## Title
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**Author**
Bergen, Benjamin K.

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# Mental Simulation in Spatial Language Processing

**Benjamin Bergen (Bergen@Hawaii.Edu)**
Department of Linguistics, 569 Moore Hall, 1890 East-West Rd.
Honolulu, HI 96822, USA

## Abstract

There is mounting evidence that language comprehension involves the activation of mental simulations (Barsalou 1999a) of the content of utterances (Barsalou 1999b, Stanfield and Zwaan 2001, Zwaan et al. 2002, Richardson et al. 2003, Bergen et al. 2003, Narayanan et al. 2004, Bergen et al. 2004). These simulations can have motor or perceptual content. Three main questions about the process remain unexplored, however. First, are lexical associations with perception or motion sufficient to yield mental simulation, or is the integration of lexical semantics into larger structures, like sentences, necessary? Second, what linguistic elements, e.g. verbs, nouns, etc., can trigger mental simulations? And third, how detailed are the visual simulations being performed? This paper presents findings pertaining to each of these questions, using a visual object categorization task that investigated whether up- or down-related language selectively interferes with visual processing in the same part of the visual field (following Richardson et al 2003). Specifically, it finds that either subject nouns or main verbs can trigger visual imagery, but only when used in literal sentences about real space - metaphorical language does not yield significant effects. This imagery is detailed as to the part of the visual field where the described scene would take place.

**Keywords:** Mental simulation, visual imagery, sentence processing, embodiment, metaphor

## Introduction

"thought is impossible without an image."
-Aristotle, *On Memory and Recollection*

From the earliest records forward, and with few exceptions, western reflections on the mind have assigned a critical place to *imagery*, the internally driven mental creation or recreation of world experiences. While certain paradigms of the second half of the twentieth century, notably symbolic cognitive science and artificial intelligence, have de-emphasized mental imagery, the past several decades have seen a steady increase in both the intensity of scientific investigation on imagery and the range of cognitive phenomena it has been shown to take part in. The recurrent finding from empirical studies using a variety of methods is that humans automatically and unconsciously engage perceptual and motor imagery when performing a broad range of cognitive tasks, like recall (Nyberg 2001) and categorization (Barsalou 1999a). The benefit of conscripting imagery for these tasks is clear - imagery provides a modality-specific, continuous representation, well suited for comparing with perceptual input or performing inference.

Recently, imagery has begun to surface in the study of how meaning is accessed during language processing. If imagery is of critical importance in other cognitive operations that involve conceptual categories and performing inferences about them, then there's good reason to think, as suggested by a number of researchers (Lakoff 1987, Langacker 1987), that it may well play a part in linguistic communication as well.

Indeed, three scholarly traditions have recently converged on the notion that language understanding critically engages mental imagery, or mental *simulation*. Theoretical work in the cognitive linguistics tradition has long emphasized the importance of access to embodied representations of the world in the use and representation of language (e.g. Lakoff 1987). Research in cognitive psychology from an embodied perspective has similarly repeatedly pointed out the importance of low-level perceptual and motor processes in higher level cognitive functions like language (Barsalou 1999a, Glenberg & Robertson 2000). And research on mental models in narrative comprehension have emphasized the role of detailed perceptual and motor knowledge in the construction of mental representations of scenes described through language (Zwaan 1999). The product of this convergence of views is a number of lines of empirical and theoretical work arguing that understanding language leads to the automatic and unconscious activation of mental imagery corresponding to the content of the utterance. This imagery may be motor or perceptual in nature, and may lead to interference with actually performing actions or perceiving percepts in the world simultaneously in some experimental setups, or may lead to the facilitatory priming of such behaviors in others, as discussed below.

This paper focuses on visual imagery, providing empirical evidence that language processing drives detailed perceptual images of described entities and their attributes. It advances the study of language-induced mental simulation in three ways. First, it demonstrates that mental imagery can be evoked by either subject nouns or main verbs in sentence stimuli. Second, it shows that while literal language about motion results in spatial imagery, the same is not true for metaphorical language, which implies that it isn't just lexical associations but rather the construction of a model of the whole sentence's meaning that drives simulation. And third, it shows that spatial imagery is specific to the direction of motion - up or down - and not just the axis of motion, as previously demonstrated (Richardson et al. 2003). On the basis of these results, it argues for a view of lexical and sentential meaning in which words pair phonological form with specifications for imagery to be performed, and larger utterances compose these imagery specifications to drive a mental simulation of the content of the utterance.

