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That's my hand! Therefore, that's my willed action: How body ownership acts upon conscious awareness of willed actions

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ABSTRACT

Whether and how body ownership ("this body is mine") contributes to human conscious experience of voluntary action is still unclear. In order to answer this question, here we incorporated two signatures (i.e., an *ad hoc* questionnaire and the sensory attenuation paradigm) of human's sense of agency ("this action is due to my own will") within a well-known experimental manipulation of body ownership (i.e., the rubber hand illusion paradigm). In two different experiments, we showed that the illusory ownership over a fake hand (induced by the rubber hand illusion) triggered also an illusory agency over its movements at both explicit and implicit level. Specifically, when the fake (embodied) hand pressed a button delivering an electrical stimulus to the participant's body, the movement was misattributed to participant's will (explicit level) and the stimulus intensity was attenuated (implicit level) exactly as it happened when the own hand actually delivered the stimulus. Our findings suggest that body ownership *per se* entails also motor representations of one's own movements. Whenever required by the context, this information would act upon agency attribution even prospectively (i.e., prior to action execution).

1. Introduction

When humans perform voluntary actions, they are aware of intending, initiating and controlling their own movements, the so-called "sense of agency" (Jeannerod, 2003). Such experience is thought to rely mainly on signals coming from the motor system. In brief, an internal forward model creates a copy of the current motor commands, which allow predicting the feedbacks that the willed action will produce. The experience of being an agent would be stronger as the match between intended/predicted and actual outcomes of the action gets closer (Blakemore, Wolpert, & Frith, 2002; Haggard & Chambon, 2012; Moore, 2016). In other words, the sense of agency emerges when the consequences of our voluntary actions are strongly consistent with the predictions of such effects made by the motor system. It is worth noticing, however, that any successful achievement of a voluntary action is also underpinned by an embodied and enduring sense that the perceived moving body parts are one's own, the so-called "body ownership" (Gallagher, 2000). Such experience is known to be rooted on multisensory signals, which constantly reach our body (Costantini & Haggard, 2007; Holmes & Spence, 2005; Petkova et al., 2011; Tsakiris & Haggard, 2005). Indeed, during voluntary actions our own body receives a variety of sensory signals, such as visual, tactile, interoceptive, thermoceptive, nocioceptive and so on. Hence, body ownership would arise from the spatiotemporal integration of all this set of information.

These considerations imply that a coherent and normal conscious awareness of voluntary action ("this willed action is being realized by my own body") requires not only motor-related signals, leading to the sense of agency, but also body-related signals, which subserve body ownership. Indeed, since human's actions are achieved mainly through the physical body (Gallese & Sinigaglia, 2010), being aware of one's own body is a key component of human self-consciousness and the prerequisite for any successful interaction with the environment (Georgieff & Jeannerod, 1998). Despite this, the current neurocognitive models of conscious awareness of willed actions are rooted almost entirely on a variety of internal efferent signals: planning, premotor processing, efference copy signals and sensorimotor predictions (e.g., Haggard, 2005, 2008).

In the present study, we experimentally manipulated the normal experience of body ownership in order to examine its impact on the experience of willed actions. To do so, we combined together the most employed experimental paradigm to alter the

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physical constraints subserving body ownership, the rubber hand illusion (Armel & Ramachandran, 2003; Botvinick & Cohen, 1998; Burin et al., 2015; Costantini & Haggard, 2007; Costantini et al., 2016; Ehrsson, Holmes, & Passingham, 2005; Ehrsson, Spence, & Passingham, 2004; Longo, Schuur, Kammers, Tsakiris, & Haggard, 2008; Mohan et al., 2012), with two signatures of sense of agency, namely the sensory attenuation paradigm (Bays, Wolpert, & Flanagan, 2005; Blakemore, Wolpert, & Frith, 1998; Stenner et al., 2014; Timm, SanMiguel, Keil, Schroger, & Schonwiesner, 2014; Voss, Ingram, Haggard, & Wolpert, 2006; Voss, Ingram, Wolpert, & Haggard, 2008) and an *ad hoc* questionnaire (Kalckert & Ehrsson, 2012, 2014). The rubber hand illusion allows inducing a temporary feeling of ownership over a fake hand measured through a perceptual mislocalization towards the fake hand and by specific questions aimed at quantifying the experience of owning the rubber hand. The illusion arises when temporally synchronous (but not asynchronous) touches are delivered onto a visible rubber hand and onto the hidden participants' hand. It is worth noticing that the pattern emerges when the rubber hand is placed in a congruent (0°) but not in an incongruent (180°) position with respect the participant's body (i.e., a mere spatiotemporal correlation between tactile and visual stimuli is not sufficient to trigger the illusory effects). It has been argued that the illusion arises because the initial conflict between vision of the rubber hand and tactile and proprioceptive sensation of the own hand is resolved by the embodiment of the rubber hand within the participant's own body representation (Botvinick, 2004; Makin, Holmes, & Ehrsson, 2008). The sensory attenuation paradigm is generally known to be an implicit index of the sense of agency (but see Dewey & Knoblich, 2014; Hughes, Desantis, & Waszak, 2013; Weller, Schwarz, Kunde, & Pfister, 2017) which suggested that they might be independent phenomena). The effect consists in the fact that the intensity of a self-generated stimulus is subjectively perceived as attenuated respect to an identical stimulus generated by others. Sensory attenuation is explained as a decrease of the attentional gain of the sensory consequences of one's own actions. Lastly, the questionnaire on agency quantifies the subjective experience of being an agent by means of explicit questions (e.g., "I felt as if I was causing the movement I saw"). In other words, the implicit measures of the sense of agency are perceptual differences between self- and externally generated action-effects, whereas explicit measures represent direct judgments of causality over the actions (Dewey & Knoblich, 2014; Synofzik, Vosgerau, & Newen, 2008).

