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# The embodiment of linguistic meaning

## Key findings from psychology and neuroscience

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Embodied views of language hold that linguistic meaning is derived from the interaction experience of the listener/speaker and the sensory, motor, and internal states that go along with it. This chapter reviews three kinds of evidence that support such views. (1) Linguistic descriptions draw upon processes and brain regions that support the event's actual sensory experience. (2) These perceptual event representations are treated by the cognitive apparatus just like real events, triggering the motor behaviours that would be elicited in such circumstances. (3) The representation of action content draws upon information encoded in the understander's own action control systems. Outstanding questions, problems, and implications of such an embodied view of linguistic meaning are discussed.

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Theorists across the fields of robotics, psychology, and neuroscience increasingly agree that cognition is not based on an abstract process of symbol manipulation, such as the process instantiated by computers/turing machines (e.g. Fodor 1998). Rather, cognition is assumed to be grounded in concrete knowledge about what we can do with our body and experience with our senses (e.g. Barsalou 1999, 2008; for a review, see e.g. Wilson 2002). According to this 'embodied' view of cognition, truly abstract thought is rare, if it exists at all. Rather, the perceptual and motor systems play central roles in all cognitive processes. The mind is understood as 'enactive': when interacting with the environment, the associated sensory (e.g. touch, sight, and hearing) and motor states are captured, and stored as so called 'perceptual symbols' of the event or entity (e.g. Barsalou 1999, 2003; Glenberg and Robertson 2000). When required, the 'experiential traces' (Zwaan 2004) captured by these perceptual symbols can be re-activated, creating a sensory and motor state that mirrors, in all relevant aspects, the state that goes along with the actual experience of the event or entity (e.g. Barsalou 1999, 2003; Decety and Grèzes 2006; Goldman 2006).

Thinking is understood as the mental operations performed on these perceptual symbols. It is not seen as an abstract process, but assumed to emerge out of action planning capabilities. When having to make a decision about a future course of action, people use the stored perceptual symbols to generate a mental representation or 'simulation' of the problematic situation that can be acted in, just as in a real scene, and therefore allows one to evaluate how a planned action would affect the environment, before actually carrying it out. The decoupling of mental from actual reality inherent in this process is assumed to be a fundamental building block of higher cognitive capabilities, such as reasoning, and the ability to think far ahead and make plans for events that will perhaps never occur (Grush 2004; Glenberg 1997; Dennett 1995).

A few examples might illustrate these ideas. In a task common to many intelligence tests, participants are asked to decide whether two objects seen from different perspectives are one and the same, or whether they have different shapes. There is now ample evidence from both experimental psychology and neuroscience that people solve this task by *mentally rotating* the objects and testing whether they can be brought into overlap (Wexler et al. 1998). A classic finding is that these judgments take longer if the angle between the objects is larger, consistent with the idea that an actual rotation takes longer if a wider angle has to be traversed. Moreover, this mental rotation process seems to be, at least partially, based on the same processes that allow one to rotate shapes with ones hands. It has been found, for example, that people that are faster at turning real figures also have faster mental rotation speeds, and that judgments are sped up or slowed down depending on whether participants make hand movements in the same or opposite direction as the movements required to bring the two figures into overlap (Wohlschläger and Wohlschläger 1998; Wohlschläger 2000). These findings suggest that the mental rotation of two figures shares resources with the processes that govern the actual rotation of objects, and multiple imaging studies confirm the activation of motor related brain areas during mental rotation (e.g. Vingerhoets et al. 2002).