## Experiment 1: Verbs

When processing language, understanders activate imagery pertaining to the direction of motion (Glenberg & Kaschak 2002, Kaschak et al. To Appear), shape (Stanfield & Zwaan 2001), and orientation (Zwaan et al. 2002) of described objects, the rate of (fictive) motion (Matlock In Press), the effector (Bergen et al. 2003, 2004) and handshape (Bergen & Wheeler 2005) used to perform an action, and the axis (horizontal vs. vertical) along which action takes place (Richardson et al. 2003, Lindsay 2003).

We take up this last element of mental simulation in this study. In seminal work, Richardson et al (2003) took verbs, associated with verticality or horizontality that were concrete or abstract, and placed them in sentences (as in 1). These were presented to subjects in the interest of ascertaining whether they would induce interference effects on the categorization of visual objects (shapes) that were presented on the screen in locations that overlapped with the sentences' implied orientation. After seeing a fixation cross for 1 second, subjects heard a sentence, then, after a brief pause (randomly selected for each trial from among 50, 100, 150, or 200ms), they saw a visual object that was either a circle or a square, positioned in one of the four quadrants of the screen (right, left, top, or bottom). Their task was to press a button indicating the identity of the object ('circle' and 'square') as quickly as possible.

(1) a. CONCRETE HORIZ: *The miner pushes the cart.*
b. CONCRETE VERT: *The plane bombs the city.*
c. ABSTR HORIZ: *The husband argues with the wife*.
d. ABSTR VERT: *The storeowner increases the price*.

The results were indicative of a clear interference effect - subjects took longer to categorize objects on the vertical axis when they followed vertical sentences than horizontal sentences, and vice versa for objects on the horizontal axis.

Three relevant questions present themselves on the basis of this work. First, how detailed are the visual simulations being performed? Second, what linguistic elements, e.g. verbs, nouns, etc., can trigger mental simulations? And third, are mental simulations performed during comprehension of language that does not have strict perceptual or motor content, like metaphorical language? This first experiment addresses the first of these questions.

### Method

In order to test the detail with which language understanders automatically perform visual imagery when processing sentences about up or down motion, we built on the methodology pioneered by Richardson et al. (2003). This work is based on the very old observation (Perky 1910) that visual imagery can interfere with simultaneous visual perception, presumably because the two activities make use of overlapping neural resources. The reasoning goes that if spatial language results in visual imagery, then it, too, should interfere with visual perception. Notice that the predicted effect is interference between language-induced imagery and visual perception in the same place in the visual field, while in other methods (e.g. Glenberg & Kaschak 2002, Zwaan et al. 2002), facilitation is used to argue for mental simulation. The main difference, as argued by Kaschak et al (To Appear), is that interference occurs when the two tasks require simultaneous use of the same motor or perceptual resources, but when they are used with a sufficient intervening temporal interval, facilitation is observed (though see a critical discussion in Bergen 2005).

Subjects were presented with sentences that denoted upwards or downwards movement (2) - no English verbs denote uniquely rightwards or leftwards motion. In order to reduce the range of possible linguistic factors on the resulting imagery, only intransitive sentences (sentences with just a subject noun phrase and a main verb) were used. In constructing these sentences all the subject nouns in the two types of sentence (up and down) were normed to be equally unassociated with up or down locations, to be equally meaningful, and to have as equal reading times as possible.

