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# From demonstration to theory in embodied language comprehension: A review

Oleksandr V. Horchak [a,*], Jean-Christophe Giger [a], Maria Cabral [a], Grzegorz Pochwatko [b]

[a] *Department of Psychology and Educational Sciences, University of Algarve, Portugal*

[b] *Institute of Psychology, Polish Academy of Sciences, Poland*

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**Abstract**

Recent findings in psychology, psycholinguistics, and neuroscience present a challenge to current amodal theories by suggesting that cognitive states are not disembodied in language comprehension. Accumulating behavioral evidence supporting this view is reviewed from research on processing of language describing concrete and abstract concepts. The extant embodied theories that support either a strong or a moderate embodied view are then presented, as are the perspectives that define how the researchers discuss the role of sensory-motor grounding in language processing. The article concludes by discussing several lines of research that might help distinguish between various theoretical approaches and resolve some of the fundamental issues that fuel much of the debate in the field.


*Keywords:* Embodied cognition; Language comprehension; Concrete concepts; Abstract concepts; Embodied theories

## 1. Introduction

An amodal system theory that emerged from the Cognitive Revolution in the 1950s remained dominant for over five decades in the area of language comprehension. According to this theory, processing of language is based on abstract, amodal symbols that are arbitrarily related to their referents. From this perspective, the mind is an abstract information processor and sensory-motor systems are not relevant to understanding high-level cognitive processes (Fodor, 1975; Newell & Simon, 1976; Pylyshyn, 1984). The idea that relations among symbols may lead to successful language processing was corroborated by several symbolic models describing how human memory is organized semantically and schematically (e.g., Bobrow & Norman, 1975; Charniak, 1978; Norman, 1975; Quillian, 1969; Rumelhart, 1975; Shank & Abelson, 1995; Smith, Shoben, & Rips, 1974) as well as computational implementations, such as Knowledge Representation Language (Bobrow & Winograd, 1977), CYC (Lenat & Guha, 1989), Hyperspace Analog to Language (Lund & Burgess, 1996), Topic Model (Griffiths & Steyvers, 2004), and Latent Semantic Analysis (LSA) of Landauer and Dumais (1997). Furthermore, the demonstrations of the most popular model, such as LSA, in picking out synonyms, measuring coherence of texts (Landauer & Dumais, 1997), and even scoring students' essays (Landauer, Laham, Rehder, & Schreiner, 1997) led some scholars to support the potential of this model to account for human meaning (e.g., Landauer, 2002; Louwerse & Ventura, 2005).

Nonetheless, about 10 years ago the dominance of amodal theory was challenged and ultimately declined by the appearance of a new embodied account of cognition. This new account is based on the idea that language processing should be viewed in the context of relationship between the mind and the body. Neuroscientific research provided sub-

* Corresponding author. Address: Faculdade Ciências Humanas e Sociais, Departamento de Psicologia e Ciências da Educação, Campus de Gambelas, 8005-139 Faro, Portugal.

*E-mail addresses:* ohorchak@ualg.pt (O.V. Horchak), jhgiger@ualg.pt (J.-C. Giger), mcabral@ualg.pt (M. Cabral), grzegorz.pochwatko@psych.pan.pl (G. Pochwatko).

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stantial support for this idea by demonstrating that the same sensory-motor regions of the brain get activated when individuals process the words and their referents (e.g., Eskenazi, Grosjean, Humphreys, & Knoblich, 2009; Gallese, 2008; Kan, Barsalou, Solomon, Minor, & Thompson-Schill, 2003; Martin, 2001, 2007; Pulvermüller, 2008; Thompson-Schill, 2003). Similarly, research in cognitive psychology and cognitive linguistics showed that visual, motor, and emotional information are activated during sentence processing (Borghi, Di Ferdinando, & Parisi, 2011; Foroni & Semin, 2009; Gibbs, 2006; Glenberg, 1997; Kaschak & Borreggine, 2008; Knoblich & Flach, 2001; Zwaan, 2004). Therefore, embodied theories of cognition rejected amodal views that symbols can become meaningful on the sole basis of other symbols and suggested instead that symbols need to be grounded to their referents in the environment.

In the past years research on embodied language comprehension has grown exponentially. In neuroscience, the researchers found that comprehension of action words in patients diagnosed with Parkinson's disease (Boulenger et al., 2008) and apraxia (Buxbaum & Saffran, 2002) was selectively impaired, suggesting that sensory-motor simulations can hardly be viewed as by-products of language processing. In cognitive psychology, the researchers such as Borghi (2004), Bub and Masson (2010), de Vega (2008), Glenberg and Kaschak (2002), Pecher, Zeelenberg, and Barsalou (2003), and Zwaan and Taylor (2006) found that modality-specific simulations can affect various language tasks in psycholinguistic embodiment experiments. What is all the more noteworthy, many other researchers, including Barsalou and Wiemer-Hastings (2005), Boroditsky and Ramscar (2002), Casasanto and Lozano (2006), Langston (2002), Pecher and Boot (2011), Richardson, Spivey, McRae, and Barsalou (2003), Santiago, Lupiáñez, Pérez, and Funes (2007), and Sell and Kaschak (2011, 2012) showed that comprehension of certain abstract concepts and sentences requires the involvement of sensory-motor simulations to the same extent as comprehension of concrete concepts and sentences. Finally, the evidence for embodied representations formed the origin of language models, including Perceptual Symbols Theory of Barsalou (1999a), Indexical Hypothesis of Glenberg and Robertson (1999, 2000), Immersed Experiencer Framework of Zwaan (2004), and Action-based Language Theory of Glenberg and Gallese (2012). In brief, recent years in science have been marked by accumulation of empirical and theoretical evidence to support a claim that bodily states and modality-specific simulations play important roles in processing of language.

The purpose of this article is twofold. First is to provide a systematic review of how sensory-motor and affective processes contribute to sentence and discourse comprehension as well as to assess the commonalities and differences among the various findings and theories that currently drive discussions in the field. Second is to provide a critical discussion of the likely future trajectory of embodiment research in the domain of language processing. The Section 2 of this article reviews the contribution of modality-specific simulations to processing of language describing concrete concepts. The Section 3 reviews how sensory-motor simulations contribute to processing of language describing abstract concepts. The Section 4 discusses and explicitly contrasts a variety of old and new theoretical approaches that support either a strong embodied view (approach acknowledging the contribution of simulation) or a moderate embodied view (mixed approach acknowledging the contribution of both language and simulation). Finally, the Section 5 ends up with conclusions and an outlook on future investigations.

One caveat is important. The purpose of this review is not to be exhaustive, and thus it differs from previous reviews in several important ways. First, our review focuses on sentence and discourse processing, whereas most of the previous reviews focus on single-word processing (e.g., Hauk, Shtyrov, & Pulvermuller, 2008; Kemmerer, 2010; Kiefer & Pulvermüller, 2012; Pulvermüller, 2008). The rationale for this choice is motivated by previous research that stressed the importance of discussing the role of sensory-motor simulations in comprehension of language segments that provide enough context to constrain the interpretation of word meaning (see Fischer & Zwaan, 2008; Zwaan & Kaschak, 2008, for discussion). Second, our review focuses on behavioral data, whereas most of the previous reviews include a considerable amount of neuroscientific data (e.g., Binder & Desai, 2011; Coello & Bartolo, 2012; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012; Taylor & Zwaan, 2009; Willems & Casasanto, 2011). Third, the current review includes a considerable amount of work on processing of abstract concepts, such as emotion, time, quantity, transfer, and metaphorical action, and this is lacking in previous reviews. Finally, the paper explicitly compares and contrasts a variety of old and new theoretical approaches to understanding of language, whereas most of the previous reviews do not delve into these particular approaches.

## 2. Review of evidence on processing of language describing concrete concepts

The purpose of the following section is to review extant empirical research demonstrating the impact of embodied simulations on processing of concrete language. Given the abundance of evidence, our purpose in this literature review is not to be comprehensive but, instead, to establish the common principles that are found in the various findings. This will help us to identify how researchers discuss the importance of embodied factor in concrete language processing with so many findings to choose from.

### 2.1. Perceptual simulation

The idea that perceptual knowledge is implicated in cognition is not new. Previous studies on spatial representations (e.g., Black, Turner, & Bower, 1979; Bower & Morrow, 1990; Gernsbacher, Varner, & Faust, 1990; Potter, Kroll, Yachzel, Carpenter, & Sherman, 1986) suggested that visual and verbal components of comprehension are interconnected. Similarly, neuroscientific evidence (e.g., Boulenger et al., 2006; Goldberg, Perfetti, & Schneider, 2006; Hauk, Johnsrude, & Pulvermüller, 2004; Martin, 2007; Oliveri et al., 2004) demonstrated that perception of objects that index auditory, gustatory, tactile, and visual knowledge triggers activity in sensory-motor areas of the brain. This section reviews four major lines of research which demonstrate that perceptual simulation is necessary for language processing.

