Embodied cognition and the problem of abstract concepts

Paweł BALCERAK*

ABSTRACT

The paper addresses the issue of abstract concepts in the embodied and grounded theories of language. This issue seems to be one of the fundamental challenges facing the theories from this group. The aim of this work is to discuss the essence of the problem and to present the most interesting attempts to solve the aforementioned challenge. To this end, we will begin by characterizing the approach of researchers in embodied cognition to the study of language. In the following section, we will look at research data showing differences in the meaning-making processes for abstract and concrete concepts by natural cognitive systems. This section will be followed by a presentation of selected strategies of addressing the problem of abstractness in the research paradigm under discussion. We will conclude with some observations about a grounded and embodied model of language as a whole.

KEYWORDS

embodiment; meaning; abstract and concrete concepts; language

* Doctor of philosophy, assistant professor at the Department of Philosophy, University of Rzeszów. E-mail: pbalcerak@gmail.com.

For a long time, there was a prevailing view in the philosophy of the mind and cognitive science, according to which the body was an insignificant element in the understanding of the nature of the mind and cognition. Over the years, a new approach to the body-mind relation has emerged in sciences dealing with these issues, namely, the concept of embodied cognition. Cognition is embodied if the physical form of a cognitive subject has a significant influence on that subject's cognitive processes. Supporters of this new approach considered the classic outlook on the independence of the body and the mind to be deeply false. Dependencies between cognitive processes and physical characteristic (such as body morphology, the construction of the sense, *etc.*) of a subject were said to pertain to all aspects of mental processes; this article addresses a small section of the issues connected with how embodied cognition relates to our knowledge of some linguistic phenomena. The paper presents the difficulties encountered by embodied concepts of language when attempting to specify the properties of abstract concepts, as well as the most common propositions for solving these problems as they occur in the subject literature. The aim of this article is not to provide a clear-cut answer to the controversies concerning this category of concepts but to present the essence of the problem and the most interesting views on this issue.

Embodied cognition can be defined as a research programme that encompasses loosely related endeavours in the area of cognitive science that share the same commitment to a critical re-evaluation of the traditional approach to cognition and cognitive processes. Empirical studies in the domain of embodied cognition offer numerous inspirations for philosophers who study the mind and related issues. On the one hand, this is due to the high diversity of the phenomena investigated by embodiment theorists; on the other hand, this results from the fact that the embodiment phenomenon puts in question deeply-rooted categories traditionally employed in sciences that explore the mind, such as computationalism, representationalism, the brain-mind identity, *etc*.

Among the broad range of topics addressed by researchers subscribing to this approach, the relationship between language and embodiment is the key focus of this article — particularly, the problem of the abstractness of some linguistic objects — such as abstract words *e.g.* weight, beauty, greenness (Ostarek & Huettig, 2019). The orthodox stance in cognitive science claimed that the human conceptual system is functionally independent of perceptual, emotional or functional systems. Conceptual content is said to be encoded in amodal symbols — non-concrete of any sensory-motor systems. Classical theories of cognition hold that there exist distinct representational formats, such as perceptual representations which are modal, whereas conceptual representations are amodal. Modal knowledge is largely acquired through bodily interaction with the environment, such that different aspects of this knowledge are stored

in different neural systems dedicated to sensorimotor processing (*e.g.*, sensory knowledge is stored in neural systems dedicated to sensory processing, whereas motor knowledge is stored in neural systems dedicated to motor processing). Amodal representations occur independently of sensory or motor stimulation. Relatively recently, increasingly popular has become a new conception implying that the meaning of concepts is somehow grounded by mechanisms of the body serving for experiencing the world. This has led to the development of the embodied conception with regard to concepts where affective and sensory-motor systems of the body play a key role (Barsalou, 2008; Gallese & Lakoff, 2005).

ABSTRACT CONCEPTS

The standard approach to the category of concept in cognitive science is to investigate them from a computational perspective. In this standpoint, concepts are entities functionally independent of our actions and perception (Hurley, 2008). Theories of embodied cognition offer a paradigm implying that mental phenomena are significantly related to a subject's sensory-motor systems. Various embodiment theories have been proposed (Shapiro, 2011; Wilson, 2002); however, in spite of differences, there is consensus that embodiment requires cognitive processes at least partially constituted or limited by extracerebral corporal processes, such as those that take place in perceptual systems, motor systems, emotional systems, and by the morphology of the body (Glenberg, 2010).

