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Language-induced mental simulation

Abstract

Researchers in the embodied approach to psycholinguistics have proposed that people understand language by mentally simulating what the language (e.g. sentences) is about. This paper explains this hypothesis, outlines what experimental evidence exists to support this, and addresses the limits of simulation-based accounts to language understanding.

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1. Introduction

Recently there has been increasing evidence in the fields of cognitive science and neuroscience for what is termed mental simulation: a theory of how information is conceptualised in the mind.

Embodied approaches to language comprehension argue that language input subconsciously induces mental simulation, in which traces of a person's prior sensorimotor experiences during interaction with the world become re-activated in the areas of the brain where perception takes place (Barsalou, 2008; Barsalou et al., 2003 [cited in Castaño & Carrol, 2020]).

The idea of mental simulation was initially lacking in empirical evidence, and Barselou's (1999) proposal was based on a Gedankenexperiment (thought experiment). Recently, converging evidence of mental simulation has emerged as researchers have devised a range of experimental techniques for testing this theory, including sentence-picture verification tasks (e.g., Stanfield & Zwaan, 2001) and eye-tracking studies (e.g., Castaño & Carrol, 2020), much of which is supported by neuroimaging.

Previously it was thought that there was an arbitrary relationship between symbols and their referents (an amodal system). This contrasts with a perceptual symbol system, in which the relationship is said to be analogue (Barselou, 1999) and a simulation is the mental representation of an object reflecting a wide range of its physical characteristics (Stanfield & Zwaan, 2001) including shape, orientation and colour.

There is evidence that challenges the amodal system (Glaser, 1992; Seifert, 1997) including neural studies that have shown that conceptual symbols and processing are grounded in the brain’s sensory-motor regions (Barselou, 1999). Furthermore, amodal symbols have no relationship to human experience, “are floating free in some mental ether and are therefore essentially meaningless” (Zwaan & Pecher, 2012:1).

This paper offers a synthesis of the key evidence to explain the hypothesis around language-induced mental simulation-based accounts of language understanding. I discuss a series of experimental and neuroimaging studies that present findings in line with the hypothesis. Section two is concerned with the visual component of simulation, a salient area, since this component is multifaceted, and considering some of these visual properties helps to create a clearer picture of what constitutes mental simulation; section three addresses other modalities, such as the auditory component; section four turns to grammatical properties found to play a role in simulation, such as verbal aspect; and section five explores the literal-metaphorical dichotomy. Finally, section six presents some counter-arguments.

2. Empirical Evidence for the Visual Component of Mental Simulation

Evidence from both experimental studies, including behavioural and eye-tracking research, and from neuroimaging studies exists in support of the visual dimension of mental simulation. This section summarises some of this research.

2.1 Orientation

Stanfield and Zwaan (2001) tested the hypothesis that language comprehenders mentally represent an object’s orientation (horizontally or vertically) based on language input. Participants read sentences that implied the orientation of an object, such as *He hammered the nail into the wall* (horizontal orientation) versus *He hammered the nail into the floor* (vertical orientation). Next, pictures were presented which either matched or mismatched the orientation of the sentences. By using different keys on a keyboard – one for "yes" and one for "no" – participants responded to each picture, deciding whether it contained an item mentioned in the previous sentence. Reaction times were measured. It was found that response times were faster for picture-sentence matches, i.e., for pictures that matched the orientation of that implied in the sentence, than for mismatches. This is consistent with Barselou's (1999) perceptual symbol system.

Pecher et al. (2009) replicated the experiment but with an added twist. This time there was delay between the sentences being read and the pictures being shown in order to avoid the potential for strategic imagery being employed by participants – the results of the previous study may have been influenced by participants consciously attempting to visualise the objects in the sentences rather than the results providing evidence for unconscious mental simulation. Although Stanfield and Zwaan (2001) had addressed this potential participant strategy in a post hoc analysis, this follow-up study provides more compelling evidence against the use of a strategy since the results of this study are comparable with the previous study.

