, a unifying coding mechanism was proposed (Yovel & Belin, 2013). This similarity may be especially relevant during the face-voice integration processes. Indeed, in order to correctly identify others people, it may be advantageous for the brain to integrate these sources of information.

### 2.1.1 Anatomical correlates of voice processing

Converging fMRI evidence suggested that voice–selective regions are mostly located along the superior temporal sulcus (STS) bilaterally (Belin et al., 2000; Ethofer et al., 2009; Gervais et al., 2004; Grandjean et al., 2005; Linden et al., 2011). In this region the cerebral activity is greater in response to vocal than to non-vocal sounds.

In order to verify the exact involvement of temporal areas in voice/non-voice discrimination ability, Bestelmeyer and colleagues (2011) adopted the rTMS which disrupt the ability of a small region of cortex, creating a temporary lesion. A group of neurologically healthy participants were submitted to two different tasks: a voice/non-voice discrimination task and a loud/quiet discrimination task. In the voice/non-voice discrimination task, participants were required to differentiate between vocal versus environmental sounds. In the loud/quiet discrimination task, participants were asked to discriminate between loud and quiet stimuli by pressing one of two buttons on a keyboard. Four pulses of rTMS at 10 Hz was applied on right temporal voice areas (TVA) and on supramarginal gyrus (SMG), chosen as a control site. The authors found that voice/non-voice discrimination ability was impaired when rTMS was targeted at the right TVA compared with the control site. Conversely, performance of the control task was not differentially affected by site of stimulation (see Figure 2.2). This finding provide the first direct link between TVA activity (especially in the right hemisphere) and voice detection ability.

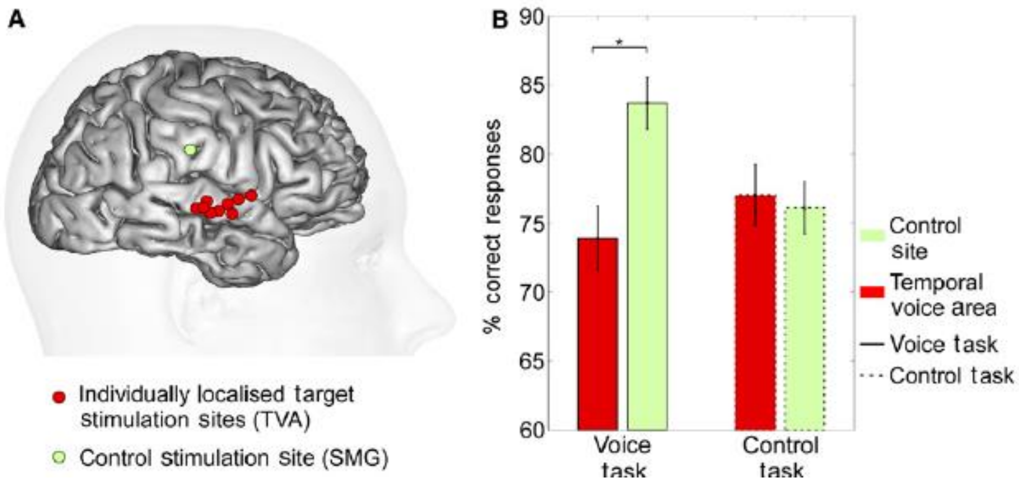

**Figure 2.2. - Functional role of the TVA in voice/non-voice discrimination**

(A) Illustration of stimulation sites adopted in Bestelmeyer et al., (2011) study's. Individually localised right temporal voice area in red; control site in green. (B) The mean accuracy in the experimental and control task as a function of the stimulation's site. rTMS applied on TVA caused significantly poorer performance compared with the control site on the voice/non-voice discrimination task *From Bestelmeyer et al., (2011).*

Looking more deeply on STS' functional roles, several studies (Andics et al., 2010; Belin and Zatorre, 2003; von Kriegstein & Giraud, 2004; Schall et al., 2014) demonstrated the existence of different functional regions. Specifically, within the right hemisphere, the posterior part of the superior temporal sulcus (pSTS) is more closely related to the acoustical processing of vocal sound, whereas the anterior part of STS (aSTS) seems to be involved in voice identity processing. Furthermore, distinct functional roles emerged also across hemispheres: indeed, areas sensitive to verbal feature are mostly located in the left hemisphere, whereas cortical areas sensitive to voice identity are dominant in the right hemisphere (Bonte et al., 2009; Belin and Zatorre, 2003; Formisano et al., 2008; von Kriegstein et al., 2003). For instance, by means of the fMRI technique, von Kriegstein and colleagues (2003) investigated the cortical response to auditory sentences, comparing two recognition tasks that either targeted the speaker’s voice or the verbal content. In this study, German sentences pronounced by an unknown speaker were adopted as experimental stimuli. Therefore, participants were familiarized with the target voice and they were asked to pay attention to the speaker’s voice or to the verbal content of the sentences. Focusing on the speaker’s voice increased the activation of the right anterior STS and precuneus, whereas focusing on the verbal content increased the activation of the left posterior middle temporal region. These findings are in line with the previous described involvement of the right temporal region in voice processing. Concerning the precuneus, since previous studies found similar activations during episodic memory retrieval (Krause et al., 1999; Schmidt et al., 2002), its recruitment likely reflects the difficulty of retaining the voice of an unknown speaker. On the other hand, the left temporal region is commonly associated with verbal semantic processing (Giraud et al., 2002; Kuperberg et al., 2000). Overall, these results clearly demonstrate that distinct brain regions underlie voice identity and speech processing.

## 2.2 Mechanisms underlying self-voice processing

There is mounting evidence suggesting that self-perception is special and involves systems that are physically and functionally different from those involved in the perception of familiar and unfamiliar stimuli. Although in this field the processing of one’s own face has received most of the attention (Platek et al., 2004, 2006; Sugiura et al., 2005; Turk et al., 2002), more recent findings suggest that the one’s own voice may be considered a special stimulus too. Accordingly, behavioural and neuroimaging studies have demonstrated that processing the one’s own compared to familiar or unfamiliar voice is subtended by distinct processes and recruits different neural networks.

A first attempt aimed to highlight brain regions associated with self and familiar voice recognition, has been carried out by Nakamura and colleagues (2001). They measured regional cerebral blood flow (rCBF) by positron emission tomography (PET). This technique allows to identify changes expressed as increase or decrease of the rCBF during two experimental tasks. Stimuli were Japanese sentences spoken by participant or by a familiar or unfamiliar person, and were binaurally presented via a pair of stereo earphones. Therefore, each participant was submitted to three different tasks: a familiar-unfamiliar voice discrimination, a self-unfamiliar voice discrimination and a vowel discrimination, designed as a control task. They found that discriminating between *self* and *familiar* voices was associated with different brain regions. Specifically, greater activity in frontal regions, such as the right inferior frontal sulcus and the parainsular cortex was found during the “Self voice” task. The authors suggest that this network reflects a retrieval effort, since participant have memory of one’s own voice, that may be different from the recorded voice. Furthermore, discriminating between *familiar* and *unfamiliar* voices was associated with activations on both the left and right hemisphere. Indeed, activations of left precuneus and left frontal pole may reflect the involvement of episodic memory functions. On the right hemisphere, authors found activations in the enthorinal cortex and temporal pole. Since a previous study demonstrated that the temporal pole was activated when participants listen to sentences containing information related to the participant’s own past (Fink et al., 1996), the authors suggested this region could represent a storehouse for auditory personal memory.

The discrimination between self and familiar voice was also investigated in an event-related fMRI study by Kaplan and colleague (2008). Participants were scanned while they viewing faces and listened to voices stimuli which could belong to the participant or to a familiar person (namely, a friend of the same race and the same gender). Thus, for each stimulus category a comparison between two conditions: "self" and "other-familiar" was carried out. When hearing one's own voice is compared with the voice of a familiar other, greater activity was found in the anterior part of the inferior frontal gyrus (IFG) in the right hemisphere. Moreover, viewing one's own face compared with a familiar other face is associated with activation of the parietal, occipital and inferior frontal lobe in the right hemisphere. The authors concluded that processing self-related stimuli across multiple sensory modalities involve a shared neural substrates, in which the right inferior frontal lobe may represents a key region in order to extract an abstract representation of the self.

The above findings are further supported by a behavioural study in which functional asymmetries related to self-voice recognition were investigated. Participants were presented with continua of auditory morphs between either their own (self) or a familiar voice and a famous voice, and were asked to stop the presentation either when the voice became ‘‘more famous" or ‘‘more familiar/self" with the right or left hand. Authors demonstrated that a difference emerged between right and left hands only for self-voice, but not for famous and for familiar voice. Indeed, when participants responded with the left-hand needed a smaller percentage of self to recognize their own voice and stop the presentation. This lateralized effect suggests a right hemisphere facilitation for processing self-related stimuli in the domain of voice, similar to what has been observed in the visual domain for self-faces (Keenan et al., 1999, 2000).

More recently, two studies investigated the neural correlates of self-voice processing by using an electrophysiological approach (Graux et al., 2013, 2015). Authors hypothesized that P3a and the mismatch negativity (MMN) responses elicited in the auditory cortex might be sensitive to discriminate between self and unknown voices. Participants were instructed to watch a silent movie on a TV screen and to pay attention to the story. They were not aware that they were going to hear distinct voices. Indeed, the authors adopted an auditory oddball paradigm during EEG recording using self and unfamiliar voices as stimuli. As a result, the P3a clearly distinguished between the self and the unknown voice since its amplitude was smaller for the one’s own voice than for unfamiliar voice. Furthermore, detection of one’ own voice was associated with an early response (“pre-MMN”) which occurred 70 ms post-stimulus onset over the left frontal region. These results suggested that the passive discrimination of one’ own voice involves neural processes that are different from those involved in discrimination of unknown voices.

In a subsequent study, Graux and colleagues (2015) further investigated whether the specificity found for the self-voice compared to unknown voices may be simply ascribed to a familiarity effect for the one’s own voice. In order to disentangle this possibility, they submitted a group of healthy participants to the same task previously adopted (Graux et al., 2013) using self, familiar and unfamiliar voices as stimuli. Interestingly, they reported a P3a amplitude smaller for self than familiar voice confirming that the processes involved in the perception of familiar and non-familiar voices were different.

Most of the previous named studies about self-voice recognition used a paradigm of explicit recognition. However, in the domain of self-recognition, there is much evidence suggesting a dissociation between implicit and explicit self-processing. For example it was recently demonstrated an intriguing dissociation between implicit and explicit self-body recognition. (Ferri et al., 2011; Frassinetti et al., 2011). Thus, aim of the study presented in Chapter 5 is to verify whether also for the voice there is a dissociation between implicit and explicit self-voice recognition in a group of neurologically healthy participants.

## 2.3 Voice recognition disorders following brain lesion

As has been already pointed out in the previous section, voice recognition is a key skill in social context. However, due to brain lesions, such as stroke or injury, abilities in recognizing familiar persons can be lost. In literature there are only a few case reports on voice identity recognition deficits. This is surprising because voice identity recognition impairments in patients with brain lesions are frequent (Neuner & Schweinberger, 2000). One reason for this lack of studies might be that voice identity recognition tests are not as readily available as face-identity recognition tests. Furthermore, voice identity recognition deficits might not be as socially impairing as face-identity recognition deficits.

The first line of research concerned the inability to recognize familiar voices. To refer to this particular condition has been coin the term of acquired phonagnosia, in which patient shows the inability to recognize familiar people on the basis of their voice (Van Lancker et al., 1989; Van Lancker & Canter, 1982). This condition is similar to the one described for face stimuli, that is the prosopagnosia in which, following a bilateral lesion of occipitotemporal medial cortex, patient is impaired in person recognition on the basis of their face (Damasio et al., 1982; Meadows, 1974).

Our ability to identify other people is associated with the ventromedial prefrontal cortex (vmPFC), that is activated by viewing familiar faces or imagining familiar voices and that, for this reason, can be considered a person identification node (PIN, Bruce & Young, 1986) Recently, some authors suggested that prosopagnosia and phonagnosia occur not only as a failure in recognition of familiarity, based on face or voice, but these conditions are due to a deficit in the white matter connections between vmPFC and face-and prosody-selective areas, respectively (Biederman et al., 2015).

Furthermore, two other studies describe a deficit in voice identity recognition following a brain lesion (Peretz et al., 1994; Van Lancker et al., 1988). They showed that recognizing a familiar voice and discriminating among unfamiliar voices are different abilities. Indeed, familiar voice recognition involves mainly the right hemisphere, whereas voice discrimination involves both hemispheres. Specifically, recognition of familiar voices is impaired by damage to the right inferior and lateral parietal lobe, whereas deficit in voice discrimination is associated with temporal lobe damage of either hemispheres (Van Lancker & Canter, 1982; Van Lancker et al., 1989).

To sum up, the evidence here reported suggested that an impairment in voice-recognition is associated with right brain damage. This findings is interesting since, as previously described (Chapter 1), also in the domain of bodily self, following a right hemisphere lesion a deficit may occur in recognize the one’s own body (Frassinetti et al., 2008, 2009, 2010).

Starting from these evidence, the study presented in Chapter 6 aimed at investigate the self-voice recognition disorder using a neuropsychological approach.

## Thesis overview

The aim of the current thesis is to investigate the mechanisms underlying the recognition of the corporeal self. The research presented here can be subdivided into two main parts: the first one focuses on one's own body processing in healthy and clinical populations.

Growing evidence suggested that we have an implicit knowledge about our body. Indeed, when performing a visual matching task with picture of body-parts belonged to the participant or to other people, neurologically healthy individuals showed the so-called self-advantage effect, that's a better performance when self than others stimuli were presented. Conversely, since this facilitation was not observed when an explicit self-body recognition is required, it has been suggested that we may access to our bodily knowledge by means of two different routes: an implicit and an explicit one. Furthermore, neuropsychological evidence suggested that the right hemisphere is crucial in the implicit recognition of self body-parts. By contrast, much less is known on the explicit recognition of bodily self. To this aim, in **Study 1** implicit and explicit dissociations in bodily self-recognition were investigated in right and left brain damaged patients. Participants were presented with rotated pictures of either self or other people hands. In the Implicit task participants were submitted to the hand laterality task, whereas in the Explicit task they had to judge whether the hand belonged or not, to them. Furthermore, the selective impairment of implicit and/or explicit bodily self-processing was investigated by comparing each patient with a sample of neurologically healthy individuals. Finally, the neural basis of such a dissociation was revealed by means of the Voxel-based lesion-symptom mapping analysis.

In **Study 2** an intriguing question concerning the relationship between the bodily self-recognition and the embodiment is investigated. Indeed, it has been recently described a groups of patients with a focal brain lesion claiming that the examiner’s hand is their own hand, showing a pathological embodiment of other’s body-parts. This phenomenon typically occurs following a lesion of the right hemisphere and demonstrates that the sense of body-ownership is altered following brain damage. In order to address whether an altered sense of bodily ownership may impair the ability to properly distinguish between what belong to the self and to other people’ body-parts, we adopted two experimental tasks designed for testing implicit (a visual matching to sample task) and explicit bodily self-recognition. The Study 2 address this critical question by comparing right brain damaged patients with and without pathological embodiment and a group of neurologically healthy controls.

The second part will be focused on self-voice recognition in healthy and clinical populations. In the domain of self-recognition, voice is a critical feature for self-other distinction. In **Study 3,** we explore whether people have an implicit and explicit knowledge of their voice. A group of neurologically healthy participants were submitted to an implicit and an explicit self-voice recognition task. They listened to pairs of pre-recorded auditory stimuli (words or pseudowords) pronounced by themselves, by a familiar or an unfamiliar person. Afterwards, in the Implicit task participants had to judge whether the pair of stimuli were pronounced by same or different speakers, whereas in the Explicit task they had to identify if one of the paired stimuli was or not their own voice.

Finally, the neural correlates of implicit and explicit self-voice recognition were explored in **Study 4** by comparing left and right brain damaged patients at the Implicit and Explicit tasks above described.

The general discussion draws together the findings from all of the above studies and suggests directions for future research.

## Chapter 3

# Implicit and explicit routes to recognize the own body: evidence from brain damaged patients

## 3.1 Introduction

The body, including its various parts, is an important component of our self and its identity and one of its most distinctive physical features. Previous studies showed that the recognition of a body (or body-parts) as one’s own body depends on a multitude of information. These studies suggest that the common feeling that *what I am looking at is my body* results from the simultaneous processing of visual components (Devue et al., 2007; Sugiura et al., 2005), somatosensory and proprioceptive signals (for a review see Blanke, 2012), and motor information (Frassinetti et al., 2009; Sugiura et al., 2006). Starting from this evidence here we focus on the contribution of visual and motor information to bodily self-processing. A relevant distinction has been recently made in the field between implicit and explicit body knowledge. In this respect, Frassinetti and colleagues (2008, 2009, 2010) investigated the implicit recognition of self body-parts, by using a visual matching to sample task. Participants were required to decide which of two vertically aligned images (high or low) matched the central target stimulus (i.e., an Implicit task). Stimuli could depict participants’ or other people’s body-parts (hand, foot, arm, leg). Results showed that participants were more accurate with self rather than others’ body-parts. This facilitation was called *self-advantage effect*. Interestingly, the self-advantage effect was not found when participants were explicitly required to judge whether the upper or the lower stimulus corresponded to their own body-parts (Frassinetti et al., 2011). This suggests possible dissociation between implicit and explicit self-advantage effect. However, neither such implicit-explicit dissociation in the self-advantage effect nor its underlying neural correlates have been demonstrated so far in brain damaged patients.

To better investigate the mechanisms of the implicit and explicit bodily self-recognition, in a following study (Ferri et al., 2011) the authors adopted a laterality judgment task, instead of the visual matching task. In a first experiment (implicit), participants were requested to report the laterality of images depicting self or other's hands presented at different angular orientations, whereas in the second experiment (explicit), participants were asked to recognize their own hand (Ferri et al., 2011). In order to perform the former but not the latter task, participants simulated a motor rotation of their own body-parts so as to match that of the observed stimulus (Ionta et al., 2007, 2012). In the laterality judgment task, a facilitatory effect (i.e., faster response times) was found in response to hand stimuli belonging to the participants (self stimuli), suggesting that the body self-advantage is based on a sensorimotor representation. This facilitatory effect was not observed in the second task, that is, during the explicit discrimination between self and others' stimuli. Overall, these results raise the possibility that bodily self-recognition is based on, at least, two different mechanisms for the implicit and explicit self-body processing, subtended by two different cerebral networks. As a consequence, different brain lesions might selectively impair either the implicit or the explicit self-body processing.

More specifically, we are confronted with the following alternatives. If implicit and explicit bodily processing are mediated by different neural networks, patients showing impairments in the Implicit task should be unimpaired in the explicit self body-parts recognition, unless the brain regions involved in body-parts explicit recognition are also damaged by the lesion. If, in contrast, implicit and explicit self body-parts recognition is mediated by the same network, patients impaired in the implicit should be impaired also in the explicit self body-parts recognition.

To test these hypotheses, patients with focal cerebral lesion (20 RBD and 13 LBD patients) and a group of healthy subjects were recruited and asked to perform two experiments.

In the first experiment participants were submitted to a laterality judgment task of rotated hands with different angular orientation (Implicit task). In the second experiment they were asked to explicitly recognize their own hand (Explicit task) (see Ferri et al., 2011 for the experimental paradigm). In both experiments, the displayed hand was the participants' hand (self condition) in half of the trials, whereas it depicted other people's hand (other condition) in the rest of the trials.

Based on previous studies, using the visual matching task, which showed that the self-advantage effect is preserved only in LBD patients (Frassinetti et al., 2008), we hypothesized the following results. In the Implicit task, a self-advantage effect should be found in LBD patients (Frassinetti et al., 2010), in addition to controls (Ferri et al., 2011, 2012), but not in RBD patients (Frassinetti et al., 2008, 2009, 2010). In the Explicit task, no self-advantage effect is predicted in healthy subjects, as well as in patients. Moreover, the observation of double dissociations between implicit and explicit bodily self-recognition together with the Voxel-based lesion-symptom mapping analysis will provide further evidence that these two aspects are functionally and anatomically distinct.

## 3.2 Materials and methods

### 3.2.1 Participants and neuropsychological assessment

Twenty RBD patients (11 males, age = 60.4±11 years; education = 10.9±4.7 years) and fourteen LBD patients (10 males, age = 60.3±10 years; education = 8.9±2.7 years) participated in the study. All patients were right handed by their own verbal report and were assessed for the presence of a general cognitive impairment through the Mini-Mental State Examination (Folstein et al., 1975). Twenty healthy participants matched for age (7 male, age = 53.7±11.6 years; education = 12.8±3.6 years) and handedness served as controls. Two one-way ANOVAs confirmed that the three groups were not significantly different for age [F(2,50)=2.09, p=.13] and education [F(2,50)=2.87, p=.07].

The presence and severity of extrapersonal neglect (Bell's Cancellation test; Gauthier et al., 1989), personal neglect (Fluff Test; Cocchini et al., 2001) and anosognosia for hemiplegia and hemianestesia (Spinazzola et al., 2008) were also assessed (for details see Table 3.1).

Patients were recruited at the Fondazione Maugeri Hospital (Castel Goffredo, Italy) and at the Villa Bellombra Rehabilitation Hospital (Bologna, Italy).

All participants, naive to the purpose of the study, gave their informed consent to participate to the study. The study was approved by the local ethics committee (Villa Bellombra Hospital and Department of Psychology of Bologna), and all procedures were in agreement with the 2008 Helsinki Declaration.

**Table 3.1 - Clinical and neuropsychological data of right (a) and left brain damaged patients (b).**

**a)**

| ID | Age | TPL | Aetiology | MMSE* | Bells ** | Fluff | AHP*** | AHE*** |
|---|---|---|---|---|---|---|---|---|
| RBD 1 | 79 | 60 | I | 30 | **5** | 2 | 0 | 0 |
| RBD 2 | 73 | 39 | I | 30 | 0 | 0 | 0 | 0 |
| RBD 3 | 48 | 19 | I | - | **5** | 1 | 0 | 0 |
| RBD 4 | 39 | 228 | I | - | 2 | 1 | 0 | 0 |
| RBD 5 | 69 | 34 | I | 24 | 4 | 1 | 0 | 0 |
| RBD 6 | 58 | 60 | I | - | - | - | 0 | 0 |
| RBD 7 | 57 | 650 | I | - | 3 | 0 | 0 | 0 |
| RBD 8 | 59 | 50 | I | - | 0 | 0 | 0 | 0 |
| RBD 9 | 56 | 59 | I | - | 0 | 2 | 0 | 0 |
| RBD 10 | 62 | 30 | I | 28 | 0 | 2 | 0 | 0 |
| RBD 11 | 54 | 392 | H | 28 | 2 | 1 | 0 | 0 |
| RBD 12 | 64 | 84 | I | - | 2 | 2 | 0 | 0 |
| RBD 13 | 71 | 39 | I | 22 | **15** | 0 | 0 | 0 |
| RBD 14 | 65 | 73 | H | 24 | **14** | **10** | **1** | **1** |
| RBD 15 | 57 | 88 | I | - | **6** | 0 | 0 | 0 |
| RBD 16 | 61 | 37 | I | - | 0 | 0 | 0 | **1** |
| RBD 17 | 64 | 79 | H | 23 | **12** | **5** | 0 | **2** |
| RBD 18 | 68 | 16 | I | 28 | 0 | 1 | 0 | 0 |
| RBD 19 | 34 | 50 | H | 30 | 0 | 1 | 0 | 0 |
| RBD 20 | 69 | 43 | I | 26 | 4 | 1 | 0 | 0 |

**b)**

| **ID** | **Age** | **TPL** | **Aetiology** | **MMSE*** | **Token Test** |
|---|---|---|---|---|---|
| LBD 1 | 51 | 82 | H | - | 29 |
| LBD 2 | 65 | 70 | H | - | - |
| LBD 3 | 44 | 93 | H | 27 | 26 |
| LBD 4 | 57 | 25 | I | 22 | 33 |
| LBD 5 | 64 | 277 | I | 27 | 29 |
| LBD 6 | 77 | 43 | I | 28 | - |
| LBD 7 | 67 | 52 | I | 22 | 26 |
| LBD 8 | 51 | 34 | H | 27 | 32 |
| LBD 9 | 47 | 51 | I | 24 | 30 |
| LBD 10 | 61 | 47 | H | 30 | 34 |
| LBD 11 | 52 | 35 | H | 25 | 30 |
| LBD 12 | 71 | 33 | H | 27 | 36 |
| LBD 13 | 63 | 31 | I | 28 | 32 |
| LBD 14 | 72 | 28 | H | 20 | 22 |

TPL = Time post lesion (days); I = ischemic stroke, H= hemorrhagic stroke; *MMSE= Mini Mental State Examination (scores are corrected for years of education and age); **Bells Test= left omissions; Fluff test= omissions; ***AHP= anosognosia for hemiplegia; ***AHE= anosognosia for hemianestesia (scoring 0= no anosognosia, 1= moderate anosognosia, 2=severe anosognosia, each value refers to the left upper limb). Bold characters indicated pathological performance.

### 3.2.2 Stimuli and procedure

Grey-scale pictures of the dorsal view of right and left hands (see Figure 3.1) were used as experimental stimuli. The hands of each participant were photographed with a digital camera in a session prior to the experiments. Hands were always photographed with constant artificial light, in the same position and at a fixed distance from the camera (40 cm).

Pictures were modified with Adobe Photoshop® CS4 software: each hand was cut from the original picture, centered and then pasted on a white background. Finally, each photograph was clockwise rotated to obtain six predefined orientation (0°, 60°, 120°, 180°, 240°, 300°), in which fingers pointing upwards defined the upright orientation. Half of the trials (n=144) depicted the participant's own left or right hand ('self' trials), whereas the other half depicted the right or left hand of three other people ('other' trials). As far as the latter one, three stimuli were selected from a database of hands pictures as the best match with each participant's hand for size, age, skin color and gender.

