OBJECT CONCEPTS AND EMBODIMENT:
WHY SENSORIMOTOR AND COGNITIVE PROCESSES CANNOT BE SEPARATED

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INTRODUCTION

The embodied perspective

The emerging view of embodied cognition holds that the body shapes the mind, and that cognitive processes are deeply rooted in the body's interactions with the world. Thus sensorimotor and cognitive processes cannot be conceived of as separate. This perspective deeply contrasts with the view of traditional cognitive science according to which the mind is an information processing device. The traditional view houses two claims concerning the relationships between perception, action and cognition. First, "low level" or sensorimotor processes are strictly separated from "high level" or cognitive processes. Perception and action are only input and output devices, having just a peripheral relationship with ""central" processes. Second, perception and action are separated as well. Perception always precedes action, and it occurs in the same way independent of the expected motor response. What is perceived is independent from movement and the motor knowledge necessary to produce action. Thus, the motor system carries out merely executive functions.

In the last years the cognitive science panorama has deeply changed. It has been proposed that cognition is embodied, that is, that it depends on the experiences that result from possessing a body with given physical characteristics and a particular sensory-motor system. The viewpoint of embodied cognition is gaining success across a wide range of disciplines, from cognitive science and neuroscience to philosophy to cognitive linguistics to artificial intelligence (Barsalou, 1999; Berthoz, 1997; Cangelosi, Bugman & Borisyuk, 2005; Clark, 1997; Prinz, 2002; Lakoff & Johnson, 1999; Langacker, 1986; Hommel, Müsseler, Aschersleben, & Prinz, 2001; O'Regan & Noe, 2001; Pulvermüller, 2003; Rizzolatti & Craighero, 1994). In the field of psychology scholars have collected an impressive body of empirical evidence in support of this view (for reviews see Pecher & Zwaan, 2005). At the same time, it has been proposed that cognition is "situated", that is that mental processes cannot be studied independently from the context in which they are used and without considering that they occur in time. A static form of representation would be not useful to aptly respond to the environment; information in memory should be updated and adapted to the present situation and context (Clark, 1997). The critique of the notion of representation has resulted in a profound change in theories and methods. For example, the emergent dynamic systems theory has contributed to re-frame the study of mental processes taking into account the fact that they occur over time (Thelen & Smith, 1994).

Object concepts, language and grounding

The traditional and the embodied perspectives propose different views of object concepts. In psychology concepts are typically defined as the minimal units of our knowledge – more precisely, a concept consist of the information we typically associate with an object, the referent of the concept, what we “know” about it. So, our concept of “car” consists of what we know about cars. Defenders of the traditional view of object concepts propose that concepts are made by symbols, and that these symbols are abstract, amodal, arbitrary (AAA). Thus, our concept of “car” would consist of a list of properties /statements that are represented in a propositional way (Fodor, 1998), as for example “tires, roof, exhaust pipe, steering wheel”. These symbols are abstract and amodal, as they are the product of the translation from a sensorimotor experience, the experience of seeing or of driving a car, to a list of properties. In deep contrast with the AAA view of concepts, the embodied view proposes that concepts are not abstract nor arbitrary but deeply rooted in sensorimotor activity. Namely, they consist of the re-enactment of the experience we had with their referents (Barsalou, 1999; Harnad, 1990; Thelen & Smith, 1994). In addition, concepts are not amodal but multimodal, and conceptual information is distributed over modality specific domains (Barsalou, Simmons, Barbey, & Wilson, 2003; Boronat, Buxbaum, Coslett, Tang, Saffran, Kimberg, & Detre, 2005; Gallese & Lakoff, 2005; Martin, Wiggs, Ungerleider, & Haxby, 1996). Thus, thinking of a “dog” leads to the activation of auditory, visual, and tactile information – the sound of the dog barking, its color, its smoothness when we caress it, etc. In other words, thinking of an object leads to a re-experiencing (simulation) of the interaction with the object.

In this perspective, the main function of concepts in presence of objects consists in activating online simulations that support interaction with objects. Overall, concepts can be conceived of as blueprints that tell us how to act, or as patterns of potential actions (Glenberg, 1997; for a review see Borghi, 2005). The same might be true also when concepts are mediated by words. Recent evidence suggests that language is grounded in perception and action (for reviews see Zwaan, 2004; McWhinney, 1999). For example, recent studies on sentence comprehension show that people form a sensorimotor simulation of the situation described by a sentence, by internally reproducing the action or situation described (Buccino et al, 2005; Glenberg & Kaschak, 2002; Klatzky, Pellegrino, McCloskey & Doherty, 1989; Zwaan & Taylor, 2005).

