



# On the relation between body ownership and sense of agency: A link at the level of sensory-related signals

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## ABSTRACT

The relation between sense of body ownership and sense of agency is still highly debated. Here we investigated in a large sample of healthy participants the associations between several implicit and explicit indexes of the two senses. Specifically, we examined the correlations between proprioceptive shift (implicit measure) and questionnaire on the subjective experience of ownership (explicit measure) within the rubber hand illusion paradigm (body ownership), and intentional binding (implicit measure), attenuation of the intensity of auditory outcomes of actions (implicit measure) and questionnaire on the subjective experience of authorship (explicit measure) within the Libet's clock paradigm (sense of agency). Our results showed that proprioceptive shift was positively correlated with the attenuation of auditory outcomes. No significant correlations were found between the explicit measures of the two senses. We argue that the individual spatiotemporal constraints subserving the integration of sensory-related signals (implicit signature) would be common to both senses, whereas their subjective experience (explicit signature) would rely on additional processes specific for any given sense.

## 1. Introduction

The complex state of self-awareness consists of several crucial components, which include sense of body ownership and sense of agency (Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008). Sense of body ownership refers to experiencing one's body and its parts as belonging to oneself (Gallagher, 2000) and generally requires the integration of afferent information from different modalities. Indeed, when all these signals match (Botvinick, 2004; Ehrsson, 2012; Holmes & Spence, 2005), the conscious experience of the own body arises. On the other hand, sense of agency is the feeling of authorship over one's own actions and of controlling their execution (Jeannerod, 2009). It requires motor intention (Haggard, 2017; Haggard, Clark, & Kalogeras, 2002; Moore, 2016) and a subsequent comparison between intended action and its perceived consequences (Sato, 2009; Wegner, Sparrow, & Winerman, 2004). The subjective experience of being the agent of voluntary actions arises when the match between intended and actual outcomes gets closer (Blakemore, Wolpert, & Frith, 2002; Burin, Battaglini, et al., 2017; Desantis, Hughes, Waszak, Waszak, & Haggard, 2012; Haggard, 2017; Moore, 2016), that is, when the consequences of our voluntary actions are strongly consistent with the predictions of

such effects.

Both body ownership and sense of agency are highly plastic neurocognitive processes, which can be altered within a variety of diseases (e.g., (Delorme et al., 2016; Ding et al., 2017; Eshkevari, Rieger, Longo, Haggard, & Treasure, 2012; Finotti & Costantini, 2016; Frith, Blakemore, & Wolpert, 2000; Gandola et al., 2012; Garbarini et al., 2016; Martinaud, Besharati, Jenkinson, & Fotopoulou, 2017; Pia, Garbarini, Burin, Fossataro, & Berti, 2015; Pia, Garbarini, Fossataro, Burin, & Berti, 2016; Piedimonte, Garbarini, Pia, Mezzanato, & Berti, 2016; Vallar & Ronchi, 2009; Wolpe et al., 2014)), or by ad-hoc experimental manipulations in healthy participants. In this latter case, the two senses are investigated in their explicit and implicit components. Whereas explicit components use direct subjective judgments about feeling of ownership over the body or being the agent of voluntary action and its consequence, implicit ones rely on indirect judgments about ownership or agency obtained by assessing a correlate of body ownership or a voluntary action (Dewey & Knoblich, 2014; Longo, Cardozo, & Haggard, 2008; Moore, 2016). Implicit measures usually involve perceptual judgments – for example, the differences in actual and perceived location of a body part (in case of sense of body ownership) or in actual and subjective timing of actions and their effects (in

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case of sense of agency) (Botvinick & Cohen, 1998; Dewey & Knoblich, 2014; Ehrsson, Spence, & Passingham, 2004). As regards body ownership, a well-known setting for manipulating it experimentally is the rubber hand illusion paradigm (Botvinick & Cohen, 1998; Costantini & Haggard, 2007; Ehrsson et al., 2004; Farnè, Pavani, Meneghello, & Ladavas, 2000; Longo et al., 2008; Tsakiris & Haggard, 2005). Here, synchronous (but not asynchronous) touches delivered to both a life-sized rubber hand and to the participant's hidden hand induce a compelling feeling of ownership over the fake hand. The misattribution is evaluated with two different measures: the first, an implicit behavioral measure called proprioceptive drift, represents the mislocalization of the perceived position of the participants' hand towards the fake hand (Tsakiris & Haggard, 2005). The second, an explicit measure, is a questionnaire, which reflects the subjective experience of the illusion (Botvinick & Cohen, 1998). With respect to sense of agency, two implicit measures – intentional binding and sensory attenuation of action outcomes – are based on perceptual differences between self- and externally-generated events and their consequences. More specifically, intentional binding refers to the differences in subjectively perceived and actual timing of actions and their sensory consequences: one's own action and its effect are subjectively perceived as being closer to each other than externally-generated actions and their effects (Haggard et al., 2002; Libet, Gleason, Wright, & Pearl, 1983). Sensory attenuation is a reduction of subjective intensity of self-generated sensory stimuli (Blakemore, Wolpert, & Frith, 1998), for example, a sound produced by a person's own button press would be perceived as less intense than an externally-generated sound of the same volume (however, while some studies consider sensory attenuation as an implicit measure of agency (Burin, Pyasik, Salatino, & Pia, 2017; Dewey & Knoblich, 2014), others argue that they might be independent phenomena (Hughes, Desantis, & Waszak, 2012; Weller, Schwarz, Kunde, & Pfister, 2017). Although both intentional binding and sensory attenuation focus on the perceptual features of actions and their effects, it has been suggested that they might represent different processes (Dewey & Knoblich, 2014) or have different constraints in terms of temporal and action-specific prediction (Desantis et al., 2012; Hughes et al., 2012). Explicit sense of agency measures refer to participants' judgments about the authorship or attribution of an action or effect, which is rated on a Likert scale (Dewey & Carr, 2013; Dewey & Knoblich, 2014; Sato & Yasuda, 2005).