A future replication study was conducted by Zwaan & Pecher (2012). Although the original results were replicated, the effect was significant only because data were taken from such a large sample. They attempt to explain this as orientation being "mostly elaborative in nature" and that it "has no causal or goal-relevance" to language comprehenders who "use causal and goal information to forge coherent mental representations of the incoming text." (p. 8)

Overall, although there appears to be an influence of orientation on mental simulation, the evidence suggests it may not be as prominent in simulations as some other sensory aspects. Chen, de Koning & Zwaan (2020) attempt to explain this. They hypothesised that the orientation effect match advantage should be greater for larger non-manipulable objects than for small manipulable objects. However, their findings contradicted their hypothesis.

As part of this same study, they conducted an experiment to test the orientation effect in several languages: Dutch, Chinese and English. Interestingly, it was found that the orientation effect differs across these languages: the effect was the greatest in Chinese, but completely absent in Dutch. Despite this, it remains limited evidence to satisfactorily conclude that the orientation effect is different for speakers of different language backgrounds since the effect in more languages warrants investigation.

2.2 Shape

Following on from the study on orientation in mental simulation, Zwaan, Stanfield and Yaxley (2002) carried out a similar experiment, this time exploring shape. Again, this was a sentence-picture task. Participants read sentences that implied the shape of an object, such as *The ranger saw the eagle in the sky,* which implicitly suggests the eagle is flying and therefore open-winged. This contrasts with *The ranger saw the eagle in its nest*, which implies a closed-winged eagle. It is important to stress that the actual shape of the bird is not directly stated. As in the experiment on orientation, participants read a sentence and then viewed a picture that either matched or mismatched the object in the sentence before determining whether the item in the picture had been mentioned in the sentence. The responses for mismatched shape and picture were slower than the responses for matched shape and picture, which lends support for the hypothesis in question. This finding is supported by replications made by Pecher et al. (2009) and by Zwaan & Pecher (2012), who actually found the influence of shape much stronger than that of orientation. Their explanation for this is that shape tends to be more relevant to the action that a sentence depicts. They exemplify with a live chicken versus a fried one, which are quite different things, and such information, i.e., about shape, is necessary for categorisation than is information about orientation. This is likely the reason that shape appears to be a more robust visual dimension in mental simulations than orientation.

Finally, Lincoln, Long & Baynes (2007) provide supporting neuroimaging evidence for shape. Briefly that the right cerebral hemisphere activates explicit shape information during sentence comprehension and the left cerebral hemisphere activates for both explicit and implicit shape information. This seems to suggest that, although explicit shape information provides much stronger mental simulation, implicit information also plays a role in language understanding.

2.3 Colour

A third property that has been widely explored in the literature is that of colour, albeit with mixed and even contradictory findings. Connell (2007) explored the representation of colour in mental simulations by conducting sentence-picture tasks. She chose sentences such as *John looked at the steak on his plate*, which implies brown versus *John looked at the steak in the butcher's window,* which suggests red, with the hypothesis being responses would be faster in the match condition. Participants were asked whether the object depicted in the picture was mentioned in the preceding sentence. Interestingly, the findings of these experiments differed quite significantly from the findings of orientation and shape. She found that responses were faster when the colours mismatched rather than when they matched. This suggests that colour may be represented differently from other properties such as shape and orientation.

Contrastingly, Zwaan & Pecher (2012), supported by Hoeben Mannaert, Dijkstra & Zwaan (2017), found a match quite the opposite of those findings obtained by Connell, suggesting that colour may be an unstable property in mental simulation. Of note, Connell (2005), in her original colour experiment, actually proposed a distinction be made between stable and unstable embodied representations to allow for this inconsistency.

A number of key pieces of converging evidence exist to address the problem of colour. For instance, Proverbio et al. (2004) provide electrophysiological evidence for the dominance of shape over colour. In fact, Wilcox (1999) points out that colour is only a secondary property of objects compared to primary properties such as shape and size, and that young infants identify objects based on these primary properties as they are unable to rely on colour as a tool for identification until almost the age of one. An additional explanation proposed by Tanaka, Weiskopf & Williams (2001) for colour being less significant in mental simulations is due to the fact it is unimodal, i.e., it can only be represented visually, unlike shape which can also contributes to tactile recognition. Finally, Vandenbeld & Rensink (2003), in a study on decay characteristics of object properties in visual short-term memory, found that memories for an object's colour decay much more quickly than they do for shape and size.