The entire research on embodied cognition includes a research path that focuses on the notion of concepts. Cognitivists tend to consider concepts as a kind of knowledge stored in the long-term memory that is used in higher-order cognitive activities (Machery, 2009). There are two approaches to the embodiment of concepts. The first one implies that the content of concepts is coded in the form of perceptual symbolism that contains the recreation of a subject's sensory and motor experiences (Barsalou, 2008). The other recognises the content of concepts in patterns of actions used by a subject (Glenberg, 1997). In the subject literature, explored is whether both these solutions could possibly be unified. This unification would consist in attributing a predictive role to a simulation and thus significant as an action pattern (Gallese, 2009). Further in the article an assumption is made that both these solutions lead to a similar effect and none of them is preferred.

Abstract concepts constitute a challenge for embodied conceptions as it is problematic to indicate a manner in which a concept such as "justice" can be captured in representations based on sensory-motor systems. Attempts at solving this dilemma refer, among others, to the category of a metaphor

(Lakoff & Johnson, 1980), a simulation (Barsalou, 1999), an emotion (Kousta *et al.*, 2011), *etc.* However, none of these solutions have gained a universal and complete recognition.

LANGUAGE IN THEORIES OF EMBODIED COGNITION

For years, studies on language in the context of its embodiment used to be focused on the grounding problem in the human sensory-motor system — and later, also the emotional system (Barsalou, 1999; Gallese & Lakoff, 2005). Researchers used to reject the so-called language of thought hypothesis, publicised by Fodor (Fodor, 1975) and the idea that a man's sensory-motor experience is processed in a para-linguistic form. As a result, not only has the role of the language of thought been diminished, but also that of natural language in cognitive processes. A popular linguistic approach called distributional semantics, where the meaning of an expression is determined by similarity in distribution/occurrence between linguistic items — such as words (Harris, 1954), was considered naturally contradictory to the idea of embodied cognition.

In the most common of its forms distributional semantics represents word meaning by taking large amount of text as input and produces a model akin to lexicon, where semantics is represented in the form of vectors. The meaning of the word is signified by a set of values determining its place in multi-dimensional space, that way semantic relations can be modelled as geometric relations. The mechanism used to obtain this distributional model is such that a similar context of use results in similar vectors; therefore, vector similarity corelates with distributional similarity, which in turn corelates with semantic similarity. For example, both the words "man" and "guy" denote male adult humans, but each of them presents different nuances. According to the distributional model the nearest neighbour, measured by the cosine between vectors, for "man" is "woman", whereas the nearest neighbour for "guy" is "bloke". Their nearest neighbour illustrates the capacity of this approach to capture both generic and specific semantic features. There are many different versions of the abstraction mechanism used for the creation of this model. Early distributional models were created by extracting co-occurrence statistics, while more recent models are based on neural networks. Only a brief introduction to this theory can be contained in this work, such that the nature of this survey requires; for more detailed discussion see Stephen Clark (Clark, 2015), Alessandro Lenci (Lenci, 2018), and Gemma Boleda (Boleda, 2020).

The counter-argument to ungrounded theories can be presented, as follows: in order to capture the meaning of a concept, the symbolic representation of this concept cannot be grounded by different symbolism; it is required to be grounded in a non-symbolic representation (Harnad, 1990).

At the end of the 20th century, new influential theories in distributional semantics have emerged, namely, the so-called HAL (Hyperspace Analogue to Language) model (Lund & Burgess, 1996), and the LSA (Latent Semantic Analysis) model (Landauer & Dumais, 1997). In line with these concepts, the access to the meaning of expressions would be obtained by means of understanding the linguistic contexts that these expressions are related to. Supporters of the embodied concept of language, who considered distributional theories to be inadequately describing cognitive processes and meaning, postulated rejection of the assumption that meaning is produced by means of manipulating abstract symbols arbitrarily related to referents. In turn, it was suggested that the focus should be put on the grounding problem (Glenberg & Robertson, 2000).

