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Review article

Affordances and neuroscience: Steps towards a successful marriage

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ABSTRACT

The concept of affordance is rapidly gaining popularity in neuroscientific accounts of perception and action. This concept was introduced by James Gibson to refer to the action possibilities of the environment. By contrast, standard cognitive neuroscience typically uses the concept to refer to (action-oriented) representations in the brain. This paper will show that the view of affordances as representations firmly places the concept in the subject-object framework that dominates both psychology and neuroscience. Notably, Gibson introduced the affordance concept to overcome this very framework. We describe an account of the role of the brain in perception and action that is consistent with Gibson. Making use of neuroscientific findings of neural reuse, degeneracy and functional connectivity, we conceptualize neural regions in the brain as dispositional parts of perceptual and action systems that temporarily assemble to enable animals to directly perceive and – in the paradigmatic case – utilize the affordances of the environment.

Although the term originates in ecological psychology, affordances are now commonly discussed in the cognitive neuroscience literature (as here) without any strict adherence to Gibson's broader theoretical position. (Makris et al., 2013, p. 797)

1. Introduction

Over the last two decades, an increasing number of cognitive neuroscientists has adopted the concept of affordance in their attempts to understand the role of the brain in action and the perception of (higher-order properties of) manipulable objects such as tools (e.g., Bach et al., 2014; Buccino et al., 2009; Cisek, 2007; Evans et al., 2016; Fagg and Arbib, 1998; Jeannerod, 1994; Kühn et al., 2014; Makris et al., 2013; Proverbio et al., 2013; Sakreida et al., 2016; Valyear et al., 2012). The ecological psychologist James Gibson originally introduced this concept to refer to the action possibilities of the environment that are available to an animal. For example, for most human-beings a chair affords sitting, a glass affords grasping, water affords drinking, and the floor affords walking across. However, when using the concept of affordance, cognitive neuroscientists typically do not refer to the action possibilities of the environment, but instead refer to (action-oriented) representations or dispositions in the brain (see e.g., Sakreida et al., 2016). In the present paper, we first show how this approach both fails to do justice to as well as exploit the power of Gibson's theoretical framework, and then sketch in bold strokes what a genuine Gibsonian neuroscience would look like.

We will start with a discussion of three influential neuroscientific accounts in which the concept of affordance is used, and transformed. We will then elaborate on how Gibson introduced the term affordance to overcome the subject-object framework that dominated psychology, and on how standard cognitive neuroscience, with its central reliance on representation and computation, firmly places the affordance concept back within this subject-object framework (see also Dotov et al., 2012). Capitalizing on Gibson's (1966) theory of perceptual systems, Anderson's (2014) recent theory of neural reuse, and reports of degeneracy in the brain (e.g., Noppeney et al., 2004), we will end with a discussion of a neuroscientific account of affordances that does do justice to Gibson's theoretical framework. It will be argued that brain regions are *parts* of perceptual and action systems that provide animals with the capacity to directly perceive and utilize affordances.

2. Affordances in standard cognitive neuroscience

The concept of affordance is often used in neuroscientific accounts, and not always incorrectly (see e.g., Anderson, 2014; Bruineberg and Rietveld, 2014; Reed, 1996). However, in this section we will limit ourselves to influential accounts, exemplary of standard cognitive neuroscience, that use the concept of affordance in ways that are not in

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line with the traditional Gibsonian notion.[1] Specifically, we will focus on the FARS (Fagg-Arbib-Rizzolatti-Sakata) model (Fagg and Arbib, 1998), Tucker and Ellis' (1998) affordance effect, and Cisek's (2007) affordance competition hypothesis.

2.1. The FARS model (Fagg, Arbib, Rizzolatti, and Sakata)

Fagg and Arbib (1998) developed a computational model of the cortical control of grasping. Their goal with this model, which they termed the FARS model, was to provide cognitive neuroscience with "[…] an antidote to an overly exclusive focus on object recognition as the goal of human processing" (p. 1277). Indeed, they aimed to shift focus toward the functional significance of objects. Fittingly, they adopted the concept of affordance, but defined it as follows:

> Gibson used the term *affordances* to mean parameters for motor interaction that are signaled by sensory cues without invocation of high-level object recognition processes. (Fagg and Arbib, 1998, p. 1277, emphasis in original)

In this interpretation, affordances are conceptualized as neural transformations of visual cues into grasps. These transformations are hypothesized to occur in a neural network involving the anterior intraparietal area (AIP), area F5 of premotor cortex, and inferotemporal cortex (Fagg and Arbib, 1998). Although they attribute their definition of affordances to Gibson, Fagg and Arbib appear to a certain extent aware of the incongruence between their interpretation and Gibson's use of the term: "[…] unlike Gibson, we imagine several intervening levels of processing between the retina and the extraction of affordances." (p. 1278). However, this is the only discrepancy Fagg and Arbib identify, and, importantly, one that does not mention the mutuality of the agent and the environment that is central to Gibson's conception of affordances (see below, Section 3.1).

