Object concepts and action

Anna M. Borghi

University of Bologna

To appear in: "The Grounding of Cognition: The role of perception and action in memory, language, and thinking" by Diane Pecher and Rolf Zwaan (Eds.), Cambridge University Press.

Website:

http://www.eur.nl/fsw/psyweb/homepage/diane_pecher/embodied_cognition/

Abstract

The idea that concepts are action-based is compatible with two possibilities. Concepts can be conceived of directly as patterns of potential action (Glenberg, 1997) or as being made of "perceptual symbols", from which it is possible to quickly extract action information (Barsalou, 1999). If concepts directly evoke actions, they allow us to respond quickly to environmental stimuli. However, we may need to interact with objects in different ways depending on our current goals and on the current situation.

I will discuss evidence in support of both claims. Motor information is incorporated directly into concepts for simple interaction with their referents, particularly with manipulable objects, but when it comes to performing complex goal-oriented actions with complex objects we may access more general perceptual and situational information and utilize it in a more flexible manner. This is true both in the presence of objects and when objects are referred to by words.

Introduction

Successful interaction with objects in the environment is the precondition for our survival and for the success of our attempts to improve life by using artifacts and technologies to transform our environment.

Our ability to interact appropriately with objects depends on the capacity, fundamental for human beings, for categorizing objects and storing information about them, thus forming concepts, and on the capacity to associate concepts with names. Concepts serve as a kind of `mental glue` that `ties our past experiences to our present interactions with the world` (Murphy, 2002). They are the cognitive and mental aspects of categories (Barsalou, Simmons, Barbey, & Wilson, 2003).

The generally accepted view sees concepts as being made of propositional symbols related arbitrarily to their referents. This implies the existence of a process by which sensorimotor experience is translated into amodal symbols. By proposing that concepts are, rather, grounded in sensorimotor activity, many authors have shown the limitations of this view (Barsalou, 1999; Harnad, 1990; Thelen & Smith, 1994). According to Barsalou (1999), concepts are perceptual symbols – i.e., recordings of the neural activation that arises during perception – arranged as distributed systems or “simulators”. Once we have a simulator it is possible to activate simulations, which consist in the reenactment of a part of the content of the simulator.

This view presupposes a close relationship between perception, action and cognition. Many recent theories argue against the existence of a separation between perception and action, favoring rather a view that incorporates motor aspects in perception (Berthoz, 1997). In theories that posit perception and action as separate spheres (Sternberg, 1969; Pylyshyn, 1999), it is not possible to envision action systems as having effects on perception, because the assumption is that the perceptual process takes place in the same way independently from the kind of response involved - manual, by saccade, etc. (Ward, 2002). The primary limitation of this view is that it is not adaptive. It is difficult to imagine the evolution of the human perceptual system as something other than an ongoing process of finding appropriate responses to the environment. Perception cannot be simply the recording of sensorial messages. It must be influenced and filtered by action.

A growing body of research emphasizes the interconnections between the "low-level" or sensorimotor processes and the "high-level" or cognitive processes. It has been proposed that cognition is embodied, i.e., that it depends on the experiences that result from possessing a body with given physical characteristics and a particular sensorimotor system. This view of cognition is clearly in opposition to the classical cognitivist view according to which mind is a device for manipulating arbitrary symbols.

The aim of this chapter is to provide indications that may serve as tools for evaluating the claims that concepts are grounded in sensorimotor experiences and that "knowledge is for acting" (Wilson, 2002). I will argue that object concepts support direct interaction with objects and also that when concepts refer to objects through words they activate action information.

This idea is compatible with two possibilities. Concepts can be conceived of directly as patterns of potential action (Glenberg, 1997) or as being made of "perceptual symbols" from which it is possible to quickly extract data that serves to inform action (Barsalou, 1999). If concepts directly evoke actions, they allow us to respond quickly to environmental stimuli. However, particular situations and goals may make it necessary to interact with objects in different ways, in which case we have to read concepts as clues to interaction and not simply as blueprints that tell us how to act (Duncker, 1945).

I will argue that both claims are true. Concepts automatically activate motor information for simple interaction with their referents, particularly with manipulable objects. But when it comes to performing complex goal-oriented actions with complex objects we may access more general perceptual and situational information and utilize it more flexibly.

1. Object concepts and interaction with objects

Imagine you are using a computer. The concept "computer" supports the interaction with the current computer. For example, before pressing each key on the keyboard, you access motor images that tell you where the different keys are.

In this perspective, the function of a concept consists in activating on-line simulations that support interaction with objects. Such simulations may also occur when there is no specific task-requirement.

Furthermore, this on-line use of concepts doesn't necessarily imply the mediation of awareness. One could be unaware of the position of the keys on the keyboard. Access to previous experience, however, allows us to understand that the keys have to be pressed instead of pinched. The unconscious mediation of conceptual knowledge makes it possible for us to extract information from the object so that we are able to interact with it successfully. The actions suggested by a particular object are known as affordances (Gibson, 1979). In this section I will first discuss the ways in which concepts help us combine affordances with previous experience of objects. I will then discuss evidence demonstrating that concepts support action.

1.1.Affordances and interaction with objects

The affordance an individual derives from an object is neither objective nor subjective. `It is equally a fact of the environment and a fact of behavior` (Gibson, 1979, pp. 129). Depending on the constraints of our body, on the perceptual characteristics of the object in question and on the situation at hand, we derive different affordances from objects. Perception is filtered and influenced by action. So affordances are interactive. An object blocking our way might afford the action of stopping, but not if the object is very low in relationship to our body.

Also, affordances are variable. As we use an object its affordances may change. Before we use tools, we conceive of them as separate objects, with their own affordances. As we use them they can change from being mere objects, and become extensions of our body (Hirose, 2001). There is evidence that peripersonal space is dynamic and can be extended and contracted through the use of a tool (Farne & Ladavas, 2000).

One might ask why we need conceptual knowledge if affordances support us in interacting successfully with objects. This question is crucial. When do concepts come into play?

According to Gibson and in the ecological tradition, affordances are based on intrinsic perceptual properties of objects. These properties are registered directly by the perceptual system without the mediation of object recognition and of semantic knowledge. `You do not have to classify and label things in order to perceive what they afford` (Gibson, 1979, p. 134). In this view, the environment is thought to contain all the information the motor system needs in order to interact with objects, surfaces, substances, other living entities. The behavioral possibilities afforded by objects are entirely specified by the pattern of stimulation that the object produces in the perceiver.

There are, however, some problems with this theory. Consider the different affordances derived from a rock blocking our way, and those derived from a bicycle. In the case of the rock, we quickly derive the affordance of stopping or of removing the obstacle. In the case of the bicycle, the handle may afford the action of grasping it, the seat of sitting, etc. Thus we may need to access conceptual information in order to know to which affordances to react.

In fact, the ability to use an object appropriately implies a capacity for combining the affordances it provides with our previous experience of that object and/or with any pre-existing knowledge of its function. In order to ride a bike, we need to access previous experience with bikes. This experience need not be direct. Infants of four months, for example, acquire information regarding the affordances of an object by observing others rather than through direct experience (Marschall and Johnson, 2003).

Furthermore, our goals in approaching an object can have an effect on our actions in relation to that object. The action of grasping the receiver of a telephone might come to us automatically, but using a telephone to call someone is the result of a mediation of goals, which differ from those involved in cleaning a telephone.

There are cases in which an objects`s shape might afford a certain response, but appropriate usage may require another response. Klatzky, McCloskey, Doherty, & Pellegrino (1987) showed that for most objects the appropriate hand posture may be predicted on the basis of the object's structure, while for some objects structure and function diverge: a knife elicits a pinch response, but functions with a clench posture. This suggests that in order to interact appropriately with certain kinds of objects we have to combine the affordances they directly elicit with knowledge of the object and of its function.