A crucial role of sensory and motor processes has now been demonstrated for a wide variety of cognitive processes. For example, people appear to judge the steepness of a hill not only by directly extracting steepness information from the visual angle, but by mentally simulating climbing it. For example, the hill is perceived to be steeper when participants are untrained, tired, or if they are wearing a heavy backpack (for a review, see Proffitt 2008). Enactive processes also appear to form the basis of person knowledge. Simply seeing the faces of famous soccer and tennis players affects one's own use of the body parts – feet and hands – primarily used in their sports. For example, identifying the face of a famous soccer player (Wayne Rooney) impairs the participants' control of their own feet (Bach and Tipper 2006; see also Tipper and Bach 2011; Candidi et al. 2010; Sinnett et al. 2011). Conversely, the actions one carries out while watching others affects how their behaviour is perceived (Bach and Tipper 2007; Tipper and Bach 2008; for a review of similar effects, see Schütz-Bosbach and Prinz 2007). This suggests that thinking of somebody else does (a) activate the actions they usually carry out, and (b) that this action knowledge is represented in terms of how we would perform the actions ourselves. Similar findings have been reported for more abstract person concepts. Activating the concept of the elderly (by letting participants read elderly-related words such as *wrinkle* or *bingo*) makes participants behave more slowly, and thinking of highly intelligent persons (such as Albert Einstein) affects the participants' use of their own mental powers (Bargh et al. 1996; Dijksterhuis et al. 1998).

It has been proposed that such enactive processes would also underlie the representation of linguistic meaning (for reviews, see Fischer and Zwaan 2008; Pulvermüller and Fadiga 2010). In other words, linguistic meaning is assumed to not rely on abstract processes or representations, but may similarly be grounded in the understander's sensory or motor experience. In such views, understanding a sentence such as *You give the hammer to Mike* relies heavily on a process of *simulation* or *re-enactment* that reinstates the content of the sentence as if it were actually experienced. It requires the understander to establish a visual representation of a hammer, of how a hammer is typically used (and for what purpose), a visual representation of a person who could be Mike, and the movement of your hand from yourself towards him. The creation of this imagined transaction is not a consequence of the understanding process but its necessary and (according to stronger accounts) sufficient condition: the re-enactment of the implied scene is tantamount to understanding the sentence.

In the following, I review some key pieces of evidence that support these ideas. I first discuss evidence that suggests that language understanding is based on the re-enactment of the described scenes in concrete perceptual terms, grounded in the sensory processes that support the event's actual experience. Second, I discuss evidence that these perceptual event representations are treated by the cognitive apparatus just like real scenes in that they trigger actual behaviours – hand movements, facial expressions, or eye movements – that would occur in such circumstances. Third, I discuss evidence that the representation of linguistic meaning draws upon information encoded in the understander's own action control systems. Finally, outstanding questions, implications, as well as problems faced by such an embodied approach to linguistic meaning are discussed.

## 1. Language comprehension is based on complex and specific visual imagery

There is now ample evidence that understanding sentences (as well as single words) involves the creation of concrete mental images (encompassing their visual, tactile and auditory components), in detail that is not actually transmitted by the sentence but which is constructed, fluently and automatically, in the understanding process. One of the first pieces of evidence that language comprehension involves such perceptual simulations comes from the finding that lexical decisions – is *dane* an actual English word? – are easier when they are made on a word that refers to an object of the same shape as the word one has judged just before (e.g. both *pizza* and *coin* refer to round, flat objects), even if the objects share no other semantic relationship (Schreuder et al. 1984). This suggests that the shape evoked by the prime word was still activated in memory, and facilitated the construction of a mental image of the object referred to by the second word, which in turn sped up lexical decisions. Even though subsequent studies have qualified this result and showed that shape information needs to be at least somewhat relevant for these effects to be observed (Pecher et al. 1998), the data nevertheless suggest that perceptual shape representations are part of object concepts.

More recent studies showed that the perceptual qualities associated with an object word not only affect subsequent lexical decisions, but also actual perception of pictorial stimuli. Meteyard et al. (2008) tested the idea that the same brain mechanisms that are used for detecting vertical motion are also engaged in weaker form when a word implying this motion is read (e.g. *rise*). The authors superimposed verbs implying upwards or downwards motion over a background of dots moving in either direction. Even though the visual motion was very subtle and presented near the recognition threshold (i.e. detected only at just above chance level), participants responded more quickly to the words when the direction of visual motion and the motion implied by the word were congruent (i.e. upwards motion combined with *rise*). Importantly, these effects were bidirectional. Visual motion at near the detection threshold was detected more easily after reading a word that implied a motion in the same direction. For example, upward motion was detected more easily after judging the word *rise* (Meteyard et al. 2007).