In spite of some clearly convincing sentence-picture match advantage results suggesting colour is indeed a component of mental simulation, it appears to remain undecided as to what extent and how consistently it is represented.

2.4 Location and motion

Bergen et al. (2007) conducted a visual object categorisation task to investigate whether language that implies a particular location in the visual field is a component of mental simulation. For example, *The cellar flooded* implies a location in the lower part of the visual field, whereas *The sky darkened* implies the upper part. Part of this study also included experiments on language suggestive of upward and downward motion as well as literal versus metaphorical location and motion. The results obtained showed that subject nouns or main verbs can trigger visual imagery, although this appears only to be when the sentence denotes literal space rather than metaphorical space. People also seem to mentally represent the locations of objects in space. These findings are supported by Liu and Bergen (2015) and by eye-tracking evidence (Spivey & Geng, 2001).

Kaschak et al. (2005) obtained more unusual findings. Participants made judgments about sentences that described motion in a particular direction such as *The horse ran away from you* (movement away) versus *The storm clouds rolled in* (movement towards) and *You raised the flag* (movement upwards) versus *You lowered the blinds* (movement downwards). In addition to this, however, the task was more complex, since the participants simultaneously watched dynamic stimuli that produced the perception of movement either in the same direction as the action specified in the sentence or in the opposite direction. Interestingly, responses were faster to sentences presented with a visual stimulus indicating motion in the opposite direction as the action described in the sentence. This mismatch initially appears to complicate matters. However, the authors propose a logical explanation for this, in that there is a conflict between the cognitive demands of processing the visual information simultaneously with the demands of constructing a mental simulation based on a language stimulus.

Overall, the evidence suggests location and motion is part of mental simulation albeit with some constraints such as concurrent processing demands and the nature of the linguistic input.

2.5 Distance, speed and visibility

Other visual components have been explored. These include a study of distance (Winter & Bergen, 2014), the results of which lend themselves well to the immersed experiencer view, which argues that a language comprehender can experience that very same scene as the protagonist depicted in the sentence including distance and perspective.

Van Dam et al. (2017) provide evidence for the presence of speed as a component in mental simulation even though fast motion events are represented more visually than events at slow speeds. This is supported by converging evidence from eye-tracking studies (Lindsay, Scheepers & Kamide, 2013; Speed, L. & Vigliocco, G., 2014).

Finally, Yaxley & Zwaan (2007) investigated visibility, providing evidence for the fact language comprehenders simulate the perceptibility of objects in their environmental contexts. This is consistent with Horton & Rapp (2003) whose investigation into the same phenomenon, but in the context of narrative, concluded that comprehenders encode linguistic information from the same perceptual perspective of protagonists in a story.

In summary, I have presented a number of studies that lend support to the hypothesis that language input induces mental simulation of a visual nature. However, research shows that mental simulation is not only a visual phenomenon, which I will now address.

3. Multimodality in Mental Simulation

Thus far, the studies cited have focussed exclusively on the visual domain of mental simulation. After these earlier studies, researchers began to become interested in other modalities that constitute mental simulation. This section addresses some of the key studies in this area.

Brunyé et al. (2010) investigated whether language comprehenders simulate implied auditory information contained in language input. For this study, participants read sentences that implicitly carried information pertaining to auditory imagery e.g., *The chainsaw buzzed as it tore through the tree trunk* before completing an unrelated sound categorisation task involving the classifying of sounds as real-world sounds or fake, computer-generated sounds. The results showed that participants categorised sounds as real more quickly when they had been implied in the preceding sentence. These findings are supported by other sentence-sound tasks (Winter & Bergen, 2014) and studies involving Auditory Imagery Experiences (Alexander & Nygaard, 2008).

