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Audio-visual sensory deprivation degrades visuo-tactile peri-personal space

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ABSTRACT

Self-perception is scaffolded upon the integration of multisensory cues on the body, the space surrounding the body (i.e., the peri-personal space; PPS), and from within the body. We asked whether reducing information available from external space would change: PPS, interoceptive accuracy, and self-experience. Twenty participants were exposed to 15 min of audio-visual deprivation and performed: (i) a visuo-tactile interaction task measuring their PPS; (ii) a heartbeat perception task measuring interoceptive accuracy; and (iii) a series of questionnaires related to self-perception and mental illness. These tasks were carried out in two conditions: while exposed to a standard sensory environment and under a condition of audio-visual deprivation. Results suggest that while PPS becomes ill defined after audio-visual deprivation, interoceptive accuracy is unaltered at a group-level, with some participants improving and some worsening in interoceptive accuracy. Interestingly, correlational individual differences analyses revealed that changes in PPS after audio-visual deprivation were related to interoceptive accuracy and self-reports of "unusual experiences" on an individual subject basis. Taken together, the findings argue for a relationship between the malleability of PPS, interoceptive accuracy, and an inclination toward aberrant ideation often associated with mental illness.

1. Introduction

Prominent models of self-consciousness stress the role of integration between multisensory exteroceptive (i.e., processing of external sensory stimuli; Blanke, 2012; Blanke, Slater, & Serino, 2015, Bermudez et al., 1995) and interoceptive (i.e., processing of sensory stimuli from within the body; Damasio, 2010; Seth, 2011; Craig, 2002, 2009; Critchley & Seth, 2012) signals as essential in the formation of a pre-reflexive form of bodily self-consciousness (BSC). BSC includes the feeling of owning a body, of being at a specific location in space, and of experiencing the world from a particular first-person perspective (Blanke & Metzinger, 2009). Intriguingly, signals relevant for BSC are not limited to the body itself – with crucial contributions from the tactile, proprioceptive and

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thermo-nocioceptive systems (see Haggard, Iannetti, & Longo, 2013 and Legrain, 2017, for theoretical postulates casting nocioception as inherently multisensory, fundamental in body representation, and most importantly for the current purpose, with a double function both in exteroception and interoception) - but they equally extend within one's peri-personal space (PPS; Blanke et al., 2015; Noel, Grivaz, et al., 2015, Noel, Pfeiffer, et al., 2015; Salomon et al., 2017; Bernasconi et al., 2018); that is, the space immediately adjacent to and surrounding the body (Di Pellegrino, Ladavas, & Farne, 1997; Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997; Serino et al., 2015). Indeed, all physical interactions between the individual's body and the external environment take place within the PPS. Accordingly, by modulating multisensory cues not only from the body, but also within the PPS, it is possible to alter the different components of BSC (Noel, Grivaz, et al., 2015, Noel, Pfeiffer, et al., 2015; Salomon et al., 2017). For example, by manipulating visuo-tactile spatio-temporal congruencies (tactile on the body and visual in the PPS) it is possible to induce ownership for an artificial hand (as in the rubber hand illusion; RHI, Botvinick & Cohen, 1998), face (as in the enfacement illusion; Tsakiris, 2008) or even the whole body (as in the body-swap illusion, Petkova & Ehrsson, 2008). Further, the administration of controlled multisensory cues at the body and within the PPS may even shift the perceived location of the self in space (as in the full body illusion; FBI, Lenggenhager et al., 2007; Noel, Grivaz, et al., 2015, Noel, Pfeiffer, et al., 2015; Salomon et al., 2017) and the direction of the first-person perspective (Petkova & Ehrsson, 2008; Ionta et al., 2011).