The above studies indicate that motion associated with a word is not coded abstractly, but directly influences – and is influenced by – perceptual processes, suggesting that it is coded in the same terms as actual motion experience. This language-perception link is so tight that even visual illusions can be induced by language. Observing repetitive stimuli causes the visual system to adapt and leads to the creation of so-called *aftereffects*. For example, after being exposed to various instances of objects moving to the left, static objects are often perceived to be moving slightly rightwards (for a review of such effects, see Webster 2011). It has now been shown that reading stories that describe similar repetitive motions can also induce such aftereffects, such that static images appeared to participants to be moving in the other direction as implied by the story (Dils and Boroditsky 2010).

Various neurophysiological studies support the notion that low-level sensory processes are involved in representing linguistic meaning. For example, reading motion sentences (*The wild horse crossed the barren field* versus *The black horse stood in the barren field*) activates areas in the visual system dedicated to the low-level analysis of moving stimuli, providing a clear indication that perceptual simulations take place during language understanding (e.g. Saygin et al. 2010). Similar findings have been reported for other sensory modalities. For example, words related to odours (e.g. *cinnamon*, *garlic*, or *jasmine*) activate olfactory areas (Gonzales et al. 2006) and words related to sounds (e.g. *telephone*) activate auditory cortices (Kiefer et al. 2008).

Importantly, these perceptual simulations appear to capture not only the semantic content carried by words, but often reflect sentence-level meaning that emerges from the integration of a word with the surrounding context. Stanfield and Zwaan (2001; see also Pecher et al. 2009) presented sentences that implied – but did not explicitly describe – the horizontal or vertical orientation of an object. For example, the sentence *John put the pencil in the cup* implies a vertical orientation of the pencil, and the sentence *John put the pencil in the drawer* implies a horizontal orientation. Immediately following the sentences, a picture was presented, and the participant decided whether the depicted object was part of the preceding sentence. Participants more quickly and accurately recognised objects when their orientation matched the orientation implied by the sentence, suggesting the automatic engagement of perceptual simulations, which generate the implied orientation of the pencil.

Finally, it is worth noting that such effects are not restricted to simple object properties like orientation, but also extend to properties such as an object's shape or its configuration. Zwaan et al. (2002) reported that reading a sentence like *The ranger saw an eagle in the sky* facilitates recognition of images of an eagle with spread wings as opposed to an eagle with its wings folded, and the opposite is true for the sentence *The ranger saw the eagle in the nest*. These findings suggest that very specific and highly detailed perceptual representations are computed 'on the fly' when understanding language, in line with the idea that perceptual simulations form the basis of the comprehension process and can supply information that is not directly encoded by the text itself.

## 2. Imagery during sentence comprehension drives action planning processes

The studies reviewed above indicate that understanding language involves a re-enactment or perceptual simulation of the scenes described in a sentence. When facing a real scene, the brain constantly extracts the various action possibilities that a person has, for example, which objects can be looked at, grasped, or sat on. The constant extraction of behaviours 'afforded' (Gibson 1979) by the environment is increasingly understood as the key function of all sensory processing, allowing even complex courses of action to be planned and controlled effectively. Evidence is now accumulating that the perceptual representations generated during language understanding elicit these action planning processes as well.

One domain for which such effects have been demonstrated is eye movements. Humans continuously scan scenes in front of them with their eyes. They make, often without being aware of it, three to four rapid eye movements – so-called *saccades* – per second on average, where the eye rapidly jumps from one relevant object to another (for a review, see Richardson et al. 2007). These constant eye movements are needed for continuously updating what is present in the visual scene. Without this, one's subjective awareness of an object would deteriorate quickly, unless it is effortfully retained in memory. Thus, rather than storing all the sensory details of an object, the cognitive system only stores its location in a scene. When these details are required for processing, the eyes flick to its position, often without the thinker noticing, and retrieve the required information, allowing the world to be used as its own best representation (Brooks 1991).