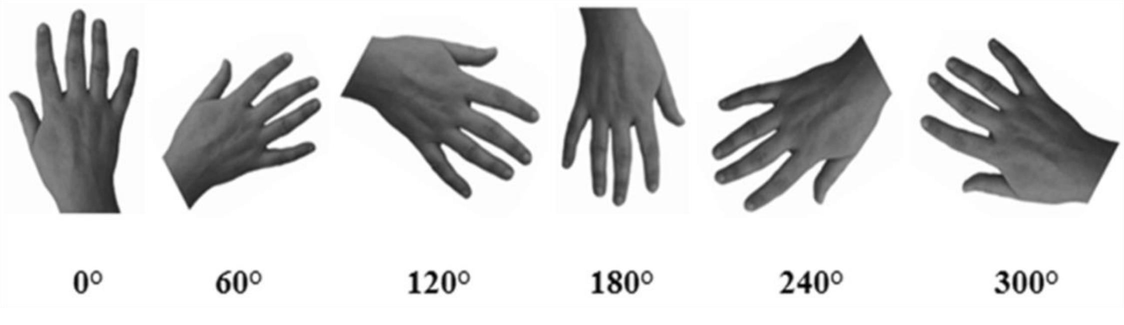

**Figure 3.1 - An example of stimuli representing hands at different orientations.**
In the Implicit task, participants were required to judge the laterality of each stimulus. In the Explicit task, participants were required to judge if the hand was or was not their own.

Participants sat in front of a PC screen, at a viewing distance of about 40 cm. A central fixation cross (500 ms duration) was presented at the beginning of each trial followed by a display containing hand’s picture on a white background. Stimuli presentation was controlled by E-Prime 2.0 (Psychology Software Tools Inc.) and each trial was timed-out by the participant’s response (up to 4000 ms).

In Experiment 1 participants had to judge the laterality (left or right) of displayed hand by pressing as accurately as possible and within the allowed time interval, a left or a right response key (“R” or “P” on keyboard). In Experiment 2, participants had to explicitly judge whether the displayed hand corresponded or not to their own hand by pressing as accurately as possible and within the allowed time interval, a left or a right previously assigned response key (“R” or “P” on keyboard). In both Experiments the response keys were counterbalanced between subjects. Since patients responded by using their not affected hand, that’s the left for RBD and the right for LBD, healthy subjects were accordingly divided in two groups: 9 who responded by using the index finger of the right hand, and 11 who using their left hand.

An adapted version of both experiments to patients showing signs of neglect or left hemianopia was designed by shifting all stimuli to the right side of the screen. Analogously, an adapted version of both experiments to patients showing right hemianopia was designed by shifting all stimuli to the left side of the screen.

Both experiments were always preceded by 8 trials as practice. Then, each experiment comprised 288 trials, 72 trials for each of the four conditions: self-right hand, self-left hand, other-right hand, other-left hand. Furthermore, each orientation was randomly presented 12 times per condition. Since Experiment 1 investigated the implicit and Experiment 2 the explicit bodily self-recognition, Experiment 1 was always conducted before Experiment 2. All participants performed both experiments in one single session lasting up to one hour.

### 3.2.3 Statistical analyses

Data from Experiment 1 (Implicit task) and Experiment 2 (Explicit task) were analyzed separately. First of all, the presence of the self-advantage effect and the strategy to solve the task (i.e., the mental rotation) were tested in healthy subjects. An ANOVA was conducted on *mean response times (RTs) for correct trials* with Owner (self and other), Laterality (left and right) and Orientation (0°, 60°, 120°, 180°, 240°, 300°) as within-subjects factors and Group (H-R= healthy subjects responding with the right finger and H-L= healthy subjects responding with the left finger) as between-subjects factor. Finally, to directly compare healthy subjects' and patients' performance two separate ANOVAs were conducted: the first, between RBD patients and healthy subjects responding with the right finger (H-R); the second, between LBD patients and healthy subjects responding with the left finger (H-L). When the variable Group was significant, patients' data were also separately analyzed.

The same ANOVAs were also conducted on *mean correct responses (accuracy)*, collapsing the Orientation factor across conditions. Where necessary, post-hoc analyses were conducted by using Tukey's HSD (Honest Significant Difference) test for equal or unequal N (in accordance with the sample size). The magnitude of effect size was expressed by $\eta^2_p$.

## 3.3 Results

### 3.3.1 Analysis on mean response times (RTs)

### Results of Experiment 1 (Implicit task)

*Analysis on healthy subjects*

The **Laterality x Owner** interaction was significant [F(1,18)=7.75 p<.01; $\eta^2_p$ =.30]: participants responded faster with self than with other people's *right* hand (self=1079 ms vs. other=1156 ms, p<.02), whereas no significant difference was found for the left hand (self=1191 ms vs. other=1174 ms, p=.87). Moreover, a significant difference emerged between right and left self hand (p<.001) but not right and left others' hand (p=.87). In addition, when participants responded to their right hand were faster compared to other left hand (p<.003, see Figure 3.2a).

The main effect **Orientation** was significant [F(5,90)=26.23 p<.0001; $\eta^2_p$ =.59], since RTs to stimuli at 180° (1386 ms) were longer than all other orientations (0°=1017 ms, 60°=1046 ms, 120°=1217 ms, 240°=1188 ms, 300°=1046 ms, p<.001 in all cases). Moreover, longer RTs were observed at 120° and 240° compared to RTs at 0°, 60° and 300°, p<.008 for all comparisons, see Figure 3.4). These results show that participants used mental rotation strategy to solve the Implicit task, both for right and left stimuli.

The variable Group and its interaction with other variables were not significant, suggesting that the responding hand did not influence the described effects.

*RBD patients and healthy subjects responding with the right finger (H-R)*

The variable **Group** was significant [F(1,27)=10.86, p<.003; $\eta^2_p$ =.29], which was mainly due to longer response time in RBD patients (1725 ms) compared to controls (1213 ms).

The main effect of **Orientation** was significant [F(5,135)=28.23, p<.0001; $\eta^2_p$ =.51] since RTs were longer at 180° (1856 ms) than at all other orientations (0°=1419 ms, 60°=1486 ms, 120°=1685 ms, 240°=1610 ms, 300°=1472 ms, p<.0004 in all cases). Moreover, longer RTs were observed at 120° and 240° compared to RTs at 0°, 60° and 300°, p<.0001 for all comparisons).

The interaction **Laterality x Orientation** was significant [F(5,135)=3.08, p<.01; $\eta^2_p$ =.10]. Post-hoc analysis showed that RBD patients performed slower with the left compared to the right hand at 0° (1506 ms vs. 1333 ms, p<.004) and at 300° (1560 ms vs. 1384 ms, p<.003).

Then, as slower performance with the left compared to the right hand was not observed in healthy subject, we wanted to test whether the significant interaction was mainly due to a specific effect of the patients' contralesional left hand. To this aim, being the variable Group significant a separate ANOVA was conducted on RBD patients' performance with Owner, Laterality and Orientation as within-subjects variables.

*Analysis on RBD patients*

First of all, analysis showed that the variable Owner (p=.14) and its interactions with other variables were not significant. These results confirmed that RBD patients, differently from healthy subjects, did not show the self-advantage effect (see Figure 3.3a).

The variable **Orientation** [F(5,95)=20.27, p<.0001; $\eta^2_p$ =.52] and the crucial interaction **Laterality x Orientation** were significant [F(5,95)=5.47, p<.0002; $\eta^2_p$ =.22]. Post-hoc analysis confirmed that RBD patients used the mental rotation strategy to solve the task both for the right hand (180°=2056 ms vs. 0°=1468 ms, 60°=1679 ms, 240°=1725 ms, 300°=1550 ms, p<.0001 for all comparisons) and for the left hand (180°=1981 ms vs. 0°=1693 ms, 60°=1651 ms, 300°=1755 ms, p<.01 for all comparisons, see Figure 3.4). Moreover, this analysis revealed that RBD patients performed slower with the left (controlesional) hand compared to the right (ipsilesional) hand at 0° (1506 ms vs. 1333 ms, p<.004) and at 300° (1560 ms vs. 1384 ms, p<.003).

*LBD patients and healthy subjects responding with the left finger (H-L)*

The variable **Group** was significant [F(1,23)=22.11 p<.0001; $\eta^2_p$=.49]: LBD patients showed longer response time (1836 ms) compared to controls (1099 ms).

The variable **Owner** was significant [F(1,23) =8.85, p<.007; $\eta^2_p$=.28]: RTs were faster for self (1473 ms) than other people's (1550 ms) body-parts processing.

The variable **Orientation** was significant [F(5,115)=21.96, p<.0001; $\eta^2_p$=.49] since RTs to stimuli at 180° (1787 ms) were longer than all the other orientations (0°=1386 ms, 60°=1399 ms, 120°=1574 ms, 240°=1520 ms, 300°=1402 ms, p<.00023 in all cases) and RTs to stimuli at 120° were longer than at 0°-60°-300° orientations (p<.002).

*Analysis on LBD patients*

A separate ANOVA conducted on LBD patients' data showed a significant effect of the variable **Owner** [F(1,13) =6.52, p<.02; $\eta^2_p$=.33]: patients performed faster with self (1786 ms) compared to other's body-parts (1886 ms) (see Figure 3.3b).

Also the **Orientation** was significant [F(5,65)=13.456, p<.0001; $\eta^2_p$=.51]: RTs to stimuli at 180° (2174 ms) were longer than at all other orientations (0°=1706 ms, 60°=1711 ms, 120°=1893 ms, 240°=1835 ms, 300°=1696 ms, p<.002 in all cases, see Figure 3.4). Since the interaction Laterality x Orientation was not significant (p=.71), LBD patients used the mental rotation strategy to solve the task with the same efficiency with the right (contralesional) and left (ipsilesional) hand.

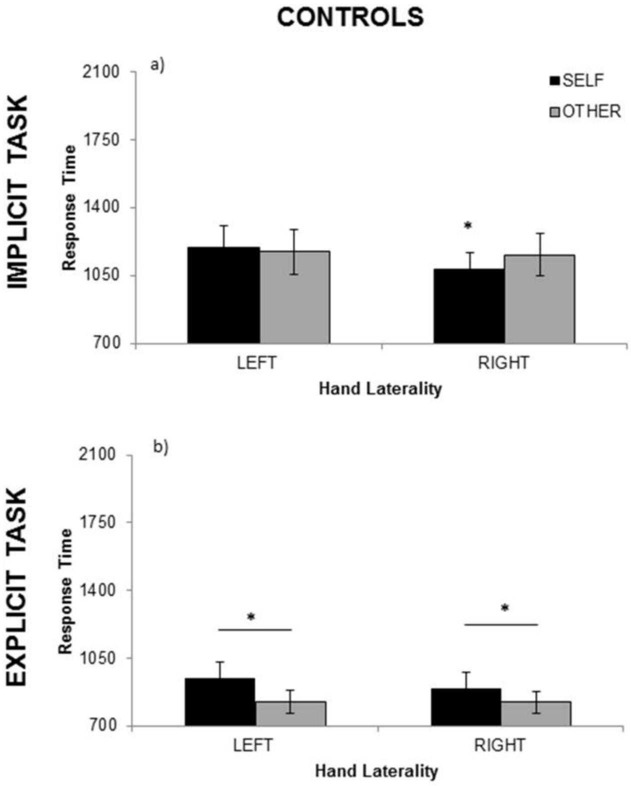

**Figure 3.2 – Mean RTs of Controls in the Implicit and Explicit task.**

The mean of RTs in the Implicit and Explicit task as a function of Ownership (Self, Other) and Laterality (left and right hand) respectively. Differences significant at p<.05 are starred. Error bars depict SEMs.

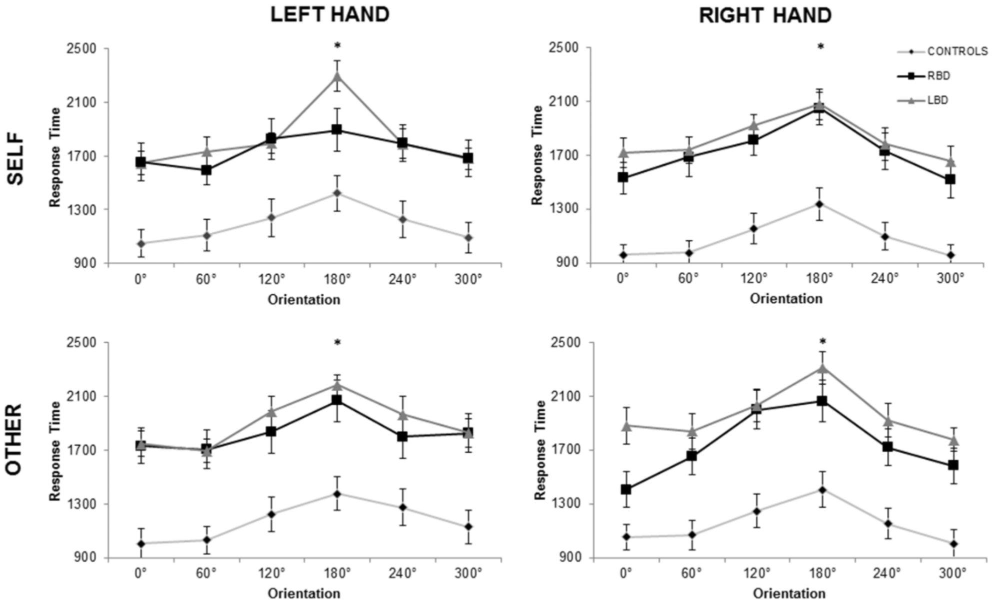

**Figure 3.3 – Mean RTs of Controls, RBD and LBD patients in the Implicit task.**

Results are displayed as a function of orientations and laterality separately for self and other’s hand. Differences significant at p<.05 are starred. Error bars depict SEMs.

## Results of Experiment 2 (Explicit task)

### *Analysis on healthy subjects*

The main effect of **Owner** was significant [F(1,18)=4.4 p<.05; $\eta^2_p$ =.21]: RTs were longer for self than for other people’s stimuli (self-disadvantage, self=917 ms vs. other=823 ms; see Figure 3.2b).

The variable Orientation was not significant (p=.38), suggesting that participants did not use mental rotation strategy to solve the Explicit task (0°=839 ms, 60°=866 ms, 120°=880 ms, 180°= 893 ms, 240°=873 ms, 300°=875 ms, see Figure 3.5).

*RBD patients and healthy subjects responding with the right finger (H-R)*

The variable **Group** was significant [F(1,27)=32, p<.0001; $\eta^2_p$=.55]: RBD patients responded slower (1573 ms) than healthy subjects (872 ms).

The variable **Owner** [F(1,27) =7.35, p<.01; $\eta^2_p$=.22] was significant showing a self-disadvantage effect (self=1550 ms vs. other=1165 ms). The interaction **Owner x Group** was significant [F(1,27) =3.89, p<.05; $\eta^2_p$=.13] since RBD patients with self stimuli (1820 ms) were slower than controls (both with self=854 ms and other=776 ms stimuli) whereas RBD patients with other's stimuli were not significantly different from controls.

Finally, the variable Orientation (p=.73, see Figure 3.5), as well as its interactions with other variables were not significant.

*Analysis on RBD patients*

When RBD patients' data were separately analyzed only the variable **Owner** [F(1,19) =14.48, p<.001; $\eta^2_p$=.43] was significant confirming a disadvantage for self-stimuli (1821 ms vs 1325 ms) (see Figure 3.3c).

*LBD patients and healthy subjects responding with the left finger (H-L)*

The variable **Group** was significant [F(1,23)=28.25, p<.0001; $\eta^2_p$=.55]: LBD patients (1510 ms) were slower than controls (868 ms). The variable **Owner** was significant [F(1,23)=8.81, p<.01; $\eta^2_p$=.28] showing a self-disadvantage effect (self=1299 ms vs. other=1133 ms). The variable Orientation (p=.20), as well as its interactions with other variables were not significant (see Figure 3.5).

*Analysis on LBD patients*

When LBD patients' data were separately analyzed only the variable **Owner** [F(1,13) =8.07, p<.01; $\eta^2_p$=.38] was significant: patients were slower for self (1641 ms) compared to other's body-parts (1378 ms; see Figure 3.3d).

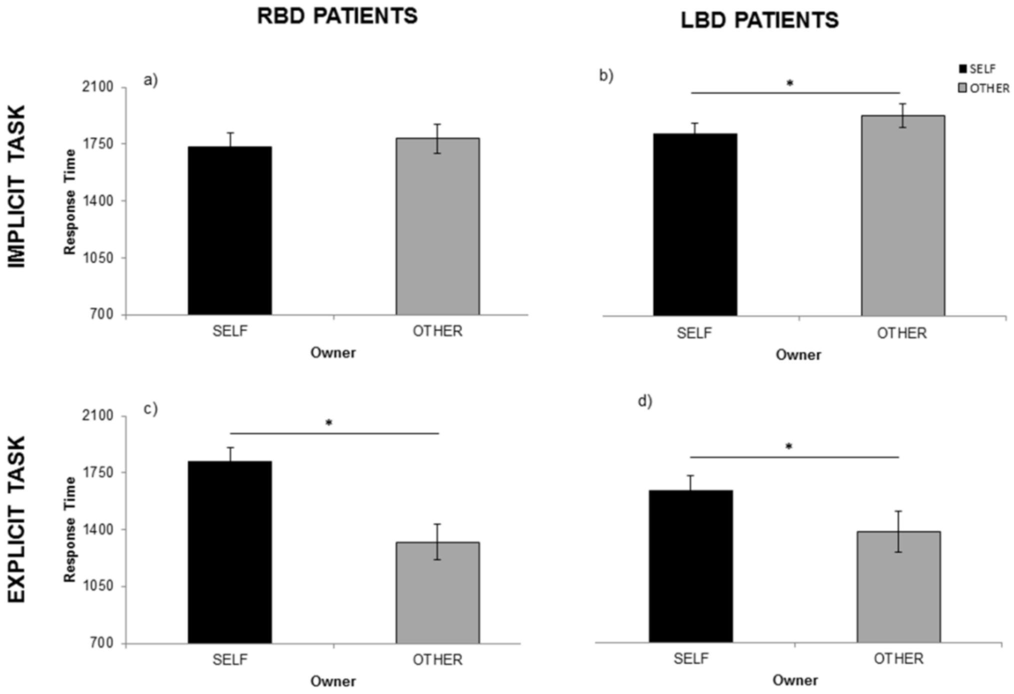

**Figure 3.4 – Mean RTs of RBD and LBD patients in the Implicit and Explicit task.** The mean of RTs in the Implicit (upper panel) and Explicit task (lower panel) as a function of Ownership (Self, Other) respectively for RBD and LBD patients. Differences significant at p<.05 are starred. Error bars depict SEMs.

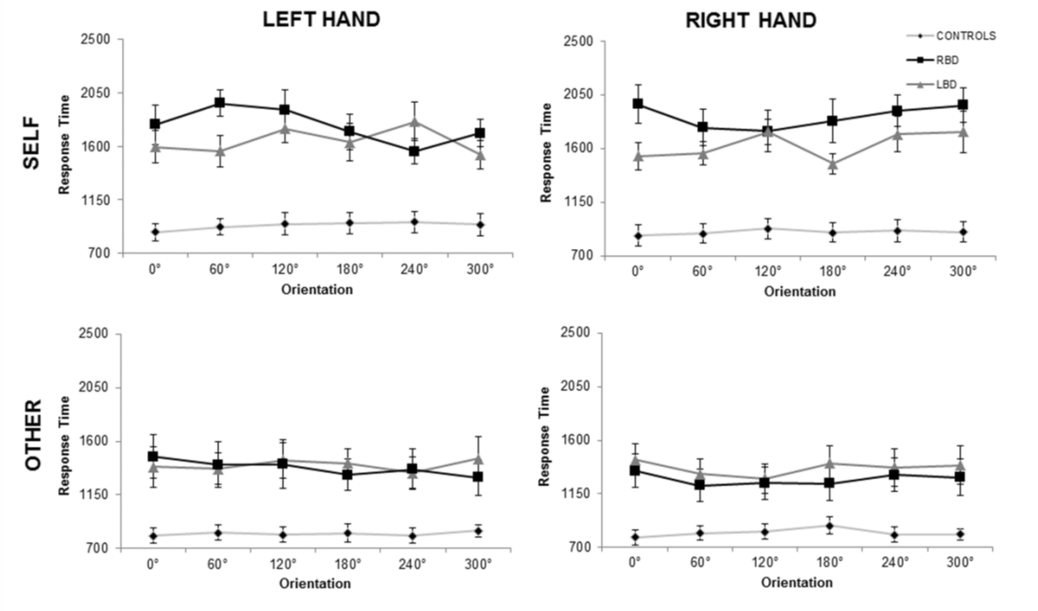

**Figure 3.5 – Mean RTs of Controls, RBD and LBD patients in the Explicit task.** Results are displayed as a function of orientations and laterality, separately for self and other's hand. Differences significant at p<.05 are starred. Error bars depict SEMs.

### 3.3.2 Analysis on accuracy

Since, the analysis conducted on response times including the Orientation factor, demonstrated that the Experiment 1, but not the Experiment 2, required a mental rotation strategy, in the further analysis the Orientation factor was collapsed across conditions.

Data of Experiment 1 (Implicit task) and of Experiment 2 (Explicit task) were separately analyzed.

First of all, to characterize the performance of healthy subjects, an ANOVA was conducted on the *means of correct responses (Accuracy)* with Owner (self and other) and Laterality (left and right displayed hand) as within-subjects factors and Group (H-R= healthy subjects responding with the right finger and H-L= healthy subjects responding with the left finger) as between-subjects factor. Finally, healthy subjects' and patients' performances were compared by using two separate ANOVAs: the former between right brain damage patients (RBD) and healthy subjects responding with the right finger (H-R), and the latter between left brain damage patients (LBD) and healthy subjects responding with the left finger (H-L).

Where necessary, post-hoc analyses were conducted by using Tukey's HSD (Honest Significant Difference) test for equal or unequal N (in accordance with the sample size). The magnitude of size effect was expressed by $\eta^2_p$.

## Results of Experiment 1 (Implicit task)

### *Analysis on healthy subjects*

The **Laterality x Owner** interaction was significant F[(1,18)=26.8 p<.0001; $\eta^2_p$ =.60]: participants were more accurate with *self right* hand than with others' right hand (self=94% vs. other=90%, p<.01) and than with self left hand (89%, p<.001).

The variable Group and its interaction with other variables were not significant.

### *RBD patients and healthy subjects responding with the right finger (H-R)*

The variable **Group** was significant [F(1,27)=21.7, p<.0001; $\eta^2_p$ =.45], because controls were more accurate than RBD patients (94% vs 68%).

The interaction **Laterality x Group** was near to be significant [F(1,27)=3.54, p=.07]. To better understand the meaning of this effect, the same analysis was conducted on RBD patients' data separately. This analysis revealed that in RBD patients the variable Owner (self=69% vs Other=68%, p =.37) and its interaction with laterality were far to be significant (self right=67%, self left=71%, other right=68%, other left=67%, p=.29).

*LBD patients and healthy subjects responding with the left finger (H-L)*

The variable **Group** was significant [F(1,22)=11.59, p<.002; $\eta^2_p$=.35]: controls were more accurate than LBD patients (89% vs. 70%).

The **Laterality x Owner** interaction was significant F[(1,22)=5.51, p<.03; $\eta^2_p$=.20]: participants were more accurate with *self right* hand (83%) than with others' right hand (77%, p<.04) and with self left hand (77%, p<.03).

The interaction between Group and the other variables were not significant.

### Results of Experiment 2 (Explicit task)

*Analysis on healthy subjects*

The main effect of **Owner** was significant F[(1,18)=4.9, p<.04; $\eta^2_p$=.21]: participants were *less* accurate with self than with others' stimuli (self-disadvantage, self=86% vs. other=92%).

*RBD patients and healthy subjects responding with the right finger (H-R)*

The variable **Group** was significant [F(1,27)=33.5, p<.0001; $\eta^2_p$=.55]: controls were more accurate than RBD patients (90% vs. 55%).

The variable **Owner** [F(1,27) =11.26, p<.002; $\eta^2_p$=.29] was significant showing a self-disadvantage effect (self=52% vs. other=80%). The interaction **Owner x Group** was significant [F(1,27) =3.82, p<.05; $\eta^2_p$=.13] since the self-disadvantage effect was significant only in RBD patients (self=36% vs. other=74%, p<.0005). Moreover, RBD patients with self stimuli (36%) were less accurate than controls (both with self=85% and other=94% stimuli, $p<.0004$ for both comparisons) whereas RBD patients with other's stimuli were not significantly different from controls.

*LBD patients and healthy subjects responding with the left finger (H-L)*

The variable **Group** was significant [$F(1,22)=11.1$, $p<.003$; $\eta^2_p=.34$]: controls (88%) were more accurate than LBD patients (68%). The variable **Owner** was significant [$F(1,22)=5.12$, $p<.04$; $\eta^2_p=.67$] showing a self-disadvantage effect (self=71% vs. other=83%).

The interaction Group x Owner was not significant ($p=.13$): the self-disadvantage effect was present also in LBD patients (self=58% vs. other=78%).

## 3.4 Lesion study

Brain lesions were identified by Computed Tomography and Magnetic Resonance digitalized images (CT/RMI) of 15 RBD and 11 LBD patients. For each patient, the location and extent of brain damage was delineated and manually mapped in the stereotactic space of the MNI by using the free software MRIcro (Rorden & Brett, 2000).

As first step, MNI template was rotated (pitch only) to approximate the slice plane of the patient's scan. A trained rater (MC), using anatomically landmarks, manually mapped the lesion onto each correspondent template slice. After that, drawn lesions were inspected by a second trained rater (FF) and in case of disagreement, an intersection lesion map was used. Finally, lesions maps were rotated back into the standard space applying the inverse of the transformation parameters used on the stage of adaptation to the brain scan.

### *3.4.1. Lesion overlap*

To localize and to measure the lesion extension of the two patients' groups, the lesion of RBD and of LBD patients were separately overlaid on the ch2 template provided by MRIcro and the region of maximum overlap was extracted.

The region, that contained the overlap of at least 50% of RBD patients' lesions (that is seven patients), was located in the paraventricular area and involved caudate nucleus (22, -7, 18) and thalamus (23, -15, 20) (for a graphical representation, see Figure 3.6a).

Similarly, the region of maximum overlap, that contained the overlap of at least 50% of LBD patients' lesion (that is, five patients) was located in the left white matter and involved the claustrum (-29, -19, 21) and the lentiform nucleus (-25, -19, 6) (for a graphical representation, see Figure 3.6b).

To compare lesions' extension we conducted a Mann Whitney U-test on the mean number of voxels involved by the lesion for each patient in the RBD patients' group and LBD patients' group. Results confirmed that the two groups were not significantly different regarding the 'total lesion volume' (p>.05).