In the early 21st century, the situation of the discussed research area was relatively clear, with the language embodiment concept competing with two alternatives, namely, the concept of the language of thought and distributional semantics (Lund & Burgess, 1996; Landauer & Dumais, 1997). The key task of theories of the embodiment of concepts was to prove that concepts provoke a simulation, and are not arbitrary and amodal. These were said to be grounded in perceptual and emotional systems (*i.e.* interoception of the autonomic nervous system activity related to emotions) rather than in linguistic information. Words are considered a kind of indicators of referents; a function they fulfil by being specific pointers to simulations (Barsalou *et al.*, 2008). The situation started shifting at the end of the first decade of the 21st century with the advent of the LASS (Language and Situated Simulation) model (Barsalou *et al.*, 2008), in which it is argued that both these systems, *i.e.*, the linguistic (amodal) system and the simulation (modal) system, cooperate in the meaning representation.

The LASS model implies that relations between symbols in linguistic activities play a significant part, particularly in the first stage of processing, when they act as indicators of conceptual content. The linguistic system seems best for quick judgment situations, because it presents the potential to provide a response before deep conceptual processing manages to take place. For example, stimulus in the form of the word "cactus" leads to activation of other relevant words — such as "prickly" — before any detailed conceptual representation of this plan is engaged. This mechanics is known under the name of a linguistic shortcut. It allows people to take advantage of computationally cheaper information from the linguistic system to inform a response before more expensive, but also more precise, representations are fully available (Connell & Lynott, 2013). It is implied that a simulation represents deep conceptual information, in contrast to a linguistic representation that is superficial (Barsalou, 2008). Depending on the specific linguistic activity, the linguistic system would either use modal mechanisms or not, while each simulation would be

preceded by a faster and more available mechanism for analysing associations between expressions. Adoption of these assumptions gave rise to meaning-making models whose purpose is to show that the integration of sensory-motor information and linguistic information leads to a creation of a more comprehensive image of the category of meaning. For instance, it is proposed that semantic representations are a result of a statistical combination of sensory and distributional data (Andrews, Vigliocco, & Vinson, 2009). These two types of data provide different yet mutually complementary information. The former informs of the sensory-motor characteristics of the object being described, whereas the latter focuses on encyclopaedic knowledge, as the authors put it. In 2012, a model was proposed that allows directly non-grounded words to be subjected to sensory-motor grounding. In that model, a simulation caused by a word refers not to perceptual states related to the referent of that word, but to perceptual states related to words linked to that word (Johns & Jones, 2012).

With the advent of the LASS model, it has become reasonable to ask whether convincing evidence for the existence of two separate modal and amodal processing systems could be found within the human cognitive system?

ABSTRACTNESS-CONCRETENESS IN LANGUAGE PROCESSING

Let us adopt a working assumption stating, "the linguistic (amodal) system should play the central role in the semantic processing of abstract concepts, unlike the processing of concrete concepts". Let us consider some research data that could support this thesis.

One of the first pieces of evidence for inconsistencies between the functioning of abstract concepts and that of concrete concepts comes from behavioural studies on concreteness and the imageability effect. Imageability tends to be defined as the subjective ease in with a word causes the formation of a sensory-motor mental image (Paivio, 1971). Although imageability is a different category than concreteness — with the latter usually specified as the extent to which a given object can be directly experienced by the senses — a significant coextensiveness of these measures can be noticed. Researchers tend to identify high-imageability objects with concrete objects, whereas low-imageability objects tend to be identified with abstract objects. In other words highly-imaginable words (*e.g.* mother, brick, book) are usually concrete nouns, and vice versa words with low-imageability rating (*e.g.* number, fear) are usually abstract nouns. High-imageability objects seem to have a number of cognitive advantages over their low-imageability counterparts, as they are characterised by higher availability and a higher processing speed (Paivio, 1986). There are two main explanations for these phenomena. The first one is called the dual code theory (Paivio, 1971). In this conception, the cognitive advantages of one

word type result from the higher availability of perceptually encoded information of high-imageability words. The other is called context availability theory (Schwanenflugel, 1991). The context availability theory implies the existence of only one representation system and explains cognitive differences by the higher number of pieces of context information stored in the semantic memory, which contains high-imageability words.

