Toward a Physiological Understanding of Presence and Embodiment

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Introduction

- Accumulating evidence suggests that the origins of self-consciousness are the consequence of integrating information from multiple sensory modalities. This illusion of the self is referred to as bodily self-consciousness (BSC).
- Current scientific literature proposes that BSC results from the perception of presence and embodiment.
- Traditionally, embodiment is induced by applying congruous visuotactile stimulation between a virtual or rubber extremity, and real extremity hidden from view (Figure 1A).
- Presence is induced using synchronous front or back stroking paradigms to generate full body illusions. Presence altering experiments such as these use cameras or virtual reality head mounted displays (HMDs) to alter the user's visual perspective (Figure 1B).
- While there are numerous perceptual experiences that can influence subjective experiences of BSC, research suggests that embodiment and presence may be supported by partially, or fully dissociated networks (Longo et al., 2008; Maselli & Slater, 2013; Guterstam et al., 2015).

BSC Components May Have Distinct Neural Correlates

- Areas presumed to be activated during experiences of bodily self consciousness include the dorsal and ventral visual streams, the parietal cortex, the premotor cortex, the mesial temporal areas (including the hippocampus, amygdala and insula), precuneus, the brainstem and the thalamus (Figure 2) (Baumgartner et al. 2008; Petkova, 2011; Ionta et al., 2011, 2014; Clemente, 2013; Guterstam et al., 2015).
- Embodiment particularly has been associated with areas including the ventral premotor cortex and intraparietal sulcus. These areas have been linked to the integration of multisensory signals that are believed to maintain an accurate central representation of one's body in space (Graziano et al., 1997; Guterstam et al., 2015).
- Presence has been largely attributed to the hippocampus, retrosplenial cortex, insula, posterior cingulate cortex, precuneus, and temporoparietal junction, which are areas that have been implicated in egocentric and allocentric representations of space, perceived self location, and head direction in virtual worlds (Guterstam et al., 2015; Ionta et al., 2011, 2014).

The Significance of the Insula in the Culmination of BSC in Virtual Reality

- The insula regulates the integration of multisensory signals linked to interoceptive attention (awareness of bodily signals including the gut, heartbeat),vestibular and proprioceptive fields, sense of agency, awareness of pain and emotion (Figure 3), and our perception of time (Craig, 2009; Johnston & Olson, 2015, Macauda et al, 2019).
- Clemente et al. (2013), have shown that insula increases in fMRI BOLD activation during a free virtual navigation task compared to watching a video, or viewing pictures of the same object.
- Guterstam et al., (2015) observed changes in insula activity in response to perceived changes in perceived head direction and bodily threat.
- Although activity in the insula has been observed in studies measuring experiences of embodiment and presence separately, it is inconclusive as to what the functional role the insula plays in the manifestation of presence and embodiment.
- The insula may act as to provide a global representation of BSC by using Bayesian statistics to compute the most accurate representation of incoming vestibular and proprioceptive, somatosensory information in that given moment of time.

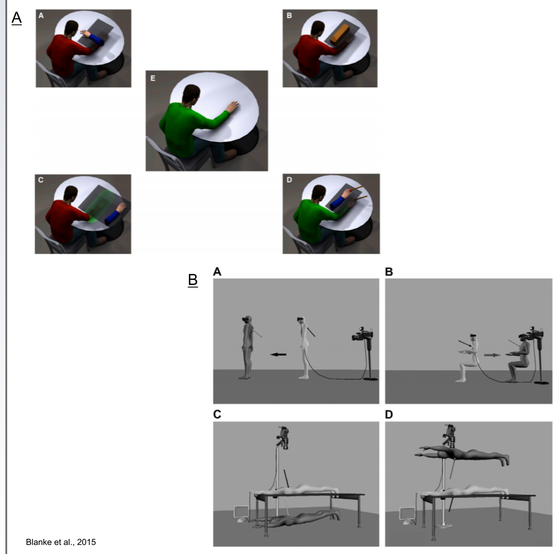
Specific Aims

1. Identify the neural correlates of embodiment in virtual environments
2. Identify the neural correlates of presence in virtual environments
3. Compare two putative models of BSC

Current Study

- Subjects will participate in a luge-style game which will be compatible with lying supine in the MR scanner bore (Figure 4).
- Cameras outside the scanner will track the movement of subject's feet so that rotating the feet left or right enables the virtual avatar to move and avoid obstacles on the course.
- A first-person, or third-person view of the body, sled, and obstacle course be presented via a MR compatible goggles.
- Generally, subjects should navigate various courses without crashing.