(2) a. UP: *The mule climbed*
b. DOWN: *The chair toppled*

65 native speakers of English participated in exchange for course credit in an introductory linguistics class at the University of Hawaii. Each trial began with a fixation cross for 1000msec. The subject then heard a sentence over headphones. After an ISI of 150ms from the end of the sentence, a circle or a square appeared in the top, bottom, left or right quadrant of the screen for 200msec. All objects appeared the same distance from the fixation cross at the center of the screen, along a central axis (e.g. objects in the upper quadrant appeared directly over the fixation cross). Subjects identified the shape as quickly as possible with a button press - 'z' indicated circle and 'x' indicated square. Their reaction time was the dependent variable. To ensure that subjects attended to the meaning of the sentences, filler sentences followed by a short yes/no comprehension question were randomly interspersed. In critical trials, the object appeared in the upper or lower quadrant. As many up- and down-related sentences were followed by an object on left or right - these were taken from the sentences discarded through the norming study.

English has a very small number of intransitive verbs of upwards or downwards motion, and the norming study determined that only five verbs in each condition were viable. As a result, the entire list of sentences was presented twice to each subject, making the object location (up or down) a within-items factor.

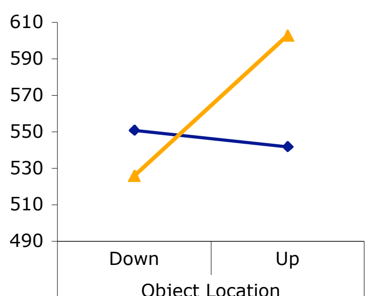
This study thus differed in design from that of Richardson et al (2003) in two critical ways. First, only intransitive sentences were used, rather than a combination of sentenecs with varied postverbal objects. This allows us to more tightly determine what the linguistic sources of imagery are. Second, the upwards and downwards directions are pulled apart in this study, rather than being conflated as in the previous work. This will tell us whether visual imagery in fact includes more spatial detail than just the axis of motion.

## Results

If subjects perform visual imagery in processing these sentences, then we should observe interference when sentence direction coincides with the object location. For example, hearing a sentence denoting upwards motion should make it harder to immediately thereafter categorize an object appearing in the upper part of the visual field, as opposed to the lower part.

One subject was eliminated for answering the sentence comprehension questions with less than 85% accuracy. Another was excluded for answering the object categorization questions with only 79% accuracy. Responses more than 3sd above or below the mean for each subject were removed and replaced these with values 3sd above or below the mean for that subject. This resulted in changes in less than 1% of the data.

The mean reaction times for the literal sentences displayed in Figure 1 below display a clear interaction effect of the predicted kind - objects in the upper part of the visual field are categorized faster following literal down sentences than following literal up sentences, and the reverse is true for visual objects in the lower part of the visual field.




| | Down | Up |
|---|---|---|
| Verb Down | 551 | 542 |
| Verb Up | 526 | 603 |

Figure 1: Mean RT for object categorization in upper and lower quadrants of the screen for up and down sentences

A 2 (sentence direction) X 2 (object location) repeated measures ANOVA showed a significant interaction between sentence direction (literal up versus literal down) and object location (up or down): $F(1,63)=5.028$; $p<0.05$, but no significant main effects of sentence type or object location.

## Discussion

There are two observations to make from the significant interaction effect seen here with sentences denoting upwards or downwards motion. First, this finding is squarely in line with what is predicted by theories of perceptual simulation in language understanding - that literal language about space should be processed using those neuro-cognitive systems responsible for perceiving the same aspects of space.

The second pertains to how specific the imagery associated with these sentences is. While it is known (Richardson et al. 2003) that the axis of motion of a sentence is accessed during language processing, the current study provides the first evidence that the spatial grain of visual imagery is in fact finer than this. Sentences denoting upwards and downwards motion selectively interfered with categorizing objects in the same part of the visual field, which indicates that motion imagery in response to these sentences is specific to the quadrant in which the content of the utterance would take place, not just the axis.

The effect we observed here was especially strong for sentences denoting upwards motion. Why might it be up sentences and not down sentences that show this effect? One plausible explanation relies on the differences in likelihood of the two types of events described. Because we live in a gravitic environment, objects tend to move downwards when there is no force observed to act on then. By contrast, fewer objects move upwards without force overtly exerted on them. Since external-agentless upwards motion events are less common in the world than equivalent downwards events, individuals might have a need for greater simulation in the case of upwards motion. This would result in greater interference with visually categorizing objects in the upper quadrant of the visual field.