Overview of the paper

In the paper I will report evidence suggesting that concepts are grounded in sensorimotor activity and automatically activate motor information. First, I will describe some connectionist Artificial Life simulations showing that the visual presentation of objects incorporates motor information and potentiates the affordances associated with objects (Borghi, Di Ferdinando & Parisi, under review). Second, I will report experimental evidence obtained in compatibility tasks and in property verification tasks with objects referred to by words (Borghi, 2004; Borghi, Bonfiglioli, Ricciardelli, Rubichi, & Nicoletti, in press; Borghi, Glenberg & Kaschak, 2004; Borghi & Scorolli, submitted). This evidence suggests that concepts mediated by words automatically activate motor information concerning simple interactions with their referents, as those involved in reaching and in grasping objects. Finally, I will provide evidence favouring the idea that object concepts are flexible and variable.

CONCEPTS; VISION AND MOTOR INFORMATION (DORSAL WAY?): EVIDENCE

Embodied theories underline the strict interaction between visual stimuli and motor information, and propose that "knowing is for acting" (Wilson, 2002). At a theoretical level, motor theories of perception such as those suggested by William James and others (see Prinz, 1987, for review), the psychology of Jean Piaget, which emphasized the role played by sensorimotor processes for development of cognition, and the ecological psychology of Gibson, have been re-discovered. A special role has been played by the notion of "affordance", proposed by Gibson (1979). Affordances are properties of an object that indicate how to interact with it; thus they pertain both perception and action, both the organism and the environment. Affordances are dynamic and variable rather than static, as they depend on the specific relationship a peculiar kind of organism has with an object in a specific context. For example, a bottle affords grasping for us, but not for a Lilliputian, as his/her hand would not have the appropriate dimensions to grasp it.

At an empirical level, many brain imaging studies (Chao & Martin, 2000; Martin et al., 1996) as well as experimental studies with various paradigms (visuo-motor priming, motor-visual priming, compatibility paradigms, etc.) have demonstrated that visual stimuli, as photographs and real objects, automatically evoke motor responses (for a review see Borghi, 2005). Thus seeing objects leads to detect their affordances, and to potentiate affordances linked to our previous interaction with objects. Here I will just report an example of an experimental study replicated with a connectionist simulation providing support for this.

A way to study whether visual stimuli automatically activate actions is to devise experimental tasks in which participants are shown an object and they are asked to produce an action which is in contrast with the action typically associated with the object. If the participant finds this task difficult, one can infer that objects are internally represented in terms of the actions with which the organism normally responds to them. For example, Tucker and Ellis (1998) showed participants on a computer screen photos of objects, such as cups, that could be presented upright or reversed, and with the handle oriented toward the left or the right. Participants performed a very simple task: they had to decide whether the object was upright or reversed by pressing a left or a right key on the keyboard. The result found was straightforward: in case of congruency between the location (left, right) of the key to press and the location (left, right) of the handle, responses were faster and more accurate than in case of incongruent mappings. This result show that, even if the handle location was not relevant to the task, it influenced the motor response. It suggests that handles automatically evoke (afford) a motor response, that they activate the tendency to reach/grasp them, no matter what the task at hand is.

Studies similar to the previously mentioned one have been replicated with different kinds of connectionist simulations. Typically, however, these simulations do not imply the usage of an "embodied" method. Instead, we tried to replicate the results obtained by Tucker and Ellis (1998) using an Artificial Life embodied simulative approach. In our simulations we used artificial "embodied" organisms (simulated robots) which do not only have a simulated "nervous system" (an artificial neural network), but also have a body which interacts with a physical environment. More specifically, the organisms we simulated possessed a visual and a motor system (see also Borghi, Parisi & Di Ferdinando, 2005; Parisi, Borghi, Di Ferdinando & Tsiotas, 2005). The visual system allows the organisms to see different objects, one at a time. Thus, our organisms can see containers such as cups that might be upright or reversed, with a left- or right-oriented handle. The motor system consists of a single arm composed by two segments that the organisms can move in order to reach different spatial locations. The arm sends proprioceptive information to the organisms specifying the arm's current position. The behaviour of the organisms is controlled by a neural network.

