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Six challenges for embodiment research

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Abstract:

20 years after Barsalou's seminal perceptual symbols paper (Barsalou, 1999), *embodied cognition*, the notion that cognition involves simulations of sensory, motor, or affective states, has moved in status from an outlandish proposal advanced by a fringe movement in psychology to a mainstream position adopted by large numbers of researchers in the psychological and cognitive (neuro)sciences. While it has generated highly productive work in the cognitive sciences as a whole, it had a particularly strong impact on research into language comprehension. The view of a mental lexicon based on symbolic word representations, which are arbitrarily linked to sensory aspects of their referents, for example, was generally accepted since the cognitive revolution in the 1950s. This has radically changed. Given the current status of embodiment as a main theory of cognition, it is somewhat surprising that a close look at the state of the affairs in the literature reveals that the debate about the nature of the processes involved in language comprehension is far from settled and key questions remain unanswered. We present several suggestions for a productive way forward.

Key words: Embodiment, cognition, language, conceptual processing

Since Barsalou's seminal perceptual symbols paper (Barsalou, 1999), a large literature has emerged that addresses the extent to which the evolutionarily old sensory, motor, and affective systems are involved in high-level cognition (Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012). Whereas various flavors of embodiment have been proposed (Wilson, 2002), we focus on the notion of 'simulation', the activation of sensory states that resemble those active during action/perception, as a crucial cognitive mechanism. Here, we discuss six challenges for embodiment from the perspective of language processing, but our arguments are applicable to the field as a whole.

DEVELOPING DECISIVE PARADIGMS

In order to develop good theories of embodiment we need paradigms that directly probe the hypothesized perceptual processes. Large parts of the embodiment literature and the ensuing theoretical claims are based on congruency effects between aspects of linguistic and pictorial stimuli or actions. In the classic sentence-picture verification paradigm (SPV), sentences implying an object to be in a certain shape lead to faster responses to pictures of objects in congruent vs. incongruent shapes (Zwaan, Stanfield, & Yaxley, 2002). Congruency effects are important because they are straightforwardly predicted from embodied cognition accounts but appear counterintuitive based on symbolic amodal theories. Basic congruency effects however do not allow us to arbitrate between embodied and amodal accounts because language and picture stimuli/actions all involve multiple processing stages, and based on accuracy rates and reaction times (RTs) it is impossible to know at what stage interactions arise (Mahon & Caramazza, 2008). An alternative to the simulation-based interpretation of the SPV results (Zwaan et al., 2002) is that comprehenders extract abstract shape information from the sentences and pictures which are represented in a symbolic conceptual module and

hence a congruency effect arises. Standard congruency paradigms are useful to establish the informational content that is activated, but they cannot determine the nature of the underlying processes.

One way to circumvent the interpretational ambiguity of congruency effects is to create situations where stimuli (that language is predicted to interact with) are only processed at the level of interest, for instance the visual level. However, many seemingly perceptual tasks involve high-level categorization processes and common masking techniques, such as backward masking, do not consistently preclude semantic processing (Kouider & Dehaene, 2007). A technique that can overcome this problem is continuous flash suppression (CFS), as detection in CFS depends on how efficiently visual features of suppressed pictures are processed.