Regardless of the details of this effect, the crucial manipulation that yielded it was the use of verbs that were strongly associated with upwards or downwards motion. From the simulation-based perspective, this is not particularly surprising, since verbs of motion are supposed to indicate processes and relations holding of referents. What would happen, though, if nouns were manipulated while verbs were held constant? Do nouns that denote objects that are canoncally associated with the upper or lower part of the visual field yield the same sort of interference? This is the topic of the next study.

# Experiment 2: Nouns

Motion verbs very obviously can encode direction of motion, so it is not surprising that, when placed in sentences, they yield visual imagery in language understanders. But nouns are somewhat trickier. While deverbal nouns like *a climb* or *a drop* might be predicted to show similar effects, it is less clear what to make of nouns that are simply canonically associated with a particular region in space, like *ground* or *ceiling*. Do sentences describing events involving such objects yield selective imagery in the given parts of the visual field?

Recent work on visual imagery during language understanding has demonstrated that mentioned objects are represented with a good deal of visual detail. For instance, Stanfield & Zwaan (2001) and Zwaan et al. (2002), had subjects read sentences, then name or make a judgment about an image of an object that had been mentioned in the sentence. They found that implied orientation of objects in sentences (like *The man hammered the nail into the floor* versus *The man hammered the nail into the wall*) affected how long it took subjects to perform the object task - it took longer to respond to an image that was incompatible with the implied orientation or shape of a mentioned object. For example, reading a sentence about a nail hammered into a wall primed the horizontal nail image, as contrasted with a sentence about a nail hammered into the floor. Similar results were found for shape of objects, such as a whole egg versus an egg in a pan. These results imply that shape and orientation of objects, are represented in mental simulations during language understanding. But we don't yet know about locations in space - is the location where an object is canonically found represented as part of the mental simulation evoked by an utterance?

### Method

63 subjects from the same population described in section 3 above participated in this study. The method was globally identical to that in the first experiment, with the exception of the critical sentences. In this experiment, instead of sentences with a verb denoting upwards or downwards motion, as above, in critical trials subjects saw sentences with vertically neutral verbs paired with nouns that were canonically associated with upness or downness (3), selected as described above from the norming study. The Up and Down Noun sentences showed no significant difference in reaction time: or meaningfulness.

(3) a. DOWN: The cellar flooded.
 b. UP: The ceiling cracked.

### Results

Two subjects with mean response times more than 2s.d. from the grand mean were removed. Two additional subjects were removed for lower than 80% accuracy on the comprehension questions. Responses more than 3s.d. greater or smaller than the subject's mean RT were replaced with values 3s.d. greater or less than their mean. This resulted in the modification of less than 1% of the data.

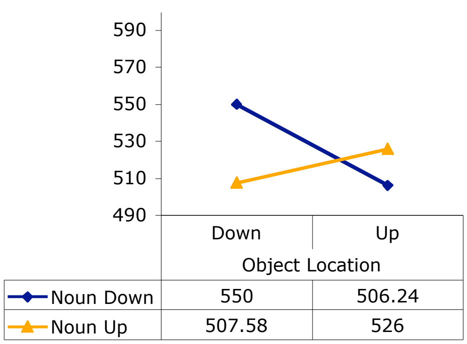



Figure 2: Mean RT for object categorization in upper and lower quadrants for up and down noun sentences

Considering only correct responses, the means were as shown in Figure 2. As in Experiment 1, there is interference between sentence direction and object location. Indeed, a repeated measure subjects ANOVA showed a significant interaction between object location and sentence direction ($F(1,58)=5.756$; $p<0.05$). There were no significant main effects of object location or sentence direction.

### Discussion

The striking finding here is that sentences with subject nouns that are canonically associated with upness or downness selectively interfere with the visual processing of objects in the same parts of the visual field. This complements other work on visual imagery associated with objects in sentence understanding, which shows that both the shape (Stanfield & Zwaan 2001) and orientation (Zwaan et al. 2002) of objects are primed by sentences that imply those particular shapes or orientations for objects.

