Object concepts and mental images

Anna Borghi and Claudia Scorolli,

University of Bologna

Abstract

The paper focuses on mental imagery and concepts. First we discuss the possible reasons why the propositional view of representation was so successful among cognitive scientists interested in concepts. Then a novel perspective, the embodied view, is presented. Differently from the classic cognitivist view, this perspective acknowledges the importance of perceptual and motor imagery for concepts. According to the embodied perspective concepts are not given by propositional, abstract and amodal symbols but are grounded in sensorimotor processes. Neural and behavioral evidence favouring this perspective is presented. The paper discusses the continuity, but also the differences, between the imagery view and the embodied view of conceptual representation.

Key words: imagery – motor imagery – concepts – representation - embodiment

1.Introduction

This paper will focus on the relationship between mental imagery and concepts. We will start by indicating possible reasons why the propositional view of representation has gained popularity in cognitive science, and trying to highlight some of its shortcomings. Then we will focus on a recent view of conceptual representation that acknowledges the importance of perceptual and motor imagery. In this perspective concepts are not given by propositional, abstract and amodal symbols but are grounded in sensorimotor processes. We will describe neural and behavioral evidence favouring this perspective. At a more general level, in this paper we aim at showing the deep continuity, but also the differences, between the imagery view of representation and one of the most successful recent theories of concepts, the "embodied" theory.

2.The propositional view of concepts and meaning: some reasons of its success

The propositional view has been and probably still is the dominant view among cognitive scientists who study concepts. Image-based theories have been quite popular among philosophers since the antiquity (Barsalou & Prinz, 1997; Prinz, 2002). Aristotle claimed "The soul never thinks without an image". Among others, Epicurus, Lucretius, Locke, and Berkeley underlined the importance of perceptual aspects for knowledge. The belief that images were crucial for

thinking remained popular into the first part of the last century. In more recent times image-based views seemed to lose a lot of their appeal. Cognitive scientists have always demonstrated a certain resistance to imagery and preferred to endorse propositional-based theories. Let us address the question of why this happened and of why the propositional view had such a great success in the study of concepts.

A first reason is that the complexity of cognitive computations calls for the symbolic nature of representations, and language is the most powerful symbolic system in our possession. The advantage of propositional symbols is that, similarly to words, they are productive and can be differently combined in order to generate new meanings. Thus they can provide a powerful explanation of the way cognition works.

A second reason of why the propositional view was endorsed by the majority of cognitive scientists is that the most part of research on concepts was conducted using experimental paradigms that involved language. Consider for example a typical task used in order to access conceptual organization, the property generation task. In this task participants are required to produce all the properties that come to their mind for a given concept (for example, dog: tail, fur, head, barks, etc.). The output of such a task is a list of features. It is quite an easy step to identify the production output with the way in which objects are represented. Given that in standard feature production tasks participants generated features in order to describe concepts, this suggested that the way in which concepts were represented was based on propositional features.

A further reason of the resistance of cognitive scientists to an image-based view of concepts might be due to the theoretical and methodological weaknesses of the mental imagery perspective within the broad context of cognitive science. The literature on mental imagery was often misunderstood, and this misunderstanding led to simplifications that induced scientists to endorse a more easily defendable propositional view.

A final reason might lie in the fact that, in the years, different successful computational models of propositional view have been proposed (Collins & Loftus, 1975; Newell & Simon, 1976; Turing, 1950). Among the most recent models, Latent Semantic Analysis (LSA; Landauer & Dumais, 1997) and Hyperspace Analogue to Language (HAL; Burgess & Lund, 1997) have shown using disembodied symbols that statistical linguistics indeed approximates behavioral results (Foltz, Kintsch & Landauer, 1998; Landauer, McNamara, Kintsch & Dennis, 2006). Consider for example LSA (Landauer and Dumais, 1997) that uses a high-dimensional space to measure the association between words found in texts. LSA provides an index of a type of co-occurrence of words in similar texts, and this index has been demonstrated to be significantly correlated with psychological effects depending on associations, such as semantic priming.

