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The body and cognition: The relation between body representations and higher level cognitive and social processes

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The relation between the body and higher-order mental functions has been a topic of discussion for many decades, if not centuries, in philosophy as well as psychology, and has more recently been widely discussed in cognitive neuroscience, robotics, and artificial intelligence. In philosophy, the so-called mind-body problem has a long tradition. This discussion traces back to ancient Greek philosophers, but the debate was renewed by René Descartes' radical statement that the mind "is entirely and truly distinct from the body [and the brain] and may exist without it" (Descartes, 1975). While most contemporary philosophers reject his idea of a substance dualism, the role of the body in shaping conscious experience continues to be controversial (Gallagher, 2005). Influential philosophers directly opposed his mind-body dualism by stressing the importance of bodily experience (e.g., James, 1890; Merleau-Ponty, 1945), and recent theories have been progressively converging their emphasis on the high relevance of bodily processes (i.e., the nonconceptual representations and processing of body-related information) in cognitive processes and self-consciousness (e.g., Bermúdez, 1998; Damasio, 1994; Gallagher, 2000, 2005; Varela, Thompson, & Rosch, 1991). Indeed, the idea of embodied cognition has gained increasing influence in psychology and neuroscience in recent decades (see e.g., Barsalou, 2008 for an extensive review). This notion is based on the embodiment thesis, which states that "many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent's beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent's cognitive processing" (Wilson & Foglia, 2011). Empirical examples have been substantiated in a wide range of cognitive functions, including numerical processing, visual attention, social cognition, memory, and language (Barsalou, 2008; Fischer, 2012). While embodied cognition initially emphasizes the relation between the physical body and cognitive function, it has also become increasingly clear that the sense of the body is plastic and is not only dependent on incoming sensory information but also on internal representations of our body, some of which are highly cognitive in nature. Body representations and the underlying neural mechanisms have received increasing attention in cognitive neuroscience over the last few decades. There has been a lively debate about the functional architecture of body representations and various theoretical models have been proposed (e.g., Berlucchi & Aglioti, 1997; Longo, Azañón, & Haggard, 2010; Moseley, Gallace, & Spence, 2011; Paillard, 1999; de Vignemont, 2010). While many of these models were built on clinical data from disorders of the bodily self, the development of new paradigms to alter bodily experiences has refined and extended such models. These paradigms typically confront healthy participants with ambiguous multisensory information about their body, during which bottom-up signals from unimodal sensory systems are integrated and decoded by higher, multisensory levels of the hierarchy to construct an updated body representation (Botvinick & Cohen, 1998; Ehrsson, 2007; Kammers, de Vignemont, Verhagen, & Dijkerman, 2009; Lackner, 1988; Lenggenhager, Tadi, Metzinger, & Blanke, 2007; Stratton, 1899; Tsakiris & Haggard, 2005). Bodily awareness can be quite easily manipulated in healthy participants, and such paradigms thus provide an interesting tool to study the link between body representations and cognition beyond the research classically performed in the embodied cognition domain. Several studies have demonstrated that illusory

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changes in body awareness influence a broad variety of higher-level cognition processes. For example, experimentally altered body perception can affect the perception of the size and distance of external stimuli (Banakou, Groten, & Slater, 2013; van der Hoort, Guterstam, & Ehrsson, 2011) and even episodic memory (Bergouignan, Nyberg, & Ehrsson, 2014). These experimental body manipulation paradigms can also modulate social cognition, such as social distance perception (Mazzurega, Pavani, Paladino, & Schubert, 2011) or implicit biases (Maister, Sebanz, Knoblich, & Tsakiris, 2013; Peck, Seinfeld, Aglioti, & Slater, 2013) (for a recent review) see Maister, Slater, Sanchez-Vives, and Tsakiris (2015). Similarly, patient studies have evinced that longer-term alterations in body awareness also affect cognitive processes, such as perspective-taking (Besharati et al., 2016), and that peripheral alteration of bodily signaling due to physical loss of a body part can also influence visual spatial perception (Makin, Wilf, Schwartz, & Zohary, 2010). These studies therefore suggest that, in order to understand how the body influences cognition and vice versa, one needs to investigate the relation between three different components: peripheral sensorimotor signals, higher order body representations, and cognitive function.