#### 2.1.1. The effects of implied perceptual features on immediate sentence comprehension

In this line of research, participants were presented with sentences describing objects or animals in various visuospatial configurations. After reading (listening) the sentence, participants were presented with a picture of the object or animal that the sentence described. The task consisted in judging whether the object (animal) was mentioned in the sentence. For example, Stanfield and Zwaan (2001) tested the hypothesis that people mentally represent the orientation of an object implied by the sentence. They asked participants to view a series of sentences (e.g., "John pounded the nail into the wall"; "John pounded the nail into the floor"), each followed by a picture in either vertical or horizontal orientation. During the experiment picture orientation either matched or mismatched the orientation implied by the sentence. The participants' task was to indicate whether the object was mentioned in the sentence by pressing a key labeled "Yes" or a key labeled "No" on a computer. The major result was that participants were faster to respond to picture stimuli that matched orientation implied by the sentence rather than mismatched. A similar Match advantage was found in related studies of Zwaan, Stanfield, and Yaxley (2002) on simulation of shape (e.g., "The ranger saw the eagle in the sky"; "The ranger saw the eagle in its nest"), Zwaan, Madden, Yaxley, and Aveyard (2004) on simulation of motion (e.g., "The shortstop hurled the softball at you"; "You hurled the softball at the shortstop") and Yaxley and Zwaan (2007) on simulation of visibility (e.g., "Through the fogged goggles, the skier could hardly identify the moose"; "Through the clean goggles, the skier could easily identify the moose"). Finally, in the most recent studies Zwaan and Pecher (2012) replicated and Engelen, Bouwmeester, de Bruin, and Zwaan (2011) extended Stanfield and Zwaan (2001) and Zwaan et al.'s (2002) findings regarding simulation of orientation and shape. Apparently, all these findings are consistent with the predictions derived from the embodiment claim: understanding a sentence suggesting a particular perceptual feature for an object calls on the same neural and bodily states involved in real perception of an object.

#### 2.1.2. The effects of implied perceptual features on long-term sentence comprehension

Stanfield and Zwaan (2001) and Zwaan et al. (2002) in their experiments demonstrated that sentence comprehension proceeded better when the picture that immediately followed the sentence matched the orientation and shape of the object that was connoted by the sentence. With an idea to demonstrate that details of sensory-motor simulations are retained over longer periods, Pecher, Van Dantzig, Zwaan, and Zeelenberg (2009) asked participants to first read the complete list of sentences and then perform speeded judgment tasks on the pictures that tested memory for the sentences. Importantly, one group of participants engaged in a memory-decision-response task right after reading the sentences and the other group only in 45 minutes after sentence presentation. The results showed that recognition memory for pictures in both groups was better if the picture matched the implied shape or orientation of the object in an earlier presented sentence. The major contribution of this finding was that simulation affected sentence processing even when sentence reading and picture recognition were separated in time (45-min delay), suggesting that perceptual simulations affect both immediate and long-term comprehension processes.

#### 2.1.3. Specificity of the processing mechanisms required to construct simulations

In this line of research, the researchers explored the relationship between processing mechanisms required to construct a simulation and language comprehension. For instance, Kaschak et al. (2005) instructed participants to view dynamic black-and-white stimuli (in the direction towards or away from the person) and simultaneously listen to sentences that described motion in either the same or different direction as the motion of the stimuli (e.g., "The car approached you"; "The horse ran away from you"). The task consisted in pressing a key labeled "Y" if the sentence made sense, and a key labeled "N" if the sentence did not make sense. The major result was that responses were faster for sentences presented with a visual stimulus depicting motion in the opposite direction as compared to the action described in the sentence. A mismatch advantage was also found in a similar study of Kaschak, Zwaan, Aveyard, and Yaxley (2006) when participants read sentences that stressed auditory aspects (e.g., "The surfer heard the next wave crashing toward him"; "The victims screamed as the rising water swept them away down the river"). The results of these two studies are particularly valuable in terms of identifying boundary conditions that specify how simulations are constructed. Kaschak and collaborators concluded that two factors weighed heavily in favor of a Match or Mismatch advantage: temporal overlap (timing of the stimulus and sentence to be processed) and integratability (the extent to which the stimuli can be integrated into the simulation). More broadly, the researchers suggested that when participants simultaneously view a visual stimulus and listen to a sentence (Kaschak et al., 2005), a Match advantage occurs when the sentence and the stimulus are integratible (e.g., when one sees an image of an eagle in the sky while reading and processing the sentence "I see an eagle in the sky"), and a Mismatch advantage occurs when the sentence and the stimulus are not easily integratible (e.g., when one sees an image of a black dot in the upper part of the computer screen while reading and processing the sentence "I see an eagle in the sky"). At the same time, when participants simultaneously view sentences that stress auditory aspects and listen to a stimulus (Kaschak et al., 2006), a Mismatch effect occurs due to competition for processing resources in the auditory perception system (i.e., perception of auditory stimulus requires the resources of perceptual auditory system, thus making them less available for a simulation of a sentence stressing auditory aspects). Finally, when a stimulus and a sentence are presented sequentially, a Match advantage arises under the condition that the percept and the sentence are integratible.

#### *2.1.4. Interference between visuospatial memory load and comprehension*

In this line of research, Fincher-Kiefer (2001) and Fincher-Kiefer and D'Agostino (2004) instructed participants to read narratives in either high-imagery or low-imagery conditions by manipulating memory load. More broadly, participants read sentences about scenes while maintaining either interfering visual information or noninterfering verbal information in their working memory and later were asked to recall all memory load sentences. The major result was that the recall of described scenes was impaired when memory contained irrelevant visual information, but not when it contained neutral verbal information. This pattern of results was taken as a support to the claim that situation models generated from text comprehension include perceptual processing and simulations. These studies are important for psycholinguistic embodiment research as they are among the first to our knowledge to indicate that perceptual simulations may affect processing above the level of a sentence (also see Spivey & Geng, 2001, for discussion of eye movements during processing of texts describing spatial scenes).

### *2.2. Action simulation*

The importance of the motor system has been recurrently stressed in studies addressing the role of action for memory (Glenberg, 1997), categorization (Ross, 1996), cognition (Johnson, 1987), and evolution (Rizzolatti & Arbib, 1998). In recent times, however, research from psychology, neuroscience, and cognitive linguistics has also demonstrated the importance of the motor system for language comprehension (see Fischer & Zwaan, 2008; Gallese, 2007; Gibbs, 2006; Pulvermüller, 2002, for reviews). This part presents five major lines of research in which the case of action is presented.

#### *2.2.1. The effects of congruency between motor action and the action described in the sentence on sentence comprehension*

In this line of research, participants were asked to perform different motor actions while reading sentences to test whether compatibility between motor action and the action described in the sentence facilitates sentence processing. For example, Glenberg and Kaschak (2002) asked participants to view series of sensible sentences that either described transfer toward the reader (e.g., "Open the drawer") or away from reader (e.g., "Close the drawer") as well as series of nonsense sentences (e.g., "Boil the air") that did not imply any transfer. The task was to judge if sentences made sense by pressing one of the vertical keys on a three-button box that required a movement either toward or away from the body. The researchers found that responses were faster when the motion implied by the sentence matched the actual hand motion. This matching advantage was called the action sentence compatibility effect (ACE). ACE effect was also reported in experiments of Borreggine and Kaschak (2006), Taylor, Lev-Ari, and Zwaan (2008), and Zwaan and Taylor (2006), which demonstrated that understanding the meaning of the sentence calls on experience with real motor action. At the same time, an experiment of Zwaan and Taylor (2006) revealed that ACE effect turned out to be quite specific: an activation of compatible motor responses was localized on the verb region of the sentence, but not on the preverb-, postverb-, and sentence-final regions. This pattern of results allowed the researchers to hypothesize that maintaining focus on the action by following the verb with an adverb implying action might cause motor resonance to affect both the verb and the adverb that follows it. This prediction was tested in subsequent studies that fall within the second line of research addressing the role of linguistic focus in simulation of action.

#### *2.2.2. The role of linguistic focus in action simulation*

This line of research aims to investigate whether linguistic focus helps to identify the dynamics of action simulation within a sentence. For instance, Taylor and Zwaan (2008) asked participants to read sentences in which the verbs were followed by adverbs that either kept focus on the action (e.g., "When he saw a gas station, he exited slowly") or on the agent (e.g., "When he saw a gas station, he exited eagerly"). The principal finding was that motor resonance affected both the verb and the adverb that followed it, but only when the postverbal adverb maintained focus on a matching action. In another recent study, Masson, Bub, and Lavelle (in press) investigated whether shifting the focus from proximal goals of the agent to distal goals of the agent affects the dynamics of motor resonance in sentence comprehension. More broadly, the researchers asked participants to perform a cued reach and grasp response while listening to sentences that described a functional motion (executed to use an object for its intended purpose, and thus corresponding to a reach response) and a volumetric motion (executed to pick up an object, and thus corresponding to a grasp response). The major result was that duration of motor resonance was evanescent when sentences described the proximal intention first (e.g., "John lifted the pencil to clear the desk") and persistent when sentences described the distal intention first (e.g., "To clear the desk, John lifted the pencil"). Masson et al. (in press) interpreted this finding as evidence of hierarchy between the two types of actions, suggesting that the focus of volumetric movements is limited to a word denoting an object and the focus of functional movements extends to other regions of the sentence.