1.1.1. Two routes to action?

An influential view regarding the relationships between action and conceptual knowledge claims that there are two different routes to action, a direct visual route, mediated by the dorsal system, and another route that implies access to semantics and is mediated by the ventral system. This view is supported by behavioral data (Rumiati & Humphreys, 1998). Further evidence concerns double dissociations found in patients with optic aphasia who fail to name visually presented objects but whose ability to gesture with them is preserved, and in apraxics, who are able to name and recognize objects but not to act appropriately with them.

However, recent data suggest that a direct non-semantic route to action might exist, but that it is very limited and that there are deep interactions between perception, action, and knowledge.

Experiments with action-decision and size-decision tasks conducted using Positron Emission Tomography (PET) indicated that words and pictures do not activate different neural areas (Phillips, Humphreys, Noppeney and Price, 2002). Rather, pictures activate the same areas but to a lesser degree, probably due to the role played by affordances in facilitating motor responses. The only specific areas activated for pictures concerned novel objects, where it is necessary to spend some time in structural processing, as there is no previous usage and action information to access. Buxbaum, Sirigu, Schwartz, & Klatzky (2003) found that apraxics are able to associate an appropriate hand posture to novel objects but not to real objects. Thus, affordances in the classic, Gibsonian sense, might be activated only by novel objects. When we have previous experience with objects, it comes into play and influences interaction with them.

A less restrictive possibility is that manipulatory gestures in response to an object`s affordances can be performed without accessing conceptual knowledge, but that it is impossible to perform gestures appropriate to the object`s use as mediated by goals. Along these lines, Buxbaum et al. (2003) suggest that prehensile postures such as pinch and clench might be mediated simply by the dorsal system, thus not requiring access to knowledge regarding an object, while exploratory hand postures such as palm and poke, linked as they are with object identity, are always mediated by the ventral system. However, prehensile postures should also be related to object identity. Even a simple action such as grasping a familiar object by its handle requires a motoric representation of how to grasp, but also an object-relative representation of where to grasp based on the object identity. Preshaping, manipulation and tactile exploration of objects are mediated by knowledge. For example, even without visual feedback from the hand, the size of the grip aperture correlates with the object`s size. However, knowledge is not sufficient: visual stimuli potentiate object affordances. Prehension movement directed at objects within the peripheral visual field are inaccurate and improper (Jeannerod, 1994).

With a dual task paradigm,Creem & Proffitt (2001) showed that the ability to grasp common objects such as a hammer or a toothbrush appropriately, by, for example, reaching for a handle even if it is not oriented towards us, decreased with a semantic interference task, but not with a spatial interference task. This suggests that combining conceptual knowledge with affordances derived from objects is a necessary component of grasping them in an appropriate manner (Buxbaum, Schwartz & Carew, 1997).

This mediation of conceptual knowledge is unconscious. Actions are driven by implicit knowledge of object attributes. The response is automatic. However, the implicit and the explicit modes of processing are not isolated (Jeannerod, 1997). Klatzky et al. (1987) presented evidence that people have explicit knowledge of how to manipulate objects. People are able to reliably report which class of hand shape (clench, pinch, poke, palm) would be used to manipulate a certain object, to report which objects can be manipulated given a certain hand shape, and to report in which functional context (hold-pick up; feel-touch; use) a given hand shape had to be used.

Overall, the data are compatible with a second view, according to which there is an integrated distributed system for semantics, vision and action rather than separate modules (Allport, 1985). Different information is activated depending on the goal being pursued. According to this view, semantic and sensorimotor information interact in allowing appropriate object use in such a manner that “the contribution from the functional/associational domain is actually enhanced by the involvement of sensorimotor elements recruited directly from perception” (Buxbaum et al., 1997, pp. 248).

This does not mean that visual imput and memory input have the same effect on action. For example, Wing, Turton, & Fraser (1986) have shown that grasping directed at memorized objects involves larger grip aperture than that directed at visual objects. In interaction with the memory input the visual input is necessary to adjust the grip appropriately. Neither sensorimotor nor semantic information is necessary and sufficient for performing appropriate actions. The visual input potentiates the affordances associated with the object – e.g., the handles, or the kind of grasp (Tucker & Ellis, 1998, 2001). This notion is compatible with the idea that we may have forms of representations or world models, but that they are partial and action-based~~,~~ and must be integrated with information on the current environment and needs (Clark, 1997).

1.2. Neural basis: What and How Systems

The fact that we can do different things with objects is the basis for Jeannerod's (1994, 1997) proposal that we have both a pragmatic and a semantic representation of objects. Pragmatic representation, which is largely automatic, involves a rapid visuomotor transformation of the object which is simply considered as a goal for acting. When our action is based on a pragmatic representation, we program and adjust object-oriented actions on-line in response to object properties. Semantic representation implies the integration of the features of an object into a meaningful identity, and it is generally conscious. The actions it generates are based on the memorized characteristics of objects. On the basis of this distinction, an object`s attributes can be classified with regard to different aspects of object-oriented behavior. Size, shape, texture are probably relevant to both forms of representation, color just to the semantic, weight just to the pragmatic.

Notice that these two forms of object representation are not separate but that they may be integrated and influence each other. Anatomically, this is possible given the many connections linking the dorsal and the ventral system.

In fact, this distinction between pragmatic and semantic representation is compatible – but does not overlap - with Milner and Goodale's hypothesis (1995) that we have two differently specialized visual processing systems. The dorsal system, originally conceived of as a spatial system used for coding the location of an object ("where" system), is now seen as a "how" system, dedicated to the computation of the movements of the effectors required to bring objects into proximity. It has been demonstrated in experiments conducted on monkeys that a large population of neurons in the dorsal stream is involved in the coding of hand grasping movements. The teams of Rizzolatti and Sakata have highlighted the role played by neurons in area F5 of the monkey, an area that forms the rostral part of the ventral premotor cortex, and in the intraparietal sulcus (area AIP). Canonical F5 neurons discharge both when the monkey sees the object and when it performs a goal-directed action such as manipulating, holding, tearing or grasping a graspable 3D object. Some of these neurons are selective for different types of grip: precision grip, finger prehension, whole-hand prehension (Rizzolatti & Luppino, 2001). Overall, the dorsal system can be conceived of as an integrated perception-action system specialized in forming visuomotor representation of objects based on their physical characteristics, and in transforming visual information into information regarding the graspability of objects in terms of affordances. This happens when information about goals is not specified, and when correctness of action is guaranteed even when there is no functional information about objects.

Unlike the dorsal system, which operates in real time, the ventral system is specialized in computing and storing information about objects over long time intervals.

As we have seen, in most cases conceptual information has to be combined with visual information for a person to interact correctly with objects, for example to access what kind of grip is appropriate for manipulating them. In these cases, the dorsal system may receive input from the ventral system.

This leads to a reconsideration of the idea that semantic knowledge is represented only in the ventral stream. Instead, it seems plausible that object knowledge is represented in various areas, and that the premotor cortex plays a major role. Dorsal and ventral premotor activation might be part of a frontotemporal circuit connecting object meaning with motoric responses.

1.2.1. A possible mechanism: motor imagery

More and more authors share the view that visual object representation includes motor information. A plausible mechanism for allowing this is the automatic activation of motor imagery. Motor imagery is a special kind of mental imagery involving the self. It corresponds to a subliminal activation of the motor system. Recently it has been shown that this system is involved not only in producing movements, but also in imagining actions, learning by observation, understanding the behavior of other people and recognizing tools (Decety, 1996; Jeannerod & Frak, 1999). In monkeys, neurons in area F5 discharge even when acting with the object is not required by the task (Fadiga, Fogassi, Gallese & Rizzolatti, 2000). Similarly, in humans tools or graspable objects activate the premotor cortex even when no response is required. The mechanism of simulation guarantees that the system is flexible enough to shift to other action simulations if the situation requires it.