On the other hand, focusing on internal as opposed to external bodily cues, experimentally induced altered states of BSC due to the administration of conflicting exteroceptive sensory signals (Botvinick & Cohen, 1998; Lenggenhager et al., 2007; Ehrsson, 2007) have been shown to affect aspects of interoception such as autonomic responses (Ehrsson, Wiech, Weiskopf, Dolan, & Passingham, 2007) and neural representations of cardiac afferents (Park et al., 2016). In the case of the RHI (Botvinick & Cohen, 1998), for instance, illusory ownership for a rubber hand is associated with a reduction of the skin temperature of the participant's real hand (Moseley et al., 2008, but see de Haan et al., 2017) and an increase in its histamine reactivity (Barnsley et al., 2012). Similar temperature effects have been reported for the FBI (Salomon, Lim, Pfeiffer, Gassert, & Blanke, 2013). In addition, there exists a negative relation between an individual's capacity for interoceptive accuracy (in this case operationalized as the ability to detect their own heartbeats without measuring their pulse) and their proneness to the RHI (Tsakiris, Tajadura-Jimenez, & Costantini, 2011) and the enfacement illusion (Tajadura-Jimenez et al., 2012, 2013). These results suggest that individuals with low interoceptive accuracy might rely more heavily on external sensory cues in forming a representation of their bodily self, and hence be more prone to illusions mediated by multisensory external cues. More directly, recent data demonstrated a strong relationship between exteroceptive and interoceptive sensory signals in giving rise to BSC (Suzuki, 2013; Aspell, 2013; Adler, Herbelin, Similowski, & Blanke, 2014). Indeed, artificially introduced matches (illusion condition; vs. mismatches or control condition) between cardiac and visual signals provoke the RHI (Suzuki et al., 2013) and the FBI (Aspell et al., 2013; see also Adler at al. (2014) for a FBI using respiratory signals), much in the same way that spatially concordant visual-tactile stimuli promote the illusion. Thus, it appears that there are strong relationships between the manner in which individuals process exteroceptive and interoceptive sensory signals, and in addition, this relationship appears to modulate BSC.

Although prior studies have attempted to manipulate interoceptive accuracy in order to measure concomitant body representation changes (Ainley, Tajadura-Jiménez, Fotopoulou, & Tsakiris, 2012, 2013; Stevens et al., 2011; Khasha et al., 2008; Fairclough & Goodwin, 2007; Maister & Tsakiris, 2013) few have studied the relationship between the processing of interoceptive and exteroceptive signals within and beyond the PPS. Indeed, within this framework, Legrain and colleagues have highlighted the nocioceptive system as one straddling interoceptive and exteroceptive domains (Haggard et al., 2013) to demonstrate that visual stimuli within but not beyond the PPS modulates nocioceptive processing, in particular in the temporal dimension (De Paepe, Crombez, Spence, & Legrain, 2014, 2017; Filbrich et al., 2017; further see Bultitude, Walker, & Spence, 2017 for recent corroborative evidence from a different group). Nonetheless, a direct causal manipulation offsetting the weighting between exteroceptive and interoceptive signaling, and subsequently measuring the impact of this remapping on PPS and BSC is lacking. Indeed, while the relationship between interoceptive accuracy and BSC has been described in prior work (Tsakiris et al., 2011; Tajadura-Jimenez et al., 2012, 2013; Aspell et al., 2012), only a single study (Ferri, Ardizzi, Ambrosecchia, & Gallese, 2013) has attempted to investigate whether interoceptive accuracy was associated with an autonomic response (more precisely, respiratory sinus arrhythmia) indexing PPS. Further, while the above mentioned study (Ferri et al., 2013) showed a positive association between interoceptive accuracy and an autonomic response to interpersonal stimulation (i.e., another person's hand approaching the participant's body) at the boundary of the PPS anchored on the hand (i.e., the peri-hand space; see Serino et al., 2015), no study has investigated the relation between interoception and fundamental characteristics of an individual's PPS, such as it's size (i.e., the spatial extent over which exteroceptive signals modulate somatosensory processing on the body) or it's gradient (i.e., the sharpness in the division between peri- and extra-personal space), as well as their respective link (interoception and PPS) to the experience of the self in space.

Indeed, if the neural encoding of the PPS (and thus the boundary between the peri- and extra-personal space) is conceived as encoding the interface between the individual's body (or body-related space) and the environment, it is possible that PPS and interoceptive accuracy interact in building one's BSC (see Noel, De Niear, Lazzara, & Wallace, 2017, for a similar argument). If true, one would expect a relationship between the spatial extent (i.e., size) and/or shape (i.e., gradient or the way in which 'far' and 'near' space are distinguished) of one's PPS and interoceptive accuracy. Further, it may be that certain PPS representations, such as the peri-trunk space (i.e., the PPS anchored on the trunk) – due to its association with self-location (Blanke, 2012; Blanke et al., 2015) – and not others, such as the peri-face space (i.e., the PPS anchored on the face), are related to interoception accuracy and BSC.

As a result of these questions, the first aim of this study is to highlight potential relationships between PPS, interoceptive accuracy, and BSC by attempting to manipulate the relative strength of exteroceptive and interoceptive signals. To this aim, we submitted healthy subjects to a short session of audio-visual deprivation in an anechoic chamber, in an attempt to reduce exteroceptive processing and hence potentially enhance interoception processing. That is, we conceived that the most direct approach in testing the

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