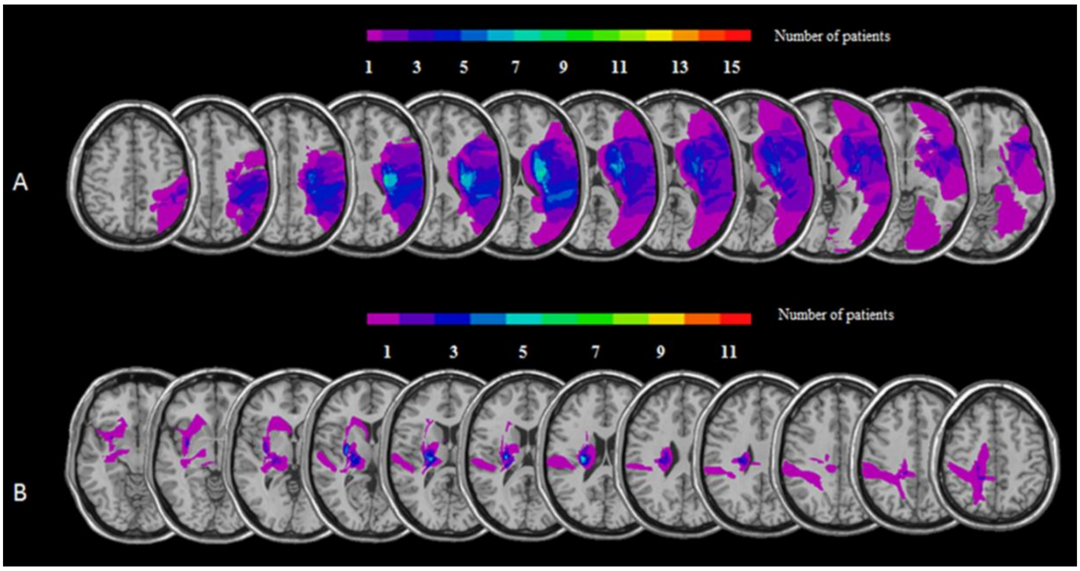

**Figure 3.6 – Overlay lesion plots of the 15 RBD (a) and 11 LBD (b) patients superimposed onto MNI template.** The region frequency of brain lesions in each area is expressed according to the color scale ranging from violet (lesion present in one patient) to red (lesion present in all patients).

### *3.4.2. Voxel-based lesion-symptom mapping analysis*

Following mapping of individual lesions we performed a VLSM analysis (Bates et al., 2003; Verdon et al., 2010) to explore the anatomical regions related to selective impairment in implicit and explicit bodily self-processing. An index of self-processing (calculated as: self minus other stimuli accuracy) was used as predictors for the patients' performance, separately for Implicit and Explicit tasks. We adopted the Brunner-Munzel test (Brunner & Munzel, 2000) to perform statistical comparisons on a voxel-wise basis, as implemented in NPM

(Non Parametric Mapping) and MRIcron software. Brunner-Munzel tests were performed at each voxel using the performance measure as dependent variable. In order to avoid producing inflated Z-scores, tests were run using permutation derived correction (permFWE; Kimberg & Schwartz, 2007; Medina et al., 2010). Areas showing significant relationship (P was set at 0.05) with behavioral deficit were identified. Only voxels affected in at least four cases (15%) were included in the analysis.

In the statistical analysis described below, the anatomical distribution of the statistical results was assessed using the Automated Anatomical Labelling map (template AAL; Tzourio-Mazoyer et al., 2002), which classifies the anatomical distribution of digital images in stereotactic space. The anatomical structures revealed by this analysis are associated with lower index of self-processing (self accuracy < other accuracy).

Mapping of **implicit self-recognition** index revealed two peaks in the **right hemisphere:** the first (Z=3.39, range -1.785 - 3.39) located in the paraventricular area involving the **caudate nucleus** (21, -8, 29) and the second peak (Z=3.26) located in the subcortical frontal region involving the **internal capsule**, the **right lenticular nucleus** (27, -11, 19) and the antero-medial portion of the **inferior fronto-occipital tract** (Catani, et al., 2012a) (see Figure 3.7a and Table 2).

Finally, mapping of **explicit self-recognition** index failed to reveal significant anatomical clusters, indeed none region survived the permFWE correction applied. However, observing Z-scores, highest values were associated with the **left hemisphere** (Z=1.96, range -1.151 – 2.5), specifically with a lesion that involved the **putamen** (-27, -22, 22). Further peaks were located in the **right hemisphere**, more specifically in the **inferior parietal lobe** (Z=1.78; 62, -35, 25; Brodmann area 40) involving angular (Z=1.78; 42, -45, 25) and supramarginal gyrus (Z=1.79; 35, -49, 29) (see Figure 3.7b and Table 3.2). In addition, lesion crossed the white fiber constituting the **superior longitudinal arcuate fasciculus** (Catani, et al., 2012b).

**Table 3.2 - Brain regions associated with Implicit and Explicit body recognition deficit.**

| MNI Coordinate (x, y, z) | | | Z-score | Brain Structure | Cluster level size |
|---|---|---|---|---|---|
| **Implicit bodily self-recognition** | | | | | |
| 21 | -8 | 29 | **3.39** | R caudate nucleus | 282 |
| 27 | -11 | 19 | **3.26** | R lenticular nucleus and internal capsule | 53 |
| **Explicit bodily self-recognition** | | | | | |
| -27 | -22 | 22 | **1.96** | L putamen | - |
| 35 | -49 | 29 | **1.79** | R supramarginal gyrus | - |
| 42 | -45 | 25 | **1.78** | R angular | - |
| 62 | -35 | 25 | **1.78** | R inferior parietal lobe, BA 40 | - |

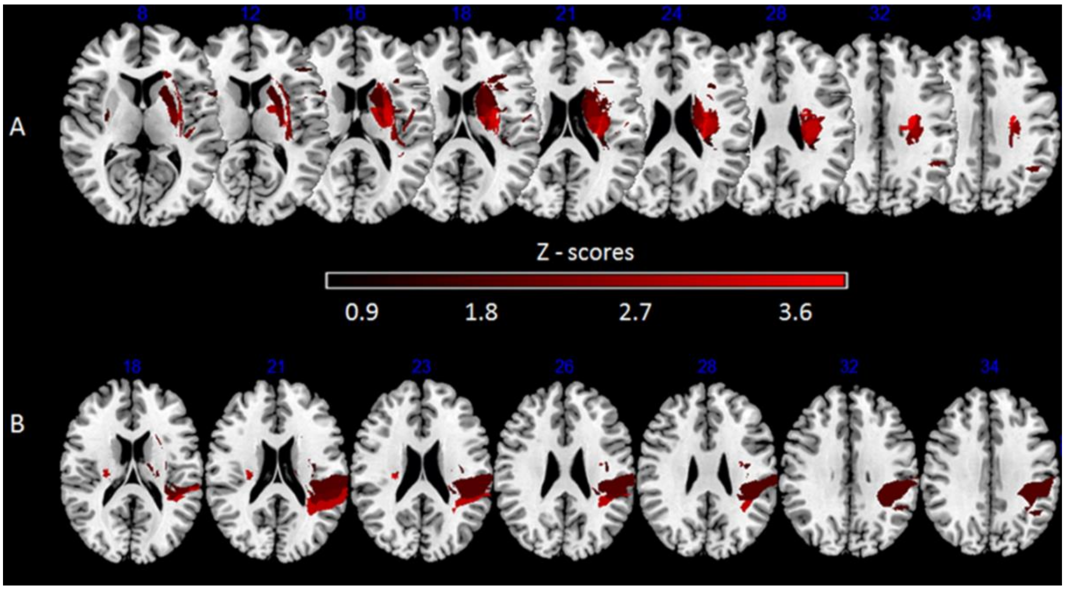

**Figure 3.7 – Representative slices from map showing the anatomical correlates of self-implicit (a) and self-explicit index (b) in the entire sample of patients.**

Maps show the Z-statistics calculated with Brunner-Munzel with permutation derived corrected. All peaks are significant at $P < 0.05$ level (upper panel).

## 3.5 Implicit and explicit dissociations

Lesion analysis above described revealed that impaired performance in implicit bodily self-recognition is selectively associated with a lesion of the right hemisphere. By contrast, even if anatomical data are not significant, impaired performance in explicit bodily self-recognition seems to be related to both left and right brain regions.

To elucidate the anatomical correlate of a selective deficit, the presence of possible dissociation in implicit and explicit self bodily knowledge was investigated in each patient. Since in the group analysis possible dissociations may have gone unobserved because of the well-known averaging artefact (Shallice, 1988), we therefore compared the performance of each patient with the performance of the control group for self body-parts, separately in the Implicit and in the Explicit task, by using a modified *t*-test which takes into account the size of the control group (Crawford & Garthwaite, 2002). This comparison revealed that 35% of RBD patients (7/20) were selectively impaired in the implicit or in the explicit self-body processing compared to controls. Crucially, the majority of them (71% = 5/7) were selectively impaired in the implicit but not in the explicit self-body processing, whereas other patients (29% = 2/7) were selectively impaired in the explicit but not in implicit self-body processing. Finally, one LBD patient (8% = 1/13) was selectively impaired in the explicit but not in implicit self-body processing.

In order to verify whether patients' lesions involved the region found in VLSM analysis associated with implicit and explicit self-body recognition, individual plots are shown. Lesion data of only three out of five RBD patients selectively impaired in the implicit self-recognition (see Figure 3.8a) and of two patients (1 RBD and 1 LBD) selectively impaired in the explicit self-recognition were available (see Figure 3.8b).

Two RBD patients (RBD 3 and RBD 4) were affected by lesions encompassing right frontal regions, similar to the region emerged with VLSM. The lesion of the third RBD patient (RBD 14) was more posterior, involving the parietal and temporal lobes. Finally, patients showing a selective impairment in explicit bodily self-processing were affected by lesions corresponding to the inferior temporal lobe in the right hemisphere (RBD 16) and the putamen in the left hemisphere (LBD 3).

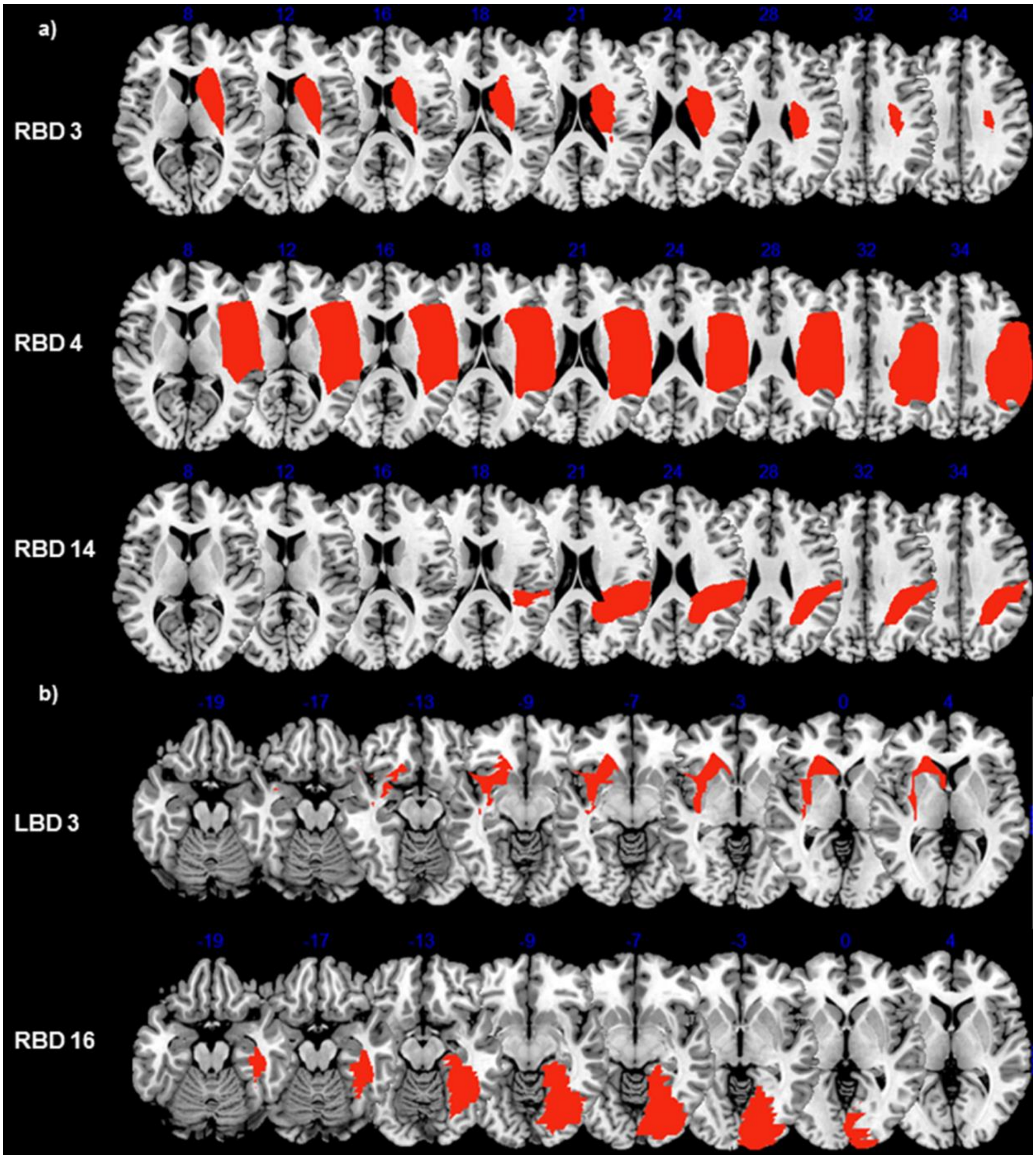

**Figure 3.8 – Brain lesion associated with implicit and explicit self-recognition deficits.**

Brain lesion plots of three RBD patients selectively impaired in implicit self body-parts recognition (a) and two patients (1 LBD and 1 RBD) selectively impaired in explicit self body-parts recognition (b), superimposed onto MNI template; individual lesions are marked in red.

## 3.6 Discussion

The main focus of the current study was to explore whether implicit and explicit recognition of self body-parts could be selectively impaired after brain lesions.

To this aim, thirty-three patients (20 RBD and 13 LBD) and twenty age-matched neurologically healthy subjects were submitted to two different tasks designed for testing implicit and explicit body-parts recognition.

In the Implicit task (Experiment 1), healthy subjects showed a better performance when the displayed hand was their own hand compared to other people's hand, showing the so called self-advantage effect. Crucially, this self-advantage was found only for the right hand but not for the left displayed hand. In contrast, such self-advantage effect could no longer be observed in the Explicit task (Experiment 2). When participants were required to judge if the displayed hand was their own hand, they were slower and less accurate with their own hand compared to others' hand.

Another critical difference between the Implicit and the Explicit task performance in healthy subjects is that different strategies were used to perform the two tasks. Mental motor rotation of body-parts is required to solve the laterality judgment task in the Implicit task (Experiment 1) (Ionta et al., 2007; Parsons, 1987, 1994; Parsons & Fox, 1998) while it is not necessary to solve the Explicit task (Experiment 2). The difference in task requirements is reflected in the classical bell-shaped function observed for response times only in Experiment 1 but not in Experiment 2 (see Figures 3.4 and 3.5). The involvement of laterality judgment in the Implicit task requires motor representation (see also Ferri et al., 2011). Since the very same Implicit task also showed self-advantage effect, one would assume the latter to be closely related to the involvement of motor (rather than merely cognitive as in the Explicit task) function in healthy subjects.

According to this hypothesis, the presence, in healthy subjects, of a self-advantage only for self-right hand stimuli is likely the consequence of the greater involvement of the left, rather than the right, sensorimotor areas in right-handers during a mental motor task (see Conson et al., 2010; Ferri et al., 2011; Gentilucci et al., 1998). An alternative interpretation of these results, that the advantage for the right displayed hand was due to a generic hand-response bias, was ruled out because the self-advantage effect for the right hand emerged independently from the responding hand.

In the Explicit task, completely different results emerged in healthy subjects in which a disadvantage for self-related stimuli was found. Taken together, data of Experiment 1 and Experiment 2 suggest that there are two ways to access to bodily self-knowledge: one way leading to an implicit, but not to an explicit knowledge, and the other way leading to an explicit knowledge. In this respect the neuropsychological approach can be useful to verify the existence of these different ways. Indeed, if this is true, only one of the two ways can be impaired after a focal brain lesion. Previous studies on RBD and LBD patients have already shown a crucial role of the right hemisphere for the implicit self-advantage effect (Frassinetti et al., 2008, 2009, 2010). The mental rotation task of right and left hand, in RBD and LBD patients, can shed new light on the contribution of patients' motor abilities to the relationship between the implicit self-recognition and the right hemisphere. Moreover, in the present study, in the same sample of LBD and RBD patients, in addition to the implicit, also the explicit self- recognition was, for the first time, investigated.

Patients' with right, but not left, brain lesions showed significant impairment in implicit self-body recognition, in which no self-advantage effect was found.

VLSM analysis (Bates et al., 2003; Verdon et al., 2010) revealed selective impairments especially in the subcortical regions such as the **caudate nucleus**, the **internal capsule** and the **lenticular nucleus** in the right hemisphere. Thus, our data suggest a right hemisphere specialization for implicit self-body recognition. This is not only in line with previous studies (Frassinetti et al., 2008, 2009, 2010) but also strengthened by the fact that 25% of RBD patients and no one of LBD patients were selectively impaired in implicit self-body recognition.

As far as the left brain damaged patients, they showed the self-advantage effect. However, this effect was not selective for the right hand, as in controls, but it was present for both hands. This can be explained by the motor impairment of the right contralesional hand that might have reduced the lateralization of this facilitation.

Taken together these findings suggest that what we observe in this study is the concurrence of two distinct effects. First of all, the mental rotation of a body-part induced by the laterality judgment task when rotated hands are displayed, and, second, the sense of body ownership that emerges when the rotated hand is ones' own hand. The laterality judgment task recruits motor areas that, in right handed subjects, are more strongly represented in the left than in the right hemisphere (Ferri et al., 2012), whereas the body ownership per se is more represented in the right hemisphere.

Such dissociation, between task requirements and sense or experience of mineness of the own body, is supported by previous studies of ours (Frassinetti et al., 2008, 2009, 2010). Using a visual matching task with body-parts as stimuli, in which the mental rotation is less strengthened, the self-advantage emerged both for left and right limbs. Moreover, neuroimaging data support the specific right hemispheric involvement in constructing the sense of body ownership (for reviews see: Decety & Sommerville, 2003; Feinberg & Keenan, 2005). Our data support the evidence found on healthy subjects by showing, for the first time, that right hemispheric lesion, do indeed lead to impairment in the sense of body ownership.

Furthermore, the regions impaired mainly involved right basal ganglia (caudate nucleus, lenticular nucleus and internal capsule) that are implicated in motor function. Coherently, several neuroimaging studies showed that the ability to physically distinguish self from non-self stimuli, such as one’s own body from another’s body and one’s own action from another’s action, primarily involved somatosensory and motor cortices (Devue et al., 2007; Ferri et al., 2012; Sugiura et al., 2006; Uddin et al., 2005). Further evidence derives from a recent study that applied single-pulse TMS to the right motor cortex and observed an increase in cortical excitability for self-specific stimuli when compared to non-self-specific stimuli (Salerno et al., 2012). Thus, based on both behavioral and anatomical data, an integrated cortical–subcortical motor network in the right hemisphere underlies implicit knowledge of bodily self.

As far as for the Explicit task, both right and left brain damaged patients better recognized others’ than self body-parts (self-disadvantage effect) suggesting that the network for the explicit recognition of one’s own body recruits areas of both hemispheres. These behavioral data are partially supported by anatomical data. Indeed, VLSM analysis suggests that the putamen in the left hemisphere and the inferior parietal lobule in the right hemisphere are crucial for explicit bodily self processing. Even if these data should be taken with caution, because this analysis failed to reveal significant clusters, the comparison of each patient’s performance with controls supports a contribution of both hemispheres in explicit self-body knowledge. Indeed, 10% of RBD patients as well as 8% of LBD patients were selectively impaired in explicit self-body recognition.

These findings are in agreement with the dissociation between implicit and explicit forms of awareness in disorders concerning bodily recognition and sense of body ownership, such as somatoparaphrenia and anosognosia (Moro et al., 2008; for a review see Vallar & Ronchi, 2006, 2009). Patients with somatoparaphrenia and anosognosia do not show an explicit knowledge but can have spared implicit awareness of their body and of its motor potentialities. However, to our knowledge, this is the first time that the opposite dissociation (an impaired implicit and a spared explicit knowledge) is described.

Very recently Moro et al. (2011) investigated the neural correlates of implicit and emergent motor awareness in patients with anosognosia for hemiplegia. Analogously with our results here, they observed that deficits in implicit and explicit awareness are associated with lesions involving different cortico-subcortical structures, the former being more anterior and the latter ones being more posterior (see also Moro, 2013).

### 3.6.1. Conclusions

In sum, the present findings lead to consider that different brain lesions may cause specific deficits in bodily self-processing. Indeed, while a network of right subcortical motor regions (including basal ganglia) underpins the implicit recognition of self body-parts, right posterior, but also left regions, may be involved in the explicit recognition of self body-parts. The existence of two of distinct networks (implicit and explicit) for self-body recognition could be particularly relevant for the diagnosis and rehabilitation of these disorders. Thus, the evaluation of implicit and explicit impairment in self-body processing should be included in the post-lesion neuropsychological assessment performed in the rehabilitative clinical practice. Furthermore, specific attention to the bodily self-processing should be carried out especially during the early phases following brain damage. Indeed, in these stages, plastic phenomena concerning both the brain and self-processing reorganization can occur. Thus, appropriate therapeutic strategies integrating sensorimotor, emotional and cognitive components may be introduced to support structure and functions of bodily reorganization of the self, including implicit aspects of the subjective experience. In sum, this could allow to improve the neuroscientific knowledge on bodily self, a crucial component of self-processing (Northoff et al., 2006; Northoff & Panksepp, 2008).

## Chapter 4

# How the pathological embodiment affects the bodily self-recognition: evidence from neuropsychological patients

## 4.1 Introduction

In the last two decades, a growing literature in neuroscience has been focused on the mechanisms which contribute to properly develop a coherent sense of body ownership (for review see de Vignemont, 2011; Blanke et al., 2015). Briefly, we constantly receive several information arising from our limbs, that's mainly visual, motor, somatosensory and proprioceptive, but we can also perceive our body from the inside, that's the interoceptive component. However, how can all these signals actually make our body as be perceived so clearly and inevitably as *mine* body, is matter of debate. In this respect, the boundary between our corporeal self and what we recognized as other people's body is crucially, since it allow us to reliably distinguish between what is and what is not mine.

Thus, here the notion of embodiment is critical. Accordingly with de Vignemont (2011), embodiment is referred to a specific processing in which an object or a body-part became part of one's own body. Along this view, embodiment is a necessary condition for the feeling of bodily ownership to occur.

Starting from neuroscientific and neuropsychological evidence, we described how we can illusory perceive an artificial body-part as one's own and how, this feeling may be lost following brain damage. Behavioral and neuroimaging studies on healthy subjects investigated the mechanisms underpinning the illusory feeling of an artificial body-part as one's own. For instance, by means of the rubber hand (RHI; Botvinick & Cohen, 1998; Tsakiris et al., 2007) or the enfacement illusion (Sforza et al., 2010; Tsakiris, 2008), and more recently adopting the full-body illusion, participants identify themselves with a seen virtual body (Ehrsson, 2007; Lenggenhager et al., 2007; Petkova & Ehrsson, 2008). Basically, in the RHI when the experimenter simultaneously strokes both the participant hand and the rubber hand, participants report feeling as if the rubber hand was part of their body. The strength of this feeling was found to correlate with a larger network of cortical areas, including premotor, posterior parietal, insula, and cerebellum (Ehrsson et al., 2004; Ehrsson, 2007). Taken together, these studies successfully highlighted how multisensory bodily signals, mainly proprioceptive and visual information, need to be integrated in order to perceive a body or a body-part as one’s own (for review see Blanke et al., 2015).

Critically, to elucidate the grounds of the sense of body-ownership further interesting efforts raised from clinical studies conducted on neurological and neuropsychological patients.

One first example is provided by somatoparaphrenic patients, who often are affected by anosognosia for their left hemiplegia, and report delusional beliefs concerning the left side of their body. Indeed, these patients claimed that their paralyzed limb belongs to someone else, showing a clear disownership of their body-parts (for a review see Vallar & Ronchi, 2009).

More recently, also the opposite behavior has been described in brain damaged patients. Indeed, Garbarini and coworkers (Garbarini et al., 2013; 2014; Garbarini & Pia, 2013; Pia et al., 2013) reported hemiplegic and/or hemianesthesic patients who misidentify other people’s hand as their own. To refer to this clinical manifestation the authors coined the term of *pathological embodiment*. Such a delusion of ownership spontaneously occurred whenever the examiner’s left hand (alien hand) was positioned between the controlesional (left) and the right patient hand, according to the patient’s egocentric coordinates. Interestingly, during the neuropsychological evaluation patients with pathological embodiment (E+) do not explicitly denying that their controlesional limb belonged to themselves (as in somatoparaphrenic delusion), however they incorporated other people's hand into their bodily representation.

In this respect, several further investigations revealed that these patients are affected by a profound alteration of their corporeal representation. For instance, the role of motor information was tested during a bimanual coupling task in which left-hemiplegic patients were asked to draw lines with their intact hand and to try to draw circles with their left hand. Crucially, in E+ patients a coupling effect, that's the ovalization of the drawn lines, was found only when the alien hand drawing circles was presented and aligned with the patient's coordinates, demonstrating that the alien arm was incorporated in the patient's motor representation (Garbarini et al., 2013). Moreover, having observed an alien arm performing a tool-use training, E+ patients overestimated the length of their arm, similarly to what was found in healthy subjects during active tool-use training (Garbarini et al., 2015). This evidence suggested that both intentional motor processes and the spatial extension of the own body representation can be modulated by an altered sense of body-ownership.

Overall, the mentioned studies demonstrated that the bodily self-representation does not necessarily match the physical body, opening up a window to the understanding of the sense of body-ownership (Brugger & Lenggenhager, 2014).

At this point, an interesting question arises spontaneously: should patients with an altered sense of body ownership, as well as E+ patients, be impaired also in self-body recognition processing? Indeed, recognition of one's self-body arise through the integration of multi-modality processes: somatosensory, proprioceptive and motor information, as well as sense of agency and body-awareness.