Here is how the simulation worked. In a first phase, we simply trained the organisms to respond appropriately to objects, as we typically do in real life. Thus, they learned to reach the object's handle, independent on whether it was on the right or on the left of the object body /protruded on the left or on the right. In a second phase, we replicated the study by T&E. Therefore, we "asked" the organisms to perform two different task. More precisely, with Task 1 they simply had to reach the object handle, with Task 2 they had to reach a button on the left or on the right to determine whether the object they saw was upright or reversed. As in the experiment by T&E, we predicted that in case of incongruent mappings the organisms would have more difficulties in learning the task than in case of congruent mapping. This is exactly what we found. Thus, we replicated the experimental results obtained by Tucker and Ellis, which show that the visual representation of an object incorporates motor information. Importantly, we replicated them with a connectionist simulation using an "embodied" method, that is reproducing an organism endowed with both a brain AND a body.

CONCEPTS, WORDS AND MOTOR INFORMATION (VENTRAL OR DORSAL-VENTRAL WAY?): EVIDENCE

Studies showing that visual stimuli automatically evoke motor information, as the previously reported studies, leave a question open. Namely, it is not clear whether in order to provide a given motor response we need to recognize and categorize objects, or whether we simply automatically respond to online visual information. According to Gibson (1979), and to the ecological tradition in general, affordances are based upon the perceptual properties of objects and are directly registered without the need to be preceded by object recognition. The underlying assumption is that the environment contains all the information necessary for us to interact with objects, surfaces, substances, and other living entities. In other words, actions and manipulations that can be carried out on and with objects are entirely specified within the pattern of stimulation that the object produces in the perceiver. More recently, the debate has focused on the role played by ventral and dorsal system in producing and explaining actions. An influential model (Milner and Goodale, 1995) proposes that visual information is processed in the brain in two different streams: the ventral and the dorsal route. Whereas the main role of the ventral stream pertains object recognition, the dorsal stream has primarily a pragmatic role. Accordingly, there would be two different routes to action: one mediated by object recognition (ventral stream), the other one implying a direct vision-action mapping (dorsal stream) (Rumiati & Humphreys, 1998). However, recent evidence suggests that the distinction implied by this model between an "acting" and a "knowing" brain might be too sharp (for a first comment / critique see Gallese, Craighero, Fadiga & Fogassi, 1999). Studies with words that denote objects contribute to settle the debate between those who believe that compatibility effects between task-irrelevant object features and the motor program adopted to carry out the task are due exclusively to the activation of the dorsal system, and those who consider that the effects indicate a role of the ventral system. Finding the same compatibility effects also with words may cast a doubt on the dorsal-only hypothesis (see Derbyshire, Ellis & Tucker, 2006; Tucker & Ellis, 2004). If the effects are found with words, indeed, we cannot rule out the involvement of the ventral system and the mediation of long-term conceptual knowledge to generate and explain “affordances” effects. Alternatively, it is also possible, as recently proposed, that there are two different routes within the dorsal stream, a dorsal-dorsal one, dedicated to online visuomotor transformation, and a dorsal-ventral one, that includes some representation of objects, which would encode the most common ways with which we interact with them (Gentilucci, 2003).

Borghi, Glenberg and Kaschak (2004) found compatibility effects between nouns of object parts that indicate spatial position (e.g. head, leg) and the direction of the movement to perform to provide the answer (e.g. a movement upward or downward). Participants sat in front of a computer screen and read sentences describing objects, as for example “There is a doll standing on the table in front of you”. Their task consisted of deciding by pressing a different key whether the word that followed the sentence referred or not to a part of the previously mentioned object (head yes, kindergarten no). The participants were randomly divided in two groups: Movement and No Movement. In order to provide the answer participants in the Movement condition were required to move upwards or downwards to press the key (yes is up, yes is down), whereas participants in the No-Movement condition had simply to press an upper or a lower key. Crucially, half of the selected parts are upper-parts, that is they are typically located in the upper part of the mentioned object (e.g., head), half are lower-parts (e.g., ankle). The results were straightforward: in the Movement condition responses were faster in case of compatibility between the part location (upper vs. lower part) and the direction of the movement to perform (upward vs. downward). In other words, it takes shorter to respond that a “cork” is part of a wine bottle if in order to respond “yes” we perform a movement upward than a movement downward; the opposite is true if we want to respond that “wheel” is part of a “car”. This compatibility effect, however, was present only in the Movement condition, not in the No Movement one.