Barrós-Loscertales et al. (2012) provides neuroimaging evidence for the mental simulation of taste. The authors explored how words that carry a meaning related to taste influence the perception of taste in the language comprehender. This involved using functional magnetic resonance imaging (fMRI) to record cerebral activity during a reading task. A range of taste words and non-taste words (used as control) were selected and presented to participants. It was found that, although all of the presented words activated the left inferior frontal and the posterior middle and superior temporal gyri, the taste-related words alone not only activated these areas much more strongly, they also produced activation in the anterior insula, frontal operculum, lateral orbitofrontal gyrus, and thalamus. The significance of this is remarkable, as it is these very areas that house the primary and secondary gustatory cortices, and so this is strong evidence for the grounding of linguistic taste information in those brain areas that process taste sensations. Further support is found in Gonzáles at al. (2006).

The evidence presented here, along with Brunyé et al. (2012) who present evidence for tactile perception, adds weight to the richness of mental simulation in that it is a multimodal phenomenon. It is becoming much clearer now what actually constitutes mental simulation. In order to complete the picture, however, I will next address non-lexical properties.

4. Grammatical Properties Represented in Mental Simulation

Since grammatical information is usually considered an abstract concept unlike more concrete features such as shape, it may seem that mentally simulating grammatical features, unlike content words, impossible. Recent research leads us to form a different view. This section outlines a small sample of studies that have attempted to show how grammatical information is contained in simulations.

Experimental studies have led to evidence that, like content words, grammar can influence the content of a mental simulation. Bergen and Wheeler (2009) investigated the role of grammatical aspect in mental simulation. They contrasted progressive aspect sentences, e.g., *John is closing the drawer* with perfect aspect sentences, e.g., *John has closed the drawer* and hypothesised that progressive aspect sentences should focus mental simulation on the dynamic action itself, i.e., in this case, the act of pushing the drawer closed, and will therefore cause activation of the motor systems. In contrast, perfect aspect should provoke mental simulation on the result of the situation, i.e., the drawer in closed position, and, therefore not activate motor simulation. Essentially, this setup takes the focus away from the lexical content of the sentences. Notice both sentences do not differ lexically; the difference is merely aspectual.

To test this hypothesis, the authors employed the Action-sentence Compatibility Effect methodology (Glenberg & Kaschak, 2002), in which participants pressed buttons: the first button to display a stimulus sentence and then a second one to indicate whether they believed the sentence to be meaningful. This second button was in a position either closer to or farther from the participant’s body in order to force hand movement in a forward or backwards direction, since previous studies (such as Glenberg & Kaschak, 2002) have shown participants perform more quickly when motion implied in the stimulus matches the response arm motion, and this is a clue to the fact they have used the motor system to mentally simulate the same action as in the stimulus. Faster manual responses were recorded when the direction of the response was the same as the direction of motion described in the stimulus. However, for perfect sentences no such effect was found. They concluded that comprehending progressive aspect input triggers the mental simulation of the dynamics of the event, whereas prefect aspect has no such effect.

Supporting studies on the role of grammar in simulations include pronoun modulation of perspective (Brunyé et al., 2009) and the interaction between syntax and semantics in comprehension (Kaschak & Glenberg, 2000).

Our picture of mental simulation is now rich: we have seen that mental simulation is not only lexically determined, but grammatically too. Nevertheless, there remains the question of other aspects of grammar. Research has tended to focus on a narrow set of grammatical features, but in order to fully support the hypothesis, there are many other features that remain to be explored, e.g., temporal representation: how tenses are represented in simulations, if at all; recursion: whether the comprehension of subordination is aided by mental simulation; and direct speech in a written text: do we simulate speech as if it is being spoken? Until more of these questions are answered, the idea that mental simulation supports the comprehension of grammatical information remains tentative.

5. The Strange Case of Metaphorical Language

Much of what has been described so far has involved literal language. But not all language is literal; in fact, much of it is metaphorical. This section explores the issue of whether mental simulation can account for this.