In order to address whether and how an altered sense of bodily ownership may abolish our ability to distinguish between self and other people' body-parts, we adopted two experimental tasks specifically developed to investigate the bodily self-representation, using implicit and explicit judgments. Indeed, it was recently demonstrated that humans have an implicit knowledge of their body. In this respect, Frassinetti and coworkers (2008, 2009, 2010) investigated the implicit recognition of self body-parts, by using a visual matching-to-sample task. Participants were required to decide which of two vertically aligned images (high or low) matched the central target stimulus. Stimuli could depict participants' or other people' body-parts. Results showed that participants' performance was more accurate with self rather than other' body-parts. This facilitation was called self-advantage effect. Intriguing, the self-advantage effect was not found when participants were explicitly required to judge whether the upper or the lower stimulus corresponded to their own body-parts (Frassinetti et al., 2011).

An important contribution to understand the neural basis of the implicit recognition of bodily self, came from neuropsychological studies conducted on patients with focal brain lesion. Previous studies (Frassinetti et al., 2008, 2009, 2010) reported a deficit in right but not in left brain damaged patients when an *implicit* self body recognition was required. These findings suggest that the right hemisphere may be involved in the implicit recognition of self body-parts.

Based on this evidence, we expected an impairment both in E+ and in E- patients when the implicit self-body recognition was investigated, similarly to RBD patients. In addition, since E+ but not E- patients misidentify others body-part as their left limb, we expected that the observed deficit also affects the recognition of other people' body-parts. Alternatively, in line with the pathological embodiment specifically show for the alien hand, E+ patients may show an advantage for other people's hand processing.

As far as the *explicit* self-body recognition, it has never been investigated in brain damaged patients. Accordingly with the pathological embodiment reported during the evaluation, we hypothesized that E+ but not E- patients more frequently misidentify as their own stimuli depicting other people's hand. Conversely, E- patients may show a selective impairment in recognize their body-parts.

## 4.2 Materials and methods

### 4.2.1 Participants and neuropsychological assessment

Twelve healthy participants (4 males, mean age ± sd = 65.9 ± 7.8 years; mean education ± sd = 9.25 ± 5.1 years; hereinafter **Control group**), twelve RBD patients without pathological embodiment (5 males, mean age ± sd = 66.7 ± 7.5 years; mean education ± sd = 9.75 ± 4 years; hereinafter **E- group**) and twelve RBD patients with pathological embodiment (6 males, mean age ± sd = 67.1 ± 11.3 years; mean education ± sd = 6.75 ± 3.1 years; hereinafter **E+ group**) were recruited to participated in the study. Two One-way ANOVAs confirmed that the three groups were not significantly different for age [$F(2, 33) = 0.04$; $p = .95$; $\eta^2_p = .01$] and education [$F(2, 33) = 195$; $p = .16$; $\eta^2_p = .11$].

All participants were right handed by their own verbal report.

To assess the presence of a general cognitive impairment the Mini-Mental State Examination (Folstein et al., 1975) was used. The presence and severity of extrapersonal neglect (Bit Conventional scale; Halligan et al., 1991), personal neglect (Fluff Test; Cocchini et al., 2001) and anosognosia for hemiplegia and hemianestesia (Spinazzola et al., 2008) were also assessed (for details see Table 4.1).

Patients were recruited at the Fondazione Maugeri Hospital (Castel Goffredo, Italy), at the Don Gnocchi Hospital and at the San Camillo Hospital (TO).

All participants, naive to the purpose of the study, gave their informed consent to participate to the study. The study was approved by the local ethics committee (Department of Psychology of Bologna), and all procedures were in agreement with the Helsinki Declaration (2008).

**Table 4.1: Clinical and neuropsychological data of right brain damaged patients according to the pathological embodiment.**

| Patient | HP | AHP | HA | AHA | Proprioception | MMSE | Personal NSU | BIT |
|---|---|---|---|---|---|---|---|---|
| **E- 1** | 1 | 0 | 0 | 0 | + | 24 | - | 136 |
| **E- 2** | 3 | 0 | 3 | 0 | - | 24 | - | 141 |
| **E- 3** | 3 | 0 | 1 | / | + | 29 | - | 144 |
| **E- 4** | 3 | 0 | 3 | 0 | - | 28 | - | / |
| **E- 5** | 3 | 0 | 0 | 0 | + | 25,5 | - | 112 |
| **E- 6** | 3 | 0 | 3 | 0 | - | 26 | - | 141 |
| **E- 7** | 1 | 0 | 0 | 0 | + | 30 | - | 134 |
| **E- 8** | 1 | 0 | 0 | 0 | + | 28,4 | - | 142 |
| **E- 9** | 3 | 0 | 3 | 0 | + | / | - | 142 |
| **E- 10** | 1 | 0 | 0 | 0 | + | 25 | - | / |
| **E- 11** | 0 | / | 0 | / | + | 28 | - | / |
| **E- 12** | 3 | 0 | 0 | / | / | 26 | - | 142 |
| **E+ 1** | 3 | 0 | 3 | 0 | - | 25 | + | 51 |
| **E+ 2** | 3 | 0 | 3 | 0 | - | 25 | - | 83 |
| **E+ 3** | 3 | 0 | 3 | 0 | + | 24 | + | 85 |
| **E+ 4** | 3 | 0 | 3 | 1 | - | 24 | + | 30 |
| **E+ 5** | 0 | 0 | 1 | 2 | - | 24 | / | 64 |
| **E+ 6** | 3 | 0 | 3 | 2 | - | 26,2 | - | 86 |
| **E+ 7** | 3 | 0 | 3 | 2 | - | 24,4 | - | 66 |
| **E+ 8** | 3 | 0 | 3 | 2 | - | 27,2 | + | 111 |
| **E+ 9** | 2 | 0 | 0 | 0 | + | 24 | - | 68 |
| **E+ 10** | 0 | 0 | 3 | 0 | - | 24 | + | 100 |
| **E+ 11** | 3 | 0 | 3 | 0 | - | 24 | / | 57 |
| **E+ 12** | 3 | 0 | 3 | 1 | + | 24,3 | / | 122 |

E- = patients without pathological embodiment; E+ = patients with pathological embodiment; HP = motor deficit; AHP = anosognosia for hemiplegia; HA = sensory deficit; AHA = anosognosia for hemianestesia (evaluated according with the following criteria: low = 1; mild = 2; severe = 3); Proprioception = indicated as present (+) or absent (-); MMSE = Mini Mental State Examination (scores are corrected for years of education and age; cut off > 24); Personal NSU = indicated as present (+) or absent (-) according with the score obtained at the Fluff Test (cut off < 2 omissions); BIT scale = score obtained at the Conventional Subscale (cut off > 129).

*Embodiment evaluation*

In order to evaluate the presence/absence of the pathological embodiment, all patients were tested with an ad hoc protocol described in a previous study before the experimental tasks (Garbarini et al., 2013).

Patients sat on a chair with both hands lying on the table. An alien (the examiner's) left hand was positioned on the table, aligned with the patient's left shoulder, in a congruent position with respect to the patient's trunk midline, between the patient's body and the patient's left hand. Three objects of different colors were placed on the table, the yellow one in front of the patient's left hand, the green one in front of the examiner's hand. Patients were asked to complete movements in order to reach their left hand with their right hand and identify their left hand on the basis of the colored objects. Patients who reach the alien hand in both requested movements will be included in E+ group (see Figure 4.1).

**Figure 4.1 – Embodiment evaluation.**

The experimenter ask the patient to identify his left hand on the basis of the colored objects and to reach his left hand with his right hand. The alien hand, belonging to the confederate, was placed between the patient' hands.

### 4.2.2 Stimuli and procedure

Stimuli were grey-scale pictures of the dorsal view of right and left hands. Participants' hands were photographed in a session prior to the experiments, according to the experimental procedure described by Frassinetti and colleagues (2011). Half of the trials (n = 32) depicted the participant's own left or right hand ('self' trials), whereas the other half depicted the right or left hand of other three people (n = 32; 'other' trials). As far as the latter one, three stimuli were selected from a database of hands pictures as the best match with each participant's hand for size, age, skin color and gender. All stimuli were presented in egocentric and allocentric perspective.

Participants sat in front of a PC screen, at a distance of about 50 cm. A central fixation cross (1000 ms duration) was presented at the beginning of each trial followed by a display containing the hands' pictures on a white background. Stimuli presentation was controlled by E-Prime 2.0 (Psychology Software Tools Inc.) and each trial was timed-out by the participant's vocal response. In Experiment 1, three stimuli were simultaneously presented in each trial, vertically aligned on the computer screen, until the participant responded. The central stimulus was presented in a black frame, and corresponded to the target stimulus. Stimuli presented in each trial were matched for visual similarity.

In Experiment 1, participants had to judge whether the upper or the lower hand corresponded to the central target. In Experiment 2, participants had to explicitly judge whether the displayed hand corresponded or not to their own hand (see Figure 4.2). Participants were instructed to verbally respond as accurately as possible by means of a microphone positioned in front of the patient's chest used to record participants' vocal responses. Then, the experimenter manually recorded the participant’ response by pressing one of the three assigned keys on the keyboard.

An adapted version of both experiments to patients showing signs of neglect or left hemianopia was designed by shifting all stimuli to the right side of the screen.

Thus, each experiment comprised 64 trials, 16 trials for each of the four conditions: self-right hand, self-left hand, other-right hand, other-left hand. Half of the trials depicted stimuli presented in egocentric perspective, whereas the other half depicted stimuli in allocentric perspective. Since Experiment 1 investigated the implicit and Experiment 2 the explicit bodily self-recognition, Experiment 1 was always conducted before Experiment 2. All participants performed both experiments in one single session lasting up to one hour.

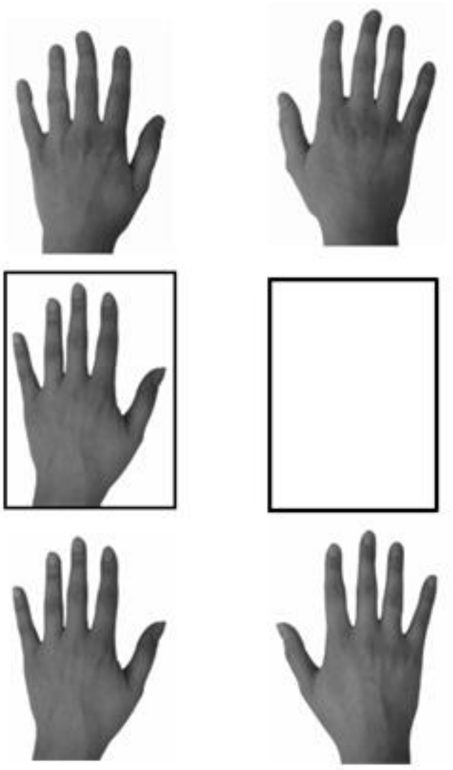

**Figure 4.2 - An example of a single trial for the Implicit task (on the left) and the Explicit task (on the right).**

### 4.2.3 Statistical analyses

Data from Experiment 1 (Implicit task) and Experiment 2 (Explicit task) were analyzed separately. We compared Self and Other conditions according with the definition adopted in a previous study (Frassinetti et al., 2008), that is trials in which at least one picture belonged to the participant (Self condition).and trials in which no stimulus belonged to the participant (Other condition).

In order to compare Controls' and patients' performance, a repeated measure ANOVA on *accuracy* (percentage of correct responses) with Owner (self and other), Laterality (left and right) and Perspective (allocentric and egocentric) as within-subjects factors and Group (Controls, E+ and E- patients) as between-subjects factor was conducted.

Post-hoc analyses were conducted by using Newman Keuls. The magnitude of effect size was expressed by partial eta square ($\eta^2_p$).

## 4.3 Results

### 4.3.1 Experiment 1

The variable **Group** was significant [F(2,33)=13.51, p<.0001; $\eta^2_p$=.45]: which was mainly due to lower accuracy for E+ patients (66%), compared to both E- patients (88%, p<.001) and Controls (88%, p<.001). Conversely, E- patients and Controls were not significantly different (p=.97).

Crucially, this main effect was qualified by a three-way interaction **Laterality x Owner x Group** [F(2,33)=7.70, p<.002; $\eta^2_p$=.32]. As far as the right hand, a self-advantage effect emerged in healthy participants: they were more accurate with self (93%) compared to other people right hand (81%; p<.05). Conversely, a lack of this effect was found both in E- patients (self right=87% vs. other right=83%; p=.28) and E+ patients (self right=61% vs. other right=70%; p=.09).

As far as the left hand, no difference was found comparing self and other stimuli in all groups (Controls: self left=89% vs. other left=91%; p=.75; E- patients: self left=93% vs. other left=89%; p=.66; E+ patients: self left=69% vs. other left=64%; p=.13).

Looking into differences across the three groups, post-hoc comparisons showed that E+ patients (64%) performed worse with the other left-hand, that is the condition in which they showed the embodiment phenomenon, compared to E- patients (89%; p<.03) and Controls (91%; p<.02). Furthermore, E+ patients (61%) performed worse with the one's own right-hand compared to E- patients (87%; p<.02) and Controls (93%; p<.001). Conversely, when E- patients were compared to Controls no such differences were observed (all p*s* >.78).

Critically, when the one's own left-hand was considered no difference was observed across the three groups (Controls=89%; E- patients=93%; E+ patients=69%; all p*s*>.08) as well as considering the other right-hand (Controls=81%; E- patients=83%; E+ patients=70%; all p*s*>.12; see Figure 4.3).

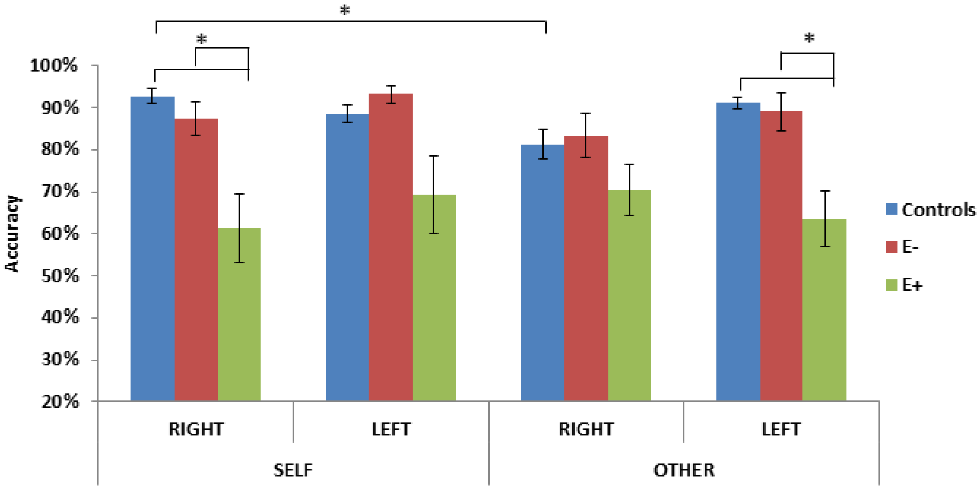

**Figure 4.3 - Accuracy for Controls, E+ and E- patients in the Implicit task**

The mean of correct response in the Implicit task as a function of Ownership (Self, Other) and Laterality (left and right hand) respectively for Controls, E+ and E- patients. Error bars depict SEMs. Differences significant at p<.05 are starred.

### 4.3.2 Experiment 2

The variable **Group** was significant [F(2,33) = 9.13, $p < .0001$; $\eta^2_p$ =.36]: both E+ (32%) and E- patients (43%) performed worse compared to Controls (58%, all ps<.03). Conversely, none difference was found comparing E+ and E- patients (p=.06).

The interaction **Owner x Group** [F(2,33) = 5.04, $p < .01$; $\eta^2_p$ =.23] was significant. First of all, with *Self'* stimuli, E- patients (27%) performed significantly worse than Controls (54%, p<.02). Conversely, comparing E+ patients and Controls (38% vs. 54%, p=.12) no difference was found. A completely different pattern of result emerged when *Other'* stimuli were considered: indeed E+ patients (24%) performed significantly worse than Controls (62%, p<.003) and E- patients (60%; p<.004). Conversely, no difference emerged between E- patients and Controls (p=.85; see Figure 4.4).

Furthermore, the three-way interaction **Owner x Perspective x Group** [F(2,33)=3.66, p<.04; $\eta^2_p$=.18] was significant. In order to look more deeply at the above described effect and taking into account the factor Perspective, post-hoc comparisons were conducted. The impaired performance observed for *Self's* stimuli in the E- group (29%) was selective for the egocentric condition (Controls=62%; p<.01). Indeed, no difference was found between E- and Controls when the allocentric condition was considered (E- patients=25% vs. Controls=45%; p=.27). As far as E+ patients, the impairment with *Others'* stimuli was found both in the egocentric (E+ patients=22% vs. Controls=56%; and E- patients=62%; p<.01) and allocentric conditions (E+ patients=27% vs. Controls = 68%; p < .003).

Finally, a self-disadvantage effect emerged both in Controls (self=45%; other=68%; all p*s*<.003) and E- patients (self=25%; other=58%; all p*s*<.001) with allocentric stimuli. A completely different effect was found in E+ patients who showed an other-disadvantage effect with egocentric stimuli (self=39%; other=25%; all p*s*<.05).

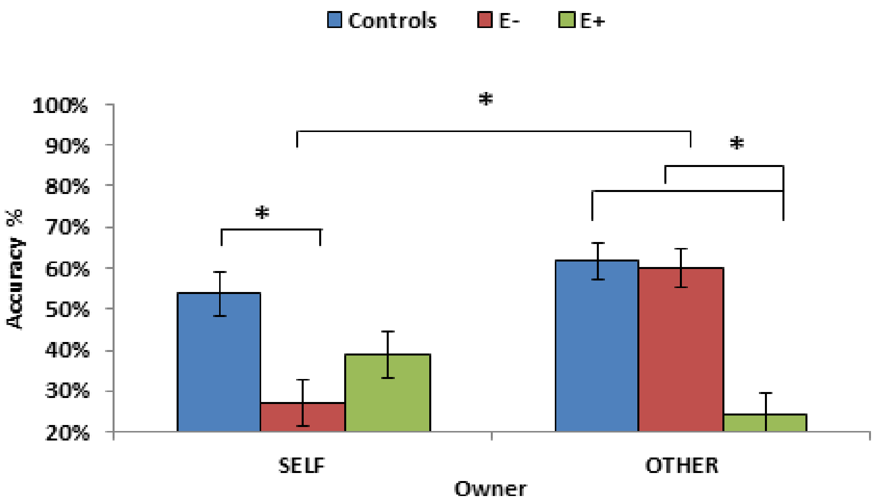

**Figure 4.4 - Accuracy in the Explicit task.**

The mean of correct response in the Explicit task as a function of Ownership (Self, Other) respectively for Controls, E+ and E- patients. Error bars depict SEMs. Differences significant at p<.05 are starred.

## 4.4 Lesion study

Brain lesions were identified by Computed Tomography and Magnetic Resonance digitalized images (CT/RMI) of 8 E+ patients and 7 E- patients. For each patient, the location and extent of brain damage was delineated and manually mapped in the stereotactic space of the MNI by using the free software MRIcro (Rorden & Brett, 2000).

As first step, MNI template was rotated (pitch only) to approximate the slice plane of the patient's scan. A trained rater (MC), using anatomically landmarks, manually mapped the lesion onto each correspondent template slice. After that, drawn lesions were inspected by a second trained rater (FF) and in case of disagreement, an intersection lesion map was used. Finally, lesions maps were rotated back into the standard space applying the inverse of the transformation parameters used on the stage of adaptation to the brain scan.

### *Lesion overlap*

To localize and to measure the lesion extension of the two patients' groups, the lesion of E+ and E- patients were separately overlaid on the ch2 template provided by MRIcro and the region of maximum overlap was extracted.

The region, that contained the overlap of at least 50% of E+ patients' lesions (green color) was mainly located in the periventricular frontal area, basal ganglia, internal capsule and extending to the temporal and parietal regions (for a graphical representation, see Figure 4.5a).

Similarly, the region of maximum overlap, that contained the overlap of at least 50% of E- patients' lesion (green color) was located in the right periventricular white matter and involved the putamen and pallidum (see Figure 4.5b).

Additionally, in order to highlight the brain lesion more frequently associated with the pathological embodiment, we subtracted the E+ lesion plot from the E- lesion plot. This approach can identify the neural correlates of a given behavior by comparing the overlay lesion plot of patients with, and patients without, the deficit of interest. This method showed that somatosensory parietal, inferior frontal and temporal regions, such as the superior temporal gyrus, are more frequently (> 50%) impaired in E+ compared to E- patients (see Figure 4.5c).

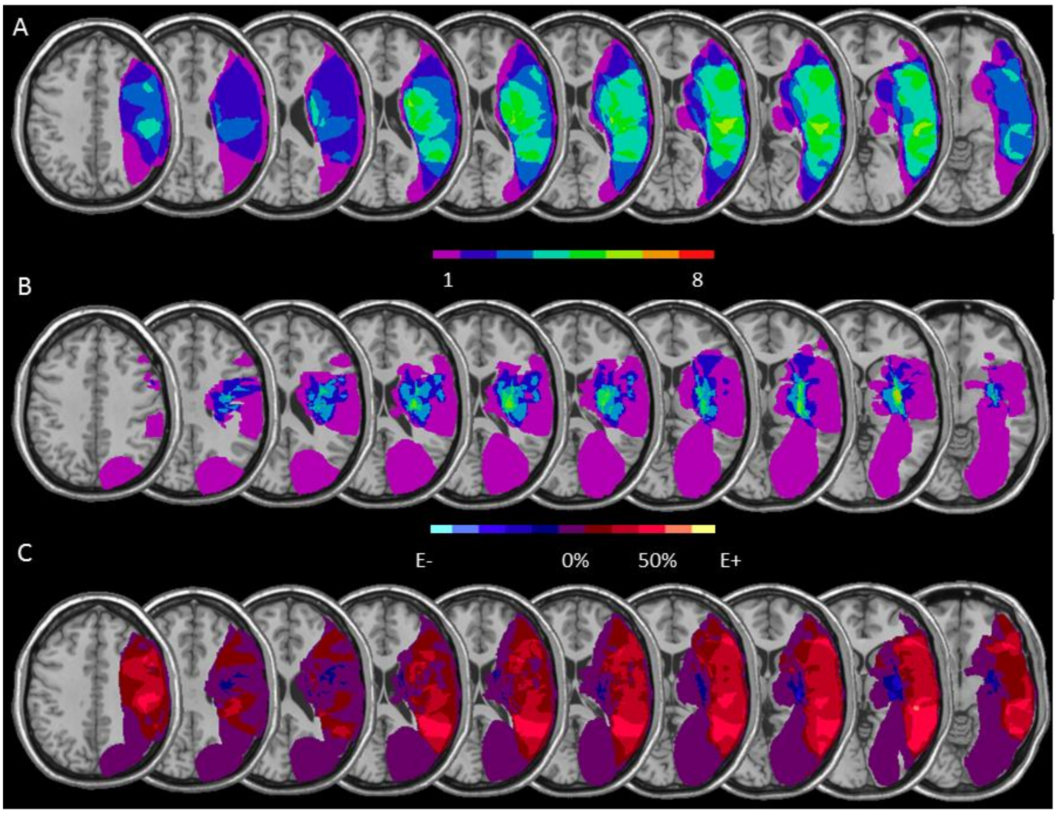

**Figure 4.5 - Overlays of lesion plots of the E+ and E- patients.**

Overlays of lesion plots of the E+ (A) and E- (B) groups. The frequency is represented trough a color scale ranging from violet (lesion in one patient) to red (lesion in all patients). Subtraction of regional lesion plots (C). Regions damaged more frequently in the E+ group respect to E- group are displayed in warm colors, from dark red to yellow.

## 4.5 Discussion

We commonly take for granted that “*our body may be the object that we know the best”,* as Fréderique de Vignemont said (2011). Nevertheless, several neuropsychological evidence clearly demonstrated that, following a brain damage, our ability to correctly recognize our body may be destroy, instead. Accordingly, recent findings demonstrated that right brain damaged patients may lost the ability to implicitly recognize their body-parts (Frassinetti et al., 2008, 2009, 2010). Furthermore, patients affected by pathological embodiment showed a clear misidentification of other people’s limbs as their own, revealing an altered sense of body-ownership (Garbarini et al., 2013, 2014). Overall, these evidence clearly suggested that the representation in which the bodily self is grounded, may be altered following a brain injury.

In the present work we sought implicit and explicit bodily recognition processing in neuropsychological patients affected by pathological embodiment. Thus, a group of RBD patients with (E+) and without (E-) pathological embodiment were compared to a group of neurologically healthy participants by using two different experiments designed for investigating implicit and explicit self-body recognition, respectively.

Different patterns of results were found in the two experimental tasks. In Experiment 1, when an explicit recognition of one's own hand was not required (***Implicit Task***), we observe a difference *across* the three groups. Controls were more accurate with self' compared to other's stimuli, showing the so-called self-advantage effect. This effect was selectively found for the right-hand, indeed no significant difference emerged comparing the self' and other's left-hand. The presence of such a facilitation when judging one's own right compared to others' hands is in line with previous results reported by Ferri and coworkers on young healthy participants (2011). Having found the "self-advantage" only for the right hand is a further argument in favor of the hypothesis that the self-advantage relies upon a sensory-motor representation (Ferri et al., 2012; Frassinetti et al., 2011). By contrast, a lack of this facilitation emerged both in E+ and E- groups, in which no significant difference were observed when self' and other's stimuli were compared, regardless of the hand laterality. This result replicate a previous neuropsychological finding and further confirmed that right brain damaged patients lost the ability to implicitly recognize their body-parts (Frassinetti et al., 2008, 2009, 2010).

Additionally, E+ patients showed a selective impairment in the implicit processing of the other's left hand. Interestingly, this impairment resembles the deficit observed during the embodiment evaluation. Indeed, E+ patients misattribute the other's left hand to themselves demonstrating that they failed to recognize the left hand as their own, while they did not show such an impairment with the right hand. The presence of such an impairment in the implicit processing of other's left hand is likely to suggest that E+ patients actually incorporated the other's left hand in their body representation up to consider it as their left hand, and thus transpose their deficit to a body-parts which actually belonged to others. One may argue that the deficit observed with the left hand may be simply due to the sensorimotor deficit which affects the left hand. However, if this would be the case, and thus left hemiplegia and or hemianestesia were sufficient to explain this phenomena, a similar deficit should occur also in the E- group, since patients were affected by similar clinical condition.