This result is important for two reasons. First, it demonstrate that “affordance” effects can be found also with words, and is in line with the growing body of evidence showing that language are grounded in perception and action. Second, it suggests that affordances effect cannot be due only to online processing of visual information, and that memory and conceptual knowledge may play a role in explaining them. In addition, it suggests that also the compatibility effects found with visual stimuli may at least in part be explained by information stored in memory – information pertaining canonical information we have on objects.

Even though studies as the previously described one demonstrate that words are grounded in action, it is possible that visual stimuli (drawings, photographs) activate motor information more strongly than words. Many studies addressing this point lead to conflicting results. I will just provide an example of a recent study on manipulability performed with both drawings and words aimed at verifying whether during categorization we access information on how to interact with objects(Borghi, Bonfiglioli, Ricciardelli, Rubichi and Nicoletti, in press). Participants were required to categorize manipulable and non manipulable objects (e.g., apples vs. elephants). They had to press a different key to decide whether the object was an artifact (e.g., boat) or a natural object (e.g., elephant). Manipulable objects produced slower response times, probably due to the fact that the motor program automatically evoked by objects interfered with that necessary to accomplish the task (key pressure). In a second experiment manipulability was made more relevant to the task: participants were required to decide whether the object could be grasped and located within a backpack or not. The change of the instructions lead to a facilitation of manipulable over non manipulable objects, probably due to the elimination of the interference between the two motor programs. Importantly, the results obtained with drawings and with words were highly similar. This striking similarity suggests that the activation of motor information is not directly evoked by the visual stimuli but it is mediated by conceptual knowledge, i.e. by the ventral system.

OBJECT CONCEPTS AND VARIABILITY

The evidence discussed so far suggests that concepts can be conceived of as patterns of potential action (Glenberg, 1997). This evidence might imply that we create a kind of “motor prototype” of objects (personal communication, Lucia Riggio) that helps us to respond as quickly as possible to information in the environment. Thus, when we see a cup, we immediately know that we have to grasp its handle in order to drink from it. Accordingly, we would represent the objects in the environment in terms of their “default” affordances, we would immediately access information on the parts that evoke frequent actions with the object. The evidence suggest that this is certainly true for simple actions, such as reaching and grasping objects. However, in order to allow us to adapt our responses to different contexts and to perform more complex actions, our concepts need to be flexible and variable. The way in which variability of concepts has been accounted for varies depending on the theoretical perspective.

The adoption of amodal views of conceptual knowledge has often led researchers to focus on the stable rather than on the flexible aspects of conceptual organization (see for example the critiques of Smith, 1995). This does not mean that symbolic amodal theories cannot account for or predict variability in conceptual organization (Landauer & Dumais, 1997). Simply, the source of this variability is ascribed to semantic relatedness between concepts and to frequency and is not attributed to the re-enactment of a sensory-motor experience. In the embodied view, instead, because knowledge is grounded in bodily and situational experience, conceptual variability is highly stressed. In fact, depending on our kind of body and on the situation we are experiencing, different conceptual aspects are activated (Barsalou, 1987). Importantly, object concepts may have different affordances, and a specific context may activate one or the other.

I will briefly describe some recent studies showing that concepts are variable and flexible, and that this flexibility is grounded in sensorimotor processes rather than in word frequency and semantic relations between words.
In a first experiment (Borghi, 2004) participants were required to imagine a different kind of interaction with simple objects such as cars or pianos. One group had to imagine observing the objects (observation), another to imagine acting with / using them (action), another group to imagine building them (building). For some objects of the list, the critical ones, participants were also required to produce a list of parts. A fourth group of participants (neutral condition) was simply required to perform the part production task without previously imaging the object. A separate group of subjects evaluated the parts produced for each object across the different conditions: they were requested to rate on a graduate scale their importance for observation, for action, or for building. Thus, for example, for the concept of "car" the “roof” was rated as more important for observation, the “steering wheel” was rated as more important for action, and the “engine” as more important for building the car. The experiment was designed in order to test two different predictions derived from the embodied view: a. if object concepts are represented as patterns of potential actions, then parts relevant for acting should be produced earlier and more frequently across the four different conditions (observation, action, building, and neutral); b. if object concepts are also variable, then visual parts should be produced earlier and more frequently in the observation than in the building condition, whereas parts relevant for building (they typically are inner parts) should be produced earlier and more frequently in the building then in the observation conditions. Both predictions were confirmed. The experiment confirms that concepts are action-based and that when we think of objects we immediately activate “default” affordances, (i.e. affordances related to frequent interactions with the object). This suggests that we build a sort of motor prototype, encoding parts more typically involved in interactions with objects. Thus object concepts have a certain degree of stability, and this stability is grounded in action. However, even though default affordances are activated first, different concept parts are activated depending on the simulated kind or interaction with objects. This suggests that conceptual organization is variable.

