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"As long as that is my hand, that willed action is mine": Timing of agency triggered by body ownership

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ABSTRACT

We investigated whether agency triggered by body ownership shares similar temporal constraints with agency induced by actual movements. We compared agency over the movements of the own hand, a fake hand and an embodied fake hand when they pressed a button delivering a stimulus to the participant's body after 500, 1000 or 2000 ms. In the first two delays, the movement of the embodied fake hand was misattributed to the participant's own will and the stimulus intensity was attenuated, as it happened when the own hand delivered the stimulus. With the longest delay, the movement of the embodied fake hand was neither misattributed to the participant's will nor the stimulus intensity was attenuated, as it happened when the fake non-embodied hand delivered the stimulus. By showing that illusory and veridical agency arise under similar temporal constraints, we further demonstrated that body ownership *per se* acts upon agency attribution.

1. Introduction

Human sense of agency, that is being aware of intending, initiating and controlling our own voluntary actions (Jeannerod, 2003), is thought to rely mainly on motor-related signals. In details, an internal forward model would build up an efferent copy of the current motor commands, which, in turn, would allow predicting the sensory consequences of a given voluntary action. Then, if actual and predicted feedbacks result strictly consistent in both spatial and temporal terms, sense of agency arises (Blakemore, Wolpert, & Frith, 2002; Haggard & Chambon, 2012; Moore, 2016). However, those actions are achieved mainly through the physical body (Gallese & Sinigaglia, 2010). Hence, being aware that the (moving) body parts are our own should necessarily contribute to the emergence of the feeling of being an active agent. The sense of one's own body is defined as body ownership (Gallagher, 2000), and it is known to be rooted on multisensory signals constantly reaching the body (Costantini & Haggard, 2007; Holmes & Spence, 2005; Petkova et al., 2011; Tsakiris & Haggard, 2005). In summary, to realize a coherent and complete sense of agency, both motor-related and body-related signals are necessary.

Despite these considerations, whether and how body ownership contributes to the construction of agency is still largely unclear. Most of the existing literature capitalized on neurological conditions/experimental manipulations in which body ownership is

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altered, and investigated the impact on the sense of agency. Within a neuropsychological approach, for instance, it has been demonstrated that an alien 'embodied' arm (Pia, Garbarini, Fossataro, Burin, & Berti, 2016) can also induce an illusory sense of agency over its movements when its actual action outcomes match patients' intended outcomes (Garbarini et al., 2013, 2015). Within intact brain functioning, interesting findings come out from studies with immersive virtual reality. It has been demonstrated, for example, that a real-sized embodied virtual avatar can give rise to an illusory sense of agency over the movements achieved by the virtual body only when participant's motor behavior is synchronized online with those of the avatar (Banakou & Slater, 2014) or when the avatar's rhythmic movements are primed in advance to the participants (Kokkinara, Kilteni, Blom, & Slater, 2016). Furthermore, another study (Kilteni & Ehrsson, 2017) demonstrated that when a fake hand moved repeatedly and synchronously with the participants' hand, somatosensory stimuli generated by that hand were attenuated when the fake hand was perceived as one's own, but not when it was not (it is worth noticing that the attenuation of self-generated stimuli, with respect to other-generated ones, is an index of sense of agency; e.g., Blakemore, Wolpert, & Frith, 1998). All these studies clearly support the idea that body ownership acts upon agency attribution. However, all of them always entailed, in one way or another, at least some efferent signals: actual motor intentions (Garbarini et al., 2013, 2015) or actual (Banakou & Slater, 2014; Kilteni & Ehrsson, 2017)/primed (Kokkinara et al., 2016) movements. This, in turn, means that they cannot provide unequivocal evidence of the role of body ownership *per se* in the conscious experience of voluntary actions.