In the present study, we investigated both the implicit and the explicit aspects of agency over an embodied fake hand (induced by the rubber hand illusion) that delivered a stimulus to the participant's body by carrying out two experiments.

2. Experiment 1

In the first experiment, we hypothesized that in synchronous, respect to asynchronous condition within the rubber hand illusion (hereinafter RHI) paradigm, participants should subjectively experience agency (explicit level) over the movement of the fake hand and should attenuate the intensity of the stimulus (implicit level) as when the own hand delivers the stimulus.

2.1. Materials and methods

2.1.1. Participants

Forty right-handed (Oldfield, 1971) healthy participants (twenty-nine female, age range 18–30 years, educational level range 13–21 years) with no previous history of neurological disease gave their written informed consent, approved by the local bioethical committee, to participate in the study.

2.1.2. Experimental design

The experiment was composed of two parts. In the first part, we aimed at obtaining baseline measures of both body ownership and sense of agency. Hence, we administered both the rubber hand illusion (hereinafter RHI) and the sensory attenuation (hereinafter SA) paradigms. In the second part, we aimed at examining the sense of agency over the embodied fake hand (as a consequence of the RHI). Hence, only those participants showing both the RHI (i.e., drift and questionnaire higher in the synchronous condition) and the SA (stimulus intensity lower in self-generated movements) effects were included in the whole experiment (40 out of 76 assessed participants). In the second part (administered after approximately 10–15 min of rest), we combined together the RHI and the SA paradigms within the same setup (hereinafter RHI + SA) in a between-subjects design (i.e., half of the participants were administered one condition and the other half – another).

2.1.2.1. Rubber Hand Illusion (RHI) paradigm. A summary of the setup and of the procedures is reported in Fig. 1a. We employed the vertical version of the RHI (Kalckert & Ehrsson, 2012, 2014). Participants sat in front of a wooden box (40 cm × 30 cm × 20 cm) located on a table. The box included an upper shelf, on which a life-sized model left hand (i.e., a plastic glove filled with flour) was placed, and a lower shelf, on which the participant's left hand (wearing the same glove) was placed. The two hands were vertically (15 cm of separation) and horizontally aligned congruently with respect to the participant's body). A barber sheet covered the space between the fake wrist and the participant's neck (thereby participant's arm was hidden from the view, facilitating the impression that the artificial hand was the participant's own outstretched hand).

As first, participants were blindfolded and asked to indicate the felt position of their own left index finger by pointing their right index finger towards a cardboard placed on the right side of the wooden box (six trials). The position reported on a ruler stickled on the cardboard was referred as pre-proprioceptive judgment (average of the six trials, the SD was $\leq$1.4 for each participant in each condition).

Secondly, participants were reminded to always keep their sight on index finger of the fake hand and, then, they were stimulated on both their own and the fake hand index fingers. In the synchronous (hereinafter *Syn Con*) condition, the two hands were stimulated simultaneously (i.e., visual and tactile stimulus were administered simultaneously within a random interval of approximately 500–1000 ms), whereas in the asynchronous (hereinafter *Asyn Con*) condition, they were stimulated for two minutes in a temporally incongruent manner (i.e., the visual stimulus preceded tactile ones within a random interval of approximately 500–1000 ms). It is worth noticing that the experimenter was unaware of the hypothesis under investigation and was trained in advance with the backdrop of metronome beats occurring accordingly to the above-mentioned intervals. After the stimulation, participants were blindfolded and asked to report again (six trials) the position of the finger on the ruler and referred as post-proprioceptive judgment (average of the six trials). The two conditions were counterbalanced between participants.

Thirdly, at the end of each condition, participants had to rate on a −3/+3 Likert scale (+3 strong agreement, 0 neither agreement nor disagreement, −3 strong disagreement) four statements of a questionnaire about their experience of ownership. Two statements (Q1 "I felt as if I was looking at my own hand" and Q2 "I felt as if the fake hand was part of my body") referred to the actual presence of the illusion (i.e., *Real* questions), two statements (Q3 "It seems