The described study suggests that conceptual variability is grounded in contexts and situation, not in associations between words. However, an objection might be raised by proponents of the amodal view of conceptual organization. Given that the results are based on a part production task, they do not completely rule out an account of concepts based on associations in a semantic network. Proponents of the amodal view might claim that production tasks are not sufficiently informative, as their results might be explained by word frequency and by the fact that there are simply stronger lexical associations, say, among words denoting parts within a given perspective than across different perspectives. For example, it could be the case that the action parts are more frequent than observation and building parts, and that the action parts are more semantically associated to the action contexts, the observation parts to the observation context and the building parts to the building context.

Two studies I will report might help to rule out this objection. Borghi, Glenberg and Kaschak (2004) aimed at demonstrating that retrieval of object parts is influenced both by their spatial organization and by the functional perspective from which we access them. Participants were required to read a sentence as, for example, “you are reading on a train” and to press two different keys on the keyboard to determine whether the noun that appeared on the screen after the sentence referred or not to the object mentioned in the sentence (e.g., caboose yes, railway no). They found that, while reading sentences describing actions to perform inside the train (e.g., You are reading on a train), participants were faster in processing inside parts than outside parts; the opposite was true for actions to perform outside the train (e.g., You are watching the train arriving). Crucially, for both inside and outside actions they were faster in processing inside and outside near parts, that is parts that are typically located near the place where the action occurs. For example, with the sentence “reading in a train” the near part “seat” was processed faster than the far part “caboose”, with the sentence “watching the train arriving” the near part “locomotive” produced faster response times than the far part “baggage car”. The results suggest that comprehension implies a simulation process: we simulate the interaction with the objects (the train, in this case), taking into account their spatial properties. In addition, they show that different parts become relevant depending on the adopted perspective. Importantly, these results were not predicted by semantic associations between words. Latent Semantic Analysis (Landauer & Dumais, 1997), a computational technique that uses a high-dimensional space to measure associations between words, was used in order to make sure that, say, inner actions were NOT more associated to inner than to outer parts. Thus traditional theories of concepts and meaning, according to which meaning is explained by semantic associations between words, would not be able to predict and explain the results.

The same is true of a recent study aimed at showing that, when objects have multiple affordances, a different context can lead to access one of them (Borghi, 2004). As in the previous experiment, participants read a sentence and were required to decide whether a noun following the sentence referred or not to a part of the object mentioned in the sentence (part verification task). The selected parts were either good affordances for a given action or not: for example "pulp" is a good affordance for the action of tasting an orange, not for the action of sharing an orange. The results indicate that parts that were good affordances for a given action were processed faster and elicited less errors than parts that were not good affordances. The result, that did not depend on semantic association between the sentence and the part-noun that followed it, suggests that affordances may vary, and that concepts' perceptual features are differentially accessed depending on the activated situation/goal.

CONCLUSION

The studies presented so far demonstrate that object concepts automatically evoke motor information. I illustrated this point by presenting examples of studies focusing on the relationship between visual stimuli and motor responses, as well as example of studies on the grounding of language in perception and action. The results show that, when we think or talk about objects, we first have access to information relevant for more frequent interactions with them (i.e., we first access "default" affordances). But this is not the whole story: our cognitive system is flexible enough to allow us to activate different kinds of affordances, depending on our current goals and on the present context / situation. Overall, the results of the studies suggest that concepts, as well as words, are both embodied and situated. They are both grounded in sensorimotor processes and flexible, as they have to play an important adaptive role: to prepare for situated action.

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