Bergen (2005) presents a trio of experiments that tested spatial language processing of literal and metaphorical sentences. The experiments focused on verbs, nouns, and metaphorical language respectively. Each experiment started by participants looking at a screen with a fixation cross quickly flashing up before a sentence being heard. Following this, a circle or a square momentarily appeared in one of the quadrants of the screen. Participants identified the shape with a button press (Z for circle; X for square) and their reaction time was measured (the independent variable). Bergen hypothesised that if the participants perform visual simulation in processing these types of sentences, then interference should occur when sentence direction matches the object location, i.e., hearing a sentence indicating upwards motion should make it more difficult to immediately designate an object appearing in an upper quadrant. The results of the experiments involving verbs and nouns that denoted literal movement confirmed this hypothesis. Contrastingly, when the sentence carried metaphorical meaning (e.g., *The prices rose*), no interaction occurred between the described sentence direction and the object location. It was thus concluded that the metaphorical uses of nouns and verbs do not evoke mental simulation in the same way literal meanings do. These findings are supported in a replication study (Bergen et al., 2007) and by neuroimaging (Schuil, Smits & Zwaan, 2013) which found that literal action verbs engage the brain's motor regions to a higher degree than non-literal action verbs.

In spite of the above evidence, Castaño & Carrol (2020) present contradictory findings based on an eye-tracking study, which found metaphorical language to indeed induce simulation of upward and downward motion. Even more surprisingly, it was discovered that the eye-movements made during semantic processing of motion were even more conspicuous for metaphorical compared to literal sentences. This kind of conflicting evidence paints an unclear picture as to the presence of metaphorical language in mental simulations. If indeed it is not, then the hypothesis for mental simulation playing a strong role in language comprehension is weakened, since a lot of language input is indeed metaphorical yet still comprehensible. Consequently, I next present evidence that suggests mental simulation may not have such a crucial role as the evidence has led us to believe.

6. Dissenting Views

The evidence presented so far has centred around an embodied theory of cognition, i.e., grounding by interaction, which involves the cerebral activation of sensorimotor areas. This should mean that if these areas are damaged, language comprehension would surely be impoverished, suggesting sensory and motor systems are essential to language comprehension. However, Mahon & Caramazza (2008) present some counter-arguments – stemming from a disembodied theory of cognition. In short, they argue that despite the reliance on the sensorimotor systems in mental simulation, neuropsychological research has shown that patients with sensorimotor impairments do not always suffer from conceptual deficiencies. Moreover, abstract concepts contain no sensorimotor information in the same way that concrete concepts do, which limits the embodied position to only a partial theory.

A further problem concerns the fact that any one concept can be represented in the real world in a number of ways. Mahon & Caramazza (2008) provide the example of DOG and make the point of its wide number of instantiations, i.e., different breeds of dog. Therefore, when the language input contains the word ‘dog’, what does the simulation consist of? A Labrador or a Chihuahua or some other breed? Surely then, unless the exact breed is made explicit, the induced mental simulation is specific to each language comprehender, most likely influenced by their specific life experiences. This creates the question of what happens when one has no prior experience of a particular concept. How is it simulated? Surely it cannot be, but does this necessarily mean the concept itself is not understood? If someone tells me they saw a vaquita carrying its babies through the trees, although I have never heard of this animal and have no idea what it looks like – so I have not been able to mentally simulate it – I still comprehend the sentence.

In summary, these counter-arguments cast doubt on the hypothesis and suggest that mental simulation is not crucial for language comprehension, but merely provides support for it.

7. Conclusion

I have presented, on the one hand, evidence from the literature in support of language-induced mental simulation as part of an embodied theory of cognition. Overall, the findings of the research described here, even if only a small sample of the available research, present themselves as rather compelling, and together create an understandable picture of what exactly constitutes language-induced mental simulation. On the other hand, it has also been made clear that there still exist some issues that need to be addressed, e.g., the problem of the representation of abstract concepts. I have also presented some dissenting evidence for the role of mental simulation, which downplays the importance of its role in language comprehension.

The hypothesis as it stands remains questionable. What can be concluded here, however, is that there is enough evidence to state that mental simulation does play a role in language understanding, but its role is not necessarily crucial, and is merely a supportive tool that may assist with language comprehension some of the time. As with any theory of language or cognition, the research is still ongoing, so a complete picture cannot be given with any certainty, and the concept of mental simulation continues to be reviewed and refined.

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