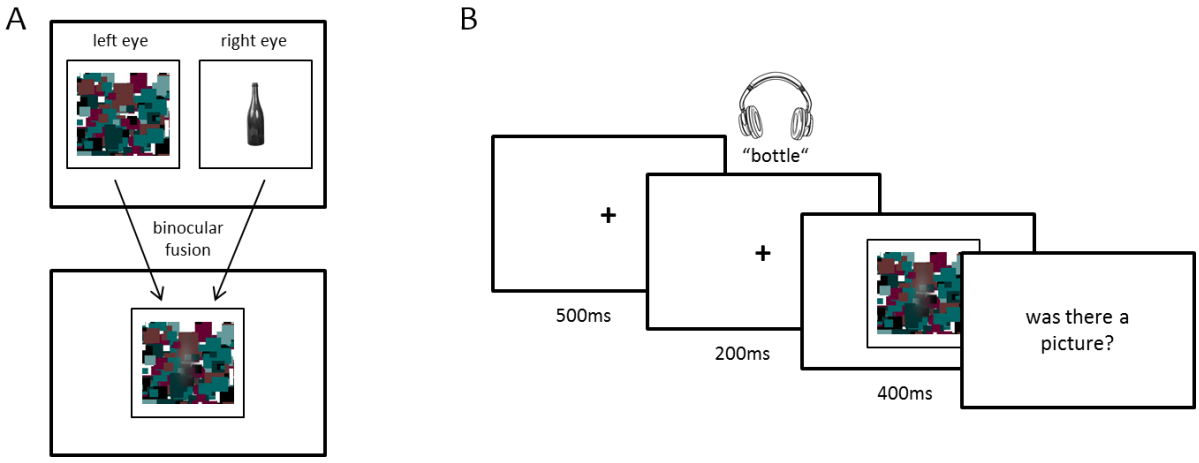

Figure 1. Continuous flash suppression. A) A static image of an object is presented to one eye, a dynamic mask is presented to the other. This leads to suppression of the object the strength of which can be set to individual participants' visibility threshold. B) This makes it possible to test the effect of processing congruent vs. incongruent words on detection sensitivity. Adapted from Ostarek & Huettig, 2017.

Two recent studies showed that hearing spoken words increases detection sensitivity to congruent pictures in CFS, suggesting that language modulates early stages of conscious vision

(Lupyan & Ward, 2013; Ostarek & Huettig, 2017b). The finding that language can modulate detection in CFS constitutes much stronger evidence for the view that semantic processing engages perceptual processes. In short, for congruency paradigms to be informative about embodiment great care needs to be taken to isolate the processes of interest. CFS is a promising method in this context and we propose that it should become the benchmark test of visual simulation.

PROBING CAUSALITY

Evidence for a causal link between simulation and language comprehension must be the gold standard for assessing embodied accounts. Interference paradigms are one way to probe causality. Converging evidence suggests that visual noise interferes with access to visual information during word processing, at least in some tasks: Visual noise makes word cues less effective with regard to visual (e.g., "is it round?") but not categorical semantic information (e.g., "is it furniture?") in word-picture verification (Edmiston & Lupyan, 2017), and it slows down responses to highly imageable concrete nouns compared to abstract nouns (Ostarek & Huettig, 2017a) in a concreteness task (where visual information is relevant) but not in a lexical decision task (LDT) and a word class judgement task (where visual information is not relevant). Causal evidence for the role of simulation in language comprehension beyond single words is still missing. A recent study that tested the effect of different types of visual interference on the shape match effect in the SPV paradigm suggests limits for a causal role (Ostarek, Joosen, Ishag, De Nijs, & Huettig, 2019), but further research is needed to determine which types of processes are active in SPV.

Transcranial magnetic stimulation (TMS) is a particularly useful neuroscientific method for probing causality in the motor domain. Given that it is easy to localize effector-specific motor areas and TMS affords precise control of timing, surprisingly little work has been published. Facilitatory effects on RTs in a LDT were obtained by using two-pulse TMS on primary motor cortex (M1) (Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005) and by offline TMS on premotor cortex (Willems, Labruna, D'Esposito, Ivry, & Casasanto, 2011). In contrast, another study observed interference of four-pulse TMS on M1 on RTs in a concreteness task and no robust effects in a LDT (Vukovic, Feurra, Shpektor, Myachykov, & Shtyrov, 2017). Thus, the available evidence does not paint a clear picture of the conditions in which facilitation, interference, or no effect is expected. Given the replication crisis in psychology (Zwaan, Etz, Lucas, & Donnellan, 2018), a crisis from which some well-known embodied cognition effects in the literature have not been exempt, a large scale pre-registered multi-lab effort applying TMS to probe causality of embodied language processing would be particularly fruitful.

UNDERSTANDING THE TASK-DEPENDENCY OF EMBODIED LANGUAGE PROCESSING

Similarly important is the systematic study of task and context effects. The available evidence strongly suggests that semantic processing is not an automatic process (Lebois, Wilson-Mendenhall, & Barsalou, 2015). Instead, contextual factors, such as the current task requirements, can lead to surprising situations where, for instance, the word "red" primes a green target more than a red target (Merikle, Joordens, & Stolz, 1995). Importantly, recent studies have begun to delineate the situations in which sensory processes are causally involved in language comprehension. The emerging picture is that visual and motoric processes are functionally relevant in situations where visual and motor information is

required by the task (Edmiston & Lupyan, 2017; Ostarek & Huettig, 2017a; Tomasino, Fink, Sparing, Dafotakis, & Weiss, 2008; Vukovic et al., 2017).