1.3. Behavioural evidence

1.3.1. From vision to action

Recently much behavioural evidence has been provided in support of the idea that visual representation of objects includes the partial activation of the motor patterns associated with their affordances. For example, a glass is represented by making accessible the information that it can be reached and grasped, in order to drink from it. Ellis & Tucker (2000) formulated the name of “micro-affordances” to refer to this phenomenon. Microaffordances are elicited automatically, independent of the goal of the actor. Accordingly, microaffordances typically do not pertain to complex actions, which are probably mediated by the actor`s goal, such as drinking. Rather, they facilitate simple and specific kinds of interaction with objects. These simple interactions with objects also imply the activation of conceptual knowledge. In fact, microaffordances are more specific than Gibsonian affordances. They do not elicit grasping, but a specific component of grasping, which is suitable to a particular object.

Ellis & Tucker (2000) and Tucker & Ellis (2001) demonstrated this by presenting participants with real objects of different size located behind a screen. Participants had to categorize the objects as natural or artefact, or to respond to a high or low auditory stimulus, using either a power grip or a precision grip. A compatibility effect between the kind of grasp and a task-irrelevant dimension, the object`s size, was found. The effect was also generated when the object was located outside the reaching space, which suggests that seeing the object activates the simulation of a specific component of grasping. A similar compatibility effect was found between the direction of the wrist rotation and the kind of grasp required by the object. For example, objects such as bottles facilitated responses with a clockwise wrist rotation, while objects such as toothbrushes facilitated a counter-clockwise wrist rotation.

Microaffordances are not only elicted as a response to the size of an object. Tucker & Ellis (1998) conducted an experiment in which they presented participants with photographs of objects with handles, such as cups. The cups were presented upright or upside down, with the handle extending to the left or to the right of the object. Participants had to indicate whether the object was upright or reversed by pressing a left or a right key. Results showed a clear effect of the compatibility between the position of the handle and the orientation of the key, indicating that seeing an object can potentiate a certain response. In a further study, Phillips & Ward (2002) presented participants with a visual object~~s~~ prime such as a frying pan with a handle. Its handle could be on the left, on the right, or in the middle, and it could be placed nearer to or further from the participant. The prime was followed after a varying SOA by an imperative target requiring a left or right hand or footpress. The researchers found that there was a correspondence effect between handle orientation and the key the participant pressed regardless of the modality (hands uncrossed, hands crossed, foot response). This correspondence effect increased with SOA. The absence of an effect of depth could mean that participants accessed conceptual information, as they mentally reached for the handle even if it was not oriented towards them. Their interpretation of the results favours the idea that the affordances of an object do not potentiate a specific response code for the hand or limb more suited to respond, but activate a more abstract spatial code, which may potentiate a wide variety of responses to the afforded side of space.

More interestingly, these data suggest that participants form a simulation of their interaction with the objects, being sensitive to the relationship between the (irrelevant) object property, the handle location, the current position of their limbs in space and the force of the effectors. The sensitivity to the current position of the limbs explains why in the crossed hand condition the hand closer to the handle is more activated. As the frying pan visually presented on the screen was empty, it might have been simpler and more economical for participants to grasp it with the hand closer to the handle. If the pan were presented with something (possibly heavy) inside, it could have been more useful to activate the ipsilateral hand. Of course, these studies test the immediate motor response to visual affordances. They do not investigate planning of a sequence of actions. If this were the case, then probably the most activated hand would be the ipsilateral hand, as it is easier to use when performing a series of actions. This sensitivity to the strength of their effectors explains why T&E did not find the compatibility effect when the effectors to provide the answer were two different fingers of the same hand and why P&W found it with foot response. Unlike the foot, fingers are too close to each other to imply a different orientation of our bodily axis towards an object located in front of us. Furthermore, fingers might be too weak to move a cup, whereas feet are surely strong enough to remove a pan by pushing its handle. Thus visual stimuli evoke a simulation of the interaction with the object in which object properties are not activated per se (handle location), but in interaction with the body properties (effectors location and force), and the current situation (e.g. empty frying pan).

1.3.2. From action to perception

The visual presentation of an object is not the only factor to potentiate the affordances associated with it. The intention to perform an action modulates visual processing by favoring perceptual features which are action related.

Bekkerin & Neggers (2002) found that the first eye movement was more accurate in selecting a target-object situated, with a given orientation, among distractors, when the object had to be grasped afterwards than when it had to be pointed to. Given that orientation is relevant for grasping but not for pointing, the results suggest that action planning influences visual processing.

Various experiments demonstrate the effects of motor-visual priming. Preparation to grasp an object facilitates the detection and discrimination of visual shapes congruent with it. Craighero, Fadiga, Rizzolatti, Umilta (1999) trained participants to prepare a grasping movement towards a bar oriented clockwise or counterclockwise. They then had to grasp it as quickly as possible upon presentation of a picture representing a bar oriented either clockwise or counterclockwise or a circle. Grasping response times were quicker when the orientation of the visually presented bar and that of the bar to grasp matched. The congruency effect was still present when the participants used effectors other than the hands, or made a response not affected by a postural relation with the grasping movement (i.e., blinking with both eyelids). It disappeared when the visual properties of the presented target did not match with those for which the grasping movement was prepared, as a pencil with the same orientation of the bar, but which could not be grasped in the same way as the bar. Thus the effect was not due to orientation effects per se, but to the matching of the motor affordances of the visual object with those of the real object.

Motor preparation also evokes a representation of the prepared action in visual terms. Vogt, Taylor & Hopkins (2003) demonstrated this with a simple response procedure. Participants, given the instruction “clockwise” or “counterclockwise” and a prime, were asked to grasp a bar in the indicated orientation. By manipulating the perspective of the hand presented as a prime, which could either match the end posture of the observer`s own hand (Own perspective) or the end posture of the hand of another person (Other perspective), they found a congruency effect for the Own perspective when a neutral hand stimulus was given as a preview and for the Other perspective when the prime stimuli was preceded by a fixation dot. The results suggest that there are two different priming effects: a visuo-motor priming effect, driven by a visual stimulus (the hand) that automatically evokes a motor response, and a motor-visual priming, planning driven, that enhances the visual processing of body parts in the Own perspective. Both mechanisms are relevant from an evolutionary standpoint. We need to react quickly to unexpected appearance of hands of conspecifics, just as we automatically react to visual objects, and we also need to select perceptual stimuli relevant for acting.

Borghi, Di Ferdinando & Parisi (2002) ran Artificial Life simulations that explain how the action intention influences categorization. They simulated an organism living in a bidimensional environment containing four different objects. The organism had a visual system with which he/she saw one object at a time and a moveable two-segment arm. He/she was aware of the arm's position at any given time thanks to proprioceptive input from the arm's segments. The organism's behavior was controlled by an artificial neural network. In the simulation, the organism had to group the stimuli by pressing the same button, in two categories which, depending on the task or action intention (which was encoded in a set of additional input units), could be formed by perceptually very similar, moderately similar, or different objects. Categories formed by perceptually dissimilar objects are goal-derived categories, i.e. categories based on common goals rather than on perceptual similarity between their members (Barsalou, 1991). Task information overrode perceptual information. The internal representations of the neural networks reflected the current task and not the perceptual similarity between the objects. However, the networks tended to form action-based categories more easily (e.g. in fewer generations) when perceptually similar objects had to be responded to by pressing the same button than when perceptual similarity and action to perform were not congruent. At hidden layers nearer the sensory input, where task information still had not arrived, internal representations reflected perceptual information.

Visual processing is not only influenced by action intention. We also implicitly code action relations of the causal kind between objects, and this influences visual selection (Riddoch, Humphreys, Edwards, Baker, & Willson, 2003). Patients with extinction, i.e., patients who, in the presence of two stimuli, report seeing only one of them, identified pairs of objects which were action-related in a correct and an incorrect way (e.g., corkscrew going into the cork at the top or at the bottom of a wine bottle). Patients were more likely to select two items in a trial if they were in the correct position for action, and if they were linked by an action relation (e.g., hammer and nail) rather than an associative relation (e.g., pencil associated with the most frequently associated word, pen).