In dual coding theory it is hypothesized that concrete words are represented in two systems: a linguistic, verbal system and an imagistic, nonverbal system. Those systems are representationally distinct but functionally related. Abstract concepts are solely represented in the first of those systems. The cognitive advantage of concrete words is explained by the fact that they profit from access information from a multiple system, when abstract ones can use only a verbal one. According to concept availability theory, both types of concepts are represented in a single verbal system. There is no difference in representation nor the processes that those representation can undergo for both types of concepts. Any advantage of concrete concepts is attributed to the way in which accessing the meaning of a word involves a network of related semantic information, and concrete words seem to have a denser and more direct connection to contextual knowledge than abstract words. In this view comprehension depends on verbal context, provided by discourse or the semantic memory of the language user.

It is actually possible to find empirical evidence suggesting neuroanatomical differences in the processing of abstract/low-imageability and concrete/high-imageability concepts. Roberta Adorni and Alice M. Proverbio (Adorni & Proverbio, 2012) conducted an experiment involving a lexical selection task and a functional EEG study of the central nervous system, and found evidence of increased activity in the left medial frontal gyrus and the left temporal cortex, with simultaneous lowered activity in the extrastriate visual areas when abstract words were processed. Other researchers point to the different influence that the level of concreteness of processed words has on the left and right brain hemispheres (Huang, Lee, & Federmeier, 2010). These studies imply that there are different expression processing systems depending on their levels of concreteness and/or imageability, which contradicts the single system hypothesis put forward in theories such as the context availability theory.

Neuroimaging provides further support for the hypothesis concerning anatomical differences in the processing of the two concept types discussed in this article. In 2005, a group of researchers conducted an experiment that consisted of presenting to participants three words placed on top of a triangle. Then, the study participants were asked which of the two words on the bottom of the triangle was semantically closer to the word on the top. The CNS functional imaging study showed higher activity in the left superior temporal cortex and the left inferior frontal cortex when abstract concepts were analysed, whereas higher activity in association areas when concrete concepts were analysed

(Sabsevitz *et al.*, 2005). Despite the fact that the CNS functional imaging study findings concerning the processing of various types of concepts are not conclusive, meta-analyses suggest that it is highly likely that these specific areas of the brain are responsible for analysing abstract concepts (Wang *et al.*, 2010). To test these assumptions, in 2009, a group of researchers conducted an experiment entailing transcranial magnetic stimulation of the specified brain regions (Papagno *et al.*, 2009) using a series of impulses (rTSM). According to the study findings, the capacity to perform lexical tasks on abstract concepts decreases in time when the left superior temporal cortex and the left inferior frontal cortex are stimulated. This result is consistent with the expected role of these areas in operating abstract concepts.

Further support for the investigated thesis was provided by the field of cognitive neuropsychology. Research involving case studies of individuals who suffered brain injuries demonstrates that in individuals with left-hemispheric brain injuries, a greater impairment for the processing of abstract concepts was determined. In turn, individuals with right-hemispheric brain injuries show difficulties in operating concrete concepts (Katz & Goodglass, 1990; Martin & Saffran, 1992). What is more, some researchers imply that certain cases of aphasia with verb-specific impairment can be better qualified as the impaired use of low-imageability words (Bird *et al.*, 2003; Crepaldi *et al.*, 2006). All this information seems to support the thesis concerning (at least partial) difference on the level of neuro-anatomical systems that serve for operating low- and high-imageability expressions.

The working hypothesis we commenced this brief research review with was, "a linguistic (amodal) system should play a central role in the processing of abstract concepts, in contrast to the processing of concrete concepts". Apparently, empirical data confirm the hypothesis that has been put forward, demonstrating that different brain regions are responsible for the processing of abstract concepts and the processing of concrete concepts. What is more, the areas responsible for the processing of abstract concepts have been already identified as significant for various linguistic processes (Price, 2009).