Even though some propositional models of representation, as for example LSA, can be powerful instruments useful to investigate associations between words, they have the limits of using ungrounded and disembodied symbols. Arguments from Harnad, Searle and others have shown that meaning cannot rise without symbols grounding, so it follows that models like LSA cannot account for the emergence of meaning, or at least they cannot fully explain it. Namely, in accordance with claims of propositionalists, they equate meaning with relationships between abstract and amodal symbols that are arbitrarily linked to their referents in the world.

3. The embodied view of concepts and its relationship with image-based views of cognition

In the last ten years much has changed. The resistance of cognitive scientists to imagery-based representations has been overcome by the emergence of a new perspective, the embodied view, that is rapidly gaining success. According to this perspective knowledge is grounded in sensorimotor systems; knowledge acquisition and use are influenced by the characteristics of our body and its peculiar way to interact with the environment. Studies adopting an embodied

perspective have produced an impressive amount of behavioral results that cannot be accounted for by propositional models based on the idea that meaning emerges from associations in a semantic network. Importantly for the aim of this paper, the endorsement of an embodied perspective has lead scholars to re-evaluate an image-based view of knowledge.

According to the embodied view, 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 an object or of an entity leads to a re-experiencing (simulation) of the interaction with that object or entity. For example, thinking of a "dog" leads to the activation of multimodal information – the sound of the dog barking, its colour and shape, the smoothness of its fur while we caress it, etc. In this view, concepts are thus conceived of as "simulators", as they make it possible to run simulations (Barsalou, 1999; Barsalou et al., 2003). Simulations consist of re-enactments of our sensorimotor experiences with objects and entities. Namely, the neural areas recruited when we think about an object or an entity and prepare to act are the same that are recruited when we perceive and interact with its referent.

Adopting an embodied view of concepts implies the rejection of the idea of a transduction process from perceptual and motor states to propositional symbols. Here we advance three arguments useful to reject the idea of a transduction.

The first argument concerns the way evolution works. Evolution typically proceeds in a conservative way. There is no clear reason why in human beings a further process, the process of transduction, should be introduced between the object experience and the way we retain information on object.

The second argument regards the way science and scientific explanation typically work. In science the most parsimonious explanation of a process is typically the best one. If a simple explanation of a process can be provided, there is no reason why one should advance a more complicated explanation of the same process. The propositional explanation is clearly more complex than the embodied explanation. Namely, the first implies a transduction of experience into propositional symbols, that are arbitrary linked to their referents (objects and entities). On the contrary, the embodied explanation simply claims that while thinking and speaking we reactivate our previous experiences with objects and entities.

The third argument in favour of the embodied view is a provocative argument. In principle, there should be no need to defend an imagery based view of concepts. Objects have visual, acoustic, tactile features, and there is a rich body of evidence demonstrating that they are represented through the activation of visual, acoustic, tactile etc. brain areas. As we will show below, there is much recent evidence showing that object processing, as well as processing of words referring to objects, activate sensori-motor areas of the brain. So, in principle we would need counter-evidence, that is evidence showing that concepts are NOT grounded in sensorimotor processes. As far as we know, there is no convincing demonstration of the existence of a transduction process. Therefore, scholars who claim that object concepts are represented through propositional, quasi-linguistic symbols rather than modality specific features should provide convincing demonstrations of their claim.

As it should be clear from our presentation so far, the image-based and the embodied vision of concepts share the idea that concepts are not amodal, abstract, arbitrary and propositional symbols. However, this does not mean that imagery can be conceived of in a simplistic way as the process of creating "images in the head". Also, it does not mean that images can be equated to "visual images".

Concepts cannot be equated to "images" in the head because they are not holistic representations, but they are componential in nature. They are given by the activation of modality specific features across different domains. In line with connectionist claims, concepts are represented in a sub-symbolic rather than in a symbolic way (Elman, Bates, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1997): the single components are not symbolic per se, but meaning arises

and symbols emerge from the activation of neurons in different modality specific areas. It is the compositional character of concepts that guarantees for their productivity.