#### 2.2.3. The role of grammar in action simulation

There is now a growing literature showing that grammar may also affect the prevalence of simulation in sentence and discourse processing. For instance, Zwaan, Taylor, and de Boer (2010) asked participants to read stories implying rotation movements (sentence by sentence) while actually rotating a knob. Three types of target sentences were used: the sentences describing actions performed in the past, the sentences describing actions being performed, and the sentences describing actions intended to be performed. The major result was that motor resonance occurred only for the sentences implying past and present actions. The researchers concluded that no significant activation of compatible motor responses occurred for the sentences describing future actions due to the fact that these sentences focused on preparation rather than execution of action. The role of grammar was further specified in other related studies. For instance, Ditman, Brunyé, Mahoney, and Taylor (2010) showed that memory was better for sentences preceded by pronoun "you" rather than by pronouns "he" or "I". In another interesting research, de Vega, Robertson, Glenberg, Kaschak, and Rinck (2004) and Santana and de Vega (2013) demonstrated that comprehension of participants who read sentences describing simultaneous actions by means of the temporal adjective "while" was impaired relative to comprehension of participants who read sentences implying successive actions by means of the temporal adjective "after ".

#### 2.2.4. The role of affordances (gestural knowledge) in language comprehension

Glenberg and Kaschak (2002), Zwaan and Taylor (2006), and many others (e.g., Boreggine & Kaschak, 2006; Kaschak & Borreggine, 2008) showed that compatibility between the literal direction of hand motion and that implied by the sentence (action-sentence compatibility effect) facilitates sentence processing. The researchers such as Ambrosini, Scorolli, Borghi, and Costantini (2012), Borghi and Riggio (2009), Bub, Masson, and Cree (2008), Costantini, Ambrosini, Scorolli, and Borghi (2011), Masson, Bub, and Warren (2008b), and Myachykov, Ellis, Cangelosi, and Fischer (2013) extended these findings by demonstrating that more specific action representations based on the type of action associated with a referent in a physical world (i.e., the affordances of the objects) are evoked during language processing. For example, Masson, Bub, and Newton-Taylor (2008a), Masson et al. (2008b) developed a procedure to measure the dynamic representation of functional and volumetric hand actions implied by the sentence. They constructed a response apparatus that consisted of shapes associated with certain hand actions (e.g., horizontal grasp, horizontal pinch, vertical grasp, vertical pinch) and trained participants to produce hand actions that corresponded to those depicted in the picture (each picture depicting a hand action signaled a particular action on the apparatus). After the training session, participants listened to sentences, each referring to a certain object (the verbs used in these sentences denoted either attention/movement toward an object as in "A lawyer kicked a calculator", or a non-manual interaction with it as in "A lawyer looked at a calculator"), and immediately after made speeded responses to the pictures that appeared on the screen by lifting the hand from a button box and manually carrying out the corresponding action on the apparatus. The results showed that functional and volumetric actions were activated during comprehension of sentences that stressed interaction with objects (e.g., kick a calculator). Moreover, motor resonance occurred (functional motion was activated) even during comprehension of sentences that referred to non-manual interaction with objects (e.g., look at a calculator). The researchers interpreted their findings as suggesting that the relationship between a constructed sensory-motor simulation and the meaning of the sentence can be quite specific. That is, sentence processing may arise not from a literal meaning of the sentence, but from prior experience that best captures the functional and volumetric properties of the object (i.e., moving a calculator by hand rather than kicking it by foot). Borghi and Riggio (2009) extended Masson et al.'s (2008a,b) research by demonstrating that affordance effects can be triggered not only by nouns, but as well by verbs. To do so, the researchers instructed participants to read imperative sentences with the observation verbs (e.g., "Look at the shave brush") or action verbs (e.g., "Grasp the shave brush") and then decide whether the visual object following the sentence was the same as the one mentioned in the sentence. Among other important findings, the researchers found that response times were faster when the orientation of the object afforded action rather than non-afforded, suggesting that seeing a graspable object leads to a construction of sensory-motor simulation that requires the use of associated affordances.

#### 2.2.5. The role of effectors in language processing

This line of research reveals that language segments describing actions that involve a typical effector (e.g., hand, foot, etc.) are processed easier when there is a match between an effector implied by the language segment and that used to respond. Although most of the evidence in this area of research comes from neuropsychological studies (e.g., Hauk et al., 2004; Pulvermüller, Härle, & Hummel,

2001) and behavioral studies using word stimuli (e.g., Ahlberg, Dudschig, & Kaup, 2013), there is now a modest amount of behavioral research suggesting that simulations are also sensitive to the kind of effector connoted by the sentence. For example, Scorolli and Borghi (2007) had participants read sentences associated with specific effectors (e.g., suck a sweet – mouth effector *vs.* unwrap the sweet – hand effector; kick the ball – foot effector *vs.* throw the ball – hand effector) and then judge the sensibility of sentences. Among other findings, the researchers found an effector-sentence compatibility effect: sensibility judgments were faster when the effector used to respond matched that implied by the sentence. In a related study, Borghi and Scrolli (2009) reported evidence suggesting that the construction of simulation is sensitive not only to effectors of different functionality (e.g., mouth *vs.* hand), but also to effectors of the same functionality (left *vs.* right hand). More precisely, the researchers found that responses to sensible sentences describing hand motion were faster compared to non-sense ones when participants responded with their right hand rather than their left hand.

### *2.3. Summary*

From what we have reviewed so far, it is evident that the case of perceptual and action simulations is strong in the area of concrete language processing. The researchers approach the importance of embodiment by either amplifying evidence for the activation of embodied representations in language comprehension or establishing boundary conditions that define the prevalence of simulation in understanding of language. As discussed previously, such boundary conditions can be temporal overlap and integratability in the domain of perception, and linguistic focus, grammar, affordances, and the kind of effector involved in response in the domain of action. Finally, as our review of the literature has shown, several researchers made replications of original studies (e.g., Zwaan & Pecher, 2012; Santana & de Vega, 2013) to build stronger theoretical conclusions. We think that replication studies are important for current research as they help remove biases that can be inherent in a single experiment. The "embodiment" literature is quite large in the domain of concrete language processing and increasing generalisability of findings is an essential next step in this kind of research.

## 3. Review of evidence on processing of language describing abstract concepts

There is little question that sensory-motor simulations play important roles in the process of concrete language comprehension. However, an increasing number of researchers begins to challenge the adequacy of embodiment theory by asking how humans understand abstract concepts that by definition have no physical referents and are not easily imageable (e.g., Dove, 2009; Mahon & Caramazza, 2008; Pezzulo & Castelfranchi, 2007). Indeed, the number of studies addressing the role of embodiment in concrete language processing outweighs the number of studies addressing the role of embodiment in abstract language processing. On balance, it is also fair to say that the supporters of embodied account of cognition have already provided enough empirical support suggesting that sensory-motor simulations are at least somewhat involved in processing of abstract language as well as identified theoretical approaches that explain how abstract language is grounded (see Pecher, Boot, & Van Dantzig, 2011, for a review). Acknowledging the importance of this topic, we review how several recent papers tackle the problem of abstraction with respect to processing of emotion, time, quantity, transfer, and metaphorical action.

### *3.1. Emotion*

An increasing amount of research has been conducted to test whether reenactment of congruent or incongruent emotional state affects language comprehension. For example, Havas, Glenberg, and Rinck (2007) asked participants to read sentences describing emotional or non-emotional events while being in a matching or mismatching emotional state. The major result was that sentences describing pleasant events were processed faster when participants were smiling ("pen in the teeth" condition). Conversely, unpleasant sentences were processed faster when participants were prevented from smile ("pen in the lips" condition). Horchak, Giger, and Pochwatko (in press-a) extended this finding by showing that a matching positive emotional state also affects language processing at a more global discourse level. Using a differnt procedure, Havas, Glenberg, Gutowski, Lucarelli, and Davidson (2010) provided further evidence in support of emotion simulation. The participants were injected a botulinum toxin-A (BTX) to temporarily paralyze a facial muscle responsible for frowning. Later, they were instructed to read sad and angry sentences. The researchers found that reading of sad and angry sentences was slowed after Botox injections, suggesting that being prevented from frown makes it more difficult to simulate sadness and anger. Finally, Foroni and Semin (2009), using EMG measurement of the zygomatic major and cirrugator supercilii muscle regions, found that motor resonance was induced when participants processed adjectives describing emotion (e.g., happy, sad), but to a lesser extent than when participants processed action emotional verbs (e.g., to smile, to frown). Thus, it can be concluded that the effect of sensory-motor simulation is stronger for concrete emotional words than for abstract emotional words. Put together, the results of all these studies are in harmony with embodiment theory as they suggest that sentence comprehension is facilitated when the suggested mood of the sentence is congruent with the concurrent mood of the comprehender.