1.3.3. Interactive properties and categorization

Iachini & Borghi (submitted) used a sorting task to test the importance of interactive properties for categorization. The material consisted of boxes varying in shape (square versus triangular), size (small versus large) and kind of handle (liftable versus not liftable). The boxes were built to make it possible to lift them without using the handle, but participants had to extend the hand in an unnatural position. Also, size was manipulated, but not in such a way as to deeply influence interaction with objects. Depending on the condition, during the learning phase participants had to observe the boxes (only vision), to touch and lift the boxes without seeing them (only motor), to observe, touch and lift the boxes (vision and motor), and to observe the experimenter touching and lifting the boxes (mirror). Then participants had to sort the boxes into two groups.

If sorting were predicted by perceptual salience, shape should be the preferred dimension for sorting, followed by size. If the objects activate a simulation of the possible actions to perform with them, the fact of whether or not they were easy to lift should acquire relevance. This hypothesis was confirmed. Across conditions, sorting was predicted by both shape and liftability, which differed significantly from size. The relevance of shape can be explained by the fact that shape automatically activates motor information.

1.3.4. From vision to function?

The findings reported thus far indicate that there is an interaction between action-relevant object properties, such as shape and part location, size and orientation, and the kind of action to perform. Viewing an object automatically activates action related properties, and motor preparation influences the perceptual processing of an object.

However, the studies reported do not address the issue of whether or not the visual perception of an object automatically invokes motoric representation of the object`s function. To test for this, Bub, Masson & Bukach (2003) asked participants to learn to associate a color to one of four hand postures (pinch, poke, open grasp, close grasp) to mimic in relation to an object. Photos of objects were presented, which could be congruent or not with the hand posture (e.g., a needle is congruent with a pinch posture). Participants had to respond with a given posture to the color of the picture. There was no congruency effect between the hand posture and the object. The congruency effect appeared only when it was required to direct attention to the object identity.

The results indicate that images of objects do not automatically evoke their function. This happened only when information about function and form evoked the same motoric response. This suggests that manipulation and functional information might differ and that only the first is automatically elicited by visual stimuli.

Buxbaum, Veramonti & Schwartz (2000) report cases of apraxic patients with impaired manipulation knowledge but intact function knowledge. These cases double dissociate from a case of an agnosic described by Sirigu, Duhamel, & Poncet, (1991) who was able to determine how to manipulate certain objects, but wasn`t able to define their function or the context in which they would be utilized.

Gerlach, Law, Paulson (2002), used PET on participants who had to decide whether an object was natural or man-made in a picture categorization task. The left premotor cortex, concerned with motor function, was more activated during categorization of manipulable objects, such as vegetables-fruit and clothing, than during categorization of animals and non-manipulable artifacts. The effect of manipulability was independent of the function and the category of the object.

Kellenbach, Brett & Patterson (2003) asked participants to judge actions and functions associated with manipulable and non-manipulable artifacts (e.g., a hammer or a traffic light). PET showed that the response of the left ventral premotor cortex and the left middle temporal gyrus was stronger in the case of manipulable objects, whereas no regions of the cortex were more activated by function relative to action judgements about artifacts. These results indicate that the brain responds preferentially to how we interact with objects, rather than to what they are used for, and confirm that action and function information do not overlap.

Summary

The neural and behavioral data presented in this section are consistent with the idea that interaction with objects occurs in different ways. In the case of novel objects affordances directly guide actions. In the case of known objects, there are two possible outcomes. When we perform simple actions, visual input and object knowledge support us as we extract affordances automatically ("knowing how"). In this case concepts can be seen as patterns of potential action that support us in extracting affordances (Glenberg, 1997). When we perform complex actions, visual input and object knowledge are integrated with functional knowledge of objects, goals, and sensitivity to context. This integration makes it possible to extract the affordances relevant for current goals and for an appropriate object use ("knowing what for"). In this case, concepts should rather be thought of as residuals of perceptual experience, from which it is possible to extract action information that is relevant for the current situation quickly (Barsalou, 1999). Both visions of concepts are true depending on the situation.

2. Object concepts, action, and language

Evidence reviewed in the first section suggests that visual stimuli activate motor-action information and that motor preparation enhances visual processing. The second section of the chapter focuses on object concepts expressed through words, i.e. concept-nouns. The hypothesis tested is that concept-nouns also activate action and motor information (Barsalou, in press).

2.1.Affordances and concept-nouns

If object information is stored in terms of affordances, it is plausible that words that refer to objects activate the same affordances as the objects themselves. However, the same object could actually possess many affordances. In the case of a car, the steering wheel could afford driving, while the seat could afford sitting. Thus, it is plausible that not all affordances are activated during a simulation, only affordances elicited by canonical actions as well as affordances relevant for the current goals (Zwaan, Stanfield, & Yaxley, 2002) (see Carlson and Kenny's chapter).

Borghi (in press) verified whether objects are represented as patterns of potential actions by focusing on their parts. In a first experiment, three groups of participants were required to perform an imagery decision task. They had to decide if they could imagine using or acting with, building, or seeing certain objects. For a subset of critical concept-nouns — all complex artifacts such as bicycle, mixer, piano — they were also required to produce the names of component parts. In the building and seeing situations, participants produced more part names. It appeared that when they simulated action using one of the objects, they selectively focused on certain parts. The produced parts were submitted to a group of raters who judged the importance of each part for using or acting with, building and seeing each object. The average rating of each part for each perspective (action-use, building and vision) was then multiplied by the frequency of the produced parts for each participant and by the position in which the part was produced. Results showed that parts produced more frequently and earlier across situations were those rated as relevant for acting with the object. However, depending on the kind of simulated interaction with objects (building versus vision), different parts became salient for concepts. In a second experiment, participants were simply required to produce the parts of the critical concept-nouns without performing the imagery decision task. Also in this neutral condition the parts relevant for actions were rated as most important and produced earlier. This suggests that object concepts are action-based. In addition, the number of parts produced in the neutral situation paralleled that of parts produced in the action situation, and was lower than the number of parts produced in the building and vision situation. Much as occurred in the action situation, participants in the neutral situation focused selectively on a certain number of parts. Interestingly, these parts were those relevant for acting with objects. The results indicate that affordances relevant for canonical actions with objects are activated, but that the activation of affordances is modulated by the simulated situation.

In language comprehension, sentence structure guides the selection of affordances. In various papers, Glenberg and collaborators have shown that sentences combine and are understood if the combination, or mesh, of affordances works. For example, if we can mentally envision that the combination of affordances can accomplish a goal described by a sentence, we understand the sentence and judge that it makes sense. Glenberg & Robertson (2000) found that sentences such as “After wading barefoot in the lake, Erik used his shirt to dry his feet.” were judged more sensible than sentences like “After wading barefoot in the lake, Erik used his glasses to dry his feet.” This indicates that affordances derived from objects in the world, not words, constrain the way in which ideas can be meshed and combined.

Borghi (in press) asked participants to read sentences describing actions (e.g., "The woman shared the orange"). The sentences were followed by the name of a part of the object mentioned in the sentence or by the name of a part of something else. Participants had to press one key if the name referred to a part of the object mentioned in the sentence, another key if it did not. Parts of the objects were either parts from which it was easy to extract affordances or not. For example, the action of sharing the slices of an orange can be more easily simulated than the action of sharing its pulp, due to the perceptual properties of the parts "slices" and "pulp". Parts from which it was easy to derive affordances for the goal expressed by the sentence were processed earlier than other parts.