Language understanding appears to reinstate this process, with described objects being mentally located at specific positions in space, which can be detected by measuring the subtle eye movements participants make during the understanding process. For example, Spivey and Geng (2001; see also Borghi et al. 2004) recorded eye movements while participants listened to descriptions of spatial scenes, for example: *Imagine that you are standing across the street from a 40-story apartment building. At the bottom there is a doorman in blue. On the 10th floor, a woman is hanging her laundry out the window. On the 29th floor, two kids are sitting on the fire escape smoking cigarettes. On the very top floor, two people are screaming.* While listening to sentences with location information (the last three sentences in the above example), participants made more eye movements towards the locations than in any other direction. Similarly, Bach and Zaefferer (2010) observed that when participants were asked to judge whether a sentence accurately described an object that was previously observed, hand movements to the object's previous position were activated, consistent with the idea that a visual image of the target scene was generated and that it activated automatic action planning processes.

Interestingly, this effect was modulated by whether the sentence was a declarative or interrogative sentence, being larger for interrogatives.

Such effects are not restricted to attention in space. In a recent study (Bach et al. 2010) we gave the participants the task to semantically judge whether objects denoted by words were either found indoors or outdoors, and indicate their judgment by making one of two gestures with their hands: a round, circle movement or a square movement. Participants performed this task easily, but their gestures were influenced by the shape of the referent objects. Round gestures were made faster, and performed more accurately, for words denoting round objects, and square gestures were performed more efficiently for words denoting square objects. Importantly, the shape of objects did not only influence selection of the gestures, but their actual shapes as well, rendering square gestures more circle-like and circles more square-like when word and gesture were incongruent. These data do not only reveal a tight link between language and gesture, but also indicate that perceptual simulations of an object's shape are triggered when making semantic judgments about the referent words. Moreover, the activation of such sensory states provides a basis for action control, facilitating the production of gestures that trace the object's shape (cf. Hommel et al. 2001; Prinz 1990, 1997).

Similar effects are found for the actions that are most suitable for actual interactions with objects. Objects with handles on the left facilitate responses with one's left hand, while handles on the right prime responses with the right hand (e.g. Tucker and Ellis 1998). Similarly, seeing a large cup pre-activates whole-hand 'power grips', while seeing a tiny pea activates precision 'pinch' grips with thumb and index fingers, even when the actor has no intention of interacting with the object (e.g. Tucker and Ellis 2001, 2004). Various studies now show that similar effects are observed when participants only see or hear a word denoting the object (e.g. Bub et al. 2008; Glover et al. 2004; Tucker and Ellis 2004). For example, in the study of Tucker and Ellis (2004), subjects judged whether objects referred to by words were natural or man-made by manipulating a response device that either required a power grip or a precision grip. As it was the case for actually seeing objects, power grip responses were faster to words denoting larger objects and pinch grips were faster to words denoting smaller objects.

## 3. Sentence comprehension draws upon the understander's own action knowledge

In many cases, sentences describe actions: goal-directed interactions of an actor and the environment. As before, studies indicate that these sentences lead to a perceptual representation of the situation. Importantly, however, these perceptual simulations appear to be grounded, at least in part, in the internal simulation of the action, and the anticipation of its visual, proprioceptic, and kinaesthetic consequences (for reviews, see Borghi 2005; Pulvermüller 2005). Various techniques have been developed that can make these mental simulations of action experimentally detectable.

In one of the earliest studies (Glenberg and Kaschak 2002), participants performed forwards and backwards motions with their hands to indicate whether sentences made sense or not. The authors observed what they called an 'action sentence compatibility effect': the time it took participants to initiate the movements depended on whether the movement was similar to the action described by the sentences. Participants found it easier to move their own arm forwards when they used this movement to make sensibility judgments of sentences that describe a forward motion (*He closed the drawer*). In contrast, reading a sentence implying a backwards movement of the actor's arm (e.g. *He opened the drawer*) facilitated backwards movements relative to forwards movements. These findings suggest that, consistent with simulation accounts, when understanding language, people place themselves within the described scenes and mentally perform the described actions.

Importantly, as it was the case for the simulation of sensory events, these action simulations appear to provide the comprehender with information that is not encoded directly by the sentence. Zwaan and Taylor (2006) had subjects read sentences, such as: *Because / the music / was too loud, / he / turned down / the / volume*. To proceed through the words of the sentence, participants had to turn a knob either clockwise or counter-clockwise. It was found that these rotations were faster in the congruent cases. For example, clockwise motions were faster when the verb suggested that somebody turned up the volume (a movement that also involves a clockwise motion) than when the verb suggested that the volume was turned down (a counter-clockwise motion). Importantly, these effects were only found on the verb but not on the following (or preceding) words, suggesting that the action simulation was tied to verb understanding. These findings therefore suggest that to construct a representation of the sentence meaning, participants relied on their own action knowledge, specifically the movements required for creating the relevant effect in the environment (e.g. turning up the volume).

