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Affordance processing in segregated parieto-frontal dorsal stream sub-pathways

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ABSTRACT

The concept of *affordances* indicates "action possibilities" as characterized by object properties the environment provides to interacting organisms. Affordances relate to both perception and action and refer to sensory-motor processes emerging from goal-directed object interaction. In contrast to stable properties, affordances may vary with environmental context. A sub-classification into *stable* and *variable* affordances was proposed in the framework of the ROSSI project (Borghi et al., 2010; Borghi and Riggio, 2015, 2009). Here, we present a coordinate-based meta-analysis of functional imaging studies on object interaction targeting consistent anatomical correlates of these different types of affordances. Our review revealed the existence of two parallel (but to some extent overlapping) functional pathways. The network for stable affordances consists of predominantly left inferior parietal and frontal cortices in the ventro-dorsal stream, whereas the network for variable affordances is localized preferentially in the dorso-dorsal stream. This is in line with the proposal of differentiated affordances: stable affordances are characterized by the knowledge of invariant object features, whereas variable affordances underlie adaptation to changing object properties.

Contents

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1. Introduction

The concept of *affordance* was introduced by the ecological psychologist Gibson (Gibson, 1979). Affordances indicate "action possibilities" as characterized by object properties the environment provides to interacting organisms. Affordances relate to perception as well as action and refer to sensory-motor processes emerging from goal-directed object interaction. For instance, the handle on a cup provides an affordance for grasping and holding it. In the traditional Gibsonian view, affordances are recorded by the perceptual system in a direct way, thus, motor responses are directly activated by objects' affordances, independently of whether the object is recognized or not. In other words, responding to affordances does not require access to knowledge about the object. The organisms' behavioral possibilities afforded by an object are exclusively determined by the pattern of stimulation given by the object itself.

There is, however, growing experimental evidence that affordances are not (necessarily) a static property, but can vary with changes in the environment or in the perception of an organism, arising, for instance, from visual pathologies (e.g., Young, 2006). To give a specific example, Tucker and Ellis (2004) have shown a statistically indistinguishable behavioral stimulus-response compatibility effect (i.e. faster reaction times and less error rates in the compatible than in the incompatible stimulus-response condition), obtained with both object names and object images. Hence, this effect could rather be based on memorized information than on online processing of visual information. In this context, a conceptual extension in the form of a sub-classification of affordances into *stable, variable*, and *canonical* has been proposed in cognitive psychology (Borghi et al., 2010; Borghi and Riggio, 2015, 2009). According to this, *stable affordances* emerge from slow "offline" processing of visual information based on memorized object knowledge as well as previous experiences in object interaction. They refer to invariant features or object properties incorporated into an object representation, as, for example, typical grip types. Accordingly, we *know* that a marble is graspable with a precision grip. This does not imply solely the property size as a stable affordance, but there is a greater probability that size will lead to the emergence of a stable affordance than the more variable property of the location of the marble. In contrast, *variable affordances* emerge from fast online processing of visual information during actual object interaction and refer to changing or temporary object characteristics, such as orientation in space, size changes including the update of hand shape for grasping, defining overall the *current state* of the object. Finally, *canonical affordances*, which can be considered to be associated with stable affordances, are related to canonical aspects concerning object orientation (e.g., bottles are typically experienced in an upright position). It is important to mention that object orientation could thus also lead to the emergence of stable affordances as we typically observe and interact with objects in a given orientation. We do not, therefore, consider stable and variable affordances as being strictly dichotomous but rather as being arranged along a continuum.

Visual information originates in early visual cortical areas of the occipital cortex, and is classically considered to be processed over two distinct anatomical pathways (Ungerleider and Haxby, 1994; Ungerleider and Mishkin, 1982). The ventral stream, transferring information to the inferotemporal cortex, plays an essential role in the perceptual identification of objects and in the further analysis of object characteristics, and is therefore referred to as "what" system. The dorsal stream redirects information to the posterior parietal cortex mediating the required sensorimotor transformations for visually guided object-related actions. The dorsal stream was originally referred as "where" system by Ungerleider and Mishkin (1982), who proposed the dorsal stream to be responsible for localizing objects in visual space, but was later on re-conceptualized as "how" system (Goodale and Milner, 1992). This functional scope was extended insofar as the ventral stream holds a perceptual mechanism for the identification of possible and actual goal objects from visual information as well as for the selection of an appropriate course of action to deal with those objects (vision-for-perception), whereas the dorsal stream is responsible for the online implementation of possible and actual object-related actions, as well as sustaining online action control (vision-for-action) (Goodale et al., 1994; Milner and Goodale, 1995; see Milner and Goodale, 2008, for a refinement of the terminology used within this model). To sum up, even though both streams process information about object features and spatial relations, the ventral stream focuses on the enduring characteristics of objects and their relations to form a basis for long-term perceptual representations used to identify and to recognize objects, whereas the dorsal stream uses the instantaneous and egocentric coordinates of objects to mediate the visual control of object-related actions (Goodale et al., 1994; see also Goodale and Milner, 1992).

However, a further functional-anatomical refinement in terms of dorsal sub-pathways and ventro-dorsal interactions has been intensively discussed (Derbyshire et al., 2006; Gallese et al., 1999; Jeannerod and Jacob, 2005; Pisella et al., 2006; Rizzolatti and Matelli, 2003). An important contribution –initially based on studies in non-human primates (Rizzolatti and Matelli, 2003; Rizzolatti et al., 1998)– was the proposal of two distinct "dorsal" parieto-frontal sub-pathways: a *ventro-dorsal* stream and a *dorso-dorsal* stream. The ventro-dorsal stream is formed by the middle temporal visual area MT and by the visual areas of the inferior parietal lobule and the intraparietal sulcus, such as VIP and AIP, project-