The imagery components of concepts shouldn't be simply equated with visual images. Rather, concepts can be conceived of as activation of neural patterns in different modality specific domains. There is compelling evidence showing that information is distributed in the brain across modality specific areas, and that information related to different features is stored in different brain regions (Martin et al. 1996; Boronat et al., 2005). In other terms, concepts imply the simultaneous activation of visual as well as tactile, motor, acoustic, taste features. In order to be productive, the semantic system must be compositional, and its components are different kinds of features distributed in different brain areas. These domains and these features are more or less activated depending on their relevance during knowledge acquisition. Importantly, according to this view, which is different from the classic information processing view, perception and action are seen as intimately related processes. In line with this account, various evidence on cortical object representation has shown that tools and manipulable objects, unlike non-manipulable artefacts, activate motor-related areas, whereas animals and natural objects activate vision-related areas (Gerlach, Law, & Paulson, 2002).

A potential difference between the traditional image-based view and the embodied view concerns the role played by "mental representation". Even if they defended an analogical rather than propositional form of representation, still the very idea of representation was crucial for defenders of image-based views of concepts. The same was true for traditional theories of concepts. Consider for example a claim by Keil (1995): "When I think of the category of dogs, a specific mental representation is responsible for that category and roughly the same representation for a later categorization of dogs by myself or by another". In the traditional view, concepts are representation; more importantly, they are rather stable and constant representations, and this explain the stability of our behavior. In antithesis with this position, within the embodied framework the dynamicity of behaviour has been underlined. In this framework, the notion of representation has been either dropped or deeply revisited. In fact, due to its theoretical ambiguity some scholars have proposed to dismiss it. As Smith (2005) claims, the dynamical character of cognition does not require stable forms of representation. For example, depending on the context we think of dogs in very different ways: "in the context of frisbies, we think of playful puppies, in the context of race tracks, we think of streamlined (and not at all playful) greyhounds, and in the contexts of muzzles, the main thought is fear" (Smith, 2005; p. 280). Other authors, though they still make use of the notion of representation, deeply revisit it as they equate representation with the activation of multiple neuronal areas (e.g., Barsalou, 1999; Barsalou et al., 2003; Gallese & Lakoff, 2005). Our impression is that the debate within defenders of the embodied perspective focuses more on a terminological rather than on a theoretical matter. Once representation is equated with the activation pattern of multiple modality specific areas, once the dynamicity rather than the stability of concepts is stressed, once cognition is intended as "a complex set of processes bound to each other and to the world through perception and action with no fixed and segregated representations of anything" (Smith, 2005; p. 279), then the very fact of using or not the notions of concepts and of representation is not crucial. Even if one chooses to stick to the notion of representation, this notion has completely lost its original meaning.

4. Evidence of the imagery character of concepts

Immediately after the most important proposals that concepts were grounded in sensorimotor processes were formulated (Barsalou & Prinz, 1997; Barsalou, 1999), a rich body of evidence in favour of the imagery character of concepts was collected. For example, Zwaan, Stanfield and Yaxley (2002) used a recognition task in order to address whether the

linguistics input was converted into a propositional representation or into a ‘mental image’, that is a representation having an analogical relationship with its referent. They showed that, 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, whereas the opposite was true with the sentence “The ranger saw the eagle in its nest”. This result, that is not predicted by a propositional view, suggested that subjects simulated in an analogical way the object shape implied by the sentence. Further evidence shows that the spatial and functional perspective suggested by a sentence activate mental imagery. In a study by Borghi, Glenberg and Kaschak (2004), participants read a sentence describing an object or a location from an inside (e.g., "You are driving a car ") or an outside (e.g., "You are fueling a car ") perspective. Then they were presented with a word and had to verify if the word referred or not to a part of the object / location. There could be inside or outside parts (e.g., seat vs. trunk) and parts located either near or far from the place where the action expressed by the sentence typically occurs (e.g., the inside part “back seat” is far from the place where the action of “driving” occurs, whereas the inside part “steering wheel” is near to the driver-place). Subjects performed the verification task more quickly when the perspective implied by the sentence and the part perspective matched. Then, within this perspective, they were quicker to verify near parts than far parts. These results clearly showed that the different perspectives implied by the sentences influenced the accessibility of information and made different conceptual knowledge available. Importantly, using latent semantic analysis (LSA), the authors ruled out the possibility that the results were due to semantic associations between words. Thus the results cannot be accounted for by a propositional theory and strongly suggest that during sentence comprehension we use imagery to mentally scan the situation described. Interestingly, the results found in these experiments are comparable with those obtained by Kosslyn, Ball and Reiser (1978). They also found quicker responses in scanning a smaller region of the image. Crucially, whereas Kosslyn et al. asked participants to generate a mental image, in the study by Borghi et al. the task did not require any explicit engagement of perceptual information: no imagery instructions were given and participants were presented only with linguistic stimuli. Clear evidence in favour of an image-based view comes from eye tracking studies that show that participants listening to stories describing objects orient their eye movements 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).