The understander's action knowledge may also form the basis for understanding figurative language. In Glenberg and Kaschak's original study (2002), the action sentence compatibility effect has been found not only for imperatives and descriptive sentences of two types (double object *Mike handed you the pizza* and dative *Mike handed the pizza to you* constructions), but also for abstract transfer sentences. When the sentence *Liz told you the story* is read, those movements of the participants are facilitated that mirrored the flow of information between the actors, in this case, movements towards the participants' own bodies. The use of action knowledge in figurative language is supported by a study of Matlock (2004), who found evidence that readers would mentally simulate action when reading sentences containing figurative motion such as *The fence runs along the garden*. They observed that the described terrain influenced sentence understanding times. Understanding times were slower for descriptions that suggested longer paths and difficult terrain, consistent with the notion that participants mentally performed the actions on which the figurative language was based. Crucially, if the same paths where described without using action-related language (*The fence is around the garden*), these effects were eliminated.

Evidence from neuroimaging studies supports the notion that action related language draws upon knowledge stored in motor structures of the brain. For example, it has been known for a long time that action verbs and tool words (which are directly related to actions performed with them) elicit stronger activation in motor related brain areas than reading words not related to action (Martin et al. 1996). Other studies have built on the long standing observation that movements of one's arm are controlled by more lower ('ventral') parts of the motor cortex than movements of the leg, which are controlled by more upwards ('dorsal') areas (Woolsey 1963; Woolsey et al. 1979). When people read words or sentences that refer to actions performed with these body parts – such as *kick* or *push* – brain activation matches this somatotopy, with leg words activating more dorsal motor areas and hand words more ventral areas (Hauk et al. 2004; Aziz-Zadeh et al. 2008; Buccino et al. 2005). Finally, in one of the most comprehensive studies to date, Kemmerer and colleagues (2008) investigated the distribution of five different semantic features encoded by verbs across the brain. They found that whereas verbs having the semantic feature MOTION activate motion-related areas of the brain, verbs having the feature ACTION activate premotor areas, which are directly involved in planning and performing action.

These data show that activity in motor-related brain areas during language understanding directly reflects – or at least is strongly influenced by – the action content of language. One question is if these motor activations are just a fringe outcome of processing word or sentence meaning, or whether they are actually needed for language understanding. For example, it could be that actual understanding is accomplished in an a modal, symbolic semantic system, and that the reported motor and sensory effects just reflect epiphenomenal spreading activation to these systems, without a functional role. One piece of evidence that argues against this view is that motor effects are typically very fast and occur before the time interval previously associated with semantic processing. For example, Pulvermüller et al. (2005) have observed in an electrophysiological study that motor activation occurs already in the first 150 to 200 ms after reading a word, which precedes the time window typically associated with semantic processing, suggesting that activation of action knowledge is a precursor rather than a consequence of comprehension (but see Papeo et al. 2009, for a study that generally replicated the effects, but in a much later time interval, and only when the task required explicit semantic processing).

A second piece of evidence addresses the hypothesis that if motor activation provides the basis for understanding action content, then changing activity in the motor systems should have direct effects on processing of action related language. Indeed, patients with damage to the inferior frontal cortex may have corresponding deficits in categorising actions, as well as understanding action verbs (e.g. Bak et al. 2006). Such selective changes to motor systems can also be experimentally induced. In an early study, participants judged the sensibility of verb-noun pairs (e.g. *squeeze–tomato*), after making a hand shape that matched or did not match the associated action (Klatzky et al. 1989). An action-appropriate hand shape facilitated the comprehension of the word pairs. For example, the sensibility of *throw–dart* was judged more quickly when the hands had formed the appropriate shape for throwing darts than when they formed a different shape. Similar data come from neuroscientific studies. Pulvermüller et al. (2005) stimulated hand and leg areas of the motor cortex (using strong magnetic pulses) 150 ms after word onset while the participants made word/non-word judgments on arm- and leg-related words and pseudowords. Stimulating the hand motor cortex facilitated decisions on hand words, while stimulating the leg motor cortex facilitated decisions on leg words, consistent with the idea that the pre-activated hand and foot motor cortices play a critical role in word understanding.

