Neuroscience: Teleporting Mind into Body and Space

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http://dx.doi.org/10.1016/j.cub.2015.04.010

Brain imaging and a novel 'body-swop' illusion reveals distinct parietal-premotor and parietal-hippocampal networks involved in constructing a sense of body-ownership and self-location, with the posterior cingulate mediating between them.

Being able to instantly teleport to another place is a theme repeatedly explored in science fiction. The idea that, because of advanced technology, we could escape physical laws and instantaneously travel to far off places is a seductive idea both for the lazy and the adventurous. As with many ideas in science fiction, the idea of teleporting raises deep questions about what it means to be located in the world or to inhabit a body. Reports of neurological patients with out-of-body experiences show that it is possible to lose the sense of being located inside one's body [1]. Such cases are rare, making it difficult to determine from such patients the specific brain regions that underlie our sense of who we are and where we are. Using functional magnetic resonance imaging (fMRI), virtual reality and experimentally induced illusions it has been possible to gain some traction on the neural substrates of self-location and body-ownership. Research in this area has fallen into two distinct camps, those who have focused on using virtual reality to explore how the brain represents self-location and orientation (for example, [2–7]), and others who have exploited illusions to study body-ownership (for example, [8–11]). Now, as they report in this issue of *Current Biology*, Guterstam *et al.* [12] have taken the novel approach of combining these methods to determine which brain areas support both the sense of body-ownership and the sense of self-location, and the brain regions that mediate between them.

Body Illusions and Virtual Worlds
The most well-known body-ownership illusion is the 'rubber hand illusion' [13,14]. In this experimentally induced illusion, tactile stimuli are delivered to a person's visually obscured hand while that person observes the synchronous tactile stimulation of a viewed rubber hand, which leads to them believing that the rubber hand is their own hand. By introducing a time lag between the visually perceived and physically sensed tactile stimulation (asynchronous stimulation) the perceived illusory ownership of the rubber hand diminishes over time. A similar paradigm has been used with the addition of virtual reality techniques to induce the subjective feeling of whole-body ownership [15]. In this method participants observe an avatar through virtual reality goggles; using synchronous or asynchronous visual-tactile input, perception of whole-body ownership can be modulated in the person wearing the goggles. It has been shown that premotor-parietal regions play a key role in this sense of body ownership [14,16,17].

In addition to the sense that our body is ours, we also keep track of where we are in the world, our sense of self-location. Recording single units in the hippocampus, parahippocampal and parietal regions of rodents has provided detailed evidence for a network of spatial cells that code self-location and orientation [18,19]. Studying humans, researchers have combined fMRI with the use of virtual reality or real-world stimuli to decode location [2,4,5] and orientation in the world [3,4,7]. Such studies have shown that similar brain regions in humans and rodents code self-location and orientation.

Combining Body-swop and Location-swop Illusions
To determine which brain regions mediate the interactions between body-ownership and self-location, Guterstam *et al.* [12] took a new approach. They scanned subjects with fMRI while the subjects' perception of self-location, head direction, and body ownership was manipulated using a multisensory out-of-body illusion. Subjects wore virtual reality goggles, through which they were given video feed from three cameras (one at a time) located in the room in which they were being scanned (Figure 1). From each viewpoint, subjects could see a torso and legs of a manikin stretching into the space ahead them, consistent with the orientation of their own torso and legs in the MRI scanner. They could not see their own torso and legs because of the virtual reality goggles they were wearing.

Switching between the video feed from each of the cameras effectively allowed Guterstam *et al.* [12] to 'teleport' subjects to different locations and orientations in the room. For half of the experimental trials, an out-of-body illusion was created by an experimenter applying touches to the subject's torso synchronously with footage of an experimenter touching the torso of the manikin viewed in the video feed. On the other half of trials, touches were given asynchronously, breaking the illusion. Guterstam *et al.* [12] provide evidence from a number of tests to indicate this illusion was successful, which included subjects' own self-report of the experience.