Moreover, the presence of a similar impairment for the one's own right hand revealed that the presence of a pathological embodiment deeply affects the implicit processing of the one's own body-parts, or at least of the body-part the patient feels as part of their own body. Accordingly, here the impairment was observed both for the one's own right and other's left hand.

In Experiment 2 (Explicit Task), when bodily self-recognition was explicitly required, difference were found both *within* and *across* the three groups.

First of all, when E+ and E- patients were compared to Controls, two different pattern of results emerged. E- patients were selectively impaired with *Self* stimuli, whereas E+ patients showed a selective impairment for *Other* stimuli.

Firstly, these findings suggested that the presence of a right brain lesion impairs the ability to explicitly recognize a body-part as their own. Additionally, while following a brain lesion patients lost the ability to correctly recognize their body-part (E- patients) the presence of a pathological embodiment specifically affects patients' ability to attribute a body-part to others misattributing the other's hand to themselves (E+ patients).

Moreover, in Controls and E- patients a self-disadvantage effect was found: they performed worst with self' compared to other's stimuli. Conversely, a lack of this effect emerged in E+ patients, who showed an *other-disadvantage,* indeed they performed worst with other's rather than self's body-parts. This finding may be explained by their clinical condition: indeed, since they were impaired in self-body parts recognition and erroneously attributed the other's hand to themselves, resulting in a worse performance with Other stimuli.

From an anatomical point of view, in our study E+ patients were affected by lesions involving a wide cortical and subcortical network and extending from temporo-parietal to frontal regions. Specifically, the damage to the periventricular white matter is compatible with the ones identified for being responsible for pathological embodiment provided by Garbarini and coworkers (2013). In this respect, authors proposed that a deficit in the construction of a coherent corporeal representation is the result of a damage to the white matter tract linking subcortical structures with cortical sensory-motor areas.

Furthermore, the lesion of the right temporo-parietal region may explain the impairment in self/other distinction. In this respect, several evidence has been reported on the role of the temporo-parietal junction (TPJ) in embodiment, specifically when an integration of tactile, proprioceptive, and visual information was required. For instance, Leube and colleagues (2003) have shown that the TPJ codes multisensory conflict or disintegration between visual and proprioceptive information about one's arm position. Moreover, when transcranial magnetic stimulation is applied over the right TPJ resulted in a reduced ability to discriminate between what may or may not be part of one's body, suggesting that the rTPJ is actively involved in maintaining a coherent sense of one's body (Tsakiris et al., 2008).

In conclusion, we demonstrated that in presence of a delusion of ownership, such as the pathological embodiment, the alien hand can be so deeply incorporated into one’s own body representation to impaired the ability to recognize the one’s own body both at the implicit and explicit level. This is not surprisingly since more recently several evidence demonstrated how the altered sense of body resulting in the pathological embodiment may also affects the motor and sensory domain. Accordingly, patients showed significant interference effect of the alien hand movements on the actual movements of their own intact arm (Garbarini et al., 2013). Moreover, they referred to feel pain on the alien hand when painful stimuli were delivered on it, showing a coherent physiological reactions as if the stimulated hand was their own hand (Pia et al., 2013; Garbarini et al., 2014).

Concerning the ability to discriminate between self and others, patients with pathological embodiment and right brain damaged patients who exhibit an impairment in implicit bodily self-recognition, previously described (Frassinetti et al., 2008; 2010) represent different impairments on two opposite edges. Indeed, the first group shows a tendency to explicitly recognize as their own body parts of others, whereas the second group implicitly deny the ownership of their own body parts. If we imagine to represent the self/other discrimination along an horizontal line with “self” and “other” as two opposite edges, E+ patients’ body-ownership discrimination is biased toward “self”, whereas RBD patients’ body-ownership discrimination is biased toward “other”.

To sum up, these findings suggested that the presence of a pathological embodiment deeply affects the bodily self-representation and our ability to recognize the one’s own body.

## Chapter 5

# Who is speaking? Implicit and explicit self and other voice recognition

## 5.1 Introduction

A fundamental biological function for human species is to recognize people. To support this function, in our daily life we usually use a complex multimodal system based on multisensory (e.g. visual, auditory, etc.) recognition channels. The voice carry different types of information, for example when we hear a voice we are informed about both speaker's personal characteristics such as gender, age and identity and linguistic information. In this respect, the importance of voices as a "channel" to convey the identity of the speaker is clear when speaker's visual characteristics are not available, for example, when we answer the phone or when we listen to someone speaking from an adjacent room. In these contexts at least two different cognitive abilities are involved: the processing of voice's characteristics and the recognition of a familiar voice. The first process allows us to distinguish between vocal and non-vocal sounds (e.g. words with respect to natural sounds or animal cries), whereas the second process allows us to recognize a familiar voice among the others.

As far as the processing of voice's characteristics, fMRI studies have demonstrated the existence of "temporal voice areas" (TVAs), located bilaterally along the superior temporal gyrus, more involved in processing vocal than non-vocal sounds (Belin et al., 2000; Belin et al., 2011; Ethofer et al., 2009; Gervais et al., 2004; Linden et al., 2011). More recently, Bestelmeyer and colleagues (2011) showed that applying rTMS over the right upper bank of the superior temporal sulci (STS) compared with a control site stimulation that was the right supramarginal gyrus (SMG) impaired the voice/non voice discrimination ability.

Furthermore, a lack of this effect was found in a control task in which participants had to judge the loudness of different sounds.

Other studies have demonstrated that different regions of the superior temporal sulcus (STS) are recruited in processing different aspects of voice (Andics et al., 2010; Blank et al., 2011; von Kriegstein et al., 2003; von Kriegstein and Giraud 2004). In a fMRI study, Von Kriegstein and coworkers (2003) asked participants to recognize a target speaker or a verbal content in sentences spoken by familiar and unfamiliar speakers. Results demonstrated that posterior regions of the STS were more involved in the verbal content task, whereas anterior regions were responsive to voice recognition.

Moreover, studies using different approaches have shown that voice recognition is dissociated from other aspects of identity such as, for example, face recognition (see Gainotti, 2011, 2013 for reviews). Neuropsychological evidence shows that the right fusiform gyrus is prevalently involved in face recognition (Gauthier et al., 2000; Kanwisher et al., 1997) whereas the right superior temporal gyrus is mainly involved in voice recognition (Belin et al., 2000; Belin, 2006).

Moreover, famous voice recognition can be dissociated from unfamiliar voice discrimination. Studies on brain damaged patients have shown that patients with a right posterior peri-sylvian lesion were impaired in famous voice recognition, whereas patients with a bilateral temporal lobe lesion were impaired in unfamiliar voice discrimination (Van Lancker et al., 1988, 1989). Accordingly, neuroimaging data support the notion that familiar and unfamiliar voices are processed in different areas showing that the anterior part of the right superior temporal sulcus (STS) is more activated for familiar than for unfamiliar voices (von Kriegstein et al., 2003; Belin and Zatorre, 2003; von Kriegstein and Giraud 2004). In a PET study (Nakamura et al., 2001) using a familiar/unfamiliar decision task with friends’ voices or unknown persons’ voices, greater activities in the right temporal and left frontal pole, in the entorhinal cortex and in the left precuneus were found during the recognition of familiar voices.

Whereas the majority of studies provides evidence about familiar/unfamiliar voices discrimination, few neuroimaging (Allen et al., 2005; Nakamura et al., 2001; Kaplan et al., 2008; Rosa et al., 2008) and neurophysiological studies (Graux et al., 2013) have investigated the recognition of one’s own voice. These studies reported the involvement of different brain areas for self as compared to other’s voice recognition.

Allen and coworkers (2005), in an fMRI study, found that listening to self-generated words was associated with more activation in the left inferior frontal and right anterior cingulate cortex. By contrast, listening to other people’s generated words was associated with greater engagement of the lateral temporal cortex bilaterally. Analogously, a difference in the mismatch negativity (MMN) was found in an Event-Related-Potentials (ERP) study (Graux et al., 2013) when participants passively heard recordings pronounced by themselves with respect to when they were pronounced by unknown people.

Overall, these previous findings suggest that self, familiar and unfamiliar voices are processed as distinct information and are subtended by different cerebral areas.

However, it is worth noting that all the mentioned studies (with the only exception of the ERP study by Graux at al., 2013) used a paradigm of explicit self-voice recognition. This is particularly relevant since in the domain of self-recognition there is much evidence suggesting a dissociation between implicit and explicit self-processing. In this respect, it was recently demonstrated an intriguing dissociation between implicit and explicit self-body recognition. Interestingly, participants who implicitly recognized images representing self body-parts in a visual matching task, failed to do so when an explicit recognition of self-body images was required. Indeed, when participants had to indicate which of two vertically aligned images (high or low) matched a central target stimulus, they performed better with self rather than other' body-parts. By contrast, a lack of this facilitation was observed when participants were required to explicitly judge if the upper or the lower image corresponded to their own body-effector (Ferri et al., 2011; Frassinetti et al., 2011).

In line with this evidence, the authors proposed the existence of two-way access to our self-body knowledge which involves different mechanisms. Indeed, a sensorimotor body-representation is engaged in the implicit, but not in the explicit, recognition of one's own body-parts (Ferri et al., 2012). Thus, the aim of the present study was to verify whether also for the voice there appeared a dissociation between implicit and explicit self-voice recognition.

To this aim, a group of healthy subjects was submitted to an implicit and an explicit self-voice recognition task. In both tasks, participants listened to pairs of auditory stimuli (words or pseudowords). For both types of stimuli, speaker's voice could belong to: the participant, a familiar or an unfamiliar person. In the Implicit task, participants had to judge whether stimuli were pronounced by the same speaker or different speakers, whereas in the Explicit task participants had to identify if there was, or not, their own voice.

In line with previous evidence, we postulate that the implicit recognition of one's own voice, similarly to implicit self-body recognition, relies upon a sensory network, whereas the explicit recognition of one's own voice is based on cognitive mechanisms. For this reason, the explicit processing could be more fallacious than the implicit one (Tranel and Damasio, 1985, Berti and Rizzolatti, 1992). Thus, we hypothesize a facilitation for one's own voice in the implicit but not in the explicit task. This would prove that implicit and explicit self-voice processing is subtended by different mechanisms. Alternatively, if implicit and explicit self-voice processing is based on the same mechanisms, no difference should emerge in the two tasks.

## 5.2 Material and methods

### 5.2.1 Participants

Sixty-two right-handed healthy participants (21 males, mean age= 43.2 ± 15.1 years and 41 females, mean age= 37.6 ± 14.7 years; Mann-Whitney U test p=.10) without auditory or neurological pathology participated in the study. All participants were Italian speakers and were naive to the purpose of the research. Written informed consent was obtained from all participants.

The study was approved by the local ethics committee and all procedures were in agreement with the Helsinki Declaration (2008).

### 5.2.2 Stimuli

In a first session, voices were recorded by the same experimenter in a silent and quite room by using a recorder (Panasonic RR-XS420) positioned at a fixed distance (60 cm) from participant's trunk. Participants' voice was recorded while they pronounced Italian words and pseudowords presented on a sheet of paper (A4 format). They were invited to maintain a flat tone of voice and to pronounce items as clearly as possible. If the experimenter judged the recorded items not easily discriminable, asked participants to repeat them until they were. Words were disyllabic and high-frequency stimuli (in Italian: cane, foca, lupo, alce, rana e topo; in English: dog, seal, wolf, elk, frog, mouse) belonging to the same semantic category (animal). Pseudowords were obtained from the words by means of two letters replacement (cona, faco, lusa, leca, tupi e rona). Subsequently, each vocal stimulus was digitized at 44100 Hz, 16 bit, stereo modality, and elaborated using a dedicated software (WavePad Sound Editor) to adjust overall sound pressure and to balance the volume. The mean duration of each stimulus was 663.18 ms (SD= 100.36; range= 451-894 ms). Each stimulus could represent participant's voice (A stimulus), the voice of a familiar other (B stimulus) or the voice of an unfamiliar other (C stimulus). Each participant was asked to bring someone they encounter on a daily basis, of the same race and gender. This person served as the 'familiar other'.

### 5.2.3 Procedure

Each trial started with a central fixation point (250 ms duration), followed by the sequential presentation (500 ms ISI) of a pair of vocal stimuli. The trial was time-out as soon as the participant responded. Inter-trial timing was fixed at 1000 msec.

In each trial the two stimuli could either belong to the same person (same trials) or to different people (different trials) (see Figures 5.1a and 5.1b). Moreover, stimuli could belong to the participant (A), familiar other (B) or unfamiliar other (C). Thus, three combinations of "same" stimuli (AA, BB and CC) and three combinations of "different" stimuli (AB, AC and BC) were presented. Voices were matched for gender and regional accent. Finally, in half of the "same" and "different" trials stimuli could be identical (i.e. cane/cane or cona/cona), in the other half not (i.e. cane/foca or cona/faco). Presentation of each word/pseudoword was counterbalanced between "same" and "different" trials under the six combinations. In this way, possible spurious effects due to material were controlled. Words and pseudowords were presented in two separate blocks. In each block, 4 trials for each combination of stimuli according with the voice's owner (AA-BB-CC-AC-AB-BC) were presented for a total of 24 trials. The presentation order and the sequence of the type of stimuli (identical and non-identical) and owner factors (AA-BB-CC-AC-AB-BC) were randomized between trials, whereas the two blocks (words and pseudowords) were balanced between participants.

Participants sat in front of a PC screen at a distance of about 60 cm, and were required to press two previously assigned response keys, one for affirmative (YES) and one for negative (NO) answers. Response buttons were counterbalanced between participants. Stimuli were delivered through earphones and were presented binaurally. Stimuli presentation and randomization were controlled using E-Prime 2.0 (Psychology Software Tool ©1996-2012) running on a PC. Key press RTs and response accuracy were recorded.

In the Implicit task, participants were asked to judge whether the two voices were the "same" (half participants) or "different" (half participants). In the Explicit task, all participants were required to explicitly judge whether at least one of the two voices corresponded to their own voice.

All participants performed the two recognition tasks in one single session, with eight practice trials before the main experiment. To avoid an interference effect of the explicit recognition of one's own voice on the "same/different" task, the

Implicit Task was always conducted before the Explicit task. The whole experiment took approximately half an hour.

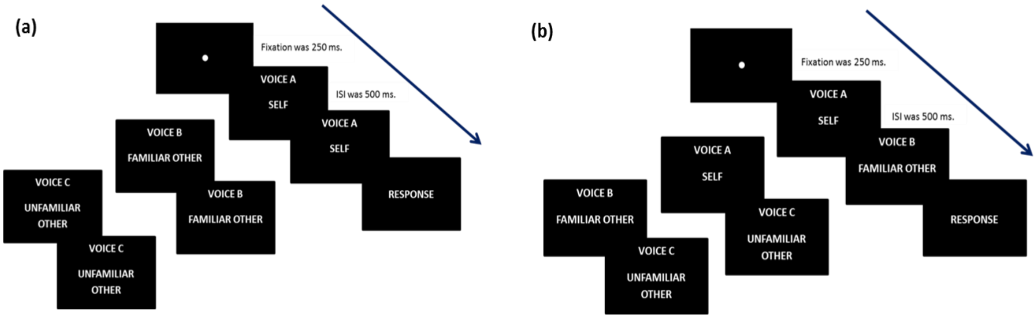

**Figure 5.1 - An example of “same” (A) and “different” owner trial (B).**

## 5.3 Results

### 5.3.1 Comparison between Implicit and Explicit task

First of all, to verify whether there was an advantage in implicit/explicit processing of one’s own voice, we compared self and other conditions according with the definition of self and other adopted in previous studies (Frassinetti et al., 2008; Frassinetti et al., 2010), that is trials in which at least one stimulus belonged to the participant (self condition: AA-AB-AC) and trials in which no stimulus belonged to the participant (other condition: BB-CC-BC). The accuracy (% of correct responses) for self and other conditions were separately computed for Implicit and Explicit task. A two (Implicit/Explicit Task) by two (Self/Other Condition) repeated measure ANOVA was used to analyze the data. The Bonferroni test was used to analyze post-hoc effects. The magnitude of effect size was expressed by $\eta^2_{p.}$

ANOVA showed no significant difference between the Implicit (85%) and the Explicit (82%) Task: [F(1,61)=1.21, p=.27]. There was a significant Self/Other

Condition main effect [F(1,61)=24.5, p<.0001, $\eta^2_p$=.29] with Other more accurate than Self condition (88% vs. 80%). This main effect was qualified by a significant Self/Other x Implicit/Explicit interaction: [F(1,61)=16.51, p<.0001, $\eta^2_p$ =.21]. The Bonferroni test showed that Other was more accurate than Self condition (90% vs. 75%; p<.0001) in the Explicit Task. By contrast, accuracy between Self and Other condition (84% vs. 85%; p=1) didn't differ in the Implicit Task. Moreover, accuracy was worse with self stimuli in the Explicit Task than with self and other's stimuli in the Implicit Task (p<.002). Instead, the Other condition didn't differ in the Implicit and Explicit task (85% vs. 90%; p=.39; see Figure 5.2).

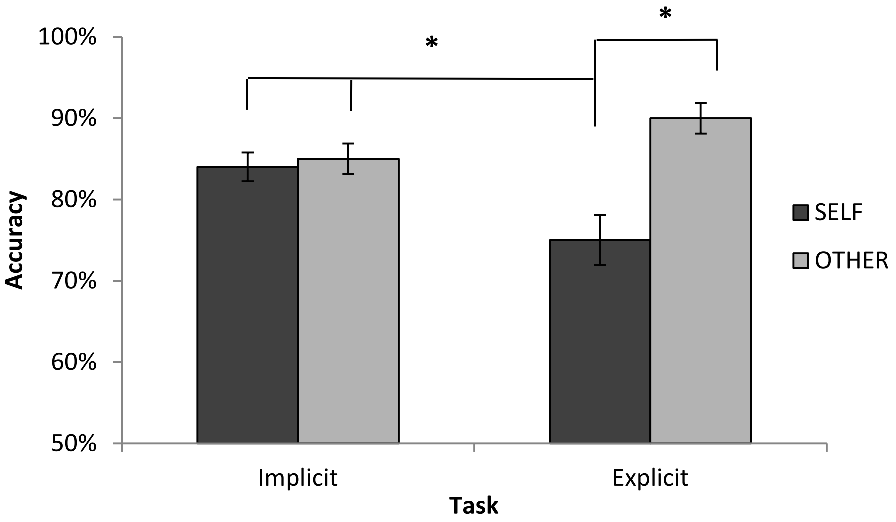

**Figure 5.2 - Accuracy in the Implicit and Explicit task.**

The mean of correct response in the Implicit and Explicit task as a function of Ownership (Self, Other). Error bars depict SEMs. Differences significant at p<.05 are starred.

### 5.3.2 Separate analyses for Implicit and Explicit task

To better understand the influence of different factors, such as Owner (same/different), Wordiness (word/pseudoword) and Type of stimulus (identical/non-identical), further analyses were conducted on Implicit and

Explicit tasks separately. Since for “same owner” (AA-BB-CC) only one source of variance (one speaker) was present whereas for “different owner” (AB-AC-BC) two sources of variance (two speakers) were present, two separate ANOVAs were conducted. More specifically, two separate ANOVAs for “Same” owner trials (AA=self-self, BB=familiar-other/familiar-other, CC=unfamiliar-other/unfamiliar-other) and “Different” owner trials (AB=self/familiar-other, AC=self/unfamiliar-other; BC=familiar-other/unfamiliar-other) were carried out, with Owner, Wordiness and Type of stimulus as within subjects variables. Post-hoc analyses were conducted by using the Bonferroni test. The magnitude of effect size was expressed by $\eta^2_{p.}$

### 5.3.2.1 Implicit Task

***Same owner***

When the “same” owner trials were separately analyzed, the variable Owner was not significant (AA=86%; BB=88%, CC=85%, p=.29, see Figure 5.3a) as well as the variable Wordiness (words=88%, pseudowords=85%, p=.20). Instead, the variable Type of stimulus was significant [F(1,61)=33.16, p<.0001, $\eta^2_p$ =.35] since participants were more accurate with identical than with non-identical stimuli (95% vs. 78%). The interactions between the three variables were not significant.

***Different owner***

When the “different” owner trials were separately analyzed, the variable Owner was not significant (AB=84%; AC=82%, BC=83%, p=.81, see Figure 5.3b) as well as the variable Type of stimulus (identical=82%, non-identical=85%, p=.25). Instead, the variable Wordiness was significant [F(1,61)=8.33, p<.005,

$\eta^2_p$ =.12] since participants were more accurate with words than with pseudowords stimuli (87% vs. 80%). The interactions between the three variables were not significant.

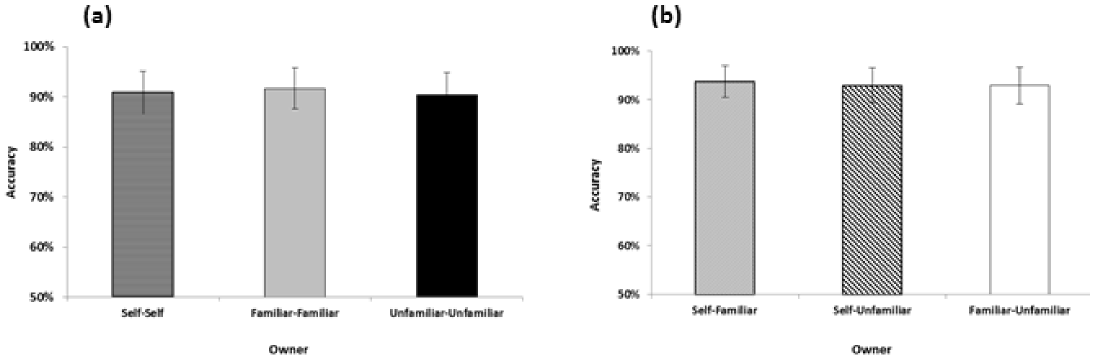

**Figure 5.3 - Accuracy in the "Same" and "Different" Condition in the Implicit task.**

The mean of correct responses in the "Same" (A) and "Different" Condition in the Implicit task as a function of Ownership (Self, Other) (B). Error bars depict SEMs. Differences significant at p<.05 are starred.

### 5.3.2.2 Explicit Task

***Same owner***

The variable Owner was significant [F(2, 122)=6.96, p<.001; $\eta^2_p$ =.10] since the condition with self stimuli (AA=79%) was worse than the conditions with familiar others' (BB=92%) and unfamiliar others' stimuli (CC=90%, p<.02 for both comparisons). The other two conditions (BB and CC) were not significantly different (p=.1, see Figure 5.4a).

The variables Wordiness (words = pseudowords = 87%, p=.94) and Type of stimulus (identical=86% and non-identical=88%, p=.23) were not significant.

The interactions between Owner X Type of stimulus was significant [F(2,122)=7.90, p<.0006; $\eta^2_p$ =.11]: the condition identical stimuli and non-identical stimuli were significantly different for self stimuli (74% vs 83%, p<.004) but not for familiar (93% vs 92% p=1) and unfamiliar stimuli (91% vs

88%, p=1). Moreover, identical self stimuli were worse than all other conditions (p<.004 for all comparisons).

***Different owner***

The variable Owner was significant [F(2, 122)=7.55, p<.0001; $\eta^2_p$ =.11] since the conditions with one self stimulus (AB=75% and AC=73%) were worse than the conditions with others' stimuli (BC=87%, p<.007 for both comparisons, see Figure 5.4b). The two self conditions (AB and AC) were not significantly different (p=1). Also the variable Wordiness was significant [F(1,61)=4.07, p<.05, $\eta^2_p$ =.06] since participants were more accurate with words than with pseudowords stimuli (80% vs. 76%).

The variable Type of stimulus (identical=79% and non-identical=78%, p=.56) as well as the interactions were not significant.

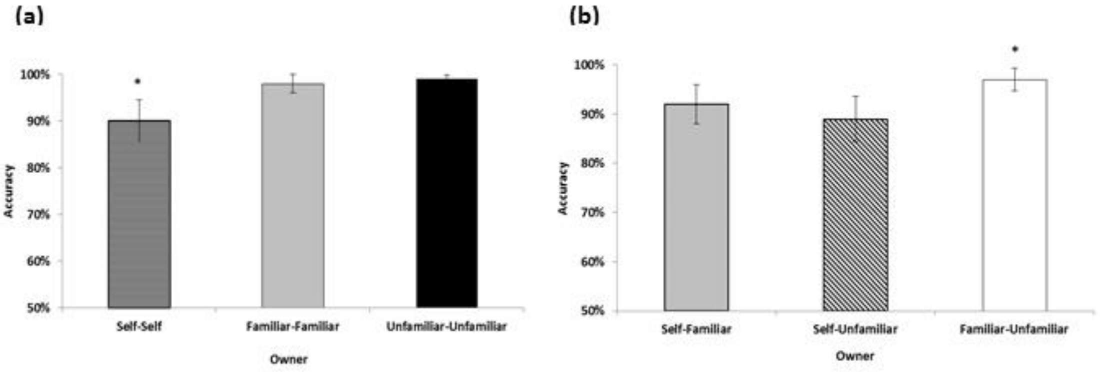

**Figure 5.4- Accuracy in the "Same" and "Different" Condition in the Explicit task.**

The mean of correct responses in the "Same" (A) and "Different" Condition in the Explicit task as a function of Ownership (Self, Other) (B). Error bars depict SEMs. Differences significant at p<.05 are starred.

## 5.4 Discussion

Here, for the first time implicit self-voice recognition is investigated and it is directly compared with explicit self-voice recognition. In our study, participants were submitted to a same/different task (Implicit task) and to a task during which they discriminated their own voice from familiar and unfamiliar voices (Explicit task).

First of all, a difference between implicit and explicit self-voice recognition was found since self-voice was better recognized in the Implicit than in the Explicit task. One could expect that the pattern of results can be affected by a different level of difficulty of the two tasks. However, this possibility can be ruled out since others' voices were implicitly and explicitly recognized with the same accuracy and no difference was found when the two tasks were directly compared.

Regarding the Implicit task, results showed no difference in accuracy between the self and other condition. Instead, in the Explicit task a lower accuracy for self than other condition was found (i.e. a self-disadvantage).

