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The relationship between human agency and embodiment

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ABSTRACT

Humans regularly feel a sense of agency (SoA) over events where the causal link between action and outcome is extremely indirect. We have investigated how intermediate (here, a robotic hand) events that intervene between action and outcome may alter SoA, using intentional binding measures. The robotic hand either performed the same movement as the participant (active congruent), or performed a similar movement with another finger (active incongruent). Binding was significantly reduced in the active incongruent relative to the active congruent condition, suggesting that altered embodiment influences SoA. However, binding effects were comparable between a condition where the robot hand made a congruent movement, and conditions where no robot hand was involved, suggesting that intermediate and embodied events do not reduce SoA. We suggest that human sense of agency involves both statistical associations between intentions and arbitrary outcomes, and an effector-specific matching of sensorimotor means used to achieve the outcome.

1. Introduction

Recent work on the sensorimotor basis of self distinguishes two key aspects of self-awareness. First, we recognise that we are the authors of our voluntary actions, and of their consequences. This aspect is called sense of agency. Second, we recognise our body as our own, and as the basis of individual experience of the world, even in the absence of any action. This aspect is sometimes referred to as body-ownership, although the key feature is the feeling of 'myness' (Gallagher, 2000) rather than any relation of possession. The feeling of ownership is closely related to the sense of agency because the body is the normal vehicle of our actions.

The sense of agency is a familiar experience, but is difficult to measure experimentally. One route involves using implicit proxy measures. For example, the interval between a voluntary action and its consequence is perceived as shorter than a control interval beginning with an involuntary movement or with another external event (Haggard, Clark, & Kalogeras, 2002). This shortening has been called the 'intentional binding' effect.

The human brain generates a sense of agency even with highly complex, devolved and indirect causal chains. For example, pushing buttons of a coffee machine can obviously involve a feeling of agency. However, the overall feeling of agency depends on a much wider range of events, including the fact that coffee comes out at the end of the brewing sequence, that

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it is delivered into the cup, and that it tastes good. Thus, even when action involves a sequence of several steps involving intermediate events, technologies, or even actions carried out by other agents, we may still feel some feeling of agency over the causal chain as a whole.

In particular, technology can augment and transform causal chains, providing increased productivity and innovative action. Thus, while sense of agency begins with the sensorimotor experience of controlling one's own body, healthy adult humans in advanced societies regularly experience sense of agency over events that are largely independent of the body. It thus remains unclear whether and how mediation by the body is actually relevant to the sense of agency. The cognitive processes underlying sense of agency could be so flexible that intermediaries in the causal chain are readily accommodated, even when these intermediaries are decoupled from, or in conflict with, bodily action. This paper focuses on whether sense of agency is fundamentally "embodied" (i.e., linked to basic sensorimotor processes) or whether it can be abstracted from normal sensorimotor control to cover unusual instrumental associations. This question is of importance in the design of new prosthetics, human interfaces and robotic agents. For example, brain-imaging studies have shown that brain plasticity leads to prostheses being integrated in the neural representation of the body (Ehrsson et al., 2008; Giraux, Sirigu, Schneider, & Dubernard, 2001; Lotze et al., 1999; Maruishi et al., 2004; Schmalzl, Kalckert, Ragnö, & Ehrsson, 2014).

The well-known rubber hand illusion (RHI – Botvinick & Cohen, 1998) has been an important experimental model for embodiment and agency. In the RHI, a fake but human-like hand is felt to be part of one's own body, either due to multisensory stimulation, or because its movements resemble the participant's voluntary actions (Tsakiris, Prabhu, & Haggard, 2006). When RHI is caused by the participant's actions, a sense of agency and a sense of ownership may both be present. Most studies agree that these two aspects of self-awareness are nevertheless dissociable (Dummer, Picot-Annand, Neal, & Moore, 2009; Kalckert & Ehrsson, 2012, 2014; Riemer, Kleinböhl, Hölzl, & Trojan, 2013), and have different brain bases (Tsakiris, Longo, & Haggard, 2010).

However, to our knowledge, no studies have systematically investigated how the sense of agency generalises outwards from one's own sensorimotor movements, by increasingly transformed mediation, to produce an intended goal outcome. While the concept of agency over external events has been extensively studied in operant learning paradigms, it remains unclear how changes and distortions in the intermediate causal chain may affect the sense of agency. In particular, when people intend to produce a particular external event through their own action, does the sense of agency depend on the body transforming intention into outcome in the normal, predicted way? Or can sense of agency persist when mediated by altered embodiment?

In Experiment 1, participants estimated the interval between a voluntary (or involuntary) action and a tone. The comparison between these conditions provides a convenient proxy measure of agency. In these two conditions, participants viewed a robotic hand moving congruently with their action. In a third condition, participants made voluntary actions, but viewed a robotic hand moving incongruently with their action. This active incongruent condition could thus represent an altered form of embodiment, and instantiate a deviant causal chain between the participant's action and the intended outcome. To address whether the intermediary presence of a robotic hand *per se* would affect the experience of agency, we included a fourth condition in which the robot hand was not present, and participants simply viewed their own hand while they made voluntary actions.

2. Experiment 1

2.1. Method

2.1.1. Participants

A total of 24 naïve participants were recruited. The sample size was based on previous studies of agency and embodiment (e.g. Kalckert & Ehrsson, 2012, 2014). Participants received £4 for their participation. The following exclusion criteria were decided in advance of the experiment: failure to produce temporal intervals covarying monotonically with actual action-tone interval, or failure to follow instructions. One participant's data was lost due to a technical error. Of the 23 remaining participants, 9 were males. The main age was 23.34 (SD = 4.558). All participants provided written informed consent prior to the experiment. The study was approved by the local ethical procedures of the Institute of Cognitive Neuroscience at University College London.

2.1.2. Procedure and material

Prior to the experiment, participants were first invited to listen to verbal instructions. They were instructed to fixate the robotic hand during the entire experiment. The experimenter was seated in front of the participant, on his/her right side (see Fig. 1A), from where she could verify the participant's gaze. The robotic hand was placed above the table at the same height as their real hand would be (see Caspar, De Beir, Magalhaes de Saldanha da Gama, Yernaux, & Cleeremans, 2014; De Beir et al., 2014 for more information about the robotic hand). The participant's arm and the box containing the motors of the robotic hand were hidden under a blanket. One keyboard was placed under the robotic hand and one under the participant's hand. Only the second was connected to the computer (see Fig. 1B). The index finger of the robotic hand was placed to visually convey the impression of pressing exactly the same key as the participant. There were four blocked conditions. In the *active congruent* condition, participants performed a voluntary key press with the index finger, and saw the robotic