Despite the significance of the interference effect shown in these first two studies, they do not conclusively shown that subjects in fact perform mental imagery of sentence meaning. The observed effects could in principle result from some sort of strictly lexical process. Perhaps the lexical representations for words like *ceiling* and *rise* share a common feature [+UP], and it is this feature, rather than a dynamic simulation of the utterance's content that's causing the interference effects we observed. Granted, one would be more likely to anticipate facilitatory priming on this account, but in order to eliminate the possibility that the effect is simply lexical, we ran another experiment, using the same set of verbs described in the first study above, but with subject nouns that could not literally move up or down. This would tell us if the interference was a result of sentence interpretation or simply lexical semantics.

## Experiment 3: Metaphorical Language

So far, we have seen that the direction of spatial imagery a language understander performs can be manipulated by up-down associations of a verb or subject noun. A first-pass account of how this would work could take the function of content words to be to pair phonological form with detailed imagistic content. On this view, there is a direct path once a word has been identified in the input stream, leading directly to evocation of appropriate imagery. In the case of words with up or down associations, this includes spatial imagery using the appropriate part of the visual field.

But words denoting spatially and visually concrete entities and events display rampant polysemy - many or most can also be used to describe aspects of abstract domains. In the case of verbs denoting movement along the vertical axis, this includes changes in quantity, in happiness, in status, and so on (Lakoff & Johnson 1980). This leads to two possible accounts. The first maintains that words directly activate imagery. As a result, sentences that include verbs denoting up or down motion should drive visual imagery even when they do not denote actual physical motion. But a second possibility also presents itself. It could alternatively be that the contributions words make to the construction of a simulation is mediated by an interpretation of larger linguistic structures in which it is embedded, like the clause. When the sentence does not denote physical motion, visual imagery does not follow in the same way it does in response to language about physical motion. Rather, on this alternative account, lexical items contribute to the construction of a simulation plan for larger linguistic structures they belong to, where the actual details of the imagery to be performed is composed from a combination of constraints imposed by linguistic constituents.

In order to determine whether lexical space associations suffice to predict the directionality of internally recreated visual scenes, we performed another experiment, using the very same motion verbs from the first study above. The critical difference in these studies was that in this follow-up, the subject nouns denoted entities that could not physically move up or down, yielding sentences that made metaphorical, rather than literal use of the motion verbs. This allowed us to test whether it was simply the verb by itself or a global interpretation of the sentence that was producing the directional visual imagery.

### Method

All the motion verbs used in the first study on literal sentences above (Experiment 1) can also describe changes in quantity or value of entities that do not have physical height, like oil prices or mortgage rates (4). Thus, to create metaphorical sentences, we used subjects like "rates" and "prices" along with the same motion verbs used in the first experiment. The sentences were normed as above. The up and down metaphorical sentences showed no significant difference in reaction time or in meaningfulness rating.. In all respects other than the critical stimuli, the experiment was exactly as described above, and was in fact run together with the noun experiment described as Experiment 2, above.

(4) a. DOWN: The rates toppled.
b. UP: The prices rose.

### Results

By contrast with the literal verb and noun sentences, there was no significant interaction between sentence direction and object location with the metaphorical sentences: F(1,58)=0.425; p=.0.517. Nor were there significant main effects of object location or sentence direction.

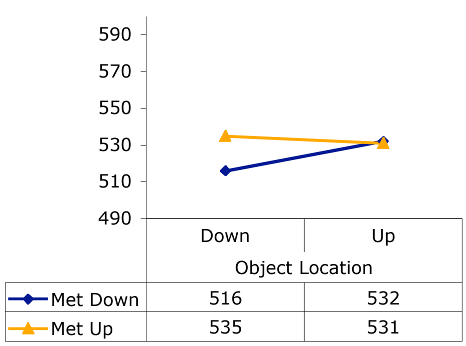



Figure 3: Mean RT for object categorization in upper and lower quadrants for metaphorical up and down sentences

### Discussion

By comparison with the earlier study, where visual imagery in particular parts of the visual field resulted from the use of verbs denoting upwards or downwards motion, this follow-up study found no such effect. From this, we can conclude that these metaphorical sentences to not drive imagery in the same way that their literal counterparts in the first study did.