The activated ‘mental images’ are not only visual, but multimodal, as an experiment by Pecher, Zeelenberg and Barsalou (2003) clearly shows. The authors selected concept nouns and properties regarding vision, motor action, audition, taste, touch and smell. Participants were presented with a sentence like ‘A *lemon* can be *sour*’ and they had to respond if the sentence was true or false. Crucially, the task did not require to create a mental image. Response times showed that switching modality, for example from a property related to taste (eg: *lemon – sour*) to an auditory property *(leaves – rustling)*, required a cost. A control experiment ruled out the possible alternative explanation that *amodal* symbols for the same modality are more associated than *amodal* symbols for different modalities. These findings clearly favour the idea that concepts imply the simultaneous activation of different modality specific domains.

Evidence discussed so far suggests that concepts are made of ‘perceptual symbols’ (Barsalou, 1999). However, in the last years many studies focused on the relevance for concepts of motor information (and of motor imagery) (Glenberg, 1997). Consider for example a study performed the Positron Emission Tomography (PET), a scanning technique for monitoring regional blood flow (Grafton, Fadiga, Arbib & Rizzolatti, 1997). Authors found a specific activation of motor areas of the brain for manipulable man-made tools, like scissors or hammer. Importantly, the left premotor cortex was activated not only when subjects had to say the use of the object or when they had to name the object, but also when the task consisted only of looking at the object. This suggests that both naming and observing tools activate motor

imagery and that perception and action are strictly interwoven. The role of motor imagery and action for concepts has been shown also in behavioural studies. For example, Borghi et al. (2004) used the same task used in the previous experiment but chose sentences that did not imply any action and selected upper and lower object parts (e.g, roof vs. wheel of a car). Participants performed the task using as responding device a vertically oriented button box.. They had to move the hand upward or downward to press the response key. Responding in a direction incompatible with the part location (e.g., responding downward to verify that a car has a roof) was slow relative to responding in a direction compatible with the part location. A recent debate concerns the degree of specificity of the simulations activated during language comprehension. Different behavioural and neuro-physiological experiments demonstrate that these simulations are quite specific (see for example Buccino, Riggio, Melli, Binkofski, Gallese, Rizzolatti, 2005).. Pulvermüller, Härle and Hummel (2001) investigated brain activity elicited by visually presented verbs that could be referred to movements of the arms (eg. *to write*), of the legs (e.g. *to walk*) or of the face muscles (e.g *to talk*). The behavioural part of the study consisted in a lexical decision task. In the physiological part they recorded Event Related Potentials (ERPs), that is a measure of the electrical activity produced by the brain in response to a sensory stimulus or associated with the execution of a motor, cognitive, or psycho-physiologic task. Behavioural results showed faster response times for face related verbs followed by arm related verbs and leg related verbs, supporting the idea that words semantic properties are reflected in the brain response they induce. Recorded ERPs revealed significant topographical differences: different kinds of verbs, referring to actions performed using different effectors, are processed in different ways in the brain. These conclusions are confirmed in a behavioural study by Scorolli & Borghi (submitted). Participants were presented with pairs of nouns and verbs that could be referred to hand and mouth actions (e.g., to unwrap vs. to suck the sweet), or to hand and foot actions (e.g., to throw vs. kick the ball). Their task consisted of deciding whether the combination made sense or not: a group of participants responded by saying *yes* loudly into a microphone, another group by pressing a pedal. Results suggest that sentence processing activates an action simulation. This simulation is quite detailed, as it is sensitive to the effector involved. Namely, a facilitation emerged in responses to 'mouth sentences' and 'foot sentences' compared to 'hand sentences' in case of congruency between the effectors – mouth and foot – involved in the motor response and in the sentence. A propositional theory can hardly account for these results. Namely, participants were simply asked to decide if a sentence like *to kick the ball* was sensible or not sensible. If concepts mediated by words were abstract, amodal and arbitrarily related to their referents, why should the sentence '*to kick the ball*' produce faster responses with the pedal than "*to throw the ball*"?