A crucial issue thus arises: To what extent does embodied language processing occur routinely? Different contexts make different aspects of (word) meanings relevant (Estes & Barsalou, 2018). It is conceivable that simulations are specifically tailored to fit those dynamic contextual demands. Nevertheless, it is apparent that most of the causal evidence stems from experiments that directly probe sensory properties of word referents. How representative are such tasks of the processes that are activated during everyday communication? A deflationary possibility is that sensory processes are only important in rare situations where one consciously reasons about sensory aspects of word meanings. On the other hand, knowledge of perceptual information is likely required in most communication situations, as people often talk about things in the here and now. It is thus necessary for future research to go the extra mile and conduct experiments in naturalistic settings to establish to what extent simulations are a routine part of language processing "in the wild" and to what extent semantic context determines the deployment of simulations.

EXPLICIT PREDICTIONS ABOUT THE DIRECTION AND TIMING OF EFFECTS

Lacking predictions about the direction of an effect typically reflects that the tested theory is not specific enough, leading to a situation where opposite experimental outcomes are interpreted as evidence for the theory. For example, Connell (2007) used a SPV experiment to test whether "mentally representing something *red* engages the neural subsystems that respond to environmental perception of that colour" and observed that pictures that *mismatched* the color implied in sentences led to reduced RTs. Several other investigators

obtained the more intuitive finding that a *match* leads to shorter RTs (e.g., Mannaert, Dijkstra, & Zwaan, 2017). All authors concluded that color is simulated during language comprehension (though see Zwaan & Pecher, 2012 for a nuanced discussion). The fact that opposing outcomes are interpreted as supporting the same claim raises serious issues about falsifiability (Popper, 2005) that can only be overcome by theories that commit to specific claims about the nature and timing of the hypothesized mechanisms, and about how these play out in a given experimental paradigm.

This is not only necessary but also achievable. Many studies have investigated the effects of words with vertical spatial associations (e.g., *cloud* is up, *foot* is down) on visual detection and discrimination tasks involving targets in up/down locations (Gozli, Chasteen, & Pratt, 2013). Implicit up/down words tend to interfere with targets in compatible locations in discrimination tasks when words and targets are semantically unrelated and targets appear within 400ms after the word, whereas facilitation is observed in detection tasks, when the time between words and targets is longer than 400ms, or when semantically related words/targets are used (Estes & Barsalou, 2018; Gozli et al., 2013). A theoretical account that explains the direction and timing of effects is that words trigger visual simulations of typical events in visual-spatial systems (Ostarek & Vigliocco, 2017). The theory predicts that in this paradigm parts of mental space (top/bottom) are attended to and temporarily occupied by simulated objects for ca. 400ms (the typical semantic processing duration for single words). Thus, interference is predicted when the simulated object is incompatible with a to-be-identified visual target but facilitation is predicted when it is compatible. This is precisely what recent behavioral studies observed (Estes, Verges, & Adelman, 2015; Ostarek & Vigliocco, 2017). Further evidence demonstrated that initial vertical attention shifts and

facilitation/interference due to a match/mismatch of the simulated and observed object are reflected sequentially in saccade trajectories (Ostarek, Ishag, Joosen, & Huettig, 2018).

THE NEED FOR AN ALL-ENCOMPASSING THEORY

Embodied accounts make a good case for language processing about concrete objects and situations, but a convincing case for how abstract concepts fit into the picture has not been made (Borghi et al., 2017; Dove, 2016). For instance, it is unlikely that a sentence such as "dignity is a basic right" will be fully captured by sensorimotor simulation, by the emotions associated with it (Kousta, Vigliocco, Vinson, Andrews, & Del Campo, 2011), or by activating a concrete domain with partially overlapping features (Lakoff & Johnson, 2008). More generally, embodiment does not provide an intuitive account of those aspects of conceptual processing that depend on high degrees of abstraction from specific events. Recognizing that simulation is not a suitable solution for certain aspects of semantic cognition, such as abstraction, thematic relationships, or fast linguistic associates, pluralistic accounts have recently been proposed where amodal and grounded (modal) representations co-exist and engage in a division of labor (e.g., Zwaan, 2014). In a particularly promising line of research, scientists have begun to unravel the hierarchical organization of conceptual content in the brain and posited a pivotal role for multimodal abstraction in association areas (Binder, 2016; Fernandino et al., 2016; see also Barsalou, Dutriaux, & Scheepers, 2018).

