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Action-dependent perceptual invariants: From ecological to sensorimotor approaches

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Abstract

Ecological and sensorimotor theories of perception build on the notion of *action-dependent invariants* as the basic structures underlying perceptual capacities. In this paper we contrast the assumptions these theories make on the nature of perceptual information modulated by action. By focusing on the question, *how movement specifies perceptual information*, we show that ecological and sensorimotor theories endorse substantially different views about the role of action in perception. In particular we argue that ecological invariants are characterized with reference to transformations produced in the sensory array by movement: such invariants are transformation-specific but do not imply motor-specificity. In contrast, sensorimotor theories assume that perceptual invariants are intrinsically tied to specific movements. We show that this difference leads to different empirical predictions and we submit that the distinction between motor equivalence and motor-specificity needs further clarification in order to provide a more constrained account of action/perception relations.

Keywords: Action; Perception; Self-motion; Invariants; Sensorimotor theories; Ecological psychology; Enaction

1. Blurring the boundary between action and perception

The idea that action and perception are not two independent cognitive domains and that perception is constitutively shaped by action has been an important research trend in the last decades. The study of active perception, or those mechanisms that allow organisms to negotiate perceptual problems by processing sensory stimulation on the basis of action, has become a thriving area of investigation in neuroscientific, psychological and computational research on perception, witness the number of reviews and theoretical analyses that have addressed this trend (Berthoz, 2000; Findlay & Gilchrist, 2003; Hurley, 1998; Port & Van Gelder, 1995; Thelen & Smith, 1994).

The idea of perception as action-dependent has been particularly emphasized by motor theories of perception, i.e. those approaches claiming that perceptual content depends in an essential way on the joint contribu-

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tion of sensory and motor determinations (Sheerer, 1984). According to motor theories, perceptual systems are able to discriminate between *reafference* (sensory input resulting from self-motion) and *exafference* (sensory input produced by external events) in virtue of their relation to *efference* (internal information elicited by self-motion). Perceptual systems receive at the same time reafference and efferent copies generated by a given movement and such information is used to perceive a specific action as self-initiated. Over time, the organism learns to establish correlations (supposedly stable and systematic for a given organism in a given environment) between reafference and efference (Gallistel, 1980). The capacity to discriminate between exafference and reafference underlies, according to motor theories of perception, several perceptual distinctions (e.g. self-motion vs. motion in or of the environment) and constancies (e.g. position constancy, see Duhamel, Colby, & Goldberg, 1992; Stark & Bridgeman, 1983).

Motor theories of perception represent a liberal view of action/perception relations, to the extent that they admit that perceptual capacities can depend on sensorimotor relations on top of purely sensory information (Hurley, 2001). They are *mildly* liberal, though, insofar as they limit the contribution of action to perception to those perceptual processes that underlie the control of motor behavior. This is consistent with the established view that part of the human perceptual system, geared towards action control and spatial behavior, draws on dedicated processes that are functionally independent from those targeted at perceptual categorization and recognition (Jacob & Jeannerod, 2003; Milner & Goodale, 1995). But can action-dependent perceptual processing extend beyond what seems to be its natural domain, i.e. perception for motor control and spatial behavior? Can action modulate a broader range of perceptual processes than mainstream perceptual theories assume? Does the perception of properties of the environment (independent on the agent's body configuration or movement) rely on action-dependent information? This is a much stronger claim of action-dependence in perception and an issue we aim to tackle in this paper.

A number of research programs have taken a more radical stance on action/perception relations, claiming that action is pervasive in the functioning of perceptual systems. The role of action in perception, they suggest, extends beyond processes targeted at the control of motor behavior and some aspects of perceptual performance intrinsically depend on the contribution of action.

Claiming that perception is *intrinsically* active, inseparable from action or even—as some have argued—reducible to a form of action (Noë, 2004), is a controversial hypothesis raising different orders of questions.

At a conceptual level, this hypothesis questions the traditional distinction between perception and action as independent cognitive domains. A lively debate has addressed this claim, and several lines of criticism have been leveled against the claim that perception cannot occur without action (Jacob, 2006; Prinz, 2006). Not surprisingly, more attention has been paid to the theoretical implications of these radical approaches than to the consequences of implementing a radical approach as an empirical research program.

From an empirical perspective, radical approaches on action/perception relations raise an interesting, often understated question. If part of perception is action-dependent, what processes and structures can be invoked to explain how perceptual systems parse and select sensory information on the basis of action? The answer that these theories seem to suggest is that perceptual systems process *action-dependent perceptual invariants*, or patterns of perceptual information that are intrinsically action-dependent.

In this paper our aim is not to address the question whether action and perception can be considered as mutually independent or to argue in favor or against radical approaches. The goal of our analysis is to articulate the very idea that perception may rely on action-dependent invariants and to contrast the way in which such a notion is characterized in these radical approaches. We propose that an analysis of this notion is a more promising testbed to assess the prospects of radical approaches to action/perception as genuine empirical programs than a generic criticism of some of their (possibly flawed) background assumptions.

1.1. Radical approaches to action/perception relations

The most prominent theories that take a radical view of the contribution of action to perceptual processes are those that belong to the *ecological approach to perception* (Cutting, 1986; Gibson, 1979; Reed, 1996). The ecological approach emphasizes the constitutively active nature of perceptual abilities, and the fact that perceptually relevant information is revealed by active interaction of the observer with the environment. A review of the eco-