Altmann & Kamide (1999) obtained similar results in an experiment with eye-tracking. Participants had to inspect a semi-realistic scene while listening to sentences such as "The boy will eat the cake". Once they heard the verb, they oriented their eyes to the only object in the display that could be eaten and was therefore compatible with the simulated action (see also Chambers, Tanenhaus, Eberhard, Filip & Carlson, 2002).

Klatzky, Pellegrino, McCloskey, and Doherty (1989) demonstrated that participants form an action simulation in which they verify the compatibility between the specific posture to use and the action to perform on the object. Iconic and verbal primes corresponding to hand shapes speeded the sensibility judgment of sentences compatible with them. For example, the hand shape for "pinch" speeded the sensibility judgment for "aim a dart."

2.2.Evidence

2.2.1.Concepts elicit actions: Indirect evidence

Evidence shows that concept-nouns elicit perceptual, situational, functional and causal information which might be relevant for situated actions.

Shape

There is much evidence of the importance for object concept-nouns of intrinsic properties, i.e. properties likely to remain relatively constant in a variety of situations, such as shape and size (Jeannerod, 1994). These properties are both perceptual and motor, and orient actions.

Different studies have shown the importance of shape and parts for objects concept-nouns (Tversky & Hemenway, 1984). Evidence on the ”shape bias” shows that from the age of two, children extend names to objects similar in shape (Smith & Samuelson, 1997). During sentence comprehension, adults mentally represent the object shape. For example, the sentence “The ranger saw the eagle in the sky” lead to a faster recognition of a picture of a bird with outstretched wings than of a bird with folded wings (Zwaan et al., 2002).

We are also sensitive to the iconic order in which parts of object are presented. Semantic relatedness judgements regarding pairs of words that respected the iconic order (“attic” presented above “basement”) were quicker than judgements regarding pairs of words that did not respect it (“basement” presented above “attic”) (Zwaan & Yaxley, in press).

Size

Even if not so salient as shape, size is also important for concept-nouns, probably due to its relevance for action, as preliminary data by Setti indicate. Participants were provided semantic association judgements for pairs of words referring to objects of the same or of different size. When prime and target were the same size, responses were quicker and more accurate than when size differed. In a further study the target followed sentences with either a manipulation or a neutral verb (e.g., The boy grasped versus saw the grapefruit). Participants had to evaluate whether the second word was from the same category as the word in the sentence. Responses were quicker when object size corresponded, even though the neutral and the manipulation sentences did not differ. However, in an explicit task, participants consistently answered that size was more important for performing actions referred to by manipulative than by neutral verbs.

Attention

The implicit intention to perform a particular action could lead to a selective focus on different perceptual properties.

Wu & Barsalou (under review) asked participants to produce the features of objects such as a watermelon and a half watermelon. With both imagery and neutral instructions, with “watermelon” participants produced primarily external properties such as skin and green. With “half watermelon” they produced mostly internal properties such as red and seeds. The results may depend on the different actions typically associated with a watermelon and a half watermelon.

Eye tracking studies show that participants listening to stories describing objects orient their eyes in the direction of the imagined object. For example they orient their eyes upward while listening to someone talk about skyscrapers, downward while listening to someone talk about canyons (Spivey & Geng, 2001; see Spivey, Richardson and Gonzales-Marquez’s chapter).

Perspective

If concepts are made of perceptual symbols, they should have perspectives, as percepts have perspectives. Perspectives pertain to interaction and vary depending on the relation between our body and the object (see Zwaan and Madden’s chapter). Given this potential variation in perspective, it would be adaptive to first access the perspectives relevant for more frequent actions, before eventually shifting to other perspectives if the situation requires it.

Borghi & Barsalou (2002) asked participants to imagine a scenario, e.g., being inside or outside a prison, and to answer whether in that situation they could expect to find a certain object. For a subset of concept-nouns, participants had to produce object characteristics. Seven raters evaluated to what extent the properties produced across the scenarios would be experienced from different perspectives (e.g. inside, outside). The ratings were then multiplied for the production frequency. The procedure was repeated in five experiments accessing different perspectives: inside-outside, near-far, top-bottom, towards-away, visual-motor-auditive. Evidence of the existence of both entrenched and situational perspectives arose. Entrenched perspectives provide default ways of constructing simulations, such as perceiving objects from the outside, from the front, up close, and visually. They are clearly action-based: typically we act with objects located in front of us, close to us, and we experience them through vision and touch. Default perspectives sometimes reinstate themselves, perhaps because of their informativeness, even when situational perspectives are appropriate. So, even when asked to adopt a situational perspective imagining being far from an object, participants adopted an entrenched perspective zooming in on it: 'pizza' always elicited more frequently near properties (e.g., olive-oil) than far properties (e.g., round).

Typically, however, situational perspectives override default perspectives, inducing perspectives relevant in the current situation, such as perceiving objects from the inside, from above, at a distance, or auditorally. So, participants produced more frequently inside than outside properties (e.g. claustrophobic versus guard-tower) when imagining being inside a prison.

Borghi, Glenberg & Kaschak (under review) examined whether or not the knowledge of object spatial organization in parts is accessed in a different way depending on the perspective relevant for the actions to perform. After reading a sentence describing an object from an inside perspective ("You are driving a car") or an outside perspective ("You are fueling a car"), participants had to verify whether or not a word appearing after the sentence named a part of the object ("steering wheel" or "trunk") by pressing two different keys. There was clearly a perspective effect in that participants verified respective parts (inside or outside) with greater speed when the sentence they read was related directly to the perspective. Another experiment demonstrated that relative distance to objects within a perspective also affects response. For example, given the inside perspective of sitting in an airplane, participants were quicker to verify the part name “tray-table” than “cockpit.” This suggests that object parts are differentially accessed depending on the perspective, and that perspective is related to the action to perform.

Motion

For interacting with different kinds of objects and entities, it is important to know how they typically move. Setti & Borghi (2003) asked two groups of participants to write how objects referred to by concept-nouns of different ontological kind move or are moved. The ontological categories included natural kinds (animals and plants), artifacts (complex artifacts and means of transport), nominal kinds, and “ambiguous” kinds or concepts which could be considered natural as well as artifact, such as milk. From the analyses of the nouns and verbs produced it emerged that there are three parameters for organizing information about the motion of an object. The most important parameter is the ability to produce a displacement, which distinguishes animals and nominal kinds - which are able to change their position - from plants, which can grow, but cannot produce a displacement. The second parameter is speed, which distinguishes means of transport, which move quickly, from plants, which move slowly. The third parameter is self-induced movement, which distinguishes nominal kinds from other concepts (Mandler, 1992). All these parameters are grounded in action. While interacting with objects and entities we use information on their displacement and speed. Knowing whether movement is self-induced is also relevant for interactions as that between hunter and prey in chase.

Context

Interacting successfully with objects implies knowing not only their perceptual and motion properties, but also where to find them. Much evidence indicates that concept-nouns activate thematic relations, i.e., relations referring to situations in which their referents typically occur. Traditionally it has been assumed that thematic organization is relevant only for preschool conceptual knowledge and that it is substituted at a later point in development by taxonomic, hierarchical organization. Recent studies highlight the relevance of thematic relations in adults (Lin & Murphy, 2001). Borghi & Caramelli (2001; 2003) found that thematic relations were produced more frequently than taxonomic ones in children aged 5, 8, and 10, and in adults. Most interestingly, among thematic relations action relations were the most often produced among 5-year-olds. Older children and adults tended rather to produce spatial relations. Objects were linked first to a specific action and at a later point thought of as embedded in contexts where typical actions are performed.

Borghi & Caramelli (submitted) asked participants to produce locations associated with basic and superordinate level concept-nouns (e.g., steak, food). With both neutral and imagery instructions, participants produced more object-locations (e.g., plate) with basic level concept-nouns, where one or a few category members can be found, whereas with superordinate level concept-nouns they produced more setting-locations (e.g., kitchen), where more category members can coexist. The same results were found in a location verification task. Again, the results may by explained by the action intention: as basic level concepts generally refer to single instances, it is more productive for acting with them to focus on a specific location. The case is different for superordinate level concepts, which refer to multiple instances.