However, this is a slippery slope because the need to ground symbols in sensory-motor systems does not disappear and hide while towers of abstraction are erected. The main challenge for embodied theories of language remains to provide a coherent account of abstraction whilst taking sensorimotor grounding seriously. This is most likely to succeed in

models whose core principles naturally afford abstraction capacities, rather than models where multiple qualitatively different systems co-exist.

ASSESSING EMERGING THEORIES WITH NOVEL NEUROIMAGING METHODS

Novel neuroimaging techniques can be highly valuable as new theories emerge. A particularly promising tool is multivariate pattern analysis (MVPA) which can be exploited to ask hypothesis-driven questions about the information reflected in activation patterns. For instance, Anderson and colleagues compared a visual model and a text-based model in their capacity to predict activation patterns elicited by written words (Anderson, Bruni, Lopopolo, Poesio, & Baroni, 2015) and demonstrated that patterns in the visual and ventral-temporal cortex reflected visual features of the word referents that participants were thinking about.

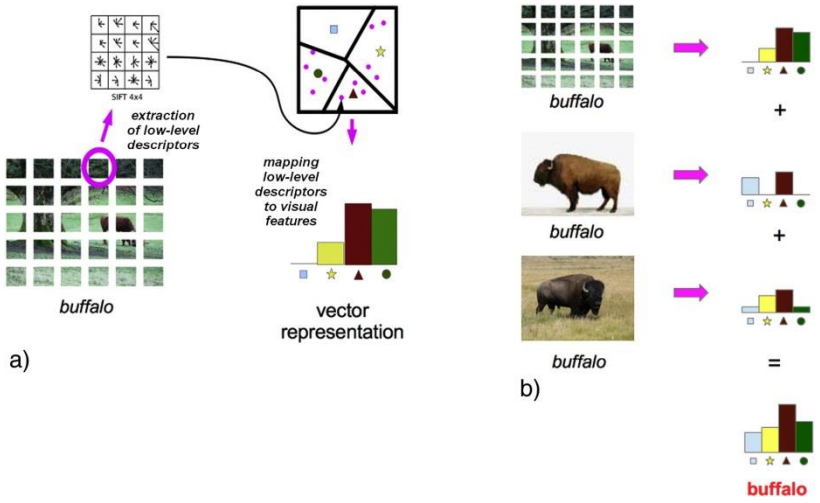

Fig. 2. a) Representation of a single image. Low-level features of images are extracted and then discretized by mapping them to a set of higher-level visual features (that have been determined in advance by clustering low-level descriptors from a larger image collection). The image is represented by a vector that records (a function of) how often each visual feature occurs in it. (b) Visual representation of a concept. Given a set of images depicting the same concept (e.g., a *buffalo*), the concept representation is obtained by summing the vectors representing all the input images. From Anderson et al. (2015).

In a similar spirit, Borghesani and colleagues (2016) demonstrated that the real-world object size of word referents is reflected in activity patterns in early visual cortex, whereas categorical semantic structure was reflected in anterior temporal regions.

Intracranial recordings deliver high temporal and spatial resolution that, in combination with MVPA, can be used to put specific hypotheses to the test. In rare cases, MVPA can be done at the single neuron level making it possible to test whether sensory-motor neurons are also tuned to sensory-motor aspects of word meanings (Yang et al., 2017), which constitutes a direct test of the simulation hypothesis in its strongest form.

Working memory and imagery have recently been found to share activity patterns with visual processing in the visual cortex (Harrison & Tong, 2009). A recent lamina-resolved functional magnetic resonance imaging study (Lawrence et al., 2018) suggests that bottom-up signals about the orientation of gratings predominantly reach layer 4 of the primary visual cortex, whereas top-down imagery signals target the deep and superficial layers.