2.2. The affordance effect (Tucker and Ellis)

In a series of behavioral experiments, Tucker and Ellis showed that actions may be potentiated after seeing an image of an object which affords these actions (Ellis and Tucker, 2000; Symes et al., 2007; Tucker and Ellis, 2004, 2001, 1998). Specifically, in their seminal study Tucker and Ellis (1998) showed participants images of common graspable objects and asked them to categorize these images as either upright or inverted by pressing a button as quickly as possible with either their left or their right hand. When the object was oriented to the right and would therefore be easiest to grasp with the right hand, reaction times (RT) for the right hand were shorter than those for the left hand, and vice versa. The authors concluded that merely seeing an object can potentiate actions that are associated with the object and coined this potentiation the 'affordance effect'. In explaining their findings, Tucker and Ellis used the following definition of affordances:

> We use the term *affordance* to refer to the motor patterns whose representations visual objects and their properties give rise to, both during explicit goal-directed acts […] as well as, we argue, before explicit intentions have been formed. (Tucker and Ellis, 1998, p. 833, emphasis in original)

Later, Ellis and Tucker (2000) describe the effects of seen objects on RT as "micro-affordances, which are said to be dispositonal [*sic*] states of the viewer's nervous system" (p. 451). They are aware that their interpretation of affordances as representations deviates from Gibson.

> In contrast to this [Gibsonian] notion of affordances being dispositional properties of objects and events, our notion has them as dispositional properties of a viewer's nervous system. (Ellis and Tucker, 2000, p. 466)

Although the initial studies by Tucker and Ellis were behavioral and did not involve measurements of brain activity, the above quote shows that they took their results to inform the way action relevant features of objects are represented in the brain. Later papers studying the neural correlates of the 'affordance effect' followed their representational definition of affordances (e.g., Grèzes and Decety, 2002; see also Creem-Regehr and Lee, 2005). Statements such as: "the parietal cortex provides affordance information" (Grèzes and Decety, 2002, p. 213) are clearly reminiscent of an interpretation of affordances along the lines of Tucker and Ellis (see Proctor and Miles, 2014 for further critique).

2.3. The affordance competition hypothesis (Cisek)

The final transformation of the affordance concept in neuroscience that will be discussed here is Cisek's 'affordance competition hypothesis' (Cisek, 2007; Cisek and Kalaska, 2010; Cisek and Pastor-Bernier, 2014; Pezzulo and Cisek, 2016). This account starts from the assumption that the brain has evolved to enable organisms to interact with their environment in adaptive ways. It is proposed that during the selection and specification of actions, the brain does not process information serially, but rather in a parallel manner, leading to representations that combine sensory, motor and cognitive elements.

> [S]ensory information arriving from the world is continuously used to specify several currently available potential actions, while other kinds of information are collected to select from among these the one that will be released into overt execution at a given moment. […] From this perspective, behavior is viewed as a constant competition between internal representations of the potential actions which Gibson (1979) termed 'affordances'. (Cisek, 2007, p. 1586)

Cisek's (2007) model incorporates regions in each of the four lobes of the cortex, as well as the basal ganglia and cerebellum, with the competition between affordances playing out in particular in reciprocal connections within fronto-parietal regions (see Cisek, 2007, Fig. 1). As we will explore in more depth below, Cisek's notion of behavior as continuous interaction and adaptation to a changing environment fits well with the ecological approach. However, his interpretation of affordances as representations of potential actions obviously does not, even if these representations are non-modular (e.g., Fuster, 2000) and their functional role is "[…] not to describe the world [in action-neutral terms], but to mediate adaptive interaction with the world" (Cisek, 2007, p. 1594).[2]

A shared – and defining – characteristic of the three accounts described above is their depiction of the concept of affordance as a neural representation of motor patterns for actions that are afforded to the observer. Declerck (2013) terms this approach the simulation theory of affordance perception (STAP) and traces its initial formulation to Jeannerod (2001, 1994; Jeannerod et al., 1995). STAP proposes that affordance perception is subserved by motor simulation mechanisms, which not only "[…] shape the motor system in anticipation to execution, but also […] provide the self with information on the feasibility and the meaning of potential actions" (Jeannerod, 2001, p. S103). Thus, "[d]uring object-directed action, a pragmatic representation is activated in which object affordances are transformed into specific motor schemas […]" (Jeannerod, 1994, p. 187). It is clear that within several influential neuroscientific accounts, affordances are representational concepts that are decidedly placed *inside* the brain (and waiting to be activated).

[1] For an excellent treatment of how Gibson's ecological approach is misrepresented in textbooks see Costall and Morris (2015).

[2] In later work (e.g., Cisek and Kalaska, 2010), Cisek no longer defines affordances as representations of potential actions, but instead follows Gibson by defining them as the action possibilities of the environment.