Situatedness

The reported evidence suggests that concepts retain information on typical contexts of objects. However, sensitivity to the current context is also a clear advantage for acting. Barsalou (1987) has shown in many experiments that concepts activate different information depending on the participant, on the moment of the day, on the context, on the point of view adopted. On the developmental side, Smith (Smith & Samuelson, 1997) has stressed the importance of variability in word extension tasks.

Function

Evidence showing the centrality of function for categorization, expecially of artifacts, is in line with the adaptive view of categorization presented here. The affordance view of function suggests in fact that the capacity to infer an object`s function depends on experience and prior knowledge of how to use an object. In antithesis with this view, the intentional view of function underlines the role played by the intention of the designer of the artifacts. However, Chaigneau & Barsalou (in press) show that when participants are given adequate information on both the actual use of the object and the setting in which it would be used, as well as its design history, the use of an object dominates over design history in the judgements expressed by participants.

Causality

The importance of causal relations for categorization is widely recognized (Keil, 1989; Sloman, Love, & Ahn, 1998). However, it is not always recognized that causality is deeply grounded in action.

One of the reasons why thematic relations are more accessible than taxonomic relations may stem from the fact that, unlike taxonomic relations, they are linked by causal relations. In particular, action and function relations presuppose causal relations - between agents and actions, between agents and the effects and products of actions, etc.

Preliminary data by Borghi, obtained with a typicality rating task performed on part names of weapons and of other artefacts, suggest that we are sensitive to the causal relations between object parts and that this sensitivity is grounded in action. The parts to rate were divided into three categories. Causal parts are those with which we typically come into contact, such as a car's steering wheel. Effect parts are those whose movement is dependent on another agent (think of the relationship between the wheels of a car and the steering wheel). Structural parts, are parts that are not related to typical actions, such as the roof of a car. Both cause and effect parts, which are action-related, were judged more salient than structural parts, while the importance of effect parts was higher for weapons, lower for other artifacts.

2.3.Concepts elicit actions: direct evidence

The reported evidence supports the view that concepts are residuates of perceptual experiences. The information accessed most easily is that relevant for typical actions, but depending on the situation we may access information useful for less typical actions. Thus action experiences are reflected in concepts, but the evidence available thus far does not lead to the conclusion that motor information is automatically activated.

Neuroimaging studies and behavioral studies support the hypothesis that some kinds of motor information are directly elicited by concept-nouns. It has been demonstrated, for example, that action is a powerful cue for recalling information on objects. Magniè, Ferreira, Giuliano, & Poncet (1999) report the case of an agnosic patient who recognized only objects with which he could recall associated actions – tools, kitchen utensils, clothes, body parts, but not animals and musical instruments (he didn`t play any instrument).

Neuroimaging

Neuroimaging studies show that object knowledge is organized as a distributed system. In this system object attributes are stored near the same modality specific areas that are active as objects are being experienced (Martin, Ungerleider & Haxby, 2001; Pulvermüller, 1999). This goes against the claim, defended by widely accepted theories regarding concept organization and representation in the brain, that conceptual information is functionally and physical independent of modality specific input and output representations and that the appropriate level of analysis for studying conceptual organization is that of whole categories, not that of features (Mahon & Caramazza, 2003). PET indicated that naming of tools, compared to naming of animals (importantly, animals were large four-legged animals, such as elephants), differentially activated the left middle temporal gyrus, an area very close to the area assumed to store information about object movement, which is also activated by action generation tasks, and the left premotor cortex, generally activated when participants imagine themselves grasping objects with their dominant hand (Martin, Wiggs, Ungerleider, & Haxby, 1996). This suggests that action and manipulation information is automatically activated by viewing objects and pictures, and that the same areas are involved when forming motor imagery and when activating information on tools. Using fMRI Simmons, Pecher, Hamann, Zeelenberg, Barsalou (2003) show that brain activation during a verification task of modal properties (Pecher, Zeelenberg & Barsalou, 2003) reflects the processed properties but is also distributed in different areas. In particular, in trials with motor properties, many areas are active, and visual areas in particular. This evidence supports a close relationship between visual and motor properties.

Behavioral

Behavioral studies support the hypothesis that motor information is directly activated in the processing of concept-nouns.

Borghi et al.(under review) demonstrated with a part verification task that concept-nouns of object parts directly activate the motor system. Sentences such as “There is a horse in front of you” were followed by parts chosen so that actions directed toward them (on the real object) required a movement upward (the head of the horse) or downward (the hoof of the horse). Responding by pressing a button in a direction compatible with the part location (e.g. responding upward to verify that a horse has a head) was faster than responding in a direction incompatible with the part location.

Preliminary evidence by Borghi and Nicoletti indicates that processing artifacts activates the kind of grip appropriate to use them. Participants categorized words and pictures in natural and artefacts by pressing different buttons. They categorized more slowly artifacts which are typically used with a precision and a power grip (e.g., harp), than artifacts used with two power grips (e.g., rake).

What happens with concept-nouns that refer to objects with which we typically interact in different ways? Action intentions expressed linguistically may modulate the activation of the motor system. Glenberg & Kaschak (2002) asked participants to provide sensibility judgements by pressing a button either moving the hand towards the body or away from the body. They found a compatibility effect between the action to perform and the sentence to process: for example, the sentence “Close the drawer” was responded to quicker while moving the hand away from the body, the sentence “Open the drawer” while moving the hand towards the body.

Preliminary evidence by Borghi indicates that the movement performed influences judgements on size. Participants judged the size of objects requiring a precision grip (i.e., pencil), and a power grip, (i.e., eggplants), in four conditions, when asked to move their hands in order to simulate a precision grip movement or a power grip movement and when asked to use pliers of two different sizes in order to mimic the same movements. Size ratings produced in the precision grip condition were lower than those produced in the power grip condition.

Summary

Overall, neuroimaging and behavioral evidence is consistent with the idea that concept-nouns activate motor responses automatically.

This has been demonstrated thus far only for simple manipulatory actions such as grasping and reaching the object`s parts, directly afforded by characteristics such as shape and size, and not for complex actions involving access to functional knowledge. Barsalou & Borghi (2002) found that when asked what is typically included in complex actions such as eating, participants produced mostly micro-actions, such as chewing. Micro-affordances probably operate at this micro-level.

The difference between manipulation and function information has interesting implications. It helps explain that the fact that children extend names on the basis of shape rather than of function is not due to their scarse sensitivity to action information (Landau, Smith & Jones, 1998). In fact, shape certainly incorporates motor information, even if not functional information.

3.True only for manipulable objects?

We have seen that concepts support interaction with objects, mostly through the use of motor imagery. Motor imagery may facilitate simple interaction with objects – responding to their organization in parts, holding them, grasping them. This is especially true for manipulable objects, independent of their ontological kind. Manipulable natural kinds, such as flowers, evoke behavioral effects similar to those evoked by manipulable artifacts. Motor imagery may also be activated for micro-interactions with non-manipulable objects. Consider buildings, for example. We do not typically manipulate them, but we may manipulate their parts.

The difference between artifacts and natural kinds might arise when we consider goal driven actions. Simple artifacts, at least, such as cups, are designed so that information relevant for micro-interactions is congruent with functional information. Probably responses to natural kinds are more frequently mediated by goals than response to artifacts, as we typically act with natural kinds in different ways, and have to extract different affordances depending on our goals – we typically drink from glasses, while we can feed, caress, perform surgery on cats. This could explain why natural kinds activate the visual areas of the cortex more than tools. Accessing more perceptual properties may guarantee more action flexibility (Parisi, personal communication).