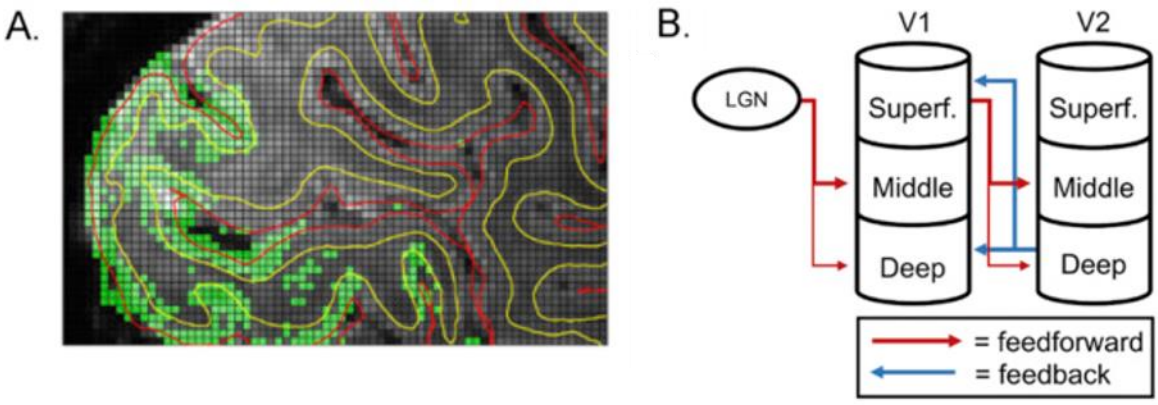

Figure 3. (A) Sagittal slice of a functional volume. The black grid shows the size and location of 0.8 mm isotropic functional voxels. Gray-white matter (yellow line) and gray matter-cerebrospinal fluid (red line) boundaries are overlaid onto the volume, showing the distribution of functional voxels across cortical depths. (B). Schematic representation of the feedforward (red arrows) connections between human LGN, V1 and V2 and feedback (blue arrows) connections between V1 and V2. V1 and V2 are split into superficial, middle and deep gray matter layers to demonstrate how laminar fMRI can be used to estimate feedforward and feedback responses by measuring layer-specific responses. Adapted from Formisano, Muckli, & de Lange (2017).

The dissociation between bottom-up and top-down signals was specific to primary visual cortex; in the subsequent regions of the visual pathway all layers were activated to the same extent. Extrapolating to simulation in language comprehension, this could be taken as an upper bound on the similarity between perception and simulation: The lowest processing stage targeted by simulation signals is expected to dissociate from sensory processing at the laminar/neural level, but activation patterns may be shared in subsequent processing stages. The types of simulated features are likely to determine which regions are targeted by simulations.

SUMMARY

Embodiment research faces important challenges including a shift towards more decisive paradigms allowing the field to pinpoint the situations in which sensorimotor processes contribute functionally to language comprehension. Whilst improved behavioral and neuroimaging approaches can go a long way, theoretical progress will be crucial to transform embodiment from a underspecified general framework of related ideas to a fully specified complete theory of semantic cognition from which precise experimental predictions can be derived.

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Endnotes:

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Recommended readings

Anderson, A. J., Bruni, E., Lopopolo, A., Poesio, M., & Baroni, M. (2015). (See references).

This study demonstrated that activity patterns in high-level visual brain regions elicited by words can be predicted by image-based models that extract visual information from natural image statistics.

Barsalou, L. W. (1999). (See references).

This classic paper spells out many of the key issues and questions that are still central aspects of current empirical and theoretical efforts today.

Zwaan, R. A. (2014). (See references).

An opinion paper proposing a pluralistic view of conceptual processing where different types of representations (such as embodied and amodal) engage in a division of labor.

Meteyard, L., Cuadrado, S. R., Bahrami, B., & Vigliocco, G. (2012). (See references).

A great review that stresses which perspectives on embodiment are most likely to succeed.

Mahon, B. Z., & Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. Journal of physiology-Paris, 102(1-3), 59-70.

A great reminder that alternative explanations (other than embodiment) can account for much of the empirical evidence and should thus not be ruled out to quickly.