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Discussion

Towards a common framework of grounded action cognition: Relating motor control, perception and cognition

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ABSTRACT

The relation between motor control and action cognition – including action-related thoughts and action-related perception – has been subject to controversial discussions in the last three decades. During these decades, cognitive neuroscience has been increasingly confronted with a huge variety of different accounts trying to understand and explain the relation between these systems, their interdependencies and the mediating mechanisms by establishing notions such as "internal models", "simulation" or "shared representation". These accounts, however, include a large array of partly overlapping, partly contradictory theories using similar terms for different mechanisms and different terms for similar mechanisms. In the absence of a systematic work-up and comparison, this array of accounts and theories leads to confusion in the field, duplication of experimental work, and unconnected parallelism of theory formation within and between different disciplines. Here we provide a systematic comparison of current models and prospective theories that deal with the relation between cognition, perception and motor control mechanisms. In a second step, we propose "grounded action cognition" as a comprehensive metatheoretical framework which defines different hypothetical possibilities of the relations between these domains, offers systematic insights into current models and theories and last but not least may help to increase comparability of empirical research in the domain of action and action cognition.

1. Introduction

There is a long tradition and interest in many different disciplines on the interplay between action and perception. This interest is led by various aims: while some disciplines investigate this interplay with the aim of understanding human 'cognitive mechanisms' (cognitive psychology, philosophy), brain mechanisms (cognitive neuroscience) or neurologic and psychiatric diseases (neurology/psychiatry), others study this relation to model skillful movements (robotics) or perceptual abilities (computational and mathematical neuroscience). Some of these traditions date back to 19th century experimental psychology and philosophical theory of voluntary action (James, 1890/1981). Others were developed more recently. For example, approaches from computational and cognitive neuroscience, starting in the early 1990s, aim at describing the precise brain systems and neuronal dynamics underlying the action–perception inter-linkage by means of internal forward/-generative models (Friston, Daunizeau, Kilner, & Kiebel, 2010; Wolpert & Miall, 1996). The focus on the linkage between action and perception has now been expanded to include also conceptual abilities and cognition in general. Specifically, growing interdisciplinary work has now begun to relate different theoretical approaches and empirical findings to explain also higher-cognitive skills like mind reading in social contexts (Gallese & Goldman, 1998) or mental imagery (Grush, 2004).

Here we take an interdisciplinary point of departure with the aim to provide a systematic comparison of current and established theoretical models and prospective theories that deal with the relation between cognition, perception and motor control mechanisms. We will in particular focus on the proposed internal representational mechanisms governing mutual relations between perception and action. Accordingly, the selection criterion for the theories to be compared in the present paper is that they make

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some substantial claim about the systematic connection between the domains of cognition, perception and motor control.[1] It is beyond the scope of the present endeavor to also take dynamic interactions between mind/brain, body and world into account as proposed by some more radical conceptions of embodied cognition (for an overview compare Shapiro, 2011; or Wilson, 2002; for certain conceptions of these radical or dynamic views see Beer, 1995; Hutto & Myin, 2013; Keijzer, 2002). Thus, we will here specifically consider internal representations that appear to draw on motor-related processes. We will use the term 'grounding' to refer to the general relation between motor processes and action perception/cognition, which seems underdetermined so far in current theories. Please also note that it is not our aim to provide a systematic review of those single theories in terms of supporting or challenging empirical evidence (for a recent review see, for example, Engel, Maye, Kurthen, & König, 2013). Instead, we here aim to systematically compare the empirical and explanatory foci those theories adopt with respect to the nature of the relation between motor control and action–cognition.

This paper comprises three sections. The first provides a brief overview of different action theories and suggests a classification by target mechanisms. In the second section, we introduce a framework that will be used to illustrate our notion of grounded action cognition as a metatheoretical view. Third and finally, our purpose is to show how existing theories can or cannot be classified into genuine grounding theories. This new classification scheme shall offer new perspectives into commonalities and differences as well as the explanatory scope with respect to the degree to which perceptual and cognitive abilities genuinely draw on motor capacities; however, it is not meant to suggest an evaluation of existing and established theories concerning their theoretical and empirical adequacy.