DISEMBODIMENT

Perhaps the gravest problem to be faced by conceptions of the embodiment of language arises from the fact that abstract concepts seem qualitatively different than concrete concepts. It is difficult to prove how representations grounded in sensory-motor systems might even only theoretically capture the content of abstract concepts, such as "truth", "justice" or "beauty". Regardless of how these concepts are produced on the neurological level of a cognitive subject, these categories seem somehow detached from this subject's sensory system.

Even passionate supporters of embodied conceptions admit that abstract concepts constitute a serious challenge to these beliefs. Advocates of embodied theories have suggested that abstract concepts are represented by dispersed neural patterns that reflect their unique content, which is by far more contextually complex and extended over a period of time than that of concrete concepts (Wilson-Mendenhall *et al.*, 2013). In this paradigm, abstract concepts pertain to phenomena, mental states, and situations, and not to objects or entities one could establish a direct interaction with. This allows more complex properties and correlations to be involved than in the case of concrete concepts, and makes room for higher semantic diversity (Borghi & Binkofski, 2014).

The debate on the place of abstract concepts in the theories of embodied language continues (Lupyan & Winter, 2018). There are some authors who claim that a completely embodied solution is possible, while some others present an opposite view. However, they all agree that concepts that seem completely abstract constitute a serious challenge for the conception within the embodied cognition paradigm. Recently, the way in which the distinction between the abstract and the concrete is perceived has changed. There is a belief that has become increasingly popular, stating that the dichotomic nature of this distinction is an unjustified simplification, since even the most abstract concepts have concrete constituents that reveal themselves in certain contexts and, analogously, abstract constituents in concrete expressions (Barsalou *et al.*, 2018). Some authors propose that this distinction should be rejected, or that these categories be redefined. Such a redefinition can be found, for instance, in the conception of a situated conceptualisation framework. In this conception, concrete concepts are grounded by external phenomena, such as actions, items, and situations. On the other hand, abstract concepts are grounded by internal phenomena, such as emotions, beliefs, desires. Aside from proposals whose purpose is to eliminate the troublesome distinction, there are several groups of approaches aimed at solving the identified problem.

The first solution comes from the area of cognitive linguistics and consists in the proposition that the understanding of abstract concepts is possible owing to the use of metaphors presenting this concept in categories experienced through the senses (Lakoff, 1987; Lakoff & Johnson, 1980). This conception has become increasingly credible due to research in the field of embodied cognition that seems to support this hypothesis. For instance, some authors prove that certain judgments about the temporal aspect of objects are based on spatial representations (Casasanto & Boroditsky, 2008). However, one may notice that the explanatory possibilities of this approach are limited. As noted in some of the above-discussed studies, not every metaphoric expression involves the subject's sensory-motor systems in some way. For this reason, a conceptual metaphor cannot explain the entirety of the metaphorical use of language, nor can it account for the totality of abstract concepts.

Another suggested solution is the already-mentioned theory of dual coding the previously described form of LASS or a more recent one, that is, word-as-tool (Borghi & Binkofski, 2014). Cognitive processes are presumed to depend on sensory-motor systems in the brain that reactivate previous experiences — that process is called sensory-motor simulation. When such a simulation is performed neural states are re-enacted from the system that were relevant for the original experience. Language can induce such a simulation performing the role of a simulation catalyst. In these conceptions, linguistic forms do not serve solely as a simulation catalyst, they can also allow one to use the social-cultural experience. The acquisition of abstract concepts requires long-term participation in the social-cultural reality, which makes them dependent on linguistic forms. The reason why sociality is important for abstract concepts, is that we often rely on others to fix our references. This process is based on the following observation: reflecting on our own concepts we realize that to fully capture their meaning we need the contribution of others. In accordance with these conceptions, amodal internalised language serves as one of the representation plane (Paivio, 2013). The one consisting of relations between linguistic symbols, corresponding to these recognised by distributional semantics. These symbolic properties of language may provide an explanation for the phenomenon of abstract concepts (Dove, 2014). In the dual coding theory, hybrid approaches that combine an embodied approach and a distributional approach to semantic memory seem promising (Andrews, Frank, & Vigliocco, 2014). The distributional model based on linguistic information appears to be particularly effective in describing abstract concepts (Louwerse, 2011). The very same model encounters difficulties related to grounding outside of the relations between symbols (Harnad, 1990). The hybrid model is intended to serve for working around that problem. The authors of these models are focused on using advantages related to describing abstract concepts while working around the grounding problem at the same time. Empirical studies show that the results of such a model are better correlated with observational findings than a model that employs one type of representation only. A group of researchers using a Bayesian probabilistic model demonstrated how word meaning can be learned using both data types. They theorise that human semantic representations are the derived statistic combination of these two types of data. The semantic representations learned that way are measurably more realistic, which can be shown by comparison to a set of human-based measures of semantic similarity (Andrews, Vigliocco, & Vinson, 2009).