A very impressive demonstration of this principle has been provided by a recent study. Havas and colleagues (2007) exploited the phenomenon that giving people a pen to hold either between their teeth (without touching it with the lips) or their lips (without touching it with the teeth) requires tensing the muscles engaged in smiling and frowning, respectively. This simple manipulation allows researchers to induce subtle facial expressions, without the participants being aware of this. The two ways of holding the pen affected both valence judgments of words and sensibility judgments of positive and negatively charged sentences, with sentences more easily being judged as sensible when the induced emotional expression matched the emotion in the sentence. Similar effects emerge from treatments with Botulin ('Botox'), a procedure often used for cosmetic surgery, which smoothens the skin in the forehead but also destroys the facial nerves underneath, reducing the participant's ability to frown. It was found that participants that had received such treatments were specifically impaired (compared to a control group) in judging sentences with negative emotional content. This clearly suggests that emotional expressions are not just a consequence of understanding language. Rather, the capability to produce such expressions may be a requirement to understanding negative emotion implied by language itself (Havas et al. 2010).

## 4. Problems, questions, and implications

Embodied accounts of language have direct implications for various phenomena. One example is the link between language and gesture. When people talk, even on the phone, they often find themselves producing iconic gestures: without any conscious intention, their hand movements capture the actions and objects they speak about (e.g. Iverson and Goldin-Meadow 1998). The link between language and gesturing is so tight that various theorists have described both as an integrated system (e.g. McNeill 1992). Gesturing supports speech production in various ways. For example, it enhances verbal fluency (Krauss et al. 1996; Kita 2000) and automatically transmits information that complements the information transmitted by language (e.g. Melinger and Levelt 2004), even information that may not be consciously available to the speaker (Goldin-Meadow and Wagner 2005). Various accounts have been put forward to explain this tight link. It has been proposed, for example, that gesturing reduces cognitive load by offloading spatial information onto the motor system (Goldin-Meadow et al. 2001), supports the segregation of complex sentence material into discrete elements for verbalisation (e.g. Kita 2000), or facilitates lexical access of words in the mental lexicon (e.g. Krauss et al. 2000). Even though gesturing might well have these benefits, the general tendency to gesture may arise on a more basic level and reflect the basic way how concepts are represented. According to this view, gestures are a natural consequence of activating experiential traces of the objects and actions specified by a sentence, which then automatically bias the speaker to pantomime the described actions (e.g. Glenberg and Kaschak 2002), or trace the shape of the described objects (Bach et al. 2010).

Another question is whether the activation of these embodied concepts is necessary for understanding or whether it is merely a by-product of an abstract understanding process. Opponents of embodied cognition theories have argued that it may actually not be very surprising that language understanding activates motor and perceptual codes (cf. Mahon and Carammazza 2008). After all, even abstract, symbolic networks would need to ultimately be connected to an output (motor) and input (perception) layer, from which behaviour can be controlled and information about the environment be collected. Via spreading activation such motor and perceptual information could be activated and give rise to the reported effects, even in a system in which understanding occurs exclusively on the basis of abstract, symbolic codes (cf. Mahon and Carammazza 2008). As noted, various studies have shown that changes in sensory or motor systems – induced either experimentally or due to brain or nerve damage – have direct repercussions on language understanding (and cognition in general), often going along with specific changes in understanding word meanings related to the affected sensorimotor systems (for critical discussions, see Willems and Casasanto 2011; Mahon and Caramazza 2008). For example, as discussed above, disrupting the systems engaged in the bodily responses to negative information (frowning muscles) affects the evaluation of negatively charged messages in particular (Havas et al. 2010).