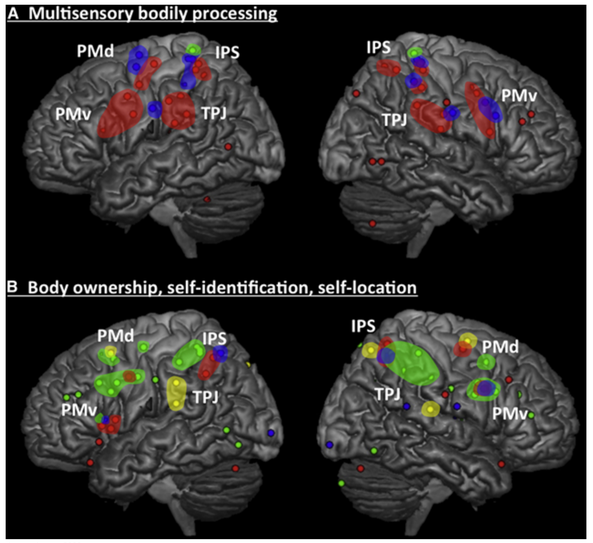
FIGURE 1



Blanke et al., 2015

(A) Embodiment is the feeling of ownership towards a real or virtual extremity. The illusion of embodiment dependent on the position and orientation of the extremity in relation to the body.
(B) Presence is defined as the feeling of being located in a place in time. Presence is traditionally induced in laboratories with cameras and HMDs.

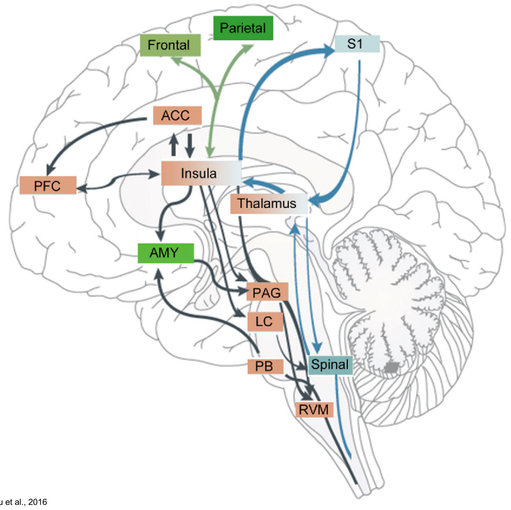
FIGURE 2



Leggenhager, 2009

(A) Brain areas selectively responding to multisensory inputs within the PPS around the hand (red), face (blue) or trunk (green).
(B) Brain areas active during manipulations of BSC, underlying ownership for the hand (red) or face (blue), self-identification (green), or self-location (yellow). The colored shadows highlight clusters of activations.

FIGURE 3



Lu et al., 2016

The insula is highly interconnected with many brain regions involved with BSC including emotion related structures like the amygdala, anterior cingulate cortex, and orbitofrontal cortex. Exteroceptive and interoceptive information believed to diverge into insula giving rise to self-awareness. The insula may provide richer context and integration of information and emotion and establish the link between physical and subjective consciousness.

FIGURE 4

The experimental game design was created using Unity's game development software. Above is an example of a high embodiment condition in which visual feedback via the avatar will correspond to the subject's movement and participants will view the game from a first-person perspective.

Methods

Experiment 1: Embodiment

- Designed to measure whether fronto-parietal networks, including the insula, are correlated with changes to perceived embodiment in virtual environments.
- The *high-embodiment* condition will involve controlling the avatar in first person with the visual feedback corresponding to the subject's actual movement.
- The *low-embodiment* condition will be identical except that visual feedback for the avatar will be uncorrelated with the subject's body motion. Moving the feet will still move the sled correctly, but the avatar's legs will make random movements that are not correlated with the user input.

Experiment 2: Presence

- Will measure whether temporal-parietal networks, including the insula are correlated with changes to perceived presence in virtual environments.
- The *high-presence* condition will be identical to the high-embodiment condition above.
- In the *low-presence* condition, the subject will view the avatar from the third-person perspective.

Post-scan questionnaires and in-game queries of embodiment presence will be used to measure subjective reports throughout each experiment.

Expected Outcomes

- Congruous haptic and visual feedback viewed from first-person perspective should illicit greater subjective experiences of embodiment and presence compared to low embodiment and presence conditions (measured by subjective reports).
- High embodiment and high presence conditions should elicit a greater functional BOLD response than low embodiment or low presence conditions in brain regions corresponding with embodiment and presence, respectively.
- An increase in insula activity for high embodiment and presence conditions should also be observed, given its role in sensory integration and self-awareness.
- It is predicted that embodiment is a prerequisite for presence and that perceptual experiences of BSC are mediated by the insula in addition to the PCC.
- Unlike the model proposed by Maselli and Slater, specific regions within the brain are predicted to mediate experiences associated with presence and embodiment as suggested by Guterstam et al. (2015) and Tsakiris (2017).

Conclusions

- This study seeks to develop a mechanistic explanation for BSC in virtual reality, and ultimately establish a more rigorous scientific foundation for the imminent wave of virtual reality technology on the horizon.
- This insula may provide as a potential region of interest given the accumulating evidence showing its recruitment during traditional, non-interactive and interactive front and back stroking BSC inducing paradigms.
- The insula has been implicated in subjective experiences involving emotional valence, heartbeat awareness, and integrating bodily signals (Wang et al., 2019). Further exploring the role the insula in mediating embodiment and presence during fully immersive virtual games may be important in establishing physiological mechanisms of BSC.
- Understanding the physiological mechanisms of BSC in virtual reality may further validate its usefulness in science, business, and education. Providing answers to foundational questions may inform educational designers about how virtual reality should be developed to improve engagement, engender motivation, and fostering learning. Furthermore, conclusions drawn from this experiment may be used to further understand clinical alterations of body representation (Case et al., 2020).

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