To solve the problem of abstract concepts in embodied conceptions of language, some researchers have directed their attention towards the human emotional system (Wilson-Mendenhall *et al.*, 2011). Is has been successfully proven that by controlling concept parameters, such as imageability, abstract concepts had an advantage regarding reaction time over concrete concepts — they were

better available and faster retrieved (Kousta *et al.*, 2011). This contradicts the results of the above-mentioned research on cognitive differences between abstract and concrete concepts. This advantage is said to be explained by a difference in the emotional valence between abstract and concrete concepts. The semantic system is said to be differently organised in respect to these two types of concepts. The content of concepts is to be based on the information provided by the senses, as well as linguistic information both for abstract and concrete concepts. In turn, specifying which sensory information will play a crucial role in determining the content of a concept depends on its character. Considering concrete concepts, this will be the sensory-motor information, while in the case of abstract concepts, this will be the internal information derived from the affective system.

CONCLUSION

In the article, we have provided a closer look at categories of abstract concepts and the manner in which linguistic phenomena — such as meaning making, *etc.* — related to the semantic aspects of language are covered in the paradigm of embodied cognition. This has allowed us to identify the problem of the disembodiment of abstract concepts that is rooted in the differences in how abstract and concrete concepts are represented. Owing to a review of empirical studies, a thesis was advanced, one claiming that these differences are reflected already at the level of the biological foundations of cognitive processes. This was followed by the analysis of selected solutions directed to the problem of abstract concepts as part of embodied cognition.

The picture that seems to arise from this research is that of a two-factor conception with coexisting different representation levels, namely, the modal and the amodal. The former corresponds to the use of sensory-motor data, whereas the latter corresponds to manipulating linguistic objects in line with symbolic processing and transformation rules. This representation seems consistent with the assumptions of the embodied conceptions of cognition. Their purpose is to mark the role of perceptual, emotional or functional systems of the subject in cognitive processes and mental phenomena, whereas in the discussed conception, the interaction between both these dimensions with the purpose to produce a shared outcome is emphasised; an outcome of natural language semantics.

In the history of linguistic studies, theories with similar characteristics have appeared. For instance, Willard V.O. Quine's concept of semantic holism. In this theory, there are two dimensions that affect the semantic value of an expression, how the expression relates to the world, and the relations between expressions, whereas no expression has a semantic value that would

be determined solely by one of these dimensions. In turn, the meaning of each concept is determined by complex correlations between these dimensions within the entire system. Likewise, the idea of the bi-factorial nature of meaning, which states that for the meaning of expressions to be described completely one must take into consideration various types of phenomena, has already appeared in the past. This idea can be found as far back as in Gottlob Frege's works (Frege, 1892), who postulates that in order for semantics to be complete, the sense (the content of a concept) should be considered aside from the meaning (which in his conception comes down to a reference). Therefore, it seems reasonable to acknowledge that the above-described studies are another instance of recognising that creating a successful semantic theory is a complex endeavour, one that requires more than a single aspect approach. Theories of the embodiment of concepts approach the problem in a manner similar to Frege's solution by introducing more than one aspect of meaning. An attempt that brings us closer to the solution, albeit one still insufficient. Nonetheless, this attempt has been widely used in practice, providing researchers who investigate empirical science with a paradigm that allows them to link the world of quantifiable empirical research data to the hardly indefinable world of the sense (Dijkstra *et al.*, 2014).