As far as the self-disadvantage effect found for the explicit self-voice recognition, it is in line with previous evidence. For example, Rosa and colleagues (2008) with a forced-choice identification task, showed that participants were overall less accurate with self-voice (86%) compared to unfamiliar voice (95%). Similar results are reported by Hughes and Nicholson (2010) using face pictures and recorded voices. In their experiment, stimuli could belong to the participant or to another person and were combined in four different presentations: self-face/self-voice, self-face/other-voice, other-face/self-voice and other-face/other-voice. Participants were required to perform three different tasks: visual self-recognition, acoustical self-recognition and a third task where both visual and acoustical stimuli were combined. Authors found that when vocal and facial stimuli were separately presented, participants were less accurate for self than other's stimuli, both with face and voice stimuli. Interestingly, in the concurrent presentation, the worst accuracy was found in the condition where both stimuli, face and voice, belonged to the participant.

The worse performance with self than others' voice in the Explicit task could be attributed to the fact that the sound of hearing one's own voice while speaking is perceived differently than while hearing one's own recorded voice. The discrepancy between one's own recorded voice and how each one subjectively hears one's own voice is due to conduction through air and bones that modifies the voice's characteristics (Maurer & Landis, 1990).

Thus, it is possible that participants did not recognize a stimulus as their voice because it is not heard as they were used to and it didn't match the voice-stimulus stored in memory. This hypothesis is also supported by a recent study by Xu and colleagues (Xu et al., 2013). Indeed, authors observed a facilitation in self-voice recognition only after specific manipulation of formant voice-structures.

Also neuroimaging evidence is in line with this hypothesis. Nakamura and colleagues (2001), comparing brain activity during self and unfamiliar voices recognition, found a selective involvement of the right frontal cortex when self rather than unfamiliar voices were presented. The authors proposed that this activation reflects retrieval effort, ascribed to a cognitive effort during self-voice recognition. This effect could be due to the fact that recorded voices, used as stimuli in the experiment, were quite different from one's own voices stored in subject's memory.

Furthermore, other studies suggest that when people are confronted with hearing a recording of their own voice, they tend to first respond with a negative affective reaction due to a discrepancy between what they expect to hear and what they actually hear. This negative reaction can be a possible explanation of the difficulty to match the heard voice with the "representation" of one's own voice and, in turn, of the self-disadvantage effect emerging in the Explicit task. In contrast, this sort of reaction doesn't occur when they hear others' recorded-voice (Holzman & Rousey, 1966). The wide diffusion of mobile technologies in everyday life can have contributed to familiarize people with others' voice heard through artificial channels with light distortion. Accordingly with this assumption, in our study, although participants recognized their own voice with high accuracy, they better recognized others' recorded voice.

The difficulty to explicitly recognize self-voice (self-disadvantage) is particularly evident when the couple of presented stimuli are two identical (dog-dog) rather than two non-identical stimuli (dog-seal), both pronounced by the participant. This could be due to the fact that hearing two identical stimuli provided participants with less acoustic variability than two different stimuli. Therefore, they could exploit less acoustic cues to recognize their own voice.

Regarding the Implicit task, an effect driven by stimuli' characteristics was observed: participants performed better with identical than non-identical stimuli when they were pronounced by same speakers and with words than pseudowords when stimuli were pronounced by different speakers. The facilitation for identical than non-identical stimuli in the 'same owner condition', can be explained with a sort of congruent-effect between “same-owner”/“same-stimuli”. Conversely, the facilitation for words than pseudowords found in the “different owner condition”, suggests that well-known words could help participants to focus on acoustic characteristics when voices are different. In any case, even if stimuli’ characteristics influenced the same/different voice judgment, they did not interact with implicit recognition of speaker identity. Indeed, no interaction between stimuli’ characteristics and Owner factor was found in the Implicit task.

In conclusion, this study provides evidence suggesting that self-voice recognition processes are supported by different mechanisms and perhaps there are two distinct ways to access to self-voice knowledge: an implicit and an explicit one. This dissociation was put in evidence by both clinical and anatomo-functional studies. From a clinical point of view, a dissociation between implicit and explicit processing was described in brain damaged patients (i.e. in patients with blindsight, neglect, prosopoagnosia and anosognosia). Additionally, using a neuropsychological approach, Moro and colleagues (2011) investigated the neural correlates of implicit and explicit motor awareness in patients with anosognosia for hemiplegia. The authors found that deficits in implicit and explicit processes are associated with lesions involving different cortico-subcortical structures, the former being more anterior and the latter ones being more posterior (see also Moro, 2013). Consistently, fMRI studies on healthy participants confirmed the involvement of frontal areas in implicit bodily self-recognition (Devue et al., 2007; Ferri et al., 2012).

Similarly, one’s own face recognition also seems to recruit different networks when implicit rather than explicit processing was required. Indeed, implicit recognition of one’s own face activated right inferior frontal regions and the right insula (Devue et al., 2007), whereas explicit self-face recognition involved a wider distributed network across frontal, parietal and occipital regions (Kaplan et al., 2008; Uddin et al., 2005, 2006).

To sum up, this evidence suggested that there are two distinct ways to access to recognition of self- voice, face and body-parts: the implicit and the explicit one. The neural bases of the implicit and explicit self-voice recognition should be more deeply investigated in future studies.

## Chapter 6

# Implicit and Explicit self- other voice discrimination in brain damaged patients

## 6.1 Introduction

When we are engaged in a conversation with someone else, we simultaneously catch information not only about the linguistic content but also about the identity of the speaker. However, these two aspects of speech are processed largely independently (von Kriegstein & Giraud, 2004; Schall et al., 2015). Here, we sought to investigate the mechanisms underlying voice identity recognition, which is an important aspect of self/other distinction.

In the neuropsychological domain, relatively few studies investigated voice recognition disorders revealing how voice recognition impairment might occur due to brain lesion (for a review see Blank et al., 2014; but also Lang et al., 2009; Peretz et al., 1994; Van Lancker et al., 1989; Van Lancker & Canter, 1982). For example, Van Lancker and coworkers (1989) submitted left and right brain damaged patients to two different tasks. In the voice discrimination task participants were presented with pairs of unfamiliar voices and were required to decide whether the paired stimuli were same or different, whereas in the voice recognition task, familiar voices were adopted and participants were asked to recognize the target voice. Authors observed that defects in *voice discrimination* might occur following brain lesion including both left or right temporal lobe, whereas *voice recognition* was selectively impaired in right brain damaged patients.

So far, none of the mentioned studies were focused on self-voice processing. Despite the lack of study on this field, it might be of great interest to elucidate how self-stimuli were processed in the acoustical domain. Indeed, several findings across different sensory modalities demonstrated how self-related information might be considered as a special stimulus (for reviews see Blanke, 2012; Longo, 2015). For instance, in a recent study (Rosa et al., 2008) participants were explicitly asked to decide whether acoustical stimuli represented or not their own voice: participants were less accurate with self-voice (86%) compared to unfamiliar voice (95%). Furthermore, authors demonstrated a selective left-hand/right-hemisphere advantage for self-voice, supporting the existence of distinct mechanisms for processing self and other's related stimuli. Accordingly, neuroimaging data revealed that selective brain regions, such as the right (Kaplan et al., 2008) and the left inferior frontal gyri, (Allen et al., 2005) discriminate the sound of one's own voice compared to other people's voice.

Most of these studies adopted an explicit paradigm, in which participants were directly asked to recognize their own voice (Allen et al., 2005; Rosa et al., 2008). Only few studies investigated the implicit recognition of self-voice, for instance by recording event related potentials while participants passively listened to acoustic stimuli pronounced either by the participant or by a familiar person or an unknown person (Graux et al., 2013, 2015).

The distinction between implicit and explicit processing of self-related stimuli is particularly relevant since several studies have demonstrated the different contribution of implicit and explicit self-body knowledge to our sense of self. Indeed we are faster and/or more accurate in performing a discrimination task when one of the two displayed stimuli represents our own body, showing an implicit recognition of self-related stimuli (Ferri et al., 2011; Frassinetti et al., 2011). By contrast, we do not show such facilitation when we are explicitly required to recognize our body. Neuropsychological studies have demonstrated that implicit recognition of one's own body is lost in brain damaged patients following a right fronto-parietal lesion. This evidence suggested a critical role of this brain network in processing self body-parts stimuli, at least when an explicit recognition is not required.

As far as voice recognition, very recently a similar dissociation was demonstrated in healthy participants (Candini et al., 2014). Crucially, this study directly compared implicit and explicit self-voice recognition by using the same stimuli and two different tasks: a voice identity discrimination task (Implicit task) and a self-voice recognition task (Explicit task). Participants listened to pairs of pre-recorded auditory stimuli pronounced by themselves, by a familiar or an unfamiliar person. Afterwards, in the discrimination task (Implicit task) participants had to judge whether the pair of stimuli were pronounced by same or different speakers. A facilitation in discriminating self versus other people's voice is the expression of an implicit self-voice knowledge. In the recognition task (Explicit task) participants had to identify if one of the paired stimuli was or not their own voice. Authors reported that healthy participants performed worse when were asked to explicitly, rather than implicitly, recognize their own voice, whereas no difference was found when others' voices were considered. These findings suggested that implicit and explicit self-voice recognition are subtended by different mechanisms.

A fundamental contribution to our knowledge about the dissociation between implicit and explicit processing was given by neuropsychological studies. Indeed, focusing on neuropsychological disorders, from memory (Gabrieli et al., 1995, Tulving, 1991) to body-representation (Moro, 2013; Tranel & Damasio, 1985) as well as from visual to spatial deficits (Berti et al., 1994; Bertini et al., 2013; Làdavas et al., 1993) much evidence has been reported of such a dissociation. However, until now implicit and explicit self-voice recognition has never been directly compared in brain damaged patients. Here, in this theoretical framework, we investigate the distinct contribution of right and left hemisphere to implicit and explicit self-voice recognition.

To this aim, we recruited a sample of healthy participants and brain damaged patients affected by right or left focal lesions. Participants were submitted to two different tasks designed for testing implicit and explicit self-voice recognition. The former is configured as a voice identity discrimination task (Implicit task) and the latter one as a self-voice recognition task (Explicit task).

We expect distinct pattern of results with right (RBD) and left brain damaged (LBD) patients in implicit and explicit self-voice recognition. In the *Implicit task*, we expect a deficit in RBD but not in LBD patients with self-voice, similarly to what has been found for self-stimuli in the visual domain (Frassinetti et al.,  2008, 2009, 2010). This would prove that the right hemisphere is involved in the implicit processing of corporal self-related stimuli regardless of the modality of presentation (visual or acoustic), As far as the *Explicit task*, we expect a deficit in self-other voice discrimination both in RBD and in LBD patients. This would be in line with neuroimaging studies showing that both left and right hemispheres are relevant in processing the identity of acoustical stimuli (Allen et al., 2005; Kaplan et al., 2008).

## 6.2 Materials and methods

### 6.2.1 Participants

A total of twenty consecutive brain damaged patients were recruited at the Fondazione Maugeri Hospital (Castel Goffredo, Italy) and at the Sol et Salus Hospital (Rimini, Italy) to participate in the study. Ten of them were affected by right hemispheric lesion (RBD; 8 males; mean±sd age = 67.5±8.61 years; mean±sd education = 7.4±4.17 years) and ten patients were affected by left hemispheric lesion (LBD; 5 males; mean±sd age = 70.7±5.3 years; mean±sd education = 5.9±1.5 years).

Ten healthy participants (Controls; 4 males, mean±sd age = 64.6±6.1 years; mean±sd education = 10.4±5.7 years) matched for gender and handedness served as controls. Two one-way ANOVAs showed that three groups (Controls, RBD and LBD patients) did not significantly differ neither for age [F(2,27)=1.42, p=.26] nor for education [F(2,27)=2.78, p=.08].

All participants were right handed by their own verbal report and without auditory pathology. All participants were Italian speakers and naive to the purpose of the study. Written informed consent was obtained before taking part in the experimental procedure. The study was approved by the local ethics committee (Department of Psychology, Bologna) and all procedures were in agreement with the Declaration of Helsinki (2008).

### 6.2.2 Neuropsychological assessment

All patients were administered the Mini-Mental State Examination (Folstein et al., 1975) to screen for a general cognitive impairment. Furthermore, the Token Test (De Renzi & Vignolo, 1962) and the Bell’s Cancellation (Gauthier et al., 1987) were adopted to assess verbal comprehension and extrapersonal neglect, respectively (see Table 6.1 for more details).

**Table 6.1: Clinical and neuropsychological data of left and right brain damaged patients according to the lesion site.**

| **Demographical and clinical details** | | | | **Neuropsychological Examination** | | |
|---|---|---|---|---|---|---|
| Patient | TPL | Age | Education | MMSE | TOKEN TEST | Bell's Test |
| LBD 1 | 28 | 71 | 8 | 19,4 | 22 | 1 |
| LBD 2 | 39 | 77 | 5 | 24 | 29,5 | 0 |
| LBD 3 | 40 | 62 | 5 | 22 | 26,25 | 6 |
| LBD 4 | 45 | 71 | 8 | 27,2 | 35,75 | 0 |
| LBD 5 | 59 | 69 | 4 | 24,4 | 26,5 | -5 |
| LBD 6 | 84 | 64 | 6 | 24 | 32,25 | 0 |
| LBD 7 | 1825 | 71 | 5 | 24,5 | 29 | 0 |
| LBD 8 | 2850 | 68 | 8 | 30 | 30,25 | -1 |
| LBD 9 | 6245 | 77 | 5 | 30 | 27,5 | 0 |
| LBD 10 | 71 | 77 | 5 | 24 | 26,5 | 0 |
| RBD 1 | 27 | 73 | 5 | 28,3 | 32 | 0 |
| RBD 2 | 71 | 57 | 7 | 28 | 33 | 9 |
| RBD 3 | 113 | 75 | 5 | 24,7 | 31 | 11 |
| RBD 4 | 128 | 56 | 3 | 27,2 | 31,75 | 5 |
| RBD 5 | 164 | 60 | 13 | 25,5 | 30,75 | 7 |
| RBD 6 | 192 | 77 | 4 | 24 | 26,5 | 6 |
| RBD 7 | 744 | 80 | 3 | 26,5 | 31,25 | -2 |
| RBD 8 | 1100 | 66 | 13 | 24,2 | 31 | 2 |
| RBD 9 | 1541 | 62 | 13 | 25,5 | 31,25 | 7 |
| RBD 10 | 1620 | 69 | 8 | 30 | 34 | 0 |

LBD = left brain damaged patients; RBD = right brain damaged patients; TPL = Time post lesion (days); Education and Age are indicated in years. MMSE = Mini Mental State Examination (scores are corrected for years of education and age; cut off > 24); Token Test = cut off > 26.5; Bell’s Test = contralesional minus ipsilesional omissions (cut off < 5).

### 6.2.3 Stimuli

In a first session, voices were recorded in a silent room by using a recorder positioned at 60 cm from participant's trunk. Participants' voice was recorded while they pronounced Italian words and pseudowords presented on a sheet of paper (A4 format). They were invited to maintain a flat tone of voice and to pronounce items as clearly as possible. If the experimenter judged the recorded items not easily discriminable, asked participants to repeat them until they were.

Words were disyllabic and high-frequency stimuli (in Italian: cane, foca, lupo, alce, rana e topo; in English: dog, seal, wolf, elk, frog, mouse) belonging to the same semantic category (animal). Pseudowords were obtained from the words by means of two letters replacement (cona, faco, lusa, leca, tupi e rona). Subsequently, each vocal stimulus was digitized at 44100 Hz, 16 bit, stereo modality, and elaborated using dedicated software (Cool Edit Pro) to adjust overall sound pressure and to balance the volume. The mean duration of each stimulus was 623.5 ms (SD = 89.5; range = 532-816 ms). Each stimulus could represent participant's voice (A stimulus), the voice of a familiar other (B stimulus) or the voice of an unfamiliar other (C stimulus). Each participant was asked to bring someone they encounter on a daily basis, of the same race and gender. This person served as the 'familiar other'.

### 6.2.4 Procedure

Each trial started with a central fixation point (250 ms duration), followed by the sequential presentation (500 ms ISI) of a pair of vocal stimuli. The trial was time-out as soon as the participant responded. Inter-trial timing was fixed at 1000 msec.

According to Candini et al. (2014), in each trial the two stimuli could either belong to the same person (same trials) or to different people (different trials). Moreover, stimuli could belong to the participant (A), familiar other (B) or unfamiliar other (C). Thus, three combinations of “same” stimuli (AA, BB and CC) and three combinations of “different” stimuli (AB, AC and BC) were presented. Voices were matched for gender, age and regional accent. Finally, in half of the “same” and “different” trials stimuli could be identical (i.e. cane/cane or cona/cona), in the other half not (i.e. cane/foca or cona/faco). Presentation of each word/pseudoword was counterbalance between “same” and “different” trials under the six combinations. Words and pseudowords were presented in two separate blocks. In each block, 4 trials for each combination of stimuli according with the voice’s owner (AA-BB-CC-AC-AB-BC) were presented for a total of 24 trials. The presentation order and the sequence of the type of stimuli (identical and no-identical) and owner factors (AA-BB-CC-AC-AB-BC) were randomized between trials, whereas the two blocks (words and pseudowords) were balanced between participants.

Participants sat in front of a PC screen at a distance of about 60 cm, and were required to press two previously assigned response keys, one for affirmative (YES) and one for negative (NO) answers. Response buttons were counterbalanced between participants. Stimuli were delivered through earphones and were presented binaurally. E-Prime 2.0 (Psychology Software Tool ©1996-2012) was adopted to control stimuli presentation and randomization. Key press RTs and response accuracy were recorded.

First of all, participants were instructed to ignore the linguistic content and to attend to the voice. In the Implicit task, participants were asked to judge whether the two voices were the “same” (half participants) or “different” (half participants). In the Explicit task, all participants were required to explicitly judge whether at least one of the two voices corresponded to their one own voice. Additionally, no feedback on the accuracy of given responses was provided during the experiment (see Figure 6.1).

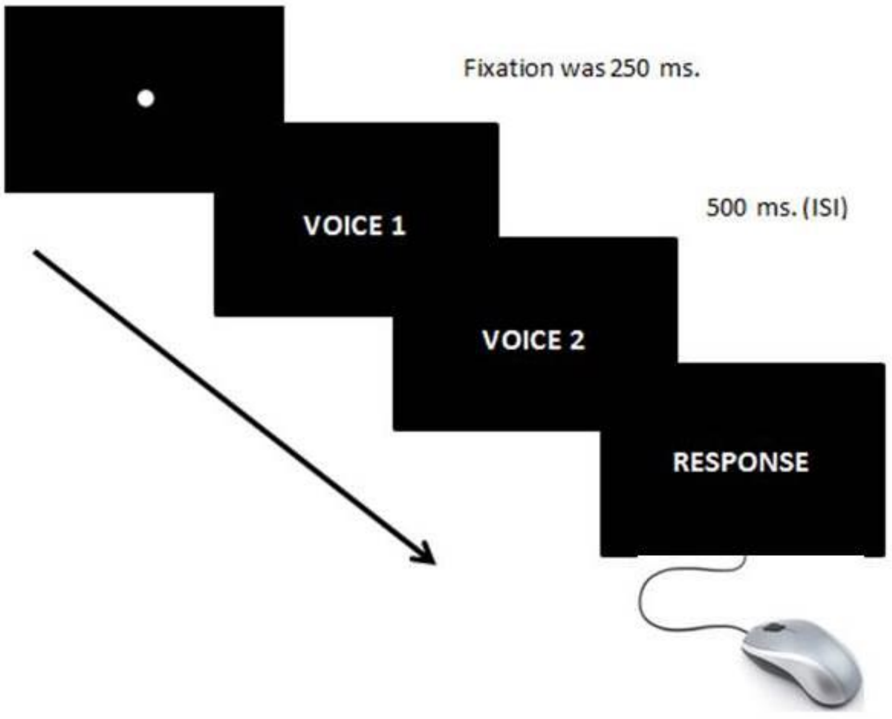

**Figure 6.1 - An example of experimental trial.**

The picture depicted an example of experimental trial in which two paired voices were subsequently presented.

All participants performed the two recognition tasks in one single session, with eight practice trials before the main experiment. Auditory stimuli used during the training period were not used in the subsequent experiment. To avoid an interference effect of the explicit recognition of one’s own voice on the "same/different" task, the Implicit Task was always conducted before the Explicit task. The whole experiment took approximately half an hour.

### 6.2.5 Statistical analysis

We compared Self and Other conditions according with the definition adopted in our previous study (Candini et al., 2014), that is trials in which at least one stimulus belonged to the participant (Self condition: AA-AB-AC) and trials in which no stimulus belonged to the participant (Other condition: BB-CC-BC).

To elucidate possible differences across the three groups, we conducted an Analysis of Variance (ANOVA) on accuracy (% of correct responses) with Group (Controls, RBD and LBD patients) as between-subject factor, with Task (Implicit/Explicit task) and Owner (Self/Other condition) as within-subject factors. Post-hoc comparisons were conducted by using Duncan Test. The magnitude of effect size was expressed by partial eta square ($\eta^2_p$).

## 6.3 Results

### 6.3.1 Comparison between healthy participants, RBD and LBD patients

A significant effect of the **Group** factor was found [F(2,27)=8.92, p<.001, $\eta^2_p$=.39] which was mainly accounted for by lower accuracy for both RBD and LBD patients' groups (RBD Patients = 63%; LBD Patients = 64%, p<.009 for all comparisons) compared to Controls (82%). Conversely, RBD and LBD patients were not significantly different (p=.76). The variable **Task** [F(1,27)=8.02, p<.009, $\eta^2_p$=.23] (Implicit = 74% vs. Explicit = 65%) was significant. Furthermore, a significant three-way interaction with **Group x Owner x Task** was found [F(2,27)=4.54, p<.02, $\eta^2_p$=.25]. When patients and Controls were directly compared, post-hoc comparisons showed completely different effects in RBD and LBD patients in the Implicit and in the Explicit task. First of all, in the ***Implicit task***, with *Self* stimuli, RBD patients (62%) performed significantly worse than Controls (86%, p<.04). Conversely, comparing LBD patients and Controls (68% vs. 86%, p=.11) no difference was found. As far as *Others'* stimuli, no differences were found in each group as well as across the three groups (RBD = 68%; LBD = 71%; Controls = 87%; all ps>.10).

Furthermore, in the ***Explicit task***, with *Other* stimuli, RBD patients (50%) performed significantly worse than Controls (89%; p<.001) and LBD patients (73%; p<.05). Conversely, with *Self* stimuli, LBD patients (44%) performed significantly worse than Controls (65%, p<.05) and RBD patients (71%; p<.02). Crucially, no significant difference emerged for *Other* stimuli comparing LBD patients and Controls (p=.14), nor for *Self* stimuli comparing RBD patients and Controls (p=.61; see Figure 6.2A). Moreover, a self-disadvantage was found both in Controls (Self = 65% vs. Other = 88%; p<.05) and LBD patients (Self = 44% vs. Other = 73%; p<.02), but not in RBD patients (Self = 71% vs. Other = 50%; p=.07) (see Figures 6.2B-D).

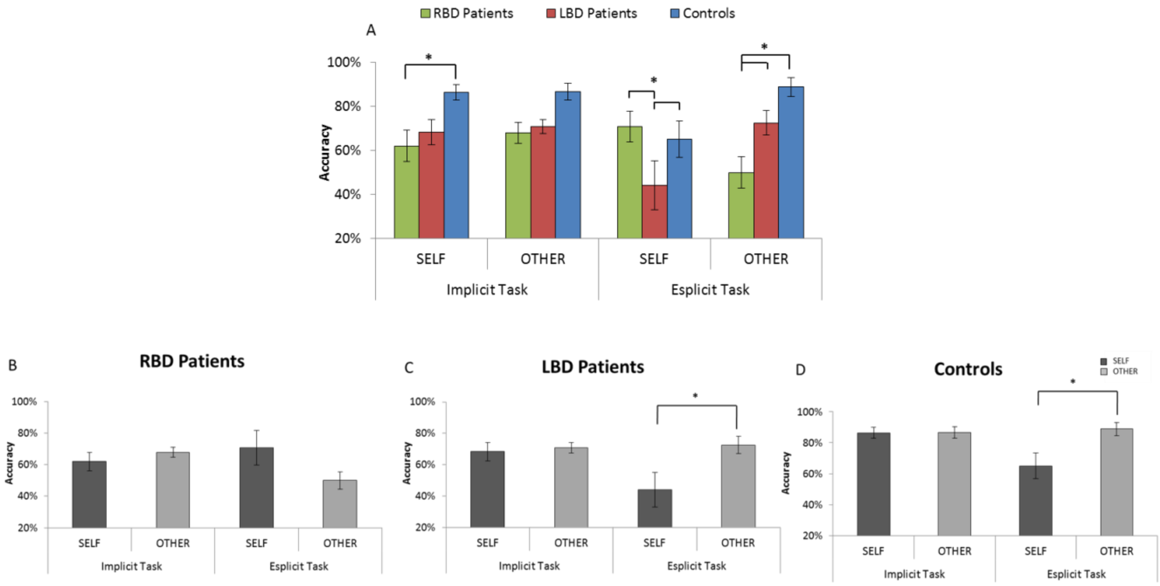

**Figure 6.2 - Accuracy in the Implicit and Explicit task**

The comparison between RBD and LBD patients and Controls (A) and each experimental group RBD (B) and LBD patients (C) and Controls (D) respectively. Between-group (2A) and within-group (2B-D) differences significant at p<.05 are starred. Error bars depict SEMs.

To better understand the nature of errors made by patients in the explicit recognition of self-voice, False Alarms (erroneous recognition of Self non present) and Omissions (erroneous rejection of Self present) were compared in RBD and LBD patients. Significant differences were found revealing different patterns in RBD and LBD patients. Indeed, RBD (50%) made higher False Alarms than LBD patients (27%; $t_{18} = -2.50$; $p<.02$; see Figure 6.3A), since they more frequently misattributed the other's voice to themselves when their one's own voice was not actually present. Conversely, LBD (56%) made higher Omissions than RBD patients (30%; $t_{18} = 1.94$; $p<.05$; see Figure 6.3B).