Several possible explanations present themselves for this result. First, it could be that the metaphorical sentences about changes in quantity simply did not selectively drive visual imagery in the given parts of the visual field. Instead, on this account, imagery in metaphorical sentence processing could focus on concrete scenes that might correspond to the described event. For instance, *The prices rose* could trigger imagery of happy storeowners or price tags on merchandise being replaced. A second possibility is that while visual imagery was triggered with the metaphorical sentences subjects, it was less vivid and therefore less detectible through the experimental instrument we were using than was the imagery resulting from literal sentences. Third, it could be that visual imagery was indeed performed, just on a different time-scale than the interference-producing imagery evoked by literal language. Note that these explanations are not mutually exclusive - given the inter-individual variability that imagery can be expected to exhibit, it would not be surprising if across different types of language, imagery differed radically.

A final possibility is that the metaphorical sentences in fact yielded no imagery of any type. This possibility is not entailed by the results shown above, which only show that the metaphorical and literal sentences do not display the same sort of visual imagery at the same point in sentence processing. Moreover, this position runs into the difficulty of having to explain how exactly the abstract language would be deeply understood, and how inferences would be generated and propagated, without using any imagery at all.

Regardless of exactly why we found no visual imagery effect in the metaphorical sentences, the basic finding, that words with visually imageable senses do not consistently produce the same sort of imagery is in line with other findings of a similar nature (Stanfield and Zwaan 2001, Zwaan et al. 2002).

## General Discussion

Processing sentences that denote events that would tend to take place in a particular part of the visual field yields interference on actually using the same part of the real visual field, as measured by decreased performance in an object categorization task. This is true whether the location of the event is indicated by a verb (Experiment 1) or a sentential subject (Experiment 2). However, having an up- or down-associated lexical item in a sentence does not suffice to produce interference. The sentence must literally encode a scene involving the relevant location in the visual field, as metaphorical uses of motion verbs (Experiment 3). We can conclude from this that it is not lexical priming that yields the interference but rather the performance of mental imagery corresponding to the meaning of an utterance.

What purpose would such automatic and generally unconscious imagery serve? Several authors have suggested different functions for the construction of a mental simulation on the basis of language using detailed modal knowledge. One critical role of imagery is to produce detailed inferences (Narayanan 1997), which can both allow an understander to gain a rich notion of the utterance's content - such as a situation model of the described scene (Zwaan 1999), and also to prepare the understander to understand future utterances, or to respond relevantly. Second, the construction of a mental simulation prepares the understander for situated action (Bailey 1997, Barsalou 1999b, Glenberg & Kaschak 2002). Finally, some language may be disambiguated only through the performance of imagery (Bergen & Chang 2005).

Indeed, various models of language rely heavily on perceptually and motorically grounded representations as the backbone for the language understanding process. Of particular note, Kaschak and Glenberg (2002) argue that language understanding proceeds through the meshing of simulation constraints from language, and the subsequent mental simulation of afforded actions, to prepare for situated responses. Zwaan (1999, 2004) has argued similarly that language comprehension proceeds through the construction of modal mental models, and Barsalou (1999) has suggested that language hooks into simulators - systematic patterns of reactivation of representations of perceptual and motor experiences. Finally, Embodied Construction Grammar (Bergen & Chang 2005) bases language understanding on mental simulation, but differs in that it is a procedural model of how the individual linguistic items making up an utterance produce a mental simulation.

## Conclusion

Visual interference effects produced by linguistic input are reliable and replicable, in a number of methodological permutations. These findings as a whole can be taken as evidence that perceptual systems - in particular the visual system - are unconsciously and automatically engaged in the process of natural language understanding. Given that spatial imagery is automatically engaged during language use, it seems that a complete account of how words and utterances are understood requires knowing how they drive imagery. The same may hold of grammatical markers and sentence patterns (Glenberg & Kaschak 2002, Bergen & Chang 2005). More broadly, the observation of language driving imagery suggests yet another way that embodied human experience shapes language processing. Our similar bodies and experiences, yield shared imagery, a common currency that facilitates effective communication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