REFERENCES

Adorni, R. & Proverbio, A.M. (2012). The neural manifestation of the word concreteness effect: An electrical neuroimaging study. *Neuropsychologia*, *50*, 880–891.

Andrews, M., Frank, S., & Vigliocco, G. (2014). Reconciling embodied and distributional accounts of meaning in language. *Topics in Cognitive Science*, *6*, 359–370.

Andrews, M., Vigliocco, G., & Vinson, D. (2009). Integrating experiential and distributional data to learn semantic representations. *Psychological Review*, *116*, 463–498.

Barsalou, L.W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577–609.

Barsalou, L.W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645.

Barsalou, L.W., Dutriaux, L., & Scheepers, C. (2018). Moving beyond the distinction between concrete and abstract concepts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1752), 20170144. DOI: https://doi.org/10.1098/rstb.2017.0144

Barsalou, L.W., Santos, A., Simmons, W.K., & Wilson, C.D. (2008). Language and simulation in conceptual processing (pp. 245–284). In: M. De Vega, A.M. Glenberg, & A.C. Graesser (Eds.). *Symbols, embodiment, and meaning*. Oxford: Oxford University Press.

Bird, H., Howard, D., & Franklin, S. (2003). Verbs and nouns: The importance of being imageable. *Journal of Neurolinguistics*, *16*, 113–149.

Boleda, G. (2020). Distributional semantics and linguistic theory. *Annual Review Linguistics*, *6*, 213–234. DOI: 10.1146/annurev-linguistics-011619-030303.

Borghi, A.M. & Binkofski, F. (2014). Words as social tools: An embodied view on abstract concepts (= *Briefs in Cognition series*). New York: Springer.

Casasanto, D. & Boroditsky, L. (2008). Time in mind: Using space to think about time. *Cognition*, *106*, 579–593.

Clark, S. (2015). Vector space models of lexical meaning (pp. 493–522). In: S. Lappin & C. Fox (Eds.). *The handbook of contemporary semantic theory*. Hoboken: Wiley-Blackwell.

Connell L. & Lynott, D. (2013). Flexible and fast: Linguistic shortcut affects both shallow and deep conceptual processing. *Psychonomic Bulletin & Review*, *20*, 542–550.

Crepaldi, D., Aggujaro, S., Arduino, L.S., Zonca, G., Ghirardi, G., Inzaghi, M.G., Colombo, M., Chierchia, G., & Luzatti, C. (2006). Noun–verb dissociation in aphasia: The role of imageability and functional location of the lesion. *Neuropsychologia*, *44*, 73–89.

Dijkstra, K., Eerland, A., Zijlmans, J., & Post, L.S. (2014). Embodied cognition, abstract concepts, and the benefits of new technology for implicit body manipulation. *Frontiers in Psychology*, *5*, 757. DOI: 10.3389/fpsyg.2014.00757.

Dove, G. (2014). Thinking in words: Language as an embodied medium of thought. *Topics in Cognitive Science*, *6*, 371–389.

Fodor, J.A. (1975). *The language of thought*. Cambridge: Harvard University Press.

Frege, G. (1892). Über Sinn und Bedeutung. *Zeitschrift für Philosophie und philosophische Kritik*, *100*, 25–50.

Gallese, V. (2009). Motor abstraction: A neuroscientific account of how action goals and intentions are mapped and understood. *Psychological Research*, *73*, 486–498.

Gallese, V. & Lakoff, G. (2005). The brain's concepts: The role of the sensory–motor system in reason and language. *Cognitive Neuropsychology*, *22*, 455–479.

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

Glenberg, A.M. (2010). Embodiment as a unifying perspective for psychology. *Cognitive Science*, *1*, 586–596.

Glenberg, A.M. & Robertson, D. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory and Language*, *43*(3), 379–401.

Harnad, S. (1990). The symbol grounding problem. *Physica D: Nonlinear Phenomena*, *42*, 335–346.

Harris, Z. (1954). Distributional structure. *Word*, *10*(23), 146–162.