Thus, on the basis of the evidence, it can be concluded that manipulable object concepts, and in some cases object concepts overall, directly activate motor information concerning micro-interactions with their referents, i.e., interactions not mediated by goals. This is true both when we interact directly with objects and when we process concept-nouns. Evidence that concepts automatically activate motor information related to their functional characteristics is less compelling.

Things become more complicated if we consider concepts that do not refer to objects, such as abstract concepts like freedom and truth (see Barsalou and Wiemer-Hastings' chapter). The acquisition of these concepts may be grounded in interactions we have with the world and their possession can be useful for acting in the world, but they probably do not elicit motor images. However, they might elicit situations through mental imagery. Preliminary evidence by Borghi, Caramelli & Setti indicates that more than 80% of the relations produced with abstract concepts such as risk are situations. Furthermore, a growing body of evidence shows that abstract concepts can also refer indirectly to bodily experiences. Boroditsky & Ramscar (2002) showed that abstract concepts such as time are understood through the experience-based domain of space.

Conclusion

This chapter shows that object concepts play an important adaptive role. In the presence of objects and when objects are referred to by words they activate action simulations to facilitate interaction with objects. Concepts directly evoke simple motor responses, and can therefore be seen as patterns of potential action (Glenberg, 1997). However, to guarantee the flexibility necessary for interactions mediated by goals, concepts should rather be conceived of as made of "perceptual symbols", from which to extract information relevant for the hic-and-nunc (Barsalou, 1999). These two visions of concepts are complementary, and share the assumption that concepts are grounded in sensorimotor activity.

In the presence of objects, concepts help to combine affordances with previous experiences. This occurs primarily at an unconscious level. In some cases we might simply react to novel objects, in which case affordances are a direct invitation to act. In other cases, we may need to know how to manipulate objects in order to interact with them successfully. Evidence shows that visual information potentiates micro-affordances, i.e., affordances associated with object manipulation, which automatically evoke motor responses. In other cases we might need to know how to use objects, i.e. to know what kind of affordances to extract, given the current situation and goals.

What happens with concepts expressed by words? They keep track of our interaction with objects. First of all, they keep track of the experience of object manipulation. They activate micro-affordances such as those elicited by shape and size, and these micro-affordances automatically evoke motor responses. Second, concept-nouns keep track of information relevant for more complex interactions with objects by activating perceptual, contextual, functional, and causal information. This allows us to activate the affordances relevant for the current situation and goals, thus facilitating situated action. Evidence seems to indicate that at this "higher" level the motor system is not automatically activated, but that its activation is mediated by access to general perceptual and situational information.

References

Allport, D.A. (1985). Distributed memory, modular subsystems ad dysphasia. In S.K. Newman, R. Epstein (Eds.), *Current perspectives in disphasia* (pp. 32-60). Edinburgh : Churchill Livingstone.

Altmann, G.T.M. & Kamide, Y. (1999). Incremental interpretation at verbs: Restricting the domain of subsequent reference. *Cognition, 73*, 247–264.

Barsalou, L.W. (1987). The instability of graded structure, implications for the nature of concepts. In U. Neisser (Ed.), *Concepts and conceptual development. Ecological and intellectual factors in categorization* (pp. 101-140). Cambridge, MA: Cambridge University Press.

Barsalou L.W. (1991). Deriving categories to achieve goals. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 27, pp. 1-64). San Diego, CA: Academic Press.

Barsalou L. W. (1999). Perceptual Symbol Systems. *Behavioral and Brain Sciences,* 22**,** 577-609.

Barsalou, L.W. (in press). Situated Simulation in the Human Conceptual System. *Language and Cognitive Processes.*

Barsalou, L.W. & Borghi, A.M. (2002). The MEW theory of knowledge. Evidence from concepts for settings, events, and situations. In preparation.

Barsalou, L.W., Simmons, W. K., Barbey, A.K., & Wilson, C.D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Science, 7*, 84-91.

Bekkerin, H. & Neggers, S.W. (2002). Visual search is modulated by action intentions. *Psychological Science, 13,* 4, 2002.

Berthoz, A. (1997). *Le sens du movement*. Paris: Odile Jacob.

Borghi, A.M. (in press). Objects concepts and action: Extracting affordances from objects' parts. *Acta Psychologica.*

Borghi, A.M. & Barsalou, L.W. (2002). Perspectives in the conceptualization of categories. In preparation.

Borghi, A.M. & Caramelli, N. (2003). Situation Bounded Conceptual Organization in Children: From Action to Spatial Relations. *Cognitive Development, 18*, 1, 49-60.

Borghi, A.M. & Caramelli, N. (2001). Taxonomic relations and cognitive economy in conceptual organization. In J.D. Moore & K. Stenning, K. (Eds.), *Proceedings of 23rd Meeting of the Cognitive Science Society*, (pp. 98-103). London: Erlbaum.

Borghi, A.M. & Caramelli, N. (submitted). Contextual information and hierarchical levels of concepts.

Borghi, A.M., Di Ferdinando, A., Parisi, D. (2002). The role of perception and action in object categorization. In J.A. Bullinaria & W. Lowe (Eds), *Connectionist Models of Cognition and Perception* (pp. 40-50). Singapore: World Scientific.

Borghi, A.M., Glenberg, A.M. & Kaschak, M.P. (under review). Putting words in perspective.

Boroditsky, L. & Ramscar, M. (2002). The roles of body ad mind in abstract thought. *Psychological Science, 13*, 185-189.

Bub, D. N., Masson, M. E.J. & Bukach, C. M. (2003). Gesturing and naming: the use of functional knowledge in object identification. *Psychological Science, 14,* 467-472.

Buxbaum, L. J., Schwartz, M. F., & Carew, T. G. (1997). The role of semantic memory in object use. *Cognitive Neuropsychology, 14*, 219-254.

Buxbaum, L. J., Sirigu, A., Schwartz, M.F., & Klatzky, R. (2003). Cognitive representations of hand posture in ideomotor apraxia. *Neuropsychologia, 41,* 1091-1113.

Buxbaum, L. J., Veramonti, T., & Schwartz, M.F. (2000). Function and manipulation tool knowledge in apraxia: Knowing 'what for' but not 'how'. *Neurocase, 6*, 83-97.

Chaigneau, S.E. & Barsalou, L.W. (2001). The role of function in categories. *Theoria et Historia Scientiarum.*

Chambers, C.G., Tanenhaus, M.K., Eberhard, K.M., Filip, H., & Carlson, G.N. (2002). Circumscribing referential domains during real-time language comprehension. *Journal of Memory and Language, 47,* 30-49, 2002.

Clark, A. (1997). *Being there*. Cambridge, MA: MIT.

Craighero, L., Fadiga, L., Rizzolatti, G., & Umilta, C. (1999). Action for perception: A motor-visual attentional effect. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1673-1692.

Creem, S.H. & Proffitt, D.R. (2001). Grasping objects by their handles: a necessary interaction between perception and action. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 1, 218-228.

Decety, J. (1996). The neurophysiological basis of motor imagery. *Behavioural Brain Research, 77,* 45-52.

Duncker, K. (1945). On problem solving. *Psychological Monographs, 58*, 5, 270.

Ellis, R. & Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British Journal of Psychology, 91,* 451-471.

Fadiga, L., Fogassi, L., Gallese, V. & Rizzolatti, G. (2000). Visuomotor neurons: ambiguity of the discharge or \`motor\` perception? *International Journal of Psychophysiology, 35*, 165-177.

Farne, A. & Ladavas, E. (2000). Dyamic size-change of hand peripersonal space following tool use. *Neuroreport, 11,* 1-5.

Gerlach, C., Law, I., & Paulson, O. B. (2002). When action turns into words. Activation of motor-based knowledge during categorization of manipulable objects. *Journal of Cognitive Neuroscience, 14,* 1230-1239.

Gibson, J.J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Glenberg A. M. (1997). What memory is for. *Behavioral and Brain Sciences,* 20, 1-55.