Another line of research in the domain of emotion has investigated the effects of emotion simulation on preparation for situated action. For example, Mouilso, Glenberg,

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Havas, and Lindeman (2007) instructed participants to read emotional (sad and angry), neutral, and nonsense sentences. The participants' task consisted in making speeded judgments by pushing the lever either towards or away from the body for emotional sentences, and by pressing a button on top of the lever with the thumb for neutral or nonsense sentences. Among other findings, the researchers found that aggressive responses (i.e., required pushing the lever away from the body) were faster following sentences describing anger, and affiliative responses (i.e., required pulling the lever toward the body) were faster following sentences describing sadness. Lugli, Baroni, Gianelli, Borghi, and Nicoletti (2012) reported a different approach-avoidance effect. They asked participants to judge the sensibility of positively and negatively-valenced sentences describing toward transfer (e.g., "The object is nice. Bring it toward you") and away transfer (e.g., "The object is ugly. Give it to another person") while responding with a mouse in the direction that either matched or mismatched the direction described by the sentence. The researchers found that responding to sentences describing positive objects was faster with a "toward the body" hand motion. Similarly, responses to sentences describing negative objects were faster with an "away from the body" hand motion.

### 3.2. Time

The idea that time can be understood through front-back spatial representation (i.e., future is front; past is back) was extensively discussed in the literature (e.g., Boroditsky, 2000; Boroditsky & Ramscar, 2002; Gentner, Imai, & Boroditsky, 2002; Lakoff & Johnson, 1980; Matlock, Holmes, Srinivasan, & Ramscar, 2011; Núñez, Motz, & Teuscher, 2006; Torralbo, Santiago, & Lupiáñez, 2006). In recent years, however, several studies presented a few additional novel findings that warrant discussion. For instance, Sell and Kaschak (2011) investigated whether time shifts are represented spatially in comprehension of texts describing past and future events. The participants read short texts sentence-by-sentence and after reading each sentence made sensibility judgments by either moving their hand from the start button to the response button (Experiment 1) or pressing the start and response buttons without moving the hand (Experiment 2). The major results were as follows. First, responses for sentences describing future events were faster when participants responded away from their body. Conversely, responses for sentences describing past events were faster when participants responded toward their body. Second, a spatial compatibility effect occurred only when participants moved their hand to produce a response (Experiment 1). Third, a spatial compatibility effect occurred only when the texts described a large time shift (a month), but not a small time shift (a day). As another example of how time can be understood through spatial representation, Santiago et al. (2007) presented participants with words located either to the left or to the right from the fixation point and then asked to judge if words referred to past or future events. The major finding was that participants were faster in their responses when words referring to the past or future events were presented on the left side or the right side of the screen, respectively. Finally, Lakens, Semin, and Garrido (2011) extended Santiago et al.'s (2007) findings by asking participants to indicate if words presented over headphones were louder on the left or right channel (note that words were presented equally loud binaurally). Consistent with the prediction, participants judged past words to be louder on the left channel and future words on the right channel. Thus, researchers concluded that both auditory and visual (as in Santiago et al., 2007) judgments show a similar spatial bias. In brief, these findings suggest that the abstract concept of time is understood by way of analogy to representation of embodied experiences of space either along the front-back or left–right axis.

### 3.3. Quantity

There is mounting evidence that the concept of quantity can also be grounded in spatial representations. For instance, Dehaene, Bossini, and Giraux (1993) asked participants to indicate whether numbers presented on a monitor were odd or even with a left or right hand. Researchers found that participants were faster to respond to odd or even low digits (e.g., 1 or 2) when responding with a left button press, and faster to respond to odd or even high digits (e.g., 8 or 9) when responding with a right button press. This effect was coined the Spatial Numerical Association of Response Codes (SNARC). Dehaene et al. (1993) interpreted their finding as evidence that the concept of quantity is understood as a mental number line along the left–right axis. SNARC effect was also observed for phoneme detection of digits' names (Fias, Brysbaert, Geypens, & d'Ydewalle, 1996), digit magnitude classification (Bächtold, Baumüller, & Brugger, 1998), and even for ordinal stimuli such as days of the week, and months of the year (Gevers, Reynvoet, & Fias, 2003, 2004). In a most recent study, Sell and Kaschak (2012) advanced our understanding of this effect in two important ways. First, they investigated the usefulness of spatial representations in the comprehension of the concept of quantity at a more global text level. Second, whereas previous work provided evidence that the concept of quantity is represented along the left–right axis, their research explored whether quantity is understood along the metaphor-based up-down axis (i.e., more is up, less is down). To assess these questions, the researchers asked participants to read (Experiment 1) or listen to (Experiment 2) short stories sentence-by-sentence (e.g., "Much/Less runs were being scored this game"). Participants indicated that they finished reading (listening to) the sentence by either releasing their hand from the button used to display the sentence and moving it to the response button aligned on the up-down or the right-left axis, or pressing the button used to display the sentence and positioning the other hand over the response button to terminate reading the sentence. The major finding was that reading times for sentences describing increases in quantity were faster when the response was made away from the body. Conversely, reading times for sentences describing decreases in quantity were faster when the response was made toward the body. Furthermore, responding was significant both when a participant moved and did not move to respond. No compatibility effects were observed along non-metaphor-based left–right axis. Thus, this finding is consistent with the embodied account of cognition which predicts action-space (e.g., Boroditsky & Ramscar, 2002) and action-sentence compatibility effects (Glenberg & Kaschak, 2002), suggesting that language processing is grounded in bodily mechanisms of perception and action. For a similar recent study using Chinese sentence stimuli, see Guan, Meng, Yao, and Glenberg (in press).

### 3.4. Transfer

In Subsection 2.2.1 we reviewed evidence provided by Glenberg and Kaschak (2002) indicating that comprehension of sentences describing transfer of objects influenced the motor event that followed. In the same study, as well as a more recent study of Glenberg, Sato, Cattaneo, Riggio, Palumbo, and Buccino (2008), it was demonstrated that the ACE effect also occurs during comprehension of sentences describing abstract transfer. More concretely, Glenberg et al. (2008) asked participants to read abstract sentences describing abstract toward (e.g., “Anna delegates the responsibilities to you”) and away transfer (e.g., e.g., “You delegate the responsibilities to Anna”) and judge the sensibility of sentences by responding in the direction that either matched or mismatched the direction implied by the sentence. The major finding was that judgments were faster when response direction and sentence direction matched rather than mismatched. Thus, it can be concluded that comprehension of sentences describing abstract transfer events requires the resources of simulation system to the same extent as comprehension of sentences describing transfer of objects.

### 3.5. Metaphorical action

A few studies demonstrated that compatibility between literal body action and metaphorical action improves language processing. For example, in one line of research Santana and de Vega (2011) investigated whether processing of sentences describing metaphorical actions modulates action systems. Participants read metaphors (e.g., “His talent for politics made him rise to victory”) and abstract sentences similar in meaning to the metaphors (e.g., “His working capability made him succeed as a professional”), and then performed a hand motion (while reading the sentence verb) that either matched or mismatched the direction connoted by the sentence. The results revealed that responding was faster when there was a match between the direction of literal movement and that implied by the sentence. In a different line of research, Wilson and Gibbs (2007) tested whether previous real and imagined body movement enhances comprehension of metaphorical phrases. Participants learned to make different body movements or imagined making a particular body movement and then were presented with metaphorical phrases (e.g., grasp a concept) that either matched or mismatched a previous body movement (e.g., grasping movement). The researchers found that phrase reading times were faster when the previous literal or imagined body movement was congruent with the action implied by the sentence. In another experiment, Gibbs, Gould, and Andric (2006) revealed that even watching someone make a congruent body movement induced comprehension of metaphorical phrases (e.g., watching someone make a stretching motion while processing the phrase “stretch for understanding”). For similar findings see Gibbs (2006, 2013), Gibbs and Perlman (2010),