Huang, H.-W., Lee, C.-L., & Federmeier, K.D. (2010). Imagine that! ERPs provide evidence for distinct hemispheric contributions to the processing of concrete and abstract concepts. *NeuroImage, 49*(1), 1116–1123.

Hurley, S. (2008). The shared circuits model (SCM): How control, mirroring, simulation can enable imitation, deliberation, and mindreading. *Behavioral and Brain Sciences*, *31*, 1–58.

Johns, B.T. & Jones, M.N. (2012). Perceptual inference through global lexical similarity. *Topics in Cognitive Science*, *4*, 103–120.

Katz, R.B. & Goodglass, H. (1990). Deep dysphasia: Analysis of a rare form of repetition disorder. *Brain and Language*, *39*, 153–185.

Kousta, S.T., Vigliocco, G., Vinson, D.P., Andrews, M., & Del Campo, E. (2011). The representation of abstract words: Why emotion matters. *Journal of Experimental Psychology: General*, *140*, 14–34.

Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind*. Chicago: University of Chicago Press.

Lakoff, G. & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

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

Lenci, A. (2018). Distributional models of word meaning. *Annual review of Linguistics*, *4*, 151–171.

Louwerse, M. (2011). Symbol interdependency in symbolic and embodied cognition. *Topics in Cognitive Science*, *3*, 273–302.

Lund, K. & Burgess, C. (1996). Producing high-dimensional semantic spaces from lexical co-occurrence. *Behavior and Research Methods, Instruments, & Computers*, *28*, 203–208.

Lupyan, G. & Winter, B. (2018). Language is more abstract than you think, or, why aren't languages more iconic?. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1752), 20170137. DOI: https://doi.org/10.1098/rstb.2017.0137.

Machery, E. (2009). *Doing without concepts*. New York: Oxford University Press.

Martin, N. & Saffran, E.M. (1990). Repetition and verbal STM in transcortical sensory aphasia: A case study. *Brain and Language*, *39*, 254–288.

Ostarek, M. & Huettig, F. (2019). Six challenges for embodiment research. *Current Directions in Psychological Science*, *28*(6), 593–599. DOI: https://doi.org/10.1177/0963721419866441.

Paivio, A. (1971). *Imagery and verbal processes*. New York: Holt, Rinehart and Winston.

Paivio, A. (1986). *Mental representations: A dual-coding approach*. New York: Oxford University Press.

Paivio, A. (2013). Dual coding theory, word abstractness, and emotion: A critical review of Kousta et al. (2011). *Journal of Experimental Psychology: General*, *142*, 282–287.

Papagno, C., Fogliata, A., Catricala, E., & Miniussi, C. (2009). The lexical processing of abstract and concrete nouns. *Brain Research*, *1263*, 78–86.

Price, C.J. (2009). The anatomy of language: A review of 100 fMRI studies published in 2009. *Annals of the New York Academy of Sciences*, *1191*, 62–88

Sabsevitz, D., Medler, D., Seidenberg, M., & Binder, J. (2005). Modulation of the semantic system by word imageability. *Neuroimage*, *27*, 188–200.

Schwanenflugel, P.J. (1991). Why are abstract concepts hard to understand? (pp. 223–250). In: P.J. Schwanenflugel (Ed.). *The psychology of word meanings*. Hillsdale: Lawrence Erlbaum Associates.

Shapiro, L. (2011). *Embodied cognition*. New York: Routledge.

Wang, J., Conder, J.A., Blitzer, D.N., & Shinkareva, S.V. (2010). Neural representation of abstract and concrete concepts: a meta-analysis of imaging studies. *Human Brain Mapping*, *31*, 1459–1468.

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

Wilson-Mendenhall, C.D., Barrett, L.F., Simmons, W.K., & Barsalou, L.W. (2011). Grounding emotion in situated conceptualization. *Neuropsychologia*, *49*, 1105–1127.

Wilson-Mendenhall, C.D., Simmons, W.K., Martin, A., & Barsalou, L.W. (2013). Contextual processing of abstract concepts reveals neural representations of non-linguistic semantic content. *Journal of Cognitive Neuroscience*, *25*, 920–935.