2. The three main families of action theories

The large amount of highly heterogeneous, partly overlapping, partly differing theories coming from very different disciplines is often confusing. To facilitate a better overview and understanding, we here classify the existing theories into three major theoretical frameworks/families of grounded action cognition accounts: (1) Common Coding, (2) Internal Models, and (3) Simulation theories (Table 1; for a detailed description and analysis of each of these families, see next paragraph). These theories operate at different levels and interfaces between domains of action cognition and use diverse conceptual tools (see Table 1). One shared assumption of all major theories is that some kind of common representational ground for action and cognition exists. This assumption has been developed, however, at different levels of action cognition, and with crucial differences in the empirical and explanatory focus on motor control, perception or conceptual abilities (see Fig. 1). This includes fundamental differences in the abilities these theories try to account for: while some theories resort to a common ground between action and cognition to explain action planning or motor imagery, others refer to this notion to explain the understanding of other individuals' actions. The main assumptions regarding the central thesis of grounded action cognition are summarized in Table 1.

In order to understand the differences between the theories in their attempt to link the domains of action, perception and cognition, it is helpful to consider the primary domain a theory was originally developed for and how it has been extended. For example, common coding theories as well as some internal model accounts, such as motor control theory, were explicitly developed from a motor control point of view. Therefore, the theoretical concepts are grounded in notions of efferent and (re-)afferent information (i.e., motor output and sensory feedback) which have been applied not only to understand the mechanisms behind movement kinematics (motor control theory) but also to describe the semantics of action (ideomotor theory). In contrast, another version of internal models, predictive coding, was originally developed to explain visual perception and its underlying computational architecture. It has been extended to other sensory modalities as well as to action in terms of active inference (the latter being a more recent development). Hence, the key concepts in this model are rooted in assumptions around the organization of sensory input and the perception of the outside world. The ontogeny of simulation theories, the third main family of action theories, is most heterogeneous, since the notion of 'simulation' has been used to account for a variety of phenomena in the domains of action cognition and perception. For example, the notion of simulation has been used to explain a perceptual understanding of other's actions (mirror neuron theory) and the ascription of mental states to others (simulation theory), as well as the imagination of action (motor imagery) and even abstract conceptual abilities (perceptual symbols theory). Hence, understanding the primary phenomenon that each theory is trying to account for is crucial for appreciating how existing theories differ in relating the domains of cognition, perception and motor control mechanisms. The classification of the three families of theories according to their primary domain of explanation is illustrated by Fig. 1.

3. Grounded action cognition: a metatheoretical view

In our approach towards a systematic framework, we will now specify common denominators of the manifold existing assumptions regarding the relation between the three domains of action cognition, perception, control and concepts of action. Current theories and related experimental reports sometimes appear to use the same terms to explain different phenomena or mechanisms, and different terms to explain the same phenomena or similar mechanisms. For example, the term 'simulation' has been used to refer to sensorimotor processes as a reactivation of neural motor circuitries not only when observing actions but also in the context of reasoning about mental states of others. Likewise, the finding of an activation of cortical areas involved in motor control during action observation has been interpreted and labeled interchangeably as 'mirroring', 'simulating' or 'mentalizing'. Moreover, terms such as 'embodiment', for instance, have been applied in a narrow sense with reference to self-awareness as a form of bodily awareness (i.e., the embodied self) but also in a broader sense to explain a fully functional system of abstract concepts (cf. below, perceptual symbol systems theory).

Moreover, study reports sometimes use vague or even overstated wording when reporting their findings and interpreting the relation between the three domains. For instance, authors sympathetic with simulation theories often use various and quite strong expressions like cognition/perception (x) is "based" on a sensorimotor process/the sensorimotor system (y), x "arises" in y,[2] x is "localized" in y,[3] x is "derived" from y,[4] x is "specified" by y,[5] x is

[1] For this reason, the sensorimotor theory of visual consciousness by O'Regan and Noë (2001), for example, is not considered in the present framework: Although it claims that visual perception is a form of action, it does not propose a specific linking mechanism between perception and action (unlike ideomotor theory, for example).

[2] "[P]erceptual states arise in sensory-motor systems." (Barsalou, 1999, p. 577).

[3] "[I]implicit memory has been localized in sensorimotor areas of the brain." (Barsalou, 1999, p. 589).

[4] "[A]ffordances are derived from the perceptual symbols [i.e. a systematic activation pattern in the sensorimotor system]." (Glenberg & Kaschak, 2002, p. 599).

[5] "[C]onceptual processing of categories specified by motor and somatosensory features [...]." (Barsalou, 1999, p. 585).