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Right insular damage decreases heartbeat awareness and alters cardio-visual effects on bodily self-consciousness

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ABSTRACT

Recent evidence suggests that multisensory integration of bodily signals involving exteroceptive and interoceptive information modulates bodily aspects of self-consciousness such as self-identification and self-location. In the so-called Full Body Illusion subjects watch a virtual body being stroked while they perceive tactile stimulation on their own body inducing illusory self-identification with the virtual body and a change in self-location towards the virtual body. In a related illusion, it has recently been shown that similar changes in self-identification and self-location can be observed when an interoceptive signal is used in association with visual stimulation of the virtual body (i.e., participants observe a virtual body illuminated in synchrony with their heartbeat). Although brain imaging and neuropsychological evidence suggest that the insular cortex is a core region for interoceptive processing (such as cardiac perception and awareness) as well as for self-consciousness, it is currently not known whether the insula mediates cardio-visual modulation of self-consciousness. Here we tested the involvement of insular cortex in heartbeat awareness and cardio-visual manipulation of bodily self-consciousness in a patient before and after resection of a selective right neoplastic insular lesion. Cardio-visual stimulation induced an abnormally enhanced state of bodily self-consciousness; in addition, cardio-visual manipulation was associated with an experienced loss of the spatial unity of the self (illusory bi-location and duplication of his body), not observed in healthy subjects. Heartbeat awareness was found to decrease after insular resection. Based on these data we propose that the insula mediates interoceptive awareness as well as cardio-visual effects on bodily self-consciousness and that insular processing of interoceptive signals is an important mechanism for the experienced unity of the self.

1. Introduction

The study of the bodily features of self-consciousness is an intriguing topic in recent neuroscience. Normally, people experience a unitary sense of self that is felt to be localized within the boundaries of the physical body (bodily self-consciousness, BSC; Blanke, 2012; de Vignemont, 2011). Multiple sources of exteroceptive information (tactile, vestibular, visual signals) contribute to BSC. Indeed, if one or more of these signals are manipulated different components of BSC can be altered experimentally, such as the feeling that this body belongs to me (self-identification or body ownership) and the feeling of where my body is located in space (self-location) (Blanke and Metzinger, 2009). One example of such an experimental paradigm is the so-called Full Body Illusion (FBI). During this illusion people view a virtual body being stroked while they simultaneously feel touch on their own body: after several minutes of stimulation this procedure induces the feeling that the virtual body belongs to them (self-identification) and is associated with a recalibration of where subjects perceive to be localized in space, characterized by a drift in self-location towards the virtual body (Aspell et al., 2009; Ehrsson, 2007; Lenggenhager et al., 2007; Palluel et al., 2011; Petkova and Ehrsson, 2008). If the visual and tactile stimuli are administered out of synchrony, no changes in BSC occur. Thus, during the FBI two temporally synchronous exteroceptive (vision and touch) stimuli are in spatial conflict: each stimulation refers to a body, and the bodies (the real and the virtual bodies) occupy two different spatial locations.

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Exteroceptive information is not the only source contributing to BSC. It has been theorized that internal states and visceral signals are at least of equal importance for the bodily self (Craig, 2002; Damasio, 2000). Moreover, recent behavioural experiments (Aspell et al., 2013; Suzuki et al., 2013) demonstrated that exteroceptive and interoceptive signals jointly affect BSC. Thus, Aspell et al. (2013) showed that the FBI can also be induced by using a cardio-visual (CV) conflict instead of the visuo-tactile (VT) conflict as described above. Using a novel FBI-CV paradigm, during which participants view a virtual body that is surrounded by a glow flashing in synchrony with the subjects' heartbeat, it was reported that both self-identification for and drifts in self-location towards the virtual body are induced similarly to changes as observed by VT stimulation (Aspell et al., 2013). A similar procedure was shown to induce self-attribution of a virtual hand after CV synchronous stimulation in a CV version of the rubber hand illusion (Suzuki et al., 2013). The effects induced by this novel CV manipulation suggest that interoceptive (cardiac) and exteroceptive (visual) signals are integrated and that both signals and their integration are relevant for BSC.