While both sense of body ownership and sense of agency are essential for the integral feeling of self-awareness (Gallagher, 2000; Tsakiris, Schutz-Bosbach, & Gallagher, 2007), it is still unclear how and to which extent they are related. Indeed, at least two models have been proposed – one stating the additive nature of senses of agency and ownership, and the other – their independence (Tsakiris, Longo, & Haggard, 2010). According to the independence model, sense of agency and ownership are separate mechanisms (Farrer et al., 2008; Farrer & Frith, 2002; Lau, Rogers, Haggard, & Passingham, 2004; Schwartz, Assal, Valenza, Seghier, & Vuilleumier, 2005), whereas according to the additive model they are strongly linked to each other (Caspar, Cleeremans, & Haggard, 2015; Garbarini et al., 2015; Garbarini & Pia, 2013; Kalckert & Ehrsson, 2014; Longo & Haggard, 2009; Pia et al., 2016). Interestingly, an fMRI study by Tsakiris et al. (2010) reported a dissociation between behavioral and neuroimaging results: subjective reports supported the additive model, while the neuroimaging data showed no shared neural activation for sense of ownership and agency (specifically, the sense of body ownership was related to activation of midline cortical structures, and the sense of agency corresponded with the activation of pre-SMA and Brodmann Area 6). Other previous attempts to investigate the possible interactions between sense of body ownership and sense of agency combined measures of body ownership (rubber-, virtual- or robotic hand illusion) with intentional binding (Braun, Thorne, Hildebrandt, & Debener, 2014; Caspar et al., 2015), sensory attenuation (Burin, Pyasik, et al., 2017; Kiltner & Ehrsson, 2017) and/or subjective measures of sense of agency (Dummer, Picot-Annand, Neal, & Moore, 2009; Ismail & Shimada, 2016; Kalckert &

Ehrsson, 2012, 2014; Ma & Hommel, 2015; Tsakiris et al., 2010). Typically, such studies varied the position of the fake hand (congruent vs incongruent with respect to participant's point of view), agent (self- vs other-generated movements), kind of movement (active vs passive) (Kalckert & Ehrsson, 2012, 2014; Tsakiris et al., 2010) and movement congruency (congruent vs incongruent with respect to participant's movement) (Caspar et al., 2015). Some studies reported double dissociation between sense of body ownership and sense of agency but the pattern varied depending on experimental conditions. Specifically, both ownership and agency were present only in the condition of synchronous or congruent movements (Braun et al., 2014; Caspar et al., 2015; Kalckert & Ehrsson, 2012, 2014; Tsakiris et al., 2010), whereas incongruent position of the fake hand diminished sense of ownership, but not sense of agency (Braun et al., 2014; Kalckert & Ehrsson, 2012). On the contrary, passive movements of the fake hand decreased sense of agency but did not affect sense of ownership (Kalckert & Ehrsson, 2012; Tsakiris et al., 2010). However, other studies suggested that active movements increased sense of ownership, which supports the idea that agency contributes to sense of body ownership (Dummer et al., 2009; Ma & Hommel, 2015). It is worth noting that none of the above-mentioned studies addressed sense of agency per se, but rather it is studied in direct relation to sense of body ownership over an embodied hand and over an embodied movement. Specifically, Kalckert and Ehrsson (2012) suggest distinguishing between external agency (controlling an object or a tool) and body agency (controlling own arm), and claim that body agency might “contribute an additional component over and above the basic agency experienced when controlling an external object”. This is supported by their findings that stronger sense of agency was observed in the condition of active movements of the congruently-positioned fake hand (i.e., in the condition where sense of body ownership was present), and additionally, subjective ratings of ownership and agency were correlated also only in the active congruent condition.

Considering the just-mentioned somewhat controversial categories of findings, here we aimed at further investigating how, and to which extent, sense of agency and body ownership depend on similar or different mechanisms. In order to evaluate sense of agency independently from experimental modulations of body ownership, and vice versa, we measured the two senses in separate experimental settings and in all their implicit and explicit aspects. Then, we examined the intra-individual correlations among these measures. Specifically, we analyzed the correlations between the indexes of body ownership within the rubber hand illusion paradigm (i.e., proprioceptive shift and subjective experience of ownership) and the indexes of sense of agency within the Libet's clock paradigm (intentional binding, attenuation of the intensity of auditory outcomes of actions, subjective experience of authorship). This method prevents defining whether one sense contributes to the experience of other (as in some of the studies described above (Dummer et al., 2009; Ma & Hommel, 2015; Tsakiris et al., 2010)) but the pattern of correlations between several indexes of the two phenomena measured independently allows seeing whether or not the two senses share at least some properties. Significant correlations between any indexes of the two senses would point to the existence of possible common underlying mechanisms. However, due to the controversial nature of previous findings, we did not hypothesize any specific pattern of correlations.

## 2. Material and methods

### 2.1. Participants

Eighty-three right-handed (Oldfield, 1971) healthy volunteers (52 females and 31 males, age range – 19–36 years, mean age 23.5, SD 3.51) were recruited in May 2017. They gave written informed consent to participate in the study approved by the Local Bioethical committee of the University of Turin.

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