### 3.6. Summary

In the light of the studies reviewed above, it can be argued that the proponents of embodied view of cognition have partially tackled the problem of abstraction. The researchers approach the abstractness problem in the following ways. The first approach is based on conceptual metaphor theory (Lakoff, 1987; Lakoff & Johnson, 1980). The basic idea is that abstract concepts are understood metaphorically through reference to a more concrete embodied experience. Here, we have provided evidence how metaphorical use of space is used to represent such concepts as time and quantity. It is also worth noting that many other equally fruitful contributions (which were not discussed due to space limitations) demonstrated how social relations may be understood in terms of temperature (Ijzerman & Semin, 2009; Williams & Bargh, 2008), social status in terms of a vertical spatial axis (Schubert, 2005), morality in terms of cleanliness (Schnall, Benton, & Harvey, 2008), importance in terms of weight (Jostmann, Lakens, & Schubert, 2009), distance in terms of similarity (Boot & Pecher, 2010), categories in terms of containers (Boot & Pecher, 2011), and political attitudes in terms of a horizontal spatial axis (Farias, Garrido, & Semin, 2013; Oppenheimer & Trail, 2010). In brief, the case of conceptual metaphor theory in explaining abstract concepts is strong. The second well-established approach focuses on the importance of motor processes in comprehension. The primary evidence for this approach is the ACE effect first reported by Glenberg and Kaschak (2002). Here, we reviewed evidence how transfer events, metaphorical actions, and emotions (see Glenberg, Webster, Mouilso, Havas, & Lindeman, 2009, for a detailed discussion on how emotion prepares the body for appropriate actions) can be understood through action schemas. The third approach (not reviewed here due to paucity of behavioral evidence), which has received little scientific attention compared to the other two approaches, suggests that people come to represent and reason about abstract concepts with the help of aspects of experience, including objects, agents, settings, and introspections, in which such concepts are grounded. As an illustration for this claim, Barsalou and Wiemer-Hastings (2005) in a feature generation experiment found that participants tended to associate abstract concepts with social aspects of experience and concrete aspects with physical entities, suggesting that comprehension of abstract concepts relies at least partially on situated simulations. For a discussion of recent evidence from neuroscience supporting this approach see Wilson-Mendenhall, Barrett, Simmons, and Barsalou (2011) and Wilson-Mendenhall, Simmons, Martin, and Barsalou (in press).

## 4. Embodied theories of language comprehension

In the previous section a large body of empirical findings was reviewed suggesting that embodiment representations get activated when individuals process the language describing concrete and abstract concepts. At the same time, many researchers have argued that a purely embodied approach to comprehension is not very promising, given that it overlooks alternative explanations complementary to mental simulation (e.g., Louwerse, 2007, 2011) and provides only a partial solution to the problem of abstraction (e.g., Dove, 2011). As a result of these criticisms, the researchers such as Andrews, Vigliocco, and Vinson (2009), Barsalou, Santos, Simmons, and Wilson (2008), Dove (2011), and Louwerse (2007) put forward the theories suggesting that language processing arises both from sensory-motor grounding and relations between symbols. To assess the commonalities and differences between the various theories that have been proposed, we selectively review a variety of old and new theoretical approaches that support either a strong embodied or a moderate embodied view. Additionally, we will briefly discuss empirical evidence that supports the claims of each theory.

### *4.1. Theories that support a strong embodied view*

Embodied theories supporting a strong embodied view argue that human cognition is completely grounded in sensory-motor systems. To our knowledge, four strong embodied theories currently drive discussions and debates in the field (listed in ascending order of the year published): Perceptual Symbol Theory of Barsalou (1999); Indexical Hypothesis of Glenberg and Robertson (1999, 2000); Immersed Experiencer Framework of Zwaan (2004), and Action-based theory (ABL) of Glenberg and Gallese (2012).

#### *4.1.1. Perceptual symbol systems (PSS) of Barsalou (1999a)*

According to this theory, cognitive processes responsible for language comprehension use partial reactivations of sensory, motor, and affective systems to form meaningful mental representations. More broadly, during original experience of event, modality-specific areas of the brain capture patterns of activation from sensory-motor and introspective systems. Later, while thinking or remembering about the event, these modality-specific areas partially reactivate original perceptual representations (Barsalou, Simmons, Barbey, & Wilson, 2003). Under this account, understanding a sentence such as “She strokes a cat with a wide smile on her face” will require the retrieval of perceptual information to simulate entities described in the sentence (i.e., cat), the retrieval of motoric information to simulate the “stroking” action, and the retrieval of emotional “happy” state.

This theory suggests that knowledge about the world is not developed in a holistic way. Instead, it develops categorically when attentional system focuses on components of experience in the context of possible interactions with the world. The continuous experience with the world, in turn, leads to gradual integration of perceptual symbols into a distributed multi-modal system that represents the category as a whole – a simulator (see Barsalou, 2009, for further discussion). This way we develop various kinds of perceptual simulators (visual, motor, emotional, etc.) that later get integrated with simulators for the words they refer to. With such an approach to knowledge representation it is fairly easy, for example, to distinguish between an orientation of a book on a shelf and an orientation of a book on a table, and to discriminate between a sound of a voice in a cave and a sound of a voice in a living room during language comprehension. In brief, the possibility for interaction between language, body, and environment allows humans to make inferences about information that is not explicitly contained in language.

This theory has been corroborated by numerous experimental demonstrations. Here, we provide just a smattering of evidence adduced to support this theory. For example, Wu and Barsalou (2009) showed that participants reported higher accessibility to such internal properties as “seeds” or “red” while being asked to list characteristics of “half watermelon” than “watermelon”, suggesting that participants constructed perceptual simulations to generate properties of nouns and noun phrases. The importance of environment in constructing perceptual simulation was reported by Borghi, Glenberg, and Kaschak (2004). More concretely, the researchers found that participants were faster to attribute an object (denoted by a noun) to a certain location when the noun that referred to an object was available in the participant’s perspective implied by a preceding sentence. That is, participants were faster to verify a noun “sign” when it was preceded by a sentence “You are waiting outside a restaurant” than a sentence “You are eating in a restaurant”. Clearly, this finding suggests that cognition is situated and that people not only simulate the physical entities described in the sentence, but as well the environment around them. In another study, Pecher et al. (2003) showed that conceptual system is not amodal by asking participants to verify different-modality properties. More concretely, participants were first instructed to verify a property in one of six modalities such as vision, audition, taste, smell, touch, and action (e.g., property "cool" for "marble" from touch modality). Second, everyone verified a property from a different concept that belonged to either the same or different modality (e.g., "sticky" for "peanut butter" vs. "squeaking" for "bed springs"). The task consisted in judging if the concept-property item was true of false. The results revealed that participants verified the second property presented on the screen faster if it followed the first property from the same modality. Finally, the evidence on perceptual simulation reviewed in Section 2 of this article is also consistent with the PSS Theory.

#### 4.1.2. Indexical Hypothesis

Indexical Hypothesis (IH) of Glenberg and Robertson (1999, 2000) is another theory of language processing that further develops Barsalou's (1999a) model by specifying those components of perceptual symbols that are related to action, and, in particular, to function of action in comprehension of language. It was largely inspired by Glenberg's (1997) claim that a situation becomes meaningful depending on the set of actions available to a particular individual in a particular situation. For example, consider the sentence, "John sweeps the floor with a toothbrush." According to IH, first words and phrases in the sentence are indexed to analog objects, pictures, or perceptual symbols (Barsalou, 1999a) in the physical world. Second, possible combinations of interactions (affordances) with the objects are established. Because of affordances, we know that our sentence is sensible, given that it is physically possible to sweep the floor with a toothbrush even if this situation suggests that someone's day went very wrong. Third, language comprehension is coordinated by syntax that provides the reader with syntactic cues as to whether the objects and activities implied by the sentence can be successfully meshed.

Action-based specifications on language processing are all the more noteworthy as they demonstrate that one of the main functions of comprehension is preparing for situated action. For example, imagine the following situation. You cannot swim and you are in the boat that is sinking. You can see a shore ahead and understand that the boat will sink unless you bail out. So you begin to bail out the water furiously with your hands, but it does not help. You look around and suddenly an idea comes into your mind. You take off your boot and start bailing out the water with that. You notice as the edge of the boat raises about 15 inches above the water and you realize that you are saved. Point is: you saved your life with an object that is not used by others to bail out water in everyday life. This situation describes just what situatedness is all about – cognition coordinates effective action in the context of current background situations (Barsalou, 1999b; Glenberg, 1997).

#### 4.1.3. Immersed experienced framework

Immersed experienced framework (IEF) of Zwaan (2004) is another theory of language processing the basic premise of which is that language is a set of cues people use to construct sensory-motor simulation of the situation. Under this account, language understanding is similar to dynamic immersion of the comprehender into the described situation by means of activating experiential representation of language symbols (lexical, grammatical, etc.) and associated experiential representations that refer to these symbols (perceptual, motor, emotional). This theory assumes that there are three major processes of language comprehension: activation, construal, and integration. During activation, target words activate functional webs that are used during the original experience with the referent. By functional web is meant various experiences with referents in different visuospatial configurations such as orientation, shape, etc. (e.g., a bird in the sky with its wings outstretched and a bird in the nest with its wings drawn in). During construal functional webs are integrated in simulation of the event implied by language. Finally, integration refers to experientially-based transitions from one construal to another. These transitions can be, for instance, visual (e.g., scanning of the environment) in visual scenes or emotional (e.g., anger towards the protagonist) in static or dynamic scenes. Among the factors that influence successful integration are concordance with human experience, amount of overlap (refers to how much of current mental simulation has the same components of construal as the previous simulation), predictability (anticipation of next event), and linguistic cues (tense, word order, etc.). In sum, comprehension in Immersed Experienced Framework is based on the following three principles: (a) simulation of visuospatial characteristics of the objects implied by language; (b) integration of this simulation in the context of a specific event; and (c) meshing of different simulations based on personal experience, learning history, combinability, predictability, and grammatical markers. The evidence for this theory was extensively reviewed in Section 2 of this article regarding simulation of orientation, shape, visibility, and linguistic focus.

