Neuroscience and Biobehavioral Reviews 37 (2013) 491–521

Contents lists available at SciVerse ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Review

# Theories and computational models of affordance and mirror systems: An integrative review

Serge Thill[a,*], Daniele Caligiore[b,c], Anna M. Borghi[c,b], Tom Ziemke[a], Gianluca Baldassarre[b]

[a] Interaction Lab, Informatics Research Centre, University of Skövde, 54128 Skövde, Sweden
[b] Laboratory of Computational Embodied Neuroscience, Istituto di Scienze e Tecnologie della Cognizione, Consiglio Nazionale delle Ricerche (LOCEN-ISTC-CNR), 00185 Roma, Italy
[c] Embodied Cognition Laboratory (EMCO-Lab), Dipartimento di Psicologia, Università di Bologna, 40127 Bologna, Italy

ARTICLE INFO

*Article history:*
Received 20 July 2012
Received in revised form 15 October 2012
Accepted 8 January 2013

*Keywords:*
Embodied cognition
Affordance processing
Canonical neurons
Mirror system
Psychology
Neuroscience
Neurophysiology
Computational modelling
Integration

ABSTRACT

Neuroscientific and psychological data suggest a close link between affordance and mirror systems in the brain. However, we still lack a full understanding of both the individual systems and their interactions. Here, we propose that the architecture and functioning of the two systems is best understood in terms of two challenges faced by complex organisms, namely: (a) the need to select among multiple affordances and possible actions dependent on context and high-level goals and (b) the exploitation of the advantages deriving from a hierarchical organisation of behaviour based on actions and action-goals. We first review and analyse the psychological and neuroscientific literature on the mechanisms and processes organisms use to deal with these challenges. We then analyse existing computational models thereof. Finally we present the design of a computational framework that integrates the reviewed knowledge. The framework can be used both as a theoretical guidance to interpret empirical data and design new experiments, and to design computational models addressing specific problems debated in the literature.



**Contents**



* Corresponding author. Tel.: +46 0500 44 83 89; fax: +46 0500 44 84 49.
*E-mail addresses:* serge.thill@his.se (S. Thill), daniele.caligiore@istc.cnr.it (D. Caligiore), annamaria.borghi@unibo.it (A.M. Borghi), tom.ziemke@his.se (T. Ziemke), gianluca.baldassarre@istc.cnr.it (G. Baldassarre).

0149-7634/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neubiorev.2013.01.012

## 1. Introduction: affordances, canonical neurons, and mirror neurons

Studies on macaque monkeys have shown that brain area F5 (putatively homologous to human posterior Inferior Frontal Cortex, IFC, Rizzolatti and Arbib, 1998)[1] contains two varieties of visuomotor neurons: *canonical neurons* and *mirror neurons* (Di Pellegrino et al., 1992; Gallese et al., 1996; Murata et al., 1997; Raos et al., 1996; Rizzolatti et al., 1996; Sakata et al., 1995; for a more recent review see Rizzolatti and Craighero, 2004). Both canonical and mirror neurons discharge when macaques execute specific actions, for example when they grasp an object with a precision grip or a power grip.

Canonical neurons also fire when the monkey simply observes an object. This points to a mechanism for detecting object affordances and activating actions on this basis. The concept of *affordance* was first introduced by Gibson (1966), who observed that the dynamical pattern of the optic flow can be used to guide navigation *reactively* through the environment. He used the term affordance to refer to the fact that visual perception of the environment is not just passive perception of objects as such, but direct perception of the potential actions that the perceiver can carry out with them without the need for high-level processes such as reasoning about object properties. In the realm of manipulation, for example, a person seeing an object would not necessarily only perceive colours, shapes and so on, but first and foremost also directly perceive the object's "graspability", "liftability" and so on. The affordances of any given object depend not on the object alone, but also on the embodiment (in particular the actuators) of the perceiving agent. A bottle, for example, affords grasping for humans but not for dogs (for which it might afford a biting action) or ants. A key aspect of the concept of affordance is the reactive nature of the resulting sensorimotor processing that tends to trigger or prime action in an automatic fashion (although we will later see that this tendency can be strongly modulated by the context and goals of the agent).

In some of the recent literature, the concept of affordance has been extended beyond the Gibsonian interpretation to consider the *brain representations of affordances* (the possible sensorimotor interactions offered by objects, see for instance Fagg and Arbib, 1998 or Oztop and Arbib, 2002). These representations encode both the features of the objects needed to act on them (e.g., the size and location of the object) and the relation between the objects and the agent's body (e.g., that an object is within reach or in contact with a hand).

In cognitive psychology, the concept of affordances has been further developed with the definition of *micro-affordances* (Ellis and Tucker, 2000; Vainio et al., 2007), also referring to *brain representations* of possible sensorimotor interactions with objects. Micro-affordances do not concern the whole action but rather specific *action components*: for example, observing an object with a given size and orientation might activate two different components of the grasping action, such as the grip type (e.g., power vs. precision) and the wrist orientation (e.g., with the hand palm pronated or supinated).

In addition to the Gibsonian view, these extensions to the concept of affordance are very important for this review. To avoid confusion, we will use the term "(micro-)affordance representations" to refer to the brain representations of affordances unless the context clearly disambiguates between the Gibsonian and the brain-related meaning, in which case we will use the simpler term "affordances".

*Mirror neurons* (also found in the parietal cortex (PC); Fogassi et al., 2005) fire when the monkey observes another monkey or a human being perform a *goal-directed* action such as, for example, grasping an object (Rizzolatti and Craighero, 2004). This points to a mechanism for *action* or *intention understanding* (Rizzolatti and Craighero, 2004; Iacoboni et al., 2005). A crucial difference with canonical neurons is that mirror neurons do not discharge to the simple presentation of an object. This evidence has led many authors to link mirror neurons to the representation of *goals of actions* (Rizzolatti and Craighero, 2004; Iacoboni et al., 2005; Craighero et al., 2007). For example, Johnson-Frey et al. (2003) have shown through an fMRI study that the frontal mirror regions of

[1] All brain regions acronyms used in the article are summarised in Table 1 in Appendix.