However, the brain mechanisms of CV integration in general and during the FBI-CV in particular are currently unknown. One key candidate region that has been repeatedly associated with the processing of interoceptive cardiac signals using functional magnetic resonance imaging (fMRI) is the insular cortex (Critchley et al., 2004; Wiebking et al., 2014). Moreover, awareness of interoceptive signals, as measured by a heartbeat awareness task, has been related to activity of the right insula (Critchley et al., 2004; Zaki et al., 2012). Other evidence has linked the insula to bodily self-processing by associating insular activity with illusory self-attribution of a fake hand (Tsakiris et al., 2007). Neuropsychological studies also support the link between insula and BSC. Patients with right brain damage may show impaired self-attribution of their own body parts (somatoparaphrenia: see Vallar and Ronchi, 2009 for a review). The neural correlates of somatoparaphrenia include an extensive network of fronto-temporo-parietal areas, with the involvement of subcortical structures; some cases have been reported with lesion affecting deep cortical regions such as the insula (Cereda et al., 2002; Karnath and Baier, 2010; Levine et al., 1991). Moreover, patients with heautoscopy, illusory own body perceptions characterized by the feeling of seeing one's own body in extrapersonal space and strong self-identification with this illusory body, suffer from lesions centred in the insular region (Heydrich and Blanke, 2013).

In the present study we investigated the involvement of insular cortex in heartbeat awareness and the effects of cardio-visual stimulation on BSC in a patient before and after resection of a selective right neoplastic insular lesion.

2. Materials and methods

2.1. Participants

The patient was a 43-year-old male, working as pastry chef. He was admitted to University Geneva Hospital for an epileptic generalized seizure. The computerized tomography (CT) and the magnetic resonance imaging (MRI) scans showed the presence of a right neoplastic lesion, affecting the entire right insula. The lesion invaded both anterior and posterior lobules of the right insula with the exception of the caudal portion of the anterior long insular gyrus. It was in general circumscribed by the anterior, superior and inferior peri-insular sulci. However, antero-inferiorly it extended beyond the insula's transverse gyrus to the postero-medial orbital lobule of the frontal lobe; inferiorly, it spread into the planum polare of the temporal lobe; medially, it involved the capsula extrema, the claustrum, the capsula externa and abutted the putamen along its whole lateral length, as far cranially as the superior-lateral aspect of the head of the caudate nucleus. Interviews with the patient revealed that the first symptoms consisted of short euphoric states that started several months before the current hospitalization. During these states he smiled and laughed without any apparent reason or associated mirth. No other abnormal sensations or behaviours were noted. At the time of hospitalization in the Department of Neurosurgery at Geneva Hospital the patient was alert and cooperative. The neurological exam showed preserved motor, somatosensory and visual functions, which remained unimpaired also after the tumour removal. No visual or tactile extinction to double stimulation was detected. A short neuropsychological evaluation was administered to the patient. He was perfectly oriented in time (day, month, year, season, date) and in space (country, canton, city, place, floor), and completely aware about his medical/neurosurgical condition (as assessed during a clinical interview). With respect to the spatial functions, we administered to the patient two cancellation tasks and one bisection task, as classically done in standard clinical evaluation of unilateral left spatial neglect. Both before and after the surgery the patient demonstrated a good performance and within the cut off scores of the control sample: no target omission in the star cancellation test, only one omission on the left side in the letter cancellation test after surgery, and a deviation score of −1.67 mm before and +0.5 mm after the surgery. No left personal neglect was detected, asking the patient to reach a body part on the left side using the unimpaired right hand (score: 0/3). Finally, during a semi-structured interview the patient demonstrated a perfect and immediate attribution of the left and right body-parts both before and after the operation, therefore no signs of somatoparaphrenia (Vallar and Ronchi, 2009). Table 1 shows the results of the neuropsychological assessment of left spatial and personal neglect. Fig. 1 shows the magnetic resonance images of the patient's brain damage before (Fig. 1A) and after (Fig. 1B) the

Table 1
Neuropsychological evaluation of the patient to assess the presence of left spatial and personal neglect.

Test	Cut off (range)	Patient's score Before surgery	After surgery
Unilateral spatial neglect			
Target cancellation			
Star [a,b]	1(0/56)	0	0
Letter[c,d]	2(0/104)	0	1
Line bisection[b]	+0.74[#](−2.3/+5.67)	−1.67	+0.5
Personal neglect			
Reaching of body parts			
Hand[e]	0(0/3)	0	0

Scores: cancellation tasks (differences of omissions between the left and the right side of the paper); line bisection (deviation in millimetres: positive score=rightward deviation; negative score=leftward deviation); hand reaching (errors).

[#] Mean bisection deviation of controls.

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