#### 4.1.4. Action-based language

Action-based language (ABL) of Glenberg and Gallese (2012) is a model of language processing that offers a new action-based account of language comprehension by making use of neurophysiologic findings on mirror (Mukamel, Ekstrom, Kaplan, Iacoboni, & Fried, 2010) and canonical (Rizzolatti & Luppino, 2001) neurons, and by adopting controller and predictor models from theories of motor control responsible for computing goal-oriented motor commands and predicting sensory-motor effects of these commands (Grush, 2004; Wolpert, Doya, & Kawato, 2003). According to this theory, language comprehension is tantamount to predicting sensorimotor and affective effects of the performed action. For example, upon hearing the word "walk", a person's speech mirror neurons activate an associated action controller responsible for generating motor commands necessary for interaction. Later, the predictor (sensory, motor, or emotional) of the target word establishes possible consequences of the action to be performed. In other words, under this account the same hierarchical mechanisms that are utilized in controlling action (i.e., control and predictor) are then used for generating grammatical sequences in language processing. Importantly, Glenberg and Gallese (2012) make two explicit assumptions about their model. First, it is suggested that the model is not only limited to explanation of verbal instructions, but instead covers all parts of speech. Second, it is stressed that motor system, though the most important contributor, acts in a well-coordinated manner with other bodily systems (e.g., perceptual system).

Given that ABL theory is a new theoretical account, empirical evidence in support of it is admittedly quite thin. However, the available evidence that at least partially supports the claims of Glenberg and Gallese's theory (2012) led us to conclude that this approach is promising. Consider, for instance, the work of Masson, Bub, and Newton-Taylor (2008a). The researchers hypothesized that comprehension of sentences like "John looked at a calculator" or "John forgot the calculator" would evoke the physical forces required to use the described object. In line with the prediction, functional actions (referring to a situation when an object is used for its intended purpose) were primed when participants were processing these sentences. What makes this finding stand out is that motor resonance occurred during comprehension of sentences describing concepts that have no action associations. To our knowledge, ABL is the only embodied theory that explicitly acknowledged the role of action in comprehension of language that does not describe any form of physical interaction.

#### *4.1.5. Summary*

Contrary to amodal view that often places human cognition on the same footing as computer intelligence (Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005), outlined embodied theories of language comprehension suggest that the environment, situations, the body, and simulations in the brain's modality-specific systems ground core cognitive representations. The major claim that stays at the heart of these theories is that language comprehension cannot be a product of redescription or translation of amodal symbols. Apparently, strong embodied theories are mutually reinforcing accounts of language processing. For example, Perceptual Symbol System of Barsalou (1999a) shows similarities with Indexical Hypothesis of Glenberg and Robertson (1999, 2000) in that both accounts suggest that language comprehension operates on perceptual simulators. While Barsalou (1999) explains why perceptual simulators stay in the core of human conceptual system, Glenberg and Robertson (1999, 2000) replace the discussion by looking into action-based mechanisms that ensure proper operation of such perceptual simulators. Similarly, Zwaan's (2004) Immersed Experienced Framework has much in common with Indexical Hypothesis, given that both models view comprehension in an incremental fashion. For instance, while Glenberg and Robertson (1999, 2000) suggest that sentences are understood through indexing, deriving affordances, and meshing, Zwaan (2004) proposes that sentence comprehension is achieved by activation, construal, and integration. The question could therefore be raised whether indexing is similar to activation, deriving affordances – to construal, and meshing – to integration. Though this question remains unanswered for now, it is noteworthy that the basic processes behind these three steps have a lot in common in both theories. Finally, Glenberg and Gallese's (2012) Action-based Language (ABL) model on the face of it seems to have little in common with other embodied models. At the same time, though providing an original and intriguing perspective, the basic idea behind this theory is in fact quite similar to common assertions of other theories – knowledge is simulated in the context of relevant actions.

### *4.2. Theories that support a moderate embodied view*

An increasing number of researchers have proposed that language processing arises both from sensory-motor simulations and interdependencies between the words. Here, we review Language and Situated Simulation Theory of Barsalou et al. (2008) and Symbols Interdependency System of Louwerse (2007) that support such a view.

#### *4.2.1. Language and situated simulation*

Language and situated simulation (LASS) theory of Barsalou et al. (2008) suggests that multiple systems are involved in language processing: symbolic systems, simulation systems, and statistical representations that are involved in the processing of both language and simulation. In their work, the authors offer an account of language processing postulating that simulation system represents deeper conceptual processing comparing to the linguistic system. In particular, it is proposed that at the onset of language comprehension both systems (linguistic and simulation) get activated, but the linguistic system peaks first. At this stage, words are being recognized and associated linguistic forms are produced (e.g., "tree" is associated with "trunk", "branches", etc), which allows an individual to support shallow processing of information. Next, the word's representation activates simulations in the modality-specific systems, which allows an individual to represent the word in different situations, and thus engage in a deeper conceptual processing, compared to the purely linguistic processing. Therefore, when simulation is more dominant in reading comprehension tasks, people process the text deeply and form a wide number of inferences. On the contrary, when linguistic processing dominates, comprehenders appear to form shallow meaningful representations and tend to extensively rely on information explicitly given in the text. Finally, one of the most important assumptions of LASS theory is that linguistic system does not have enough power to implement symbolic operations without an involvement of simulation system because it (linguistic system) manipulates linguistic forms rather than linguistic meanings.

The claims of LASS theory were tested in the recent studies of Santos, Chaigneau, Simmons, and Barsalou (2011) and Simmons, Hamann, Harenski, Hu, and Barsalou (2008), which confirmed the prediction that comprehension originates in two systems – linguistic and simulation. For instance, in a study of Santos et al. (2011) participants were asked to generate properties for cue words that belonged to different conceptual domains. The major finding was that properties describing highly associated concepts (e.g., a tree, a trunk, etc.) were produced earlier, compared to other less associated properties describing situations and objects. This pattern of results suggests that the linguistic system peaked first and activated the associated linguistic forms. Then, the simulation system came into play and its activation was more slowly than the activation of the linguistic forms. Notably, these results are fully consistent with the predictions of LASS theory.

#### 4.2.2. Symbol interdependency system

Symbol interdependency system of Louwerse (2007) is a quite similar account of language comprehension to Barsalou et al.'s (2008) LASS theory in that it also addresses to what extent language comprehension is symbolic and embodied. Under this integrative account, language developed as a communicative short-cut for people to exchange knowledge (Louwerse, 2011). With this in mind, this theory suggests that in everyday language comprehension not all language symbols have to be grounded as much of the meaning comes from the relations between linguistic symbols. However, in some cases grounding is necessary to derive meaning. This is particularly the case when people have to process the information about spatial orientation or visual rotation that cues deep cognitive processing (see Louwerse & Jeuniaux, 2008, 2010, for discussion).

The claims of this theory were tested in a study of Louwerse (2008) as well as others (e.g., Louwerse & Jeaniaux, 2010; Louwerse & Connell, 2011). For instance, Louwerse (2008), using a computational disembodied machine like LSA, replicated Zwaan and Yaxley's (2003) findings regarding perceptual simulation in comprehension of spatial position and argued that perceptual relations are already encoded in language and are used by the comprehenders to derive meaningful representations. More broadly, using statistical linguistic frequencies obtained from the Web 1T 5-gram corpus (Brants & Franz, 2006), consisting of 1 trillion words (13,588,391 types) from 95,119,665,584 sentences, the author demonstrated that the frequency of higher objects preceding lower objects was significantly higher than lower objects preceding higher objects. Louwerse (2008) concluded that these results are not surprising, given that individuals typically do not say "down and up" or "toe and head", but rather use these phrases in reverse word order, pointing to the conclusion that the frequency of word order is an important factor in language comprehension that cannot be dismissed. Additionally, in the second experiment of the same study, participants were asked to rate the likelihood that one concept appeared above the other (ratings were made on a scale of 1–6, with 1 being extremely unlikely and 6 being extremely likely) and it was revealed that average participants' ratings correlated significantly with the word pair frequencies from the first experiment. Thus, Louwerse (2008) concluded that the comprehenders also use the interrelations between symbols to process language.