Glenberg, A. M., & Kaschak, M.P. (2002). Grounding language in action. *Psychonomic Bulletin and Review, 9,* 558-565.

Glenberg, A.M. & Robertson, D.A. (2000). Symbol grounding and meaning: a comparison of high-dimensional and embodied theories of meaning. *Journal of Memory and Language, 43*, 379-401.

Harnad, S. (1990). The symbol grounding problem. *Physica D, 42*, 335- 346.

Hirose, N. (2001). An ecological approach to embodiment and cognition. *Cognitive Systems Research, 3,* 289-299.

Iachini, T. & Borghi, A.M. (submitted). Conceptualization and sensorimotor interaction with objects.

Jeannerod, M. (1994). Object oriented action. Insights into the reach grasp movement. In K.M.B. Bennet & U. Castiello (Eds.), *Insights into the Reach to Grasp movement*, (pp. 3-15). Amsterdam: Elsevier.

Jeannerod, M. & Frak, V. (1999). Mental imaging of motor activity in humans. *Current opinion in neurobiology, 9*, 735-739.

Jeannerod, M. (1997). *The cognitive neuroscience of action*. Cambridge, MA: Blackwell.

Keil, F. (1989). *Concepts, kinds, and cognitive development.* Cambridge, MA: MIT.

Kellenbach, M.L., Brett, M., & Patterson, K. (2003). The Importance of Manipulability and Action in Tool Representation. *Journal of Cognitive Neuroscience*, *15*, 30-46.

Klatzky, R.L., McCloskey, B.P., Doherty, S., & Pellegrino, J.W.(1987). Knowledge about hand shaping and knowledge about objects. *Journal of Motor Behavior, 19,* 187-213.

Klatzky, R.L, Pellegrino, J.W., McCloskey, B.P., & Doherty, S.(1989). Can you squeeze a tomato? The role of motor representations in semantic sensibility judgments. *Journal of Memory and Language, 28*, 56-77.

Landau, B., Smith, L., & Jones, S. (1998). Object shape, object function, and object name. *Journal of Memory & Language, 38*, 1-27.

Lin, E.L. & Murphy, G.L. (2001). Thematic relations in adults' concepts. *Journal of Experimental Psychology: General, 130*, 1, 3-28.

Magniè, M.N., Ferreira, C.T., Giuliano, B. & Poncet, M. (1999). Category specificity in object agnosia: preservation of sensorimotor experiences related to object. *Neuropsychologia, 37*, 67-74.

Mahon, B. Z. & Caramazza, A. (2003). The organization of conceptual knowledge in the brain: living kinds and artifacts. In E. Margolis & S. Laurence (Eds.), *Creations of the mind: Essays on artifacts and their representation.* Oxford: Oxford University Press.

Mandler, J. M. (1992). How to build a baby: II. Conceptual primitives. *Psychological Review, 99,* 587-604.

Marschall, D. & Johnson, M.H. (2003). The “what” and “where” of object representations in infancy. *Cognition*, in press.

Martin, A., Ungerleider, L. G. & Haxby, J.V. (2001). Category Specificity and the Brain: The Sensory-Motor model of Semantic representations of Objects. In Gazzaniga MS (Ed.), *The Cognitive Neurosciences,* 2nd. Edition. Cambridge, MA: MIT.

Martin, A., Wiggs, C.L, Ungerleider, L.G., & Haxby, G.V. (1996). Neural correlates of category specific knowledge. *Nature, 379*, 649-652.

Milner, A.D. & Goodale, M.A. (1995) *The visual brain in action.* Oxford: Oxford University Press.

Murphy, G.L. (2002). *The big book of concepts*. Cambridge: MIT.

Pecher, D., Zeelenberg, R., & Barsalou, L.W. (2003). Verifying conceptual properties in different modalities produces switching costs. *Psychological Science, 14,* 119-124.

Phillips, J. C. & Ward, R. (2002). S-R correspondence effects of irrelevant visual affordance: Time course and specificity of response activation. *Visual cognition, 9,* 540-558.

Phillips, J.A., Humphreys, G.W., Noppeney, U., & Price, K.J. (2002). The neural substrates of action retrieval: An examination of semantic and visual routes to action. *Visual Cognition, 9*, 662-684.

Pulvermüller, F. (1999). Words in the brain’s language. *Behavioral and Brain Sciences, 22*, 253-336.

Pylyshyn, Z. (1999). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, 22, 341-423.

Riddoch, J. M., Humphreys, G. W., Edwards, S., Baker, T. & Willson, K. (2003). Seeing the action: neuropsychological evidence for action-based effects on object selection. *Nature Neuroscience, 6,* 82-89.

Rizzolatti, G. & Luppino, G. (2001). The cortical motor system. *Neuron, 31*, 889-901.

Rumiati, R.I. & Humphreys, G.W. (1998). Recognition by action: Dissociating visual and semantic routes to action in normal observer. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 631-647.

Setti, A. & Borghi, A.M. (2003). Information about motion in concepts of different ontological kinds In F. Schmalhofer, R.M. Young & F. Katz (Eds.). *Proceedings of the I Meeting of the European Society of Cognitive Science, Osnabrück 2003* (pp.438). London: Erlbaum.

Simmons, W.K., Pecher, D., Hamann, S.B., Zeelenberg, R., & Barsalou, L.W. (2003). fMRI evidence for modality-specific processing of conceptual knowledge on six modalities. *Meeting of the Society for Cognitive Neuroscience*, New York.

Sirigu, A., Duhamel, JR, & Poncet, M. (1991). The role of sensorimotor experience in object recognition. A case of multimodal agnosia. *Brain, 114*, 2555-2573.

Sloman, S.A., Love, B.C., & Ahn, W. (1998). Feature centrality and conceptual coherence.*Cognitive Science, 22*, 189-228.

Smith, L. B. & Samuelson, L. L. (1997). Perceiving and Remembering: Category Stability, Variability and Development. In K. Lamberts & D. Shanks (Eds), *Knowledge, Concepts, and Categories* (pp. 161-195). Hove: Psychology Press.

Spivey, M. J., & Geng, J. J. (2001). Oculomotor mechanisms activated by imagery and memory: eye movements to absent objects. *Psychological Research, 65*, 235-241.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Doder's method. In W.G. Koster (Ed.), Attention and Performance II. Amsterdam: North-Holland Publishing Company.

Thelen, E., & Smith, L.B. (1994). *A dynamic systems approach to the development of cognition and action.* Cambridge, MA: MIT.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human perception and performance, 24*, 3, 830-846.

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition, 8*, 769-800.

Tversky, B. & Hemenway, K. (1984). Objects, parts, and categories. *Journal of Experimental Psychology: General, 113*, 169-193.

Vogt, S., Taylor, P., & Hopkins, B. (2003). Visuomotor priming by pictures of hand pictures: perspective matters. *Neuropsychologia, 41,* 941-951.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9,* 625-636.

Ward, R. (2002). Independence and integration of perception and action: An introduction. *Visual Cognition, 9,* 385-391.

Wing, A.M., Turton, A. & Fraser, C. (1986). Grasp size and accuracy of approach in reaching. *Journal of Motor Behaviour,18*, 245-260

Wu, L.L. & Barsalou, L.W. (2001). Grounding Concepts in Perceptual Simulation: I. Evidence from Property Generation. Under review.

Zwaan, R., Stanfield, R. A. & Yaxley, R. H. (2002). Do language comprehenders routinely represent the shapes of objects? *Psychological Science,13*, 168-171.

Zwaan, R.A., & Yaxley, R.H. (in press). Spatial iconicity affects semantic-relatedness judgments. *Psychonomic Bulletin & Review*.

Author Note

Thanks to Andrea di Ferdinando, Tina Iachini, Diane Pecher, Rolf Zwaan and two anonymous reviewers for useful comments on an earlier draft and to Ann Gagliardi for help with English.