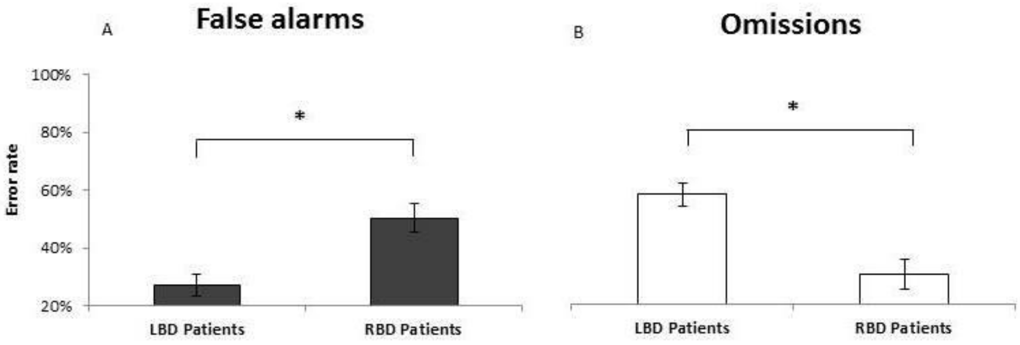

**Figure 6.3 - The mean of false alarms and omissions for LBD and RBD patients.** False alarms (A) and Omissions (B) are expressed as a percentage of error. Error bars depict SEMs. Differences significant at p<.05 are starred.

### 6.3.2 Analysis for testing the effect of time post lesion onset

Furthermore, since alterations in voice production have been described in patients following cerebral stroke (Vuković, et al., 2012), in order to exclude that the observed results might be simply ascribed to the time post lesion onset, an Analysis of Covariance (ANCOVA) was conducted on accuracy with time post lesion (indicated as days from the lesion onset) as covariate factor, Group (RBD and LBD patients) as between-subject factor, and with Task (Implicit/Explicit task) and Owner (Self/Other condition) as within-subject factors.

However, none significant effect emerged neither for the time post lesion factor [F(1,18)=0.43, p=.52], nor for its interaction with other variables (Task, Owner and Group).

### 6.3.3 Analysis for testing Wordiness and Familiarity effect

To investigate the possible effect of Wordiness (word and pseudoword) on voice recognition, further analyses were conducted on Implicit and Explicit tasks separately. Since for ‘‘same owner’’ (AA–BB–CC) only one source of variance (one speaker) was present whereas for ‘‘different owner’’ (AB–AC–BC) two sources of variance (two speakers) were present, separate ANOVAs were conducted. More specifically, two separate ANOVAs for ‘‘Same’’ owner trials (AA = self-self, BB = familiar-other/familiar-other, CC = unfamiliar-other/unfamiliar-other) and ‘‘Different’’ owner trials (AB = self/familiar-other, AC = self/unfamiliar-other; BC = familiar-other/unfamiliar-other) were carried out, with Group (Controls, RBD and LBD patients) as between-subjects factor and Wordiness (word and pseudoword) as within-subject factor.

However, in all the analysis none significant effect emerged neither for the variables Wordiness and Familiarity, nor for their interactions with other variables (Owner and Group).

### 6.3.4 Analysis for implicit and explicit dissociations within the RBD patients group

To elucidate the anatomical correlate of a selective deficit, the presence of possible dissociation in implicit and explicit self-voice processing was investigated in each patient.

Since in the group analysis possible dissociations may have gone unobserved, we therefore compared the performance of each patient with the performance of the control group for self and others' voice, separately in the Implicit and in the Explicit task, by using a modified t-test which takes into account the size of the control group (Crawford & Garthwaite, 2002).

This comparison revealed that 70% of RBD patients (7/10) were selectively impaired in the implicit or in the explicit voice processing compared to controls. Crucially, 4 out of 7 RBD patients were selectively impaired in the implicit self-voice recognition, whereas other patients (3 out of 7 RBD patients) were selectively impaired in the explicit recognition of other's voice.

## 6.4 Lesion study

To explore which cerebral areas are involved in self/other voice discrimination, brain lesions of 7 RBD and 7 LBD patients were identified by Computed Tomography and Magnetic Resonance digitalized images (CT/MRI)[1]. Then lesion location and extension were delineated and manually mapped in the stereotactic space of the MNI by using the free software MRIcro (Rorden and Brett, 2000). As first step, MNI template was rotated (pitch only) to approximate

---

[1] The CT/MRI scan of 7 out of 10 RBD patients, and of 7 out of 10 LBD patients were available.

the slice plane of the patient's scan. A trained rater (MC), using anatomically landmarks, manually mapped the lesion onto each correspondent template slice. After that, drawn lesions were inspected by a second trained rater (FF) and in case of disagreement, an intersection lesion map was used. Finally, lesions maps were rotated back into the standard space applying the inverse of the transformation parameters used on the stage of adaptation to the brain scan.

In order to extract the region that could be crucial for implicit and explicit self-other discrimination we separately overlaid lesions of left and right brain damaged patients. The maximum lesion overlap of RBD patients' lesions (green and light blue regions, which depict 4 and 3 out of 7 RBD patients, respectively) was mainly located along two different regions: one more anterior, involving cortical and subcortical frontal regions (caudate, putamen, internal capsule and the inferior frontal operculum) and the insular cortex, and one more posterior region, mainly located along the middle temporal and the angular gyri (for a graphical representation see Figure 6.4A). The maximum lesion overlap of LBD patients' lesions involved the fronto-insular region, the temporal pole and the inferior parietal lobe (for a graphical representation see Figure 6.4B).

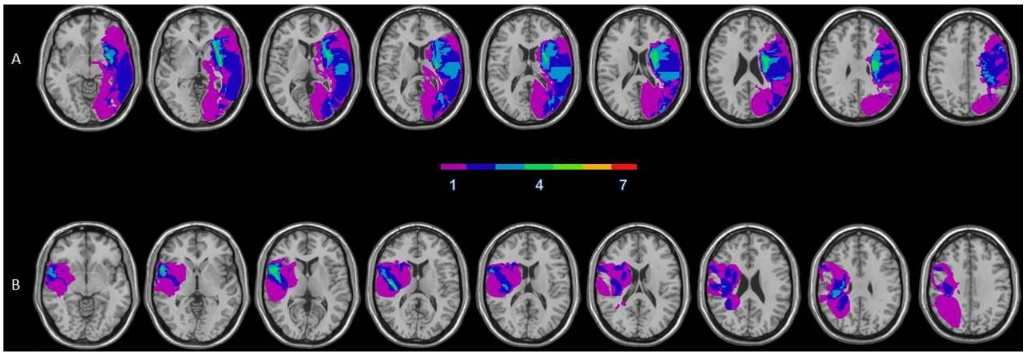

**Figure 6.4 - Overlay of reconstructed lesion plots of RBD and LBD patients superimposed onto MNI template.**

The number of overlapping lesions is illustrated by different colors coding from violet (n = 1) to red (n = 7). The region with maximum overlap is shown in green and light blue for RBD (A) and LBD patients (B) respectively.

Furthermore, since two distinct deficits were observed within the RBD patients group, we separately overlaid patients' lesions impaired with others' voice in the Explicit task and impaired with self-voice in the Implicit task.

The RBD patients who showed a selective impairment in the Explicit task when others' voice was presented were affected by lesion involving a subcortical frontal region (caudate, putamen and internal capsule) and the insular cortex (see Figure 6.5A). Conversely, RBD patients selectively impaired in implicit self-voice recognition were affected by lesion involving a more posterior region, mainly located along the superior/middle temporal and the angular gyri (see Figure 6.5B).

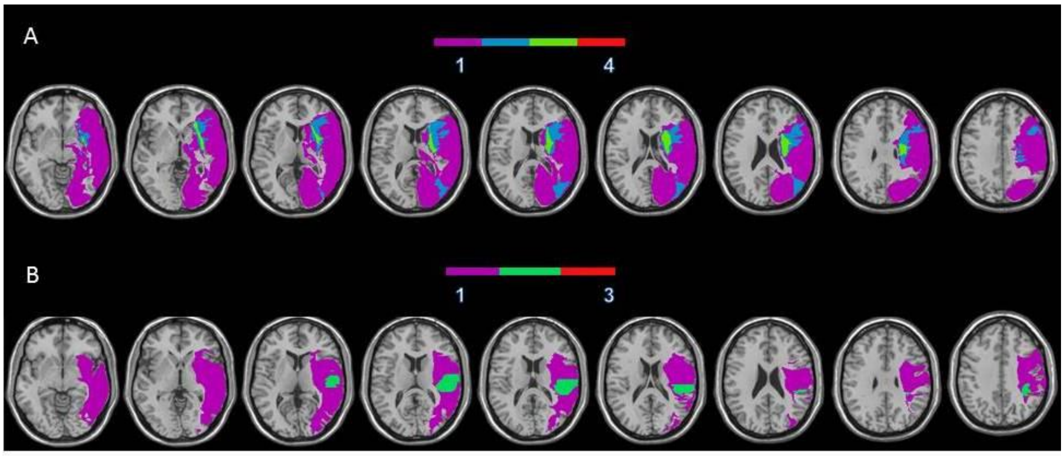

**Figure 6.5 - Overlay of reconstructed lesion plots of RBD patients.**
Lesion plots of RBD patients impaired with others' voice in the Explicit task (A) and impaired with self-voice in the Implicit task (B) superimposed onto MNI template. The region with maximum overlap is shown in green.

## 6.5 Discussion

In this study we investigated the contribution of right and left hemisphere in implicit and explicit self/other voice recognition. To this aim, RBD and LBD patients and a group of age-matched neurologically healthy subjects were submitted to two different tasks designed for testing voice discrimination (Implicit task) and voice identity recognition (Explicit Task) respectively.

Different patterns of results were found in the two experimental tasks adopted. In the discrimination task, when an explicit recognition of one's own voice was not required (***Implicit Task***), we observe a difference *across* the three groups. When the participant's voice was present, our results revealed a selective impairment of RBD patients compared to Controls in voice discrimination. This deficit was not present in LBD patients. Considering other people's voice, we did not observe any difference across the three groups.

These findings are in line with several neuropsychological studies on bodily self-representation in which patients following a right brain damage lost the facilitation, typically showed by healthy subjects and by patients with a left brain lesion, in performing a visual matching task when a stimulus depicting their own body was presented (Frassinetti et al., 2008, 2009, 2010). Taken together, the data on voice and body ownership strongly suggest that the right hemisphere is key when an implicit processing of self-related stimuli is required, regardless of their modality. More specifically, anatomical data from RBD patients with an impairment in *implicit self-voice processing* provide evidence for a crucial involvement of temporal and parietal regions.

By contrast, when an explicit self-voice recognition was required (***Explicit task***), significant differences emerged both *within* and *across* the three groups. Indeed, healthy participants as well as LBD patients showed a worse performance when at least one of the two paired stimuli was their own voice compared to when both stimuli belonged to other people (self-disadvantage effect). Interestingly, this phenomenon was not observed in RBD patients.

The self-disadvantage effect observed in healthy controls and LBD patients is in line with previous results reported by our group on young healthy participants (Candini et al., 2014). The worse performance with self than others' voice in the Explicit task could be explained by the discrepancy between one's own recorded voice and how we subjectively perceive our own voice during speaking. Indeed, it is well-known that conduction through air and bones modifies the voice's characteristics (Maurer & Landis, 1990). Thus, one may argue that participants did not recognize a vocal stimulus as their voice because this voice was not heard as they were used to and it did not match the voice-stimulus stored in memory. Consistently, a recent study suggested that after specific manipulation of formant voice-structures, participants improve their performance on self-voice recognition (Xu et al., 2013).

The absence of the self-disadvantage effect in RBD patients is mainly explained by their worse performance, compared to Controls, with others' stimuli, but not with self-stimuli.

Interestingly, a completely different performance was observed in LBD patients who exhibited a selective deficit in recognizing their own voice compared to Controls, whereas no difference was found when others' stimuli are considered.

Since the time post lesion onset did not affect patients performance (see Covariate analysis) we can hypothesize that the observed deficit is specifically related to the lesion site and cannot be ascribed to a deficit in recognizing a voice that can be modified post- compared to pre-lesion (Vuković et al., 2012).

We can hypothesize that in order to explicitly recognize a voice as our own voice, we define the boundary between what is the self and what is not. However, our judgment can be erroneous into two different ways: we can refuse the self-stimuli as our own voice, or we can misidentify the other as our own voice. These wrong judgments seem to reflect different impairments in the self/other distinction. The completely different performance observed following a right or a left brain damage are likely to suggest that in order to appropriately recognize a stimulus as belonging to the self, both hemispheres are involved, at least when the acoustical domain is investigated. Accordingly, looking more deeply on patients' type of errors in the Explicit task, we found a significant difference between RBD and LBD patients when false alarms and omissions are considered: LBD patients erroneously rejected their own voice when it was present (omissions) whereas RBD patients more frequently misattributed the other's voice to themselves when their own voice was not actually present (false alarms).

As far as LBD patients, they showed an amplified self-disadvantage effect, resulting in a pathological tendency to refuse the presented voice as their own. This deficit was associated with lesion encompassing the left hemisphere involving fronto-insular and temporal regions. In this respect, neuroimaging evidence provides support for a cerebral network lateralized in the left hemisphere which may play a role in attributing self-related information. For instance, a study conducted with schizophrenic patients, reported a similar misattribution of self-generated speech to an alien source. This misidentification was associated with functional abnormalities in the left temporal cortex and in the anterior cingulate bilaterally (Allen et al., 2007).

Regarding the misattribution of the other voice to themselves observed in RBD patients, we may suggest that this phenomena is linked with an interesting clinical behavior reported in the context of body ownership delusion, which was defined “pathological embodiment” (Garbarini et al., 2014). In this respect, hemiplegic patients who did not explicitly deny that their contralesional (left) arms belonged to themselves in everyday activity, claimed that an alien hand was their own when it was placed according to their egocentric coordinates. Thus, here we propose that RBD patients show a pathological embodiment of other people’s voice, since they misidentified other people’s voice as their own.

From an anatomical point of view, in our study RBD patients who showed a pathological embodiment of others’ voice were affected by lesions that mainly involved cortical and subcortical frontal regions (caudate, putamen and internal capsule) and the insular cortex. This lesion location may explain the tendency in self-attributing others’ voice. Indeed, the damage of putamen and paraventricular white matter is compatible with the ones identified for being responsible for pathological embodiment, provided by Garbarini and coworkers (2013). More specifically, the lesion location previously reported (Garbarini et al., 2013) involved the right basal ganglia and the periventricular region. In this respect, authors proposed that a damage to the white matter tract linking subcortical structures with cortical sensory-motor areas may lead to a deficit in the construction of a coherent corporeal representation.

Furthermore, the lesion of the right frontal lobe and the insular cortex may explain the impairment in self/other distinction. Accordingly, in a PET study when a group of healthy participants were asked to recognize their own voice from unfamiliar voice, greater activity was observed in the right parainsular cortex (Nakamura et al., 2001). Finally, in a recent fMRI study, Kaplan and colleagues (2008) demonstrated that seeing our own face and hearing our own voice mainly activated the right inferior frontal gyrus (IFG), suggesting that this region is involved in “self-representation” across different sensory modalities.

The present study for the first time has investigated the neuroanatomical substrates of self-voice recognition in brain damaged patients. Our lesions’ findings demonstrate a crucial role played by the right hemisphere in implicit processing of one’s own voice and the involvement of both hemispheres when an explicit recognition of voice identity is required. In this respect, a prominent contribution of the right and of the left hemisphere emerges for others’ and for self-voice explicit recognition, respectively.

Overall, these results suggest that self-voice conveys acoustic information which participates in shaping a comprehensive bodily self-representation and allows us to feel that our corporeal self belongs to ourselves.

## General discussion

The present dissertation aim at investigating the mechanisms through which we recognize our corporeal appearance, that's to what we commonly refer with the term "bodily self". Furthermore, our physical body also represents the actual boundary between what and what not belonged to ourselves, thus contributing to the self-other discrimination. The key question of the present thesis is whether and how our body-parts and our voice may be considered as cues to properly distinguish between self and others.

Starting from the recognition of the one's own body, mounting evidence suggested that two distinct mechanisms underlying the bodily self-recognition. Indeed, it has been shown that we have an implicit knowledge about our body, demonstrated by the self-advantage effect, that's a better performance with self' compared to others' stimuli (Frassinetti et al., 2008). Conversely, this facilitation is absent when an explicit body recognition is required (Frassinetti et al., 2011). The existence of such a dissociation between implicit and explicit processing of bodily self is in line with several evidence provided by neuropsychological studies on bodily recognition and sense of body-ownership, such as somatoparaphrenia and anosognosia (for a review see Vallar & Ronchi, 2006, 2009; Moro et al., 2008).

The present dissertation contributes to the current debate investigating whether implicit and explicit bodily self-recognition are mediated by different cerebral networks and can be selectively impaired after brain lesion. Accordingly, the study described in Chapter 3 mainly addressed this issue submitting a group of brain damaged patients to two different tasks designed to test implicit and explicit bodily self-recognition.

Our results demonstrated that in the Implicit task, controls and LBD patients, but not RBD patients, showed an advantage for self-body stimuli. In the Explicit task no facilitation emerged in controls and patients. In addition double dissociations were found: 25% of RBD patients showed a selective deficit in implicit and 10% in explicit bodily self-processing, whereas 8% of LBD patients were selectively impaired in explicit processing. Based on both behavioral and anatomical data, we suggest that an integrated right cortical–subcortical motor network underpins implicit knowledge of bodily self, whereas both hemispheres contribute to elaborate our explicit body knowledge. The existence of two of distinct networks (implicit and explicit) for self-body recognition could be particularly relevant for the diagnosis and rehabilitation of these disorders.

The ability to recognize one's own body is strictly related to the sense of body-ownership. Such a relationship became of a crucial relevance for patients who exhibited a pathological embodiment of others' people body-parts. This interesting issue has been addressed in the neuropsychological study described in Chapter 4. Specifically, we investigated whether implicit and explicit bodily self-recognition are differently affected by a disorder of bodily ownership.

Patients with (E+) and without pathological embodiment (E-) were compared during two different tasks designed to test implicit and explicit bodily self-recognition.

Our results demonstrated that E+ patients were impaired both in implicit and explicit processing of bodily self-recognition. Indeed, they showed a deficit in implicit processing of self and others body-parts. This effect was not found in E- patients. This difference suggested the presence of a profound alteration E+ group when a self-other discrimination, mainly based on visual cues, is required.

Moreover, a different performance between E+ and E- patients was found when an explicit bodily self-recognition was required. Indeed, E+ patients showed a selective impairment in explicit recognition of *other's* body-parts, whereas E- patients showed a selective impairment when an explicit recognition of *self* body-parts was required.

Finally, in Chapters 5 and 6 we explored possible dissociation between implicit and explicit self-recognition using acoustical stimuli, such as the one's own voice. First of all, the existence of distinct mechanisms in self-voice processing underlying implicit and explicit recognition was investigate in neurologically healthy individuals (Chapter 5). Participants listened to pairs of pre-recorded auditory stimuli (words or pseudowords) pronounced by themselves, by a familiar or an unfamiliar person. In the "Implicit task" participants had to judge whether the pair of stimuli were pronounced by same or different speakers whereas in the Explicit task they had to identify if one of the pair of stimuli was or not their own voice. Results showed a difference between Implicit and Explicit tasks since participants were more accurate in implicit than in explicit self-voice recognition. Moreover, in the Implicit task, participants had the same level of accuracy when they had to judge stimuli pronounced with self or others' voice. Conversely, when an explicit voice-recognition was required, they were less accurate with self than with others' voice. Here, for the first time, we demonstrated that people have an implicit and/or explicit access to self-voice knowledge.

The last study, described in Chapter 6, sought neural correlates of implicit and explicit self-voice recognition processing in neuropsychological patients. In the Implicit task, RBD patients showed a selective impairment when self-voice was presented, while no differences were found in LBD patients and Controls. In the Explicit task a different pattern of results emerged: Controls and LBD patients showed a worse performance in recognizing their own than other’s voice, whereas RBD patients performed worse compared to Controls when others’ voice recognition was required. Additionally, error analysis revealed that LBD patients erroneously rejected their own voice when it was actually presented, whereas RBD patients misidentified other people’s voice as their own.

This phenomenon resembles the above mentioned delusion of bodily ownership called “pathological embodiment”. Here, for the first time a pathological embodiment with others’ voice is reported.

Furthermore, we provide anatomical evidence supporting the involvement of right hemisphere in the implicit processing of self-voice and the contribution of both hemispheres when an explicit recognition of voice identity is required. Our findings underline the relevance of acoustic information conveyed by our voice in self/other distinction.

In conclusion, the present dissertation provide behavioral and neuropsychological evidence to support implicit and explicit processing of self-related stimuli across different sensory modalities, such as visual and acoustic. Moreover, the brain networks underline the implicit and explicit self-recognition are explored. In this respect, our findings on self-body and self-voice processing are likely to suggest that the right hemisphere is key when self’ stimuli are implicitly processed, whereas both hemispheres contribute to the explicit recognition of the one’s own bodily stimuli.

## References

Allen, P. P., Amaro, E., Fu, C. H. Y., Williams, S. C. R., Brammer, M., Johns, L. C., & McGuire, P. K. (2005). Neural correlates of the misattribution of self-generated speech. Human Brain Mapping, 26, 44–53.

Allen, P., Aleman, A., & McGuire, P., K. (2007). Inner speech models of auditory verbal hallucinations: evidence from behavioural and neuroimaging studies. International Review of Psychiatry, 19, 4, 407-15.

Garbarini, F., Rabuffetti, M., Piedimonte, A., Pia, L., Ferrarin, M., Frassinetti, F., Gindri, P., Cantagallo, A., Driver, J., & Berti, A., (2012). ‘Moving’ a paralysed hand: bimanual coupling effect in patients with anosognosia for hemiplegia. Brain, 135, 1486–1497.

Andics, A., McQueen, J. M., Petersson, K. M., Gál, V., Rudas, G., & Vidnyánszky, Z. (2010). Neural mechanisms for voice recognition. Neuroimage, 52, 1528–1540.

Bates, E., Wilson, S., M., Saygin, A., P., Dick, F., Sereno, M., I., Knight, R., T., & Dronkers, N., F. (2003). Voxel-based lesion-symptom mapping. Nature Neuroscience, 6, 448–50.

Belin, P., & Zatorre, R. J., (2003). Adaptation to speaker’s voice in right anterior temporal-lobe. Neuroreport, 14, 2105–2109.

Belin, P., (2006). Voice processing in human and non-human primates. Philosophical Transaction of Royal Society London B Biological Science, 29, 361, 1476, 2091-107.

Belin, P., Bestelmeyer, P., E., G., Latinus, M., & Watson, R. (2011). Understanding voice perception. British Journal of Psychology, 102, 4, 711-725.

Belin, P., Zatorre, R. J., Lafaille, P., Ahad, P., & Pike, B. (2000). Voice-selective areas in human auditory cortex. Nature, 403, 309–312.

Belin, P., Fecteau, S., & Bédard, C. (2004). Thinking the voice: neural correlates of voice perception. Trends in cognitive science, 8, 3, 129-35.

Berlucchi, G., Aglioti, S., M. (2010). The body in the brain revisited. Experimental Brain Research. 200, 1, 25-35

Berti A., Bottini G., Gandola M., Pia L., Smania N., & Stracciari A. (2005). Shared cortical anatomy for motor awareness and motor control. Science, 309, 5733, 488e491.

Berti, A., & Rizzolatti, G. (1992). Visual processing without awareness: evidence from unilateral neglect. Journal of Cognitive Neuroscience, 4, 345-351.

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

Bertini, C., Cecere, R., & Làdavas, E. (2013). I am blind, but I "see" fear. Cortex, 49, 4, 985-93.

Bestelmeyer, P., E., G., Belin, P. & Grosbras, M., H. (2011). Right temporal TMS impairs voice detection. Current Biology, 21, 20 R838-R839.

Biederman, I., Herald, S., Xu, X., Amir, O., & Shilowich, B. (2015). Phonagnosia, a Voice Homologue to Prosopagnosia. Journal of Vision, 15, 12, 1206.

Blank, H., Anwander, A., & von Kriegstein, K. (2011). Direct structural connections between voice- and face-recognition areas. The Journal of Neuroscience, 31, 36, 12906 – 12915.

Blank, H., Wieland, N. & von Kriegstein, K. (2014). Person recognition and the brain: Merging evidence from patients and healthy individuals. Neuroscience and Biobehavioral Reviews, 47, 717–734.

Blanke, O. (2012). Multisensory brain mechanisms of bodily self-consciousness. Nature Review, 13, 556-571.

Blanke, O., Slater, M., & Serino, A. (2015). Behavioral, Neural, and Computational Principles of Bodily Self-Consciousness. Neuron, 88, 1, 145–166.

Bonte, M., Valente, G., & Formisano, E. (2009). Dynamic and task-dependent encoding of speech and voice by phase reorganization of cortical oscillations. Journal of Neuroscience, 29, 1699–1706.

Formisano, E., De Martino, F., Bonte, M., & Goebel, R. (2008). “Who” is saying “what”? Brain-based decoding of human voice and speech. Science, 322, 970–973.

Botvinick, M., & Cohen, J. (1998). Rubber hands ‘feel’ touch that eyes see. Nature 391, 756–756.

Bruce, V., & Young, A., (1986). Understanding face recognition. British Journal of Psychology. 77, 305–327.

Brugger, P., & Lenggenhager, B. (2014). The bodily self and its disorders: neurological, psychological and social aspects. Current Opinion Neurology, 27, 6, 644-52.

Brunner, E., & Munzel, U. (2000). The nonparametric behrens-fisher problem: asymptotic theory and a small-sample approximation. Biometrical Journal, 42, 1, 17–25.

Young, A., & Bruce, V. (2011). Understanding person perception. British Journal of Psychology, 102, 4, 959–974.

Burton, A., M., Bruce, V., & Johnston, R., A. (1990). Understanding face recognition with an interactive activation model. British Journal of Psychology, 81, 361–380.

Candini, M., Zamagni, E., Nuzzo, A., Ruotolo, F., Iachini, T. & Frassinetti, F. (2014). Who is speaking? Implicit and explicit self and other voice recognition. Brain and Cognition, 10, 92C, 112-117.

Catani, M., Dell’Acqua, F., Vergani, F., Malik, F., Hodge, H., Roy, P., Valabregue, R., & Thiebaut de Schotten, M. (2012a). Short frontal lobe connections of the human brain. Cortex, 48, 2, 273-91.

Catani, M., Dell'acqua, F., Bizzi, A., Forkel, S., J., Williams, S., C., Simmons, A., Murphy, D., G., & Thiebaut de Schotten, M. (2012b). Beyond cortical localization in clinico-anatomical correlation. Cortex, 48, 10, 1262-87.

Cocchini, G., Beschin, N., & Jehkonen, M. (2001). The fluff test: a simple task to assess body representation neglect. Neuropsychological Rehabilitation, 11, 17–31.