Consistent with prior studies [14,16,17], Guterstam *et al.* [12] found
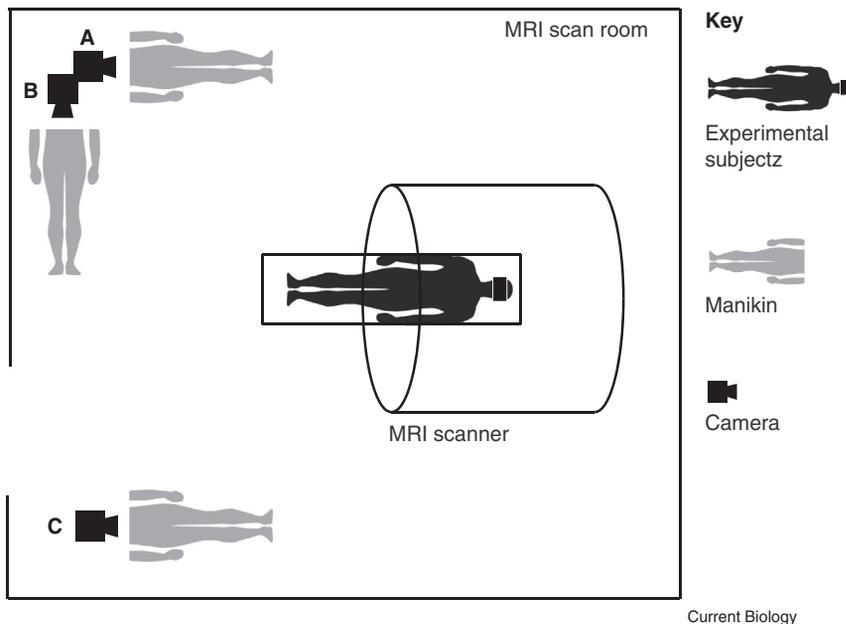
Figure 1. The multiple body-swop illusion.
The experimental subject is shown lying in the MRI scanner wearing virtual reality goggles that could receive video feed from each of the three cameras positioned across the room (positions A–C). Each of the three cameras had a manikin placed lying oriented supine, feet ahead of the camera. To induce the body-swop illusion the experimenter touched the participant's torso with a ball on a stick synchronously with footage of touches to the manikin's torso viewed through the virtual reality goggles. Videos from each camera were separately pre-recorded, such that the camera at C and its manikin were not present in the footage from camera view B. By analysing MRI data recorded during viewing the feed from cameras A and C, with and without the illusion, it was possible to determine which brain areas could decode spatial location. Similarly, comparing MRI data recorded during viewing footage from cameras A and B, with and without the illusion, made it possible to determine which brain areas could decode the facing orientation in the room.

that premotor-parietal activity reflected the extent to which subjects felt that the body viewed through the camera belonged to them. Also in agreement with some past research [2–5,7], activity in hippocampal, posterior cingulate, retrosplenial cortex, and intraparietal sulcus could be used to decode self-location. Parietal regions, including the precuneus and retrosplenial cortex contained information about the heading direction. In the new approach, Guterstam et al. [12] were able to show these brain regions could distinguish the different camera views significantly better in the synchronous than the asynchronous trials, and that activity in several regions was correlated with subject's ratings of their subjective feeling of being present in the location viewed through the camera. Thus, rather than simply showing that a network of brain regions can distinguish between locations (for example, [2,4,5]), the new

results reveal that this network of brain regions is specifically more accurate at decoding self-location when subjects felt they were present in the locations viewed.

A New Role for the Posterior Cingulate Cortex
Guterstam et al. [12] also present an exciting new discovery. They found patterns of activity in the posterior cingulate cortex became more correlated with the activity in brain areas involved in both the feeling of body-ownership (parietal regions) and the feeling of self-location (hippocampus) as the subjects experienced the body-swop illusion. The authors argue that this points to an important role for the posterior cingulate in helping integrate our sense of body-ownership with our sense of self-location. The posterior cingulate has been linked to a variety of functions such as attention, memory, decision-making

and spatial navigation [12]. It is also a core region in the 'default-mode-network' [20] — a network of brain areas that increases activity when subjects are not engaged in a specific task [20]. Because feeling present in your body, in a particular location, may vary with a variety of task and non-task demands, it seems plausible that the observation made by Guterstam et al. [12] may go some way towards explaining why a diverse range of potential roles has been ascribed to the posterior cingulate.

The approach taken by Guterstam et al. [12] opens up a number of new research possibilities. For example, the method could be extended to the use of moving camera views, allowing new insights to be made into how brain regions support spatial updating and navigation (for example, see [6]). More generally, extending the body-swop illusion to moving views may allow us to feel present on distant planets, as we 'remotely' go to where no one has gone before, experiencing body-ownership of a body sitting in a vehicle located far far away.

REFERENCES

1. Vallar, G., and Ronchi, R. (2009). Somatoparaphrenia: a body delusion. A review of the neuropsychological literature. Exp. Brain Res. 192, 533–551.

2. Hassabis, D., Chu, C., Rees, G., Weiskopf, N., Molyneux, P.D., and Maguire, E.A. (2009). Decoding neuronal ensembles in the human hippocampus. Curr. Biol. 19, 546–554.

3. Schindler, A., and Bartels, A. (2013). Parietal cortex codes for egocentric space beyond the field of view. Curr. Biol. 23, 177–182.

4. Vass, L.K., and Epstein, R.A. (2013). Abstract representations of location and facing direction in the human brain. J. Neurosci. 33, 6133–6142.

5. Marchette, S.A., Vass, L.K., Ryan, J., and Epstein, R.A. (2014). Anchoring the neural compass: coding of local spatial reference frames in human medial parietal lobe. Nat. Neurosci. 17, 1598–1606.