5. Conclusion

As we have seen, the embodied view incorporates and extends many ideas initially proposed in a different cultural and historical contexts by authors working on mental imagery. However, these ideas have been deeply modified and revisited. The critiques of authors in favour of a propositionalist account have been taken into consideration and many of the weaknesses of the traditional mental imagery approach have been eliminated. For example, proponents of the embodied cognition perspective got rid of some reductive and misleading interpretations of mental imagery, as for example the idea that we have "images in the head" or the equation of "mental imagery" with "visual mental imagery". In addition, the notion of "mental representation", that was extensively used by defenders of the image-based view of cognition, was either rejected or deeply transformed in the context of embodied views of cognition.

A final remark should be made regarding the importance of imagery for concepts according to the embodied perspective. Immediately after the most important proposals that concepts were grounded in sensorimotor processes

were formulated (Barsalou & Prinz, 1997; Barsalou, 1999), the role played by imagery (and particularly by visual imagery) for conceptual representation was stressed. As our brief review has shown, initial evidence favouring an embodied approach to concepts showed that thinking of an object or comprehending a word implied referring to the perceptual aspects of its referent (MacWhinney, 1999; Zwaan, 2004). In the last years the panorama has slightly changed. More and more authors who adopt an embodied perspective underline the importance for concepts not just of perceptual but of sensorimotor and particularly motor processes. More importantly, in the last years it has become more clear that perception and action are not separate and sequential processes but that they are deeply interwoven. In sum, the centrality of action for concepts has been fully recognized (for a review see Borghi, 2005). The recognition of this centrality has been favoured by the diffusion of studies on motor imagery and by the broad literature on the motor resonance processes triggered by mirror neurons in both monkeys and humans. Consider for example the way in which the term "motor image" has changed: whereas this term classically referred to explicit or conscious representation of an action (e.g., imagine yourself running), recent research focuses also on implicit or inconscious aspects, and with "motor imagery" we refer to a subliminal activation of the motor system (Jeannerod & Frak, 1999). At the same time, studies on mirror neurons have shown the relevance of motor resonance processes (see discussions on the role played by mirror neurons for concepts, see Borghi and Scorolli, submitted).

Once established that concepts strongly rely on sensorimotor processes, a further problem that needs be addressed concerns the ornamental character of modal representations. Proponents of an amodal, propositional view might claim that is possible that objects are represented through modality specific features, but that these features are not NECESSARY for concept representation. This objection reminds of the critiques advanced by Pylyshyn (1973) to imagine-based theories. Phylyshyn (1973; but see also 2003) argued that images were just epiphenomenal to the context of thinking. Some recent studies on sentence comprehension provide some useful cues in order to solve the question. For example, data from Borreggine and Kaschak (in press) suggest that the ACE effect, at the very least, was due to the simultaneous occurrence of a motor preparation phase and sentence comprehension. Namely, the motor resonance effect could occur either during sentence comprehension or after the sentence has been understood in order to prepare for action. If it occurred after sentence comprehension, motor imagery would not be necessary for comprehension. In order to solve this complex matter, more detailed analyses of timing during conceptual and language comprehension tasks are needed. Providing an answer to this objection represents one of the most exciting challenges of current research in the field of embodied cognition.

References

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

Barsalou, L.W. & Prinz, J.J. (1997). Mundane creativity in perceptual symbol system. In T.B. Ward, S. M. Smith, & J. Vaid (eds). *Conceptual structures and processes: Emergence, discovery, and change.* Washington, DC: American Psychological Association.

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.

Borreggine, K.L., & Kaschak, M. (in press). The Action-sentence Compatibility Effect: Its all in the timing. *Cognitive Science.*

Borghi, A.M. (2005). Object concepts and action. In D. Pecher & R.A. Zwaan (Eds). *Grounding Cognition: The role of perception and action in memory, language, and thinking.* Cambrige University Press.

Borghi, A.M., Glenberg, A.M., Kashak, M.P. (2004). Putting words in perspective. Memory and cognition,*32,* 863-873.