Conson, M., Aromino, A., R., & Trojano, L. (2010). Whose hand is this? Handedness and visual perspective modulate self/other discrimination. Experimental Brain Researches, 206, 449–453.

Crawford, J., R., & Garthwaite, P., H. (2002). Investigation of the single case in neuropsychology: Confidence limits on the abnormality of test scores and test score Neuropsychologia, 40, 1196-1208.

Damasio, A., R., Damasio, H., & Van Hoesen, G., W. (1982). Prosopagnosia: anatomic basis and behavioral mechanisms. Neurology, 32, 4, 331-41.

De Renzi, E., & Vignolo, L., A. (1962). The token test: A sensitive test to detect receptive disturbances in aphasics. Brain, 85, 665-78.

de Vignemont, F. (2011). Embodiment, ownership and disownership. Consciousness and Cognition, 20, 1, 82-93

Decety, J., & Sommerville, J., A. (2003). Shared representation between self and other: A social cognitive neuroscience view. Trends in cognitive science, 7, 527-533.

Devue C., Collette F., Balteau E., Degueldre C., Luxen A., Maquet P., & Brédart, S. (2007). Here I am: the cortical correlates of visual self-recognition. Brain Research, 1143, 169–82.

Downing, P., E. & Peelen, M., V. (2011). The role of occipitotemporal body-selective regions in person perception. Cognitive Neuroscience, 2, 3-4,186–203.

Downing, P., E., Jiang, Y., Shuman, M., & Kanwisher, N., G. (2001). A cortical area selective for visual processing of the human body. Science, 293, 5539, 2470–2473.

Ehrsson, H., H. (2007). The experimental induction of out-of-body experiences. Science, 317, 1048.

Ehrsson, H., H., Spence, C., & Passingham, R., E. (2004). That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. Science, 305, 875–877.

Ethofer, T., Van De Ville, D., Scherer, K., & Vuilleumier, P. (2009). Decoding of emotional information in voice-sensitive cortices. Current Biology, 19, 1028–1033.

Feinberg, T., E., & Keenan, J., P. (2005). Where in the brain is the self? Consciousness Cognition, 4, 661-78.

Ferri, F., Frassinetti, F., Ardizzi, M., Costantini, M., & Gallese, V. (2012). A sensorimotor network for the bodily self. Journal of Cognitive Neuroscience, 24, 7, 1584-1595.

Ferri, F., Frassinetti, F., Costantini, M., & Gallese, V. (2011). Motor simulation and the bodily self. PLoS ONE, 6, 3, e17927.

Fink, G., R., Markowitsch, H., J., Reinkemeier, M., Bruckbauer T., Kessler J., & Heiss, W., D. (1996). Cerebral representation of one's own past: neural networks involved in autobiographical memory. Journal of Neuroscience, 16, 13, 4275-82.

Folstein, M., F., Folstein, S., E., & McHugh, P., R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research, 12, 3, 189-198.

Frassinetti F., Maini M., Benassi M., Avanzi S., Cantagallo A., & Farnè A. (2010). Selective impairment of self body-parts processing in right brain-damaged patients. Cortex, 46, 3, 322-8.

Frassinetti, F., Ferri, F., Maini, M., Benassi, M.G., & Gallese, V. (2011). Bodily self: an implicit knowledge of what is explicitly unknown. Experimental Brain Research, 212, 1, 153-160.

Frassinetti, F., Maini, M., Romualdi, S., Galante, E., & Avanzi, S. (2008). Is it mine? Hemispheric asymmetries in corporeal self recognition. Journal of Cognitive Neuroscience, 20, 8, 1507-1516.

Frassinetti, F., Pavani, F., Zamagni, E., Fusaroli, G., Vescovi, M., Benassi, M., Avanzi, S., & Farnè, A. (2009). Visual processing of moving and static self body-parts. Neuropsychologia, 47, 1988-1993.

Gabrieli, J., Fleischman D.A., Keane, M.M., Reminger, S., & Morrel, F. (1995). Double dissociation between memory system underlying explicit and implicit memory in the human brain. Psychological Science, 6, 76-82

Gainotti, G. (2011). What the study of voice recognition in normal subjects and brain-damaged patients tells us about models of familiar people recognition. Neuropsychologia, 49, 9, 2273-82.

Gainotti, G. (2013). Laterality effects in normal subjects' recognition of familiar faces, voices and names. Perceptual and representational components. Neuropsychologia, 51, 7, 1151-60.

Gallagher H., L., & Frith C., D. (2003). Functional imaging of 'theory of mind'. Trends in Cognitive Science, 7, 2, 77-83.

Gallagher, I., I. (2000). Philosophical conceptions of the self: implications for cognitive science. Trends in Cognitive Science, 4, 1, 14-21.

Gallese, V., & Sinigaglia, C. (2010). The bodily self as power for action. Neuropsychologia, 48, 3, 746-55.

Gandola, M., Invernizzi, P., Sedda, A., Ferrè, E., R., Sterzi, R., Sberna, M., Paulesu, E., & Bottini, G. (2012). An anatomical account of somatoparaphrenia. Cortex, 48, 9, 1165-78.

Garbarini, F., & Pia, L. (2013). Bimanual coupling paradigm as an effective tool to investigate productive behaviors in motor and body awareness impairments. Frontiers in human neuroscience, 7, 7-37.

Garbarini, F., Fornia, L., Fossataro, C., Pia, L., Gindri, P., & Berti, A.  (2014). Embodiment of others’ hands elicits arousal responses similar to one's own hands. Current Biology, 24, 16, R738-9.

Garbarini, F., Fossataro, C., Berti, A., Gindri, P., Romano, D., Pia, L., della, Gatta F., Maravita, A., & Neppi-Modona, M. (2015). When your arm becomes mine: pathological embodiment of alien limbs using tools modulates own body representation. Neuropsychologia, 70, 402-13.

Garbarini, F., Pia, L., Piedimonte, A., Rabuffetti, M., Gindri, P., & Berti, A. (2013). Embodiment of an alien hand interferes with intact-hand movements. Current Biology, 21, 23, 2, R57-8.

Gauthier, I., Tarr, M., J., Moylan, J., Skudlarski, P., Gore, J., C., & Anderson, A., W. (2000). The fusiform "face area" is part of a network that processes faces at the individual level. Journal of Cognitive Neuroscience, 12, 3, 495-504.

Gauthier, L., Dehaut, F., & Joanette, Y. (1989). The bells’ test: A quantitative and qualitative test for visual neglect. International Journal of Clinical Neuropsychology, 11, 49–54.

Gentilucci, M., Daprati, E., & Gangitano, M. (1998). Right-handers and left-handers have different representations of their own hand. Cognitive Brain Research, 6, 185–192.

Gerstmann J. (1942). Problem of imperception of disease and of impaired body territories with organic lesions. Relation to body schema and its disorders. Archives of Neurology and Psychiatry, 48: 890e913.

Gervais, H., Belin, P., Boddaert, N., Leboyer, M., Coez, A., Barthelemy, C., Brunelle F., Samson Y., & Zilbovicius M. (2004). Abnormal voice processing in autism: A fMRI study. Nature Neuroscience, 7, 801–802.

Giraud, A., L., & Truy E. (2002). The contribution of visual areas to speech comprehension: a PET study in cochlear implants patients and normal-hearing subjects. Neuropsychologia, 40, 9, 1562-9.

Graux, J., Gomot, M., Roux, S., Bonnet-Brilhault, F., & Bruneau, N. (2015). Is my voice just a familiar voice? An electrophysiological study. Social Cognitive and Affective Neuroscience, 10, 1, 101-5.

Graux, J., Gomot, M., Roux, S., Bonnet-Brilhault, F., Camus, V., & Bruneau, N. (2013). My voice or yours? An electrophysiological study. Brain Topography, 26, 1, 72-82.

Halligan, P., W., Cockburn, J., & Wilson, B., A. (1991). The behavioural assessment of visual neglect. Neuropsychological Rehabilitation: An International Journal, 1, 1, 5-32.

Kuperberg, G., R., McGuire, P., K., Bullmore, E., T., Brammer, M., J., Rabe-Hesketh, S., Wright, I., C., Lythgoe, D., J., Williams, S., C., & David, A., S. (2000). Common and distinct neural substrates for pragmatic, semantic, and syntactic processing of spoken sentences: an fMRI study. Journal of Cognitive Neuroscience, 12, 2, 321-41.

Krause, B., J., Schmidt, D., Mottaghy, F., M., Taylor, J., Halsband, U., Herzog, H., Tellmann, L., & Müller-Gärtner, H., W. (1999). Episodic retrieval activates the precuneus irrespective of the imagery content of word pair associates. A PET study. Brain, 122, 255-63.

Schmidt, D., Krause, B., J., Mottaghy, F., M., Halsband, U., Herzog, H., Tellmann, L., Müller-Gärtner, H., W. (2002). Brain systems engaged in encoding and retrieval of word-pair associates independent of their imagery content or presentation modalities. Neuropsychologia, 40, 4, 457-70.

Holzman, P. S., & Rousey, C. (1966). The voice as a percept. Journal of Personality and Social Psychology, 4, 79–86.

Hughes, S., M., & Nicholson, S., E. (2010). The processing of auditory and visual recognition of self-stimuli. Consciousness and Cognition, 19, 4, 1124-1134.

Invernizzi, P., Gandola, M., Romano, D., Zapparoli, L., Bottini, G., & Paulesu, E. (2013). What is mine? Behavioral and anatomical dissociations between somatoparaphrenia and anosognosia for hemiplegia. Behavioural Neurology, 26, 1-2, 139-50.

Ionta, S., Fourkas, A., D., Fiorio, M., & Aglioti, S., M. (2007). The influence of hands posture on mental rotation of hands and feet. Experimental Brain Research, 183, 1–7.

Ionta, S., Perruchoud, D., Draganski, B., & Blanke, O. (2012). Body context and posture affect mental imagery of hands. PLoS One, 7, 3, e34382.

Kaiser, D., Strnad, L., Seidl, K., N., Kastner, S., & Peelen, M.,V. (2014). Whole person-evoked fMRI activity patterns in human fusiform gyrus are accurately modeled by a linear combination of face-and body-evoked activity patterns. Journal of Neurophysiology, 111,1,82–90.

Kanwisher, N., McDermott, J., & Chun, M., M. (1997). The fusiform face area: a module in human extrastriate cortex specialized for face perception. Journal of Neuroscience, 1, 17, 11, 4302-11.

Kaplan, J., T., Aziz-Zadeh, L., Uddin, L., Q., & Iacoboni, M. (2008). The self across the senses: An fMRI study of self-face and self-voice recognition. Social Cognitive and Affective Neuroscience, 3, 3, 218-223.

Keenan, J., P., McCutcheon, B., Freund, S., Gallup, G., G., Jr, Sanders, G., & Pascual-Leone, A. (1999). Left hand advantage in a self-face recognition task. Neuropsychologia, 37, 12, 1421-5.

Keenan, J., P., Wheeler, M., A., Gallup, G., G., Jr, & Pascual-Leone, A. (2000). Self-recognition and the right prefrontal cortex. Trends in Cognitive Science, 4, 9, 338-344.

Kimberg, D.,Y., & Schwartz, M., F. (2007). Power in Voxel-based lesion-symptom mapping. Journal of Cognitive Neuroscience, 19, 7, 1067-80.

Kisilevsky, B., S., Hains, S., M., Lee, K., Xie, X., Huang, H., Ye, H., H., Zhang, K., & Wang, Z. (2003). Effects of experience on fetal voice recognition. Psychological Science, 14, 3, 220-4.

Krause, B., J., Horwitz, B., Taylor, J., G., Schmidt, D., Mottaghy, F., M., Herzog, H., Halsband, U., & Müller-Gärtner, H. (1999). Network analysis in episodic encoding and retrieval of word-pair associates: a PET study. European Journal of Neurosciemce, 11, 9, 3293-301.

Kuperberg, G., R., McGuire, P., K., Bullmore, E., T., Brammer, M., J., Rabe-Hesketh, S., Wright, I., C., Lythgoe, D., J., Williams, S., C., & David, A., S. (2000). Common and distinct neural substrates for pragmatic, semantic, and syntactic processing of spoken sentences: an fMRI study. Journal of Cognitive Neuroscience, 12, 2, 321-41.

Làdavas, E., Paladini R., & Cubelli R. (1993). Implicit associative priming in a patient with left visual neglect. Neuropsychologia, 31, 1307-1320.

Lang, C.J.G., Kneidl, O., Hielscher-Fastabend, M., & Heckmann, J.G. (2009). Voice recognition in aphasic and non-aphasic stroke patients. Journal of Neurology, 256, 1303–1306.

Lenggenhager, B., Tadi, T., Metzinger, T., & Blanke, O. (2007). Video ergo sum: manipulating bodily self-consciousness. Science, 317, 1096–1099.

Leube, D., T., Knoblich, G., Erb, M., Grodd, W., Bartels, M., & Kircher, T., T. (2003). The neural correlates of perceiving one's own movements. NeuroImage, 20, 2084–2090.

Linden, D. E., Thornton, K., Kuswanto, C. N., Johnston, S. J., van de Ven, V., & Jackson, M. C. (2011). The brain’s voices: Comparing nonclinical auditory hallucinations and imagery. Cerebral Cortex, 31, 330–337.

Grandjean, D., Sander, D., Pourtois, G., Schwartz, S., Seghier, M., L., Scherer, K., R., & Vuilleumier, P. (2005). The voices of wrath: brain responses to angry prosody in meaningless speech. Nature Neuroscience, 8, 2, 145-6.

Lloyd-Fox, S., Blasi, A., Mercure, E., Elwell, C., E., & Johnson, M., H. (2012). The emergence of cerebral specialization for the human voice over the first months of life. Social Neuroscience, 7, 3, 317-30.

Longo, M.R. (2015). Implicit and explicit body representations. European Psychologist, 20, 1, 6–15.

Maurer, D., & Landis, T. (1990). Role of bone conduction in the self-perception of speech. Folia Phoniatrica, 42, 226–229.

Yovel, G., & Belin, P. (2013). A unified coding strategy for processing faces and voices. Trends in Cognitive Science, 17, 6, 263-71.

Mazoyer, B. M., Tzourio, N., Frak, V., Syrota, A., Murayama, N., Levrier, O., Salamon, G., Dehaene, S., Cohen, L., & Mehler, J. (1993). The representation of speech. Journal of Cognitive Neuroscience, 5, 467–479.

Meadows, J., C. (1974). The anatomical basis of prosopagnosia. Journal of Neurology, Neurosurgery, and Psychiatry, 37, 489-501.

Medina, J., Kimberg, D., Y., Chatterjee, A., & Coslett, H., B. (2010). Inappropriate usage of the Brunner-Munzel test in recent voxel-based lesion-symptom mapping studies. Neuropsychologia, 48, 1, 341-3.

Metzinger, T., & Gallese, V. (2003). The emergence of a shared action ontology: building blocks for a theory. Conscious Cognition 12, 4, 549-71.

Merleau-Ponty, M. (1964). The Primacy of Perception, J.M. Edie (Ed.), Evanston: Northwestern University Press.

Moro, V. (2013). The Interaction between implicit and explicit awareness in anosognosia: Emergent awareness. Cognitive Neuroscience, 4, 3-4, 199-200.

Moro, V., Berlucchi, G., Lerch, J., Tomaiuolo, F., & Aglioti, S., M. (2008). Selective deficit of mental visual imagery with intact primary visual cortex and visual perception. Cortex, 44, 2, 109-118.

Moro, V., Pernigo, S., Zapparoli, P., Cordioli, Z., & Aglioti, S., M. (2011). Phenomenology and neural correlates of implicit and emergent motor awareness in patients with anosognosia for hemiplegia. Behavioural Brain Research, 225, 1, 259-269.

Nakamura, K., Kawashima, R., Sugiura, M., Kato, T., Nakamura, A., Hatano, K., Nagumo S., Kubota K., Fukuda H., Ito K., & Kojima S. (2001). Neural substrates for recognition of familiar voices: A PET study. Neuropsychologia, 39, 1047–1054.

Neuner, F., & Schweinberger, S., R. (2000) Neuropsychological impairments in the recognition of faces, voices, and personal names. Brain Cognition, 44, 3, 342-66.

Northoff G., Heinzel A., de Greck M., Bermpohl F., Dobrowolny H., Panksepp J. (2006). Self-referential processing in our brain-a meta-analysis of imaging studies on the self. Neuroimage, 31, 1, 440-57.

Northoff, G. (2016). Is the self a higher-order or fundamental function of the brain? The “basis model of self-specificity” and its encoding by the brain’s spontaneous activity. Cognitive Neuroscience, 1, 1-20.

Northoff, G., & Panksepp, J. (2008). The trans-species concept of self and the subcortical–cortical midline system. Trends in Cognitive Science, 12, 7, 259-264.

Parsons, L., M. (1987). Imagined spatial transformations of one's hands and feet. Cognitive Psychology, 19, 178–241.

Parsons, L., M. (1994). Temporal and kinematic properties of motor behavior reflected in mentally simulated action. Journal of Experimental Psychology. Human Perception and Performance, 20, 709–730.

Parsons, L., M., & Fox, P., T. (1998). The neural basis of implicit movements used in recognizing hand shape. Cognitive Neuropsychology, 15, 583-615.

Peelen, M., V., & Downing, P., E. (2007). The neural basis of visual body perception. Nature Review Neuroscience, 8, 8, 636-48.

Peelen, M.V., & Downing, P., E. (2005). Selectivity for the human body in the fusiform gyrus. Journal of Neurophysiology. 93, 1, 603–608.

Peretz, I., Kolinsky, R., Tramo, M., Labrecque, R., Hublet, C., Demeurisse, G. & Belleville, S. (1994). Functional dissociations following bilateral lesions of auditory-cortex. Brain, 117, 1283–1301.

Peretz, I., Kolinsky, R., Tramo, M., Labrecque, R., Hublet, C., Demeurisse, G., & Belleville, S. (1994). Functional dissociations following bilateral lesions of auditory cortex. Brain, 117, 1283-301.

Petkov, C., I., Kayser, C., Steudel, T., Whittingstall, K., Augath, M., & Logothetis, N., K. (2008). A voice region in the monkey brain. Nature Neuroscience, 11, 3, 367-74

Petkova, V., I., & Ehrsson, H., H. (2008). If I were you: perceptual illusion of body swapping. PLoS ONE 3, e3832.

Pia, L., Garbarini, F., Fossataro, C., Fornia, L., & Berti, A. (2013). Pain and body awareness: evidence from brain-damaged patients with delusional body ownership. Frontiers in Human Neuroscience, 20, 7, 298.

Pia, L., Spinazzola, L., Garbarini, F., Bellan, G., Piedimonte, A., Fossataro, C., Livelli, A., Burin, D., & Berti, A. (2014). Anosognosia for hemianaesthesia: a voxel-based lesion-symptom mapping study. Cortex, 61, 158-66.

Pitcher, D., Charles, L., Devlin, J.T., Walsh, V., & Duchaine, B. (2009). Triple dissociation of faces, bodies, and objects in extrastriate cortex. Current Biology, 19, 4,319–324.

Platek, S., M., Keenan, J., P., Gallup, G., G., Jr, & Mohamed, F., B. (2004). Where am I? The neurological correlates of self and other. Brain Research Cognition, 19, 114–122.

Platek, S., M., Loughead, J., W., Gur, R., C., Busch, S., Ruparel, K., Phend, N., Panyavin, I., S., & Langleben, D., D. (2006) Neural substrates for functionally discriminating self-face from personally familiar faces. Human Brain Mapping, 27, 2, 91-8.

Rorden, C., & Brett, M. (2000). Stereotaxic display of brain lesions. Behavioral Neurology, 12, 4, 191-20.

Rosa, C., Lassonde, M., Pinard, C., Keenan, J., P. & Belin, P. (2008). Investigations of hemispheric specialization of self-voice recognition. Brain and Cognition, 68, 2, 204-214.

Salerno, S., Zamagni, E., Urquizar, C., Salemme, R., Farnè, A., & Frassinetti, F. (2012). Increases of corticospinal excitability in self-related processing. European Journal of Neuroscience, 36, 2716-21.

Schall, S., Kiebel, S.J., Maess, B., & von Kriegstein, K. (2015). Voice identity recognition: functional division of the right STS and its behavioral relevance. Journal of Cognitive Neuroscience, 27, 2, 280–291.

Schmidt, D., Krause, B., J., Mottaghy, F., M., Halsband, U., Herzog, H., Tellmann, L., & Müller-Gärtner, H., W. (2002). Brain systems engaged in encoding and retrieval of word-pair associates independent of their imagery content or presentation modalities. Neuropsychologia, 40, 4, 457-70.

Schwarzlose, R., F., Baker, C., I., & Kanwisher, N. (2005). Separate face and body selectivity on the fusiform gyrus. Journal of Neuroscience, 25, 47,11055–11059

Schwoebel, J., & Coslett, H., B. (2005). Evidence for multiple, distinct representations of the human body. Journal of Cognitive Neuroscience, 17, 4, 543–553.

Sforza, A., Bufalari, I., Haggard, P., & Aglioti, S., M. (2010). My face in yours: Visuo-tactile facial stimulation influences sense of identity. Social Neuroscience, 5, 148–162.

Shallice, T. (1988). From neuropsychology to mental structure. Cambridge, UK: Cambridge University Press.

Spinazzola, L., Pia, L., Folegatti, A., Marchetti, & Berti, A. (2008). Modular structure of awareness for sensorymotor disorders: evidence from anosognosia for emiplegia and anosognosia for hemiaenesthesia. Neuropsychologia, 46, 915-926.

Sugiura, M., Sassa, Y., Jeong, H., Miura, N., Akitsuki, Y., & Horie, K. (2006). Multiple brain networks for visual self-recognition with different sensitivity for motion and body part. Neuroimage, 32, 1905–1917.

Sugiura, M., Watanabe, J., Maeda, Y., Matsue, Y., Fukuda, H., & Kawashima, R. (2005). Cortical mechanisms of visual self-recognition. Neuroimage, 24, 143–149.

Tranel D., & Damasio A. R. (1985). Knowledge without awareness: An autonomic index of facial recognition by prosopagnosics. Science, 228, 1453-1455.

Tsakiris, M., Costantini, M., & Haggard, P. (2008). The role of the right temporo-parietal junction in maintaining a coherent sense of one's body. Neuropsychologia, 46, 12, 3014-8.

Tsakiris, M., Hesse, M., D., Boy, C., Haggard, P., & Fink, G., R. (2007). Neural signatures of body ownership: a sensory network for bodily self-consciousness. Cerebral Cortex, 17, 2235–2244.

Tulving, E. (1991). Concepts of human memory, in L. Squire: Memory: Organization and locus of change. New York: Oxford University press, 3-32.

Turk, D., J., Heatherton, T., F., Macrae, C., N., Kelley, W., M., & Gazzaniga, M., S. (2003). Out of contact, out of mind: the distributed nature of the self. Ann. N Y Acad. Science, 1001, 65–78.

Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., Mazoyer, B., & Joliot, M. (2002). Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. Neuroimage, 15, 273–289.

Uddin, L., Q., Kaplan, J., T., Molnar-Szakacs, I., Zaidel, E., & Iacoboni, M. (2005). Self-face recognition activates a frontoparietal "mirror" network in the right hemisphere: An event-related fMRI study, Neuroimage, 25, 3, 926-935.

Uddin, L., Q., Molnar-Szakacs, I., Zaidel, E., & Iacoboni, M. (2006). rTMS to the right inferior parietal lobule disrupts self-other discrimination. Social cognitive and affective neuroscience, 1, 1, 65-71.

Urgesi, C., Calvo-Merino, B., Haggard, P., & Aglioti, S., M., (2007). Transcranial magnetic stimulation reveals two cortical pathways for visual body processing. Journal of Neuroscience, 27, 30,8023–8030.

Vallar, G., & Ronchi, R. (2006). Anosognosia for motor and sensory deficits after unilateral brain damage: A review. Restorative neurology and neuroscience, 24, 4-6, 247-257.

Vallar, G., & Ronchi, R. (2009). Somatoparaphrenia: a body delusion. A review of the neuropsychological literature. Experimental brain research, 192, 3, 533-551.

Van Lancker, D., Kreiman, J. & Cummings, J. (1989). Voice Perception Deficits: Neuroanatomical correlates of phonagnosia. Journal of Clinical and Experimental Neuropsychology, 11, 665-674.

Van Lancker, D., R., Cummings, J., L., Kreiman, J., & Dobkin, B., H. (1988). Phonagnosia: a dissociation between familiar and unfamiliar voices. Cortex, 24, 195–209.

Van Lancker, D.R., & Canter, G.J. (1982). Impairment of voice and face recognition in patients with hemispheric damage. Brain and Cognition, 1, 185–195.

Verdon V., Schwartz, S., Lovblad, K., O., Hauert C., A., & Vuilleumier, P. (2010). Neuroanatomy of hemispatial neglect and its functional components: a study using voxel-based lesion-symptom mapping. Brain, 133; 880–894.

von Kriegstein, K., & Giraud, A. L. (2004). Distinct functional substrates along the right superior temporal sulcus for the processing of voices. Neuroimage, 22, 948–955.

von Kriegstein, K., Eger, E., Kleinschmidt, A., & Giraud, A. L. (2003). Modulation of neural responses to speech by directing attention to voices or verbal content. Cognitive Brain Research, 17, 48–55.

Vouloumanos, A., Hauser, M., D., Werker, J., F., & Martin, A. (2010). The tuning of human neonates' preference for speech. Child Development, 81, 2, 517-27.

Vuković, M., Sujić, R., Petrović-Lazić, M., Miller, N., Milutinović, D., Babac, S., & Vuković, I. (2012). Analysis of voice impairment in aphasia after stroke-underlying neuroanatomical substrates. Brain and Language, 123, 1, 22-9.

Xu, M., Homae F., Hashimoto R., & Hagiwara H. (2013). Acoustic cues for the recognition of self-voice and other-voice. Frontiers in Psychology, 4, 735.

Zeller, D., Gross, C., Bartsch, A., Johansen-Berg, H., & Classen, J. (2011). Ventral premotor cortex may be required for dynamic changes in the feeling of limb ownership: a lesion study. Journal of Neuroscience, 31, 4852–7.

Schall, S., & von Kriegstein, K. (2014). Functional connectivity between face-movement and speech-intelligibility areas during auditory-only speech perception. PLoS One, 23, 9, 1, e86325.