A recent study (Burin, Pyasik, Salatino, & Pia, 2017) investigated whether body ownership can act upon agency attribution in absence of any possible efferent signals. The authors obtained baseline measures of both body ownership and sense of agency. With respect to body ownership, they administered the rubber hand illusion (hereinafter RHI) paradigm (Botvinick & Cohen, 1998; Burin et al., 2015; Burin, Garbarini et al., 2017; Costantini et al., 2016; Ehrsson, Holmes, & Passingham, 2005; Longo, Schuur, Kammers, Tsakiris, & Haggard, 2008), that is a well-known experimental manipulation which, by altering the physical constraints subserving normal body ownership, allows to induce a temporary feeling of ownership over a fake body part. Consistently with the literature, in the study by Burin and colleagues the illusion (i.e., subjective rating of owning the fake hand and the perceptual mislocalization of the own hand towards the fake one) occurred when the hidden participant's own hand and the visible fake hand (placed in a congruent position with respect to participants' body) were synchronously stimulated with touches. Conversely, after asynchronous stimulation and congruent fake hand position or synchronous stimulation and incongruent fake hand position, the illusion did not occur. As regards sense of agency, those authors administered the above-mentioned sensory attenuation (hereinafter SA) paradigm (Bays, Wolpert, & Flanagan, 2005; Blakemore et al., 1998; Stenner et al., 2014; Timm, SanMiguel, Keil, Schroger, & Schonwiesner, 2014; Voss, Ingram, Wolpert, & Haggard, 2008), an implicit index of sense of agency (but see also Dewey & Knoblich, 2014; Hughes, Desantis, & Waszak, 2013 suggesting that SA and sense of agency might be unrelated). Indeed, it is known that when motor predictions and action outcomes match each other, afferences are not fully processed because they would not add new information. Consequently, the same physical stimulus is subjectively felt as less intense when it is self-generated with respect to when it is generated by someone else (Bays et al., 2005; Blakemore et al., 1998; Stenner et al., 2014; Timm et al., 2014; Voss et al., 2008). In line with previous literature, that study showed attenuation of self-generated somatosensory stimuli with respect to other-generated somatosensory stimuli. Secondly, and most importantly, the authors integrated the RHI and the SA paradigms in a single (hereinafter RHI + SA) setup. Results showed that after the kind of stimulation successfully employed to induce ownership over the fake hand (i.e., synchronous stimulation and congruent rubber hand position), participants experienced illusory agency over a one-shot movement of the fake hand occurring immediately after its stimulation. Importantly, illusory agency was observed not only at implicit level (i.e., SA) but also at explicit level (i.e., the fake hand's movements were subjectively misattributed to the participant's own will, similarly to what happened when the own hand delivered the stimuli). On the contrary, after asynchronous stimulation and congruent fake hand position or synchronous stimulation and incongruent fake hand position, both implicit and explicit sense of agency over the fake hand's movements disappeared (i.e., the movement was not subjectively misattributed to the participant's own will, and the intensity of the stimulus delivered by it was treated as when the fake non-embodied hand delivered the stimulus).

In the present study, we aimed at further examining how body ownership acts upon agency attribution. We capitalized on a previous study demonstrating the temporal constraints under which sensory attenuation for somatosensory stimuli occurs (Blakemore, Frith, & Wolpert, 1999). Specifically, the authors showed that increasing the temporal delays between action execution and felt touch (i.e., causes and effects) increased its perceived intensity, namely SA decreased. Here we investigated whether such temporal constraints stand not only for veridical (i.e., one's own hand's movement) but also for the illusory (i.e., fake embodied hand's movement) agency. We predicted that increasing the delays between a willed movement and its effects would diminish implicit (SA) and explicit (subjective ratings) indexes of sense of agency equally for the movements of one's own hand and of the fake embodied hand. This result would be crucial in further tightening the match between veridical and illusory agency, as well as highlighting the pivotal role of body ownership in guiding agency attribution.

2. Materials and methods

2.1. Participants

Twenty right-handed (Oldfield, 1971) healthy participants (14 females, age range 19–46 years, educational level range 13–19 years) with no history of neurological disease signed a written informed consent to participate in the study approved by the bioethical committee of the University of Turin. All experiments were performed in accordance with relevant guidelines and regulations.