Borghi, A.M., Scorolli, C. (submitted) Sentence comprehension and hand motion simulation.

Boronat, C.B., Buxbaum, L.J. , Coslett, H.B. , Tang, K., Saffran, E.M. , Kimberg, D.Y. , Detre, J.A. (2005). Distinction between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research, 23,* 361-73.

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., Rizzolatti, G. (2005). Listening to action related sentences modulates the activity of the motor system: A combined TMS and behavioral study. *Cognitive Brain Research, 24,* 355-63.

Burgess, C., & Lund, K. (1997). Modeling parsing constraints with high-dimensional context space. *Language and Cognitive Processes, 12*, 177-210.

Collins, A.M. & Loftus, E.F. (1975). A spreading activation theory of semantic processing. *Psychological Review, 82*, 407-428.

Elman, J. L., Bates, E. A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D., e Plunkett, K. (1997), *Rethinking Innateness. A Connectionism Perspective on Development*, Cambridge, MA, MIT Press.

Foltz, P. W., Kintsch, W. & Landauer, T. K. (1998). The measurement of textual Coherence with Latent Semantic Analysis. *Discourse Processes, 25*, 285-307.

Gallese, V., Lakoff, G. (2005). The brain's concepts: The role of the sensorimotor system in conceptual knowledge. *Cognitive Neuropsychology, 21*, 455-479.

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.

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

Grafton, S.T., Fadiga, L., Arbib, M.A., & Rizzolatti, G. (1997). Premotor cortex activation during observation and naming of familiar tools. *Neuroimage, 6*, 231-236.

Keil, F. (1995). "The growth of causal understandings of natural kinds" In: *Causal cognition: A multidisciplinary debate*. Sperber, D., Premack, D., Premack, A. (Eds.) Oxford, England, Oxford University Press.

Jeannerod, M. and Frak, V. G. 1999. Mental simulation of action in human subjects. Current Opinion in Neurobiology, 9: 735-39.

Kosslyn, S.N., Ball, T.M., & Reiser, B.J. (1978)Visual images preserve metric spatial information: Evidence from studies of image scanning, *Journal of Experimental Psychology: Human Perception & Performance, 4*, 47-60.

Landauer, T.K., Dumais, S.T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review, 104*, 211-240.

Landauer, T., McNamara, D.S., Dennis, S. & Kintsch, W. (Eds.). *LSA: A road to meaning*. Mahwah, NJ: Erlbaum.

MacWhinney, B. (1999). The emergence of language from embodiment. In B. MacWhinney (ed.). The emergence of language. London: Erlbaum (pp. 213-256).

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

Newell, A., & Simon, H.A. (1976). Computer science as empirical inquiry: Symbols and search. *Communications of the Association for Computing Machinery, 19*, 113-126.

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

Pylyshyn, Z.W. (1973). What the Mind's Eye Tells the Mind's Brain: A Critique of Mental Imagery. Psychological Bulletin, 80, 1-24.

Pylyshyn, Z.W. (2003). Mental imagery: in search of a theory. Behavioral and Brain Sciences, 25, 157.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9(2),* 129-154

Prinz, J. (2002). Furnishing the mind. Concepts and their perceptual basis. Cambridge, MA: MIT.

Pulvermüller, F., Härle, M. & Hummel, F. (2001). Walking or talking?: Behavioral and neurophysiological correlates of action verb processing. Brain and Language, 78, 143-168.

Rizzolatti, G., Craighero, L. (2004). The mirror neuron system. *Annual Review of Neuroscience, 27,* 169-192.

Scorolli, C. & Borghi, A.M. Sentence comprehension and action: Effector specific modulation of the motor system.

Smith, L. B. (2005). Cognition as a dynamic system: Principles from embodiment. *Developmental Review, 25,* 278-298.

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

Turing, A. M. (1950). Computing machinery and intelligence. *Mind, 59,* 433-460.

Zwaan, R. (2004). The immersed experiencer: Toward an embodied theory of language comprehension. In B.H. Ross (ed.), *Psychology of learning and motivation*, (vol.44, pp.35-62). New York: Academic.

Zwaan, R., Stanfield, R.A., Yaxley, R.H., 2002. Language comprehenders mentally represent the shape of objects. *Psychological Science, 13,* 168-171.