This special issue provides a state of the art overview of the current investigations and topics on the body and cognition. It assimilates interdisciplinary findings from neuropsychology, neurology, neuroimaging, and cognitive psychology, and covers the relation between body awareness and various cognitive functions in the motor and social domain. This is exemplified by the two reviews in this special issue. In an attempt to integrate and newly structure the large body of literature on the bodily self in philosophy, developmental psychology, and neuroscience, Riva, 2018 proposes a new theoretical model of body representations. He stresses the importance of both an online integration of incoming intero- and exteroceptive signals, as well as stored representations of the body (body memory), and proposes unique body representations that emerge during distinct developmental periods. While the most basic representation, the minimal selfhood, is present from birth, other representations emerge later. After the initial sensorimotor experience and agency (i.e., classical body schema) has been established, more cognitive schemata, linked to body ownership, social function, and allocentric representations, begin to emerge. These multimodal representations are integrated into what Riva labels a "body matrix": a supramodal multisensory representation of the body and the space surrounding the body, which serves to protect and extend the individual's body on both homeostatic and psychological levels. Riva then describes potential disorders of the body matrix in various clinical conditions and how these can be remedied using modern technologies.

The second review by Porciello et al., 2018 focuses on one particular experimental setup, which uses conflicting multisensory signals to alter face representation, the enfacement illusion. The authors argue that this illusion is especially relevant for studying the interaction between body representations, identity, and social aspects, as the face, more than other body parts, is crucial both for identification and social communication. The authors review current evidence for the role of exteroceptive and interoceptive signals in building body representations and self-awareness. Moreover, they discuss the neural network implicated in plastic changes of the self and link it to the predictive coding framework. This predictive coding framework is also featured in the review by Riva, 2018, who proposes its involvement in creating a supramodal body matrix, activated by central top-down attentional processing. Both reviews advocate that a combination of bottom-up multisensory signals and top-down cognitive processes constitute important components for both the stable sense of a bodily self as well as for its plasticity. Indeed, the empirical papers in this special issue have focused mostly on the role of either peripheral sensory signals or top-down representations. Overall, the empirical contributions of this special issue can roughly be subdivided into three different topics: a) sensory input, multisensory integration and aspects of body representation; b) the relation between motor function and body representations; and c) the link between body perception and cognitive function.

1. Multisensory integration and body cognition

Studies investigating the role of sensory input in relation to bodily cognition have focused on different modalities. Fossataro et al., 2018 used asynchronous visuo-tactile stimulation in a rubber hand illusion-like setup to restore the sense of ownership over the disowned own hand in stroke patients. Asynchronous stroking of the visible rubber hand and the invisible own hand is generally used as a control condition in the rubber hand illusion, since the mismatch between the bottom-up and top-down multisensory signaling typically prevents the generation of an altered sense of ownership. Previous studies have demonstrated that asynchronous tactile stroking differs from both the synchronous touch and visual only conditions in that it prevents visuo-proprioceptive integration and thus proprioceptive drift in healthy participants (Rohde, Di Luca, & Ernst, 2011). Other studies using the rubber hand or related illusions to study body ownership report a generally enhanced illusion in patients suffering from clinical disorders of corporeal awareness (Lenggenhager, Hilti, & Brugger, 2015), and demonstrate that an integration of the rubber hand into their own body representation is possible even under asynchronous stroking conditions (van Stralen, van Zandvoort, Kappelle, & Dijkerman, 2013). The group of E+ patients studied by Fossataro et al., pathologically embody the (foreign) hand of the experimenter when placed in front of them in a congruent position (Garbarini et al., 2013; but see also Gerstmann 1942). When the experimenter moved this hand, the patient claimed he moved the hand himself; when this foreign hand was touched, the patient claimed he felt the touch. Interestingly, Fossataro et al., 2018 showed that asynchronous stroking of the visible experimenter's hand and the invisible own hand in E+ patients with residual tactile sensibility resulted in a temporary reduction of pathological embodiment of the experimenter's hand. These findings suggest that a conflict between visual and tactile input influences body ownership and thus that the effects of asynchrony are bidirectional. It further sheds light on how multisensory