Such reverse impacts of sensorimotor systems on language understanding are hard to account for by symbolic models, and suggest a crucial role of sensorimotor codes in language processing. Yet, it has to be acknowledged that the effects demonstrated so far have been quite small, and could only be elucidated with sophisticated experimentation, across a large number of participants. It may therefore be that embodied concepts merely add to, or enhance primarily abstract language understanding processes. Yet again, embodiment theorists may counter with the notion that most concepts should be embodied on multiple levels. For example, the concept *ball* might be represented not only in terms of visual information about shape and luminance, but also in terms of weight and texture information, the feel of the object in one's hand, motor activation associated with the motions of throwing or kicking it, and the anticipated emotional responses that arise from using it effectively (or ineffectively).

If only some parts of the representation of *ball* are disrupted by an experimental manipulation, it may not be surprising that comprehension is still possible, as all its remaining parts are still available for processing. A challenge for future research is therefore to either find situations in which the crucial content is so restricted that it can completely be eliminated by experimental manipulations, or to devise experimental methods that allow the sensorimotor representation of a concept to be disrupted across all relevant levels, and to test whether this goes along with a complete disruption of the comprehension process.

Another question is how an embodied language system could deal with abstract language, referring to concepts that do not appear to be directly linked to sensory or motor states, such as philosophy, freedom, odd number, or god. (cf. Barsalou 2008; Borghi and Cimatti 2009, 2010). Various theories have been put forward to explain how embodied cognition can account for such concepts. One account assumes that experiential, sensorimotor information can serve as a metaphorical basis for abstract content (e.g. Lakoff and Johnson 1999; Gibbs 2003). As noted, the action sentence compatibility effect demonstrated by Glenberg and Kaschak (2002) is found even when sentences describe the transfer of information rather than actual actions (*Liz told you the story*), suggesting that actual transfer experiences also form the basis of the transfer of abstract information. Such metaphorical use of experiential information appears to be widespread. There is evidence, for example, that abstract ideas of time and numerosity are mapped onto more concrete, embodied concepts of space (Boroditsky and Ramscar 2002; Dehaene et al. 1993), that power relationships are represented in terms of relative vertical locations of the actors (up/down, Schubert 2005), that information about importance is represented in terms of felt weight (Jostmann et al. 2009) and that aesthetic experience reflects, among others, the ease with which the eyes can trace a scene (e.g. Reber et al. 2004; Topolinski 2010). A challenge for future research is to elucidate whether the formation of these links between abstract meaning and more basic sensorimotor experiences must be encouraged by a use of these metaphors in the understander's language, or whether they underlie the representation of the concepts themselves.

A second account assumes that while abstract concepts may not be associated with sensorimotor content they are nevertheless often strongly linked to emotional responses and the interoception of their bodily consequences (e.g. facial expressions, or the responses of the endocrine and autonomic nervous systems) (cf. Kousta et al. 2011). In such accounts, abstract concepts such as *justice* are based on the emotional experiences of being treated fairly, or on having one's well-deserved revenge. Similarly, concepts like *government* may build upon lower-level emotional states that arise through interactions with parents or teachers, from being on the receiving end of rule-based authority. Indeed, in a lexicon based study (Kousta et al. 2011), the well-known processing differences between abstract and concrete words could be explained if emotional content was taken into account.

Finally, it has been proposed that abstract concepts may ultimately be grounded in the use of the words itself: the effect they have on the speaker and the listener (e.g. Borghi and Cimatti 2009, 2010). In other words, whereas physical tools can be used to create effects in the physical world, words (both abstract and concrete) can be defined by the effects they have on the social world (cf. Austin 1962; Wittgenstein 1953). Abstract words in particular are proposed to be primarily encoded in such terms, rather than in terms of concrete sensorimotor experiences. Although research supporting such ideas is only now underway, such views argue that a full embodied account of language can only be achieved when, next to the sensory and motor states signalled by words, their use in guiding and controlling social interactions can be accounted for (cf. Borghi and Cimatti 2009, 2010).

## 5. Conclusions

The studies reviewed above indicate that sensorimotor activation during language understanding is ubiquitous and automatic. Concepts about events or entities appear to be 'grounded' in perceptual information (e.g. shape, orientation), information about the associated motor actions, and even the associated emotional states and behaviours. They are retrieved automatically when words or sentences are read, allowing understanders to place themselves in the described scenes, and to mentally simulate the described behaviours. This re-enactment of prior experiential states are understood not as mere by-products of language understanding, but as being equivalent with the understanding process itself.

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