6. Howard, L.R., Javadi, A.H., Yu, Y., Mill, R.D., Morrison, L.C., Knight, R., Loftus, M.M., Staskute, L., and Spiers, H.J. (2014). The hippocampus and entorhinal cortex encode the path and Euclidean distances to goals during navigation. Curr. Biol. 24, 1331–1340.

7. Chadwick, M.J., Jolly, A.E., Amos, D.P., Hassabis, D., and Spiers, H.J. (2015). A goal direction signal in the human entorhinal/subicular region. Curr. Biol. 25, 87–92.

8. Graziano, M.S., and Botvinick, M.M. (2002). How the brain represents the body: insights from neurophysiology and psychology. In Common Mechanisms in Perception and Action: Attention and Performance XIX, W. Prinz, and B. Hommel, eds. (Oxford: Oxford University Press), pp. 136–157.

9. Blanke, O., and Metzinger, T. (2009). Full-body illusions and minimal phenomenal selfhood. Trends Cogn. Sci. *13*, 7–13.

10. Serino, A., Alsmith, A., Costantini, M., Mandrigin, A., Tajadura-Jimenez, A., and Lopez, C. (2013). Bodily ownership and self-location: components of bodily self-consciousness. Conscious. Cogni. *22*, 1239–1252.

11. Tsakiris, M. (2010). My body in the brain: a neurocognitive model of body-ownership. Neuropsychologia *48*, 703–712.

12. Guterstam, A., Björnsdotter, M., Gentile, G., and Ehrsson, H.H. (2015). Posterior cingulate cortex integrates the senses of self-location and body ownership. Curr. Biol. *25*, 1416–1425.

13. Botvinick, M., and Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. Nature *391*, 756–756.

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

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

16. Ionta, S., Heydrich, L., Lenggenhager, B., Mouthon, M., Fornari, E., Chapuis, D., Gassert, R., and Blanke, O. (2011). Multisensory mechanisms in temporo-parietal cortex

support self-location and first-person perspective. Neuron *70*, 363–374.

17. Petkova, V.I., Björnsdotter, M., Gentile, G., Jonsson, T., Li, T.Q., and Ehrsson, H.H. (2011). From part-to whole-body ownership in the multisensory brain. Curr. Biol. *21*, 1118–1122.

18. O'Keefe, J., and Nadel, L. (1978). The Hippocampus as a Cognitive Map. (Oxford: Clarendon Press.)

19. Moser, E.I., Kropff, E., and Moser, M.B. (2008). Place cells, grid cells, and the brain's spatial representation system. Annu. Rev. Neurosci. *31*, 69–89.

20. Fransson, P., and Marrelec, G. (2008). The precuneus/posterior cingulate cortex plays a pivotal role in the default mode network: Evidence from a partial correlation network analysis. Neuroimage *42*, 1178–1184.

Actin-Filament Disassembly: It Takes Two to Shrink Them Fast

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http://dx.doi.org/10.1016/j.cub.2015.04.050

Actin-filament disassembly is indispensable for replenishing the pool of polymerizable actin and allows continuous dynamic remodelling of the actin cytoskeleton. A new study now reveals that ADF/cofilin preferentially dismantles branched networks and provides new insights into the collaborative work of ADF/cofilin and Aip1 on filament disassembly at the molecular level.

The highly dynamic and tightly regulated remodelling of the actin cytoskeleton is an essential requirement for many cellular processes, including endocytosis, cytokinesis and cell migration. These processes are accompanied by a constant turnover of actin structures to provide the cells with the required plasticity to quickly alter specific actin architectures in response to signalling cues and, additionally, to replenish the pool of assembly-competent, ATP-bound actin monomers to fuel new assembly reactions [1]. A paper in this issue of *Current Biology* now adds to our understanding of the molecular mechanisms behind actin-filament disassembly mediated by the combined action of the actin-binding proteins ADF/cofilin and Aip1 [2].

Key players known to accelerate filament disassembly are a family of small and ubiquitous proteins collectively called actin depolymerization factor (ADF)/cofilin [3]. Vertebrate cells express three different ADF/cofilins (ADF, cofilin 1 and cofilin 2), whereas yeast expresses a single ADF/cofilin isoform. ADF/cofilin binds in a cooperative manner preferentially to aged ADP–F-actin and mediates severing by altering the mechanical properties of the filament [4,5]. Structural and biochemical analyses revealed that cofilin binding changes the subunit tilt and increases the helical twist of the filament [4], thereby weakening

lateral contacts between actin monomers [6] and decreasing the persistence length of the filament [7]. Severing occurs preferentially at boundaries between bare and ADF/cofilin-decorated filament segments, thereby controlling the overall filament length, depending on ADF/cofilin-binding density [8]. ADF/cofilin remains bound to dissociated ADP–actin monomers and inhibits nucleotide exchange (ATP for ADP) on monomeric actin [9]. Thus, profilin and other accessory proteins, such as Srv2/cyclase-associated protein (CAP), are required to efficiently recycle ADF/cofilin-bound ADP–actin monomers back into an assembly-competent, ATP-bound state [10,11].