#### 4.2.3. Summary

In sum, moderate embodied theories are quite alike in that they propose that language comprehension is both symbolic and embodied. Both Language and Situated Simulation Theory (LASS) of Barsalou et al. (2008) and Symbol Interdependency System of Louwerse (2007) suggest that linguistic system dominates in the tasks that do not require deep processing of information (shallow comprehension) and simulation system dominates in the tasks where linguistic system is not capable of deriving meaning alone (deep comprehension). At the same time, whereas LASS theory assumes that symbolic mechanisms always utilize resources of simulation system to derive meaning (Santos et al., 2011), Symbol Interdependency hypothesis proposes that symbolic system alone can successfully cope with most of general comprehension tasks.

## 5. General discussion

We started this article by reviewing how an embodied theory of cognition accounts for comprehension of language describing concrete and abstract concepts. As our review of the literature has shown, there is now a wealth of evidence suggesting that sensory-motor grounding is necessary for language comprehension. We then discussed a variety of old and new theoretical accounts that support either a strong or a moderate embodied view and concluded that there is no common agreement among scientists as to whether one or multiple systems (i.e., symbolic, embodied, etc.) represent knowledge and whether these multiple systems can function separately from each other in language comprehension tasks. In the light of the studies and theories reviewed above, it is fair to say that there exists a risk of overestimating the role of embodied factor in language understanding. Acknowledging this issue, we now turn to the possible trajectory of "embodiment" research across four areas, the role of symbolic factor in language processing, the role of simulation in abstract language processing, specificity of simulation mechanisms, and the level of language processing. We believe that without making considerable progress on these questions, it might be premature to address the question what models (approaches) are more promising.

### 5.1. The role of symbolic factor in language processing

Although the debate on linguistic and embodied representations is not the central point in this review, together with Dove (2011), Lakens (2011), Louwerse (2007), and Lynott and Connell (2010) we acknowledge the importance to consider explanations that go beyond a strong embodied view, considering the growing evidence that language processing uses linguistic distributional information. For example, Louwerse and Connell (2011) and Louwerse and Jeaniaux (2008, 2010) demonstrated that information from language alone is capable of bootstrapping the meaning of the message via statistical linguistic frequencies and that the prevalence of embodied over symbolic factor depends on task conditions and the stimuli. A recent study found further evidence that people use distributional information during conceptual processing. Connell and Lynott (2013) carried out two experiments in which participants engaged in two conceptual combination tasks: shallow sensibility judgment and deep interpretation generation tasks. Among other important findings, the researchers found that the more often novel word combinations (e.g., elephant complaint) were juxtaposed, the faster the participants judged two-word phrases as sensible, suggesting that linguistic information alone contributes to comprehension of novel information. Furthermore, the researchers showed that the less often word combinations were juxtaposed, the faster the people were to indicate that the two-word phrases were uninterpretable, suggesting that linguistic information alone affects not only shallow, but also deep conceptual processing. However, these and similar findings should be interpreted cautiously as there seems to be a disagreement in the research community as to what co-occurrence vectors represent. For example, Pecher et al. (2011) argued that the corpora used in computational models such as, for instance, latent semantic analysis (LSA) are based on texts produced by people (see Burgess & Lund, 1997; Landauer & Dumais, 1997; Landauer, Foltz, & Laham, 1998; Lund, Burgess, & Atchley, 1995, for experiments LSA model was used), and thus they only represent how people think and produce language rather than demonstrate that mental representations are either modal or amodal. The point of Pecher et al. (2011) seems well taken, but it is fair to mention that the casual role of linguistic processing alone in language comprehension has been confirmed not only by studies using corpora, but as well by studies using property generation tasks (e.g., Santos et al., 2011). Therefore, we conclude that the current state of the literature favors a moderate embodied approach, suggesting that the role of linguistic factor should not, at the very least, be underplayed.

However, a problem that does not allow declaring a full victory for this approach is incompatibility with some other findings. For instance, Connell and Lynott (2013) and Santos et al. (2011) explicitly stated in their papers that their findings support moderate embodied theories which suggest that linguistic system alone can cope with most of the shallow comprehension tasks before deeper conceptual processing is engaged. However, one cannot but notice an apparent disconnect between these findings and the previous neuroscientific research that showed that motor system is activated very soon after a stimulus is presented, suggesting that the activation of linguistic associations does not occur before the activation of embodied representations (e.g., Pulvermüller, 2008). While there may be various reasons for such divergent findings (e.g., different stimuli, task conditions, different levels of processing, etc.), we believe that the differences in results and conclusions could be worthy of further investigation.

Another problem with a moderate account of language processing is that there seems to be no agreement among the proponents of this view as to how much symbolic language comprehension actually is. For example, Louwerse (2011) made it very clear in his article that Symbol Interdependency hypothesis (Louwerse, 2007) is quite different from LASS theory (Barsalou et al., 2008) because it does not consider embodiment to be most relevant for cognition. This discrepancy between the two views makes room for the discussion about which lines of research might distinguish between two models. In our opinion, since the major difference between the two views lies in whether a deeper simulation system follows a more shallow linguistic processing, the researchers should work to clearly delineate the characteristics of shallow and deep comprehension, and perhaps most importantly, consider studying the roles of both symbolic and embodied factors for comprehension in context (see Schuil, Smits, & Zwaan, 2013, for a recent neuroscientific evidence on how context may constrain the interpretation of the message). Furthermore, although the idea that many shallow language comprehension tasks do not require the involvement of a deeper simulation system (Louwerse & Jeuniaux, 2008) is an intriguing and compelling alternative, the discussion, in our opinion, should be replaced by the question how much information we process in a shallow fashion in our everyday life. The defeasible position of this paper is that most of our communication is driven by context (e,g, via dialogues, phone conversations, etc.), and thus it is reasonable to assume that deep comprehension is, at the very least, as common among humans as shallow comprehension. After all, unlike in the laboratory conditions, we do not usually interact with each other using only short language segments such as words, phrases or sentences.

### 5.2. The role of simulation in abstract language processing

A few researchers have suggested that the three well-known embodied approaches to understanding of abstract concepts (i.e., metaphoric extension, action schemas, and situated simulations) do not hold much promise as they tend to treat the problem of abstraction as a collection of exceptions (e.g., Andrews et al., 2009; Dove, 2011). Certainly, there is not enough empirical evidence to conclude that these approaches provide a full solution to the problem of abstraction, but the fact that this evidence has not been provided yet does not suggest that the claims of embodied theory are wrong. Therefore, the defeasible position of the authors of this paper is that sensory-motor grounding affects abstract language processing to the same extent as concrete language processing, and the absence of enough evidence is explained by the fact that abstract concepts have more diffusive representations than concrete ones, and thus are more difficult to investigate. For example, the representation of "love" may involve such visual and motor representations as "a boyfriend kissing his girlfriend" (romantic love), "a child hugging his mother" (love of parent for a child), and even "a soldier starting a fight with a flag in his hand" (the love of a citizen for his country). Thus, to measure the degree of sensory-motor simulation during a comprehension of an individual abstract word appears to be rather difficult due to different mental representations for different people.

A satisfying solution to the problem of diffusive mental representations during abstract language processing could be studying the meaning of abstract concepts in contexts using sentence or, preferably, text stimuli to restrict the number of different interpretations. That is why, we believe that the proposal of Barsalou and Wiemer-Hastings (2005) regarding the understanding of abstract concepts in the context of concrete situations is promising and should be investigated deeper. There is little question that the semantic content underlying the meaning of abstract concepts integrates perceivable entities. However, what presents a challenge to embodied theories is to demonstrate that comprehension of any given abstract concept evokes a set of sensory-motor experiences. An important step in this direction was made by Wilson-Mendenhall et al. (in press) who demonstrated that brain regions responsible for social cognition and mentalizing got activated when the comprehenders processed the meaning of the abstract concept "convince", whereas brain regions responsible for numerical cognition got activated when the comprehenders processed the meaning of the abstract concept "arithmetic". Pertinent evidence to demonstrate that embodied representations play a role in comprehension of abstract concepts may be obtained from a behavioral experiment similar to that of Wilson and Gibbs (2007) in which participants were asked to make different body movements and then read metaphorical phrases that either matched or mismatched a previous body action. The rationale for such an experiment is as follows: if the meaning of an abstract concept originates in the context of situated activity, including, for example, actions, then preparing the body for an appropriate action that constitutes a part of the semantic content underlying a given abstract concept should facilitate people's comprehension of this concept. That is, participants should be faster to indicate that a sentence "John and Mary are in love" is meaningful when they have previously performed an "embrace" action rather than, for instance, "carry" action.

Finally, we think that the researchers should also work to further emphasize the distinction between concrete and abstract concepts in order to demonstrate that language processing is not only determined by bodily states, but also by physical and social environments. An important step in that direction, in our opinion, was made by Borghi and Cimatti (2009) who argued in support of multiple representations with regard to comprehension of concrete and abstract concepts. More broadly, the researchers developed the Words as Social Tools (WAT) account a core tenet of which is that there are two different sources of grounding in comprehension of concepts: sensory-motor experience and linguistic experience. The acquisition of concrete concepts depends mainly on sensory-motor experience as the semantic representations of concrete concepts are usually quite consistent across people. The acquisition of abstract concepts mainly depends on context-specific social linguistic experiences as the semantic representations of abstract concepts are usually rather variable. Put different, given that abstract words do not have specific referents in the environment, their grounding mainly proceeds linguistically in the context of more concrete situations. Scorolli et al. (2011) provided empirical evidence in support of WAT account by instructing participants to read sentences that included compatible (concrete verb with a concrete noun or abstract verb with an abstract noun) and mixed (concrete verb with an abstract noun or abstract verb with an abstract noun) verb-noun combinations. They found that compatible combinations were processed faster than mixed ones, suggesting that multiple representations underlie the processing of concrete and abstract concepts.

### 5.3. Specificity of simulation mechanisms

Our review of the literature revealed that although most of the research efforts have been directed to demonstration of sensory-motor activation during processing of language, there is an increasing interest among researchers to investigate boundary conditions that define how much language comprehension is affected by simulation mechanisms. In particular, we found that perception may facilitate or interfere with concrete language processing depending on such factors as temporal overlap and integratability, and action-language facilitation (interference) may depend on such factors as linguistic focus, grammar, affordances, and effectors. Furthermore, Connell and Lynott (2012) suggested recently that attentional modulation (i.e., attentional demands during processing of stimuli in a specific modality) may also play a casual role in determining whether perceptual simulation facilitates or impairs concrete language processing.

In addition to testing boundary conditions with regard to concrete language processing, we believe that the time is ripe to consider boundary conditions that are consistent with embodiment of abstract concepts. Consider, for example, the sentence "We need to make a giant step to overcome this crisis" and the various ways body systems may be manipulated to enhance the metaphorical construal of this sentence (see Gibbs et al., 2006; Horchak et al., in press-b; Wilson & Gibbs, 2007, for the findings suggesting that people simulate motion in situations that are physically impossible to do). The first straightforward "embodied" manipulation could be asking participants to actually walk prior to reading the sentence. The second manipulation could be asking participants to exercise on a stationary bike prior to reading the sentence. The third manipulation could be asking participants to advance their lead leg for 30–40 cm from their follow leg while reading the sentence. Clearly, the advantage of the first two manipulations is that participants actually make a congruent body action, thus activating their action systems. The disadvantage of these manipulations is that they are separated in time with the reading of the sentence, compared to the third "lead leg" manipulation. Therefore, the question presents itself, "Can we make a reasonable inference to the best manipulation?" In our opinion, we can make such an inference and we strongly suspect that the third "lead leg" manipulation is the best because of the following reasons. First, there is now a wealth of evidence suggesting that real movement is not always necessary to enhance the metaphorical construal of the abstract phrases (e.g., Wilson & Gibbs, 2007). Second, according to PSS of Barsalou (1999), the relationship between a symbol and its referent is analogous during language processing, and therefore it is reasonable to assume that the best manipulation is determined by the degree of integratability between the physical manipulation and the simulation constructed of the sentence content. More broadly, a comprehension of the phrase "make a giant step" should lead to a creation of simulation that includes various perceptual symbols (e.g., a ground, a giant walking, a distance between a lead leg and a follow leg, forward direction. etc.). But whereas the "lead leg" manipulation would share content with the simulation of the phrase with respect to all possible perceptual symbols, the "bike" manipulation, for example, would share content with the simulation of the phrase only with respect to such perceptual symbol as direction. Nevertheless, while previous research and theories inform us about possible hypotheses and research outcomes, empirical evidence is needed to draw definite conclusions. The exploration of questions like these can be important to build stronger theoretical conclusions with regard to embodiment of abstract concepts, and therefore points the way to new research opportunities.

### *5.4. The level of language processing*

The historically prevalent symbolic model of cognition suggests that language comprehension is amodal because it functions separately from sense modalities. Under this account, comprehension arises from forming associative relations between networks of propositions, feature lists, or statistical vectors that identify objects in the world. As our review of the literature has shown, this view has been challenged by three major types of evidence: one that shows that sensory-motor grounding plays important roles in immediate or long-term sentence comprehension; a second that investigates how and when sensory-motor simulations affect sentence processing; and a third that argues that abstract language is grounded to the same extent as concrete language.

How convincing are these findings? On the positive side, the researchers consistently demonstrated the activation of embodied representations during processing of word and sentence stimuli as well as started building more specific hypothesis as to how comprehension unfolds during comprehension of short language segments. On the negative side, most of these findings, in our opinion, provide effects of shallow rather than deep comprehension, considering that participants are likely to process word or sentence stimuli in a shallow fashion when those are used out of context (see Fischer & Zwaan, 2008; Graesser, Millis, & Zwaan, 1997; Sparks & Rapp, 2010, for similar arguments). It is fair to say that a few studies reviewed in this article as well as others (e.g., see Speer, Zacks, Reynolds, & Hedden, 2005; Spivey & Geng, 2001, for findings using non-behavioral methods) have demonstrated that embodied representations are involved in discourse processing. While we agree that each of these studies has merit and strong empirical support, we suggest that more is needed to demonstrate that sensory-motor grounding is a critical component of the situation model – the highest level of text representation that is tantamount to comprehension of discourse (e.g., Rapp & Taylor, 2004; Zwaan, 2004; Zwaan & Radvansky, 1998). More precisely, it is striking that nearly all studies tested embodiment effects in discourse processing using "online" measures of comprehension (e.g., reading times, gaze durations) rather than "offline" measures of comprehension. However, such "online" measures do not take into account important "offline" mental representations that are established after reading process is completed (Graesser et al., 1997). Strong arguments about the importance of testing the overall process of comprehension that includes both online reading (e.g., word decoding, syntactic processing) and offline postreading (e.g., summarization) processes can be found in numerous research papers (e.g., Goldman & Varma, 1995; Graesser, Singer, & Trabasso, 1994; Kintsch, 1988; Trabasso & Suh, 1993; van der Broek, Young, Tzeng, & Linderholm, 1999; Zwaan & Radvansky, 1998; Zwaan & Singer, 2003). Therefore, to demonstrate that simulation system is indeed most relevant for cognition, the researchers should work to provide evidence how embodied representations affect not just "online", but as well "offline" discourse comprehension (e.g., recall of information). This can be achieved with a behavioral experiment by asking participants to read a text stressing perceptual, action, or emotional experiences while their sensory-motor or emotional systems are manipulated, and then test participants' comprehension with standardized reading assessments such as verbatim questions (Alderson, 2000) or more sensitive measures such as response times at test (e.g., indicating if the sentence presented on the computer screen is correct with regard to text's content). Depending on the theme of the text, the comprehension test could include questions testing spatial, temporal, causal, or affective knowledge.

Finally, various researchers (e.g., Rapp & Taylor, 2004; Zwaan & Radvansky, 1998) have noted that another critical component of the situation model construction and successful discourse processing is inference generation (i.e., when readers make inferences about information that goes beyond words mentioned in the text). Therefore, another question that warrants research concerns the role of simulation in more cognitively demanding tasks such as analysis, synthesis, or evaluation. The answers to this question can be obtained using a similar behavioral experiment as the one described in the previous paragraph, but using direct assessments that have been developed by researchers in the area of reading comprehension. A well-known classification of questions into textually explicit and textually implicit (Pearson & Johnson, 1978) could be adapted to develop such assessments. More concretely, the textually explicit questions would require from participants to judge if the sentence is correct with regard to text's content on the basis of information that comes directly from text. The textually implicit questions would require from participants to judge if the sentence is correct on the basis of information that is provided in the text, but is not obvious and not directly derivable from the text. In brief, if we find evidence of deeper comprehension (i.e., the role of simulations in recall of information and implicit discourse processing), this would rule out a strongly amodal-based account of language processing in which the role of sensory-motor grounding is considered peripheral.

## 6. Concluding remarks

As our review of the literature has shown, there will certainly be further debates about the importance of symbolic and embodied representations in understanding of language. In our opinion, the top priorities for future research in the domain of embodied cognition are to strengthen the case of embodiment in comprehension of abstract concepts and provide compelling evidence for the role of simulation in deeper comprehension. Another area that may help advance our knowledge on addressed topics and that has achieved a tremendous amount of research attention in recent years is computational modeling (see Lallee, Madden, Hoen, & Dominey, 2010; Pezzulo & Calvi, 2011; Pezzulo et al., 2011; Thill, Caligiore, Borghi, Ziemke, & Balsassare, 2013, for recent discussions). We believe that research of this type will help put embodied approach to language processing on firmer theoretical footing.

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