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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 27(27)

ISSN

1069-7977

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Publication Date

2005

Peer reviewed

Sentence Understanding Engages Motor Processes

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Abstract

Processing sentences describing actions performed by the hearer (e.g. *You gave Andy a pizza*) primes actually performing a motor action compatible with the one described (Glenberg & Kaschak 2002). This result has been interpreted as indicating that processing meaning involves the activation of motor control circuitry to prepare the language understander for situated action. A complementary view (Bergen & Chang 2005) argues that motor control structures are automatically and unconsciously engaged during motion language processing irrespective of whether that language pertains to the understander, because the meaning of action language is inherently grounded in motor control circuitry. To distinguish between these views, we must determine whether motor activity results from processing language about actions performed by and on third persons (e.g. *Andy gave Sara a pizza*.) Two experiments tested the scope of compatible action facilitation during sentence understanding, where sentences either encoded motion in a particular direction (e.g. *John opened the drawer*) or using a particular handshape (e.g. *Mary grabbed the marble*.) Both studies yielded significant Action-sentence Compatibility Effects, demonstrating that whether language is about the understander or not, it engages their motor system.

Keywords: sentence processing, mental simulation, motor control, Action-sentence Compatibility Effect

Introduction

Language use integrally involves perceptual and motor processes, since the production of language requires the control of facial, manual, and other effectors, and language processing begins with the detection of visual, auditory, and other perceptual cues. However, language appears to engage perceptual and motor systems and the neural structures dedicated to them in another, less obvious way. Just as performing imagery about action (Porro et al. 1996, Lotze et al. 1999) and perception (Kosslyn et al. 2001) makes use of action and perception systems, so it now appears that processing language about perceptual or motor content results in the activation of neural structures overlapping with those that would be used to actually perceive or perform the described content. The mental (re)creation of perceptual and motor experiences (among others) in order to deeply understand language goes under the rubric of *mental simulation* (Barsalou 1999).

The notion that language understanding makes significant use of perception and action imagery has been proposed in a variety of contexts (Barsalou 1999, Zwaan 1999, Glenberg & Robertson 2000, Feldman & Narayanan 2004, Gallese & Lakoff 2005, Bergen & Chang 2005). What these various views share is the idea that language understanding entails

running a mental simulation of a described scene, wherein an understander activates motor representations corresponding to what participants in the scene might do and perceptual representations of images they might perceive. The reasoning behind this is straightforward. Perceptual and motor imagery are known to play critical roles in higher cognitive functions like memory (Wheeler et al. 2000, Nyberg et al. 2001). By extension, they may well be integral to language understanding as well. On this view, viable communication involves the successful evocation of an aligned set of perceptual and motor images in the mind of a hearer (Glenberg & Robertson 1999, Bergen & Chang 2005). Recent evidence from neuroscience suggests a mechanism by which the internal imagination of a scene described by language may be effected.

Two studies provide evidence that processing motion language associated with particular body parts also results in the activation of areas of motor and pre-motor cortex involved in producing motor actions associated with those same effectors. Using both behavioral and neurophysiological evidence, Pulvermüller et al. (2001) found that verbs associated with different effectors (mouth, hand, leg) were processed at different rates and in different regions of motor cortex. More recently, Tettamanti et al. (m.s.) have shown through an imaging study that passive listening to sentences describing mouth versus leg versus hand motions activate different parts of pre-motor cortex (as well as other areas, specifically BA 6, BA 40, and BA 44).

From a broader perspective, to the extent that evidence is found indicating that imagery plays a role in language understanding, this bolsters an embodied view of meaning, in which the particular experiences a language user has had in their life, in their body, create the substantive basis for language production and understanding, as suggested by a number of authors, like Barsalou (1999), Zwaan (1999), Glenberg and Robertson (2000), Bergen, et al. (2003), Feldman and Narayanan (2004), Bergen and Chang (2005), and Matlock (To Appear), and MacWhinney (In Press).

While important and productive lines of research are beginning to gain momentum in the area of mental simulation and language understanding, there has been insufficient focus thus far on the exact linguistic mechanisms that trigger mental simulation. More specifically, there are two questions that have yet to be addressed in previous studies. The first concerns the types of language that trigger simulation and the second concerns the degree of detail involved in simulation.

It is of critical theoretical importance to determine how prevalent language-triggered motor simulation is – whether it occurs only when people process language about

themselves, or whether it is used to process sentences describing motor actions regardless of who the described actor is. Motor simulation has been argued to serve as the basis for understanding language about actions in general (e.g. by MacWhinney In Press, Feldman & Narayanan 2004, Gallese and Lakoff 2005, and Bergen and Chang 2005). This perspective views the internal (re)creation of motor control events as critical to processing language about actions. This claim cannot be evaluated solely on the basis of language involving the interlocutor as a participant because this language is precisely the type of language most likely to induce motor imagery. Rather, the case must be made by demonstrating that language not about the interlocutor nevertheless results in activation of the specific motor control systems that would perform the described actions.

While both motor and perceptual imagery have been shown in various experiments to be automatically and unconsciously activated by language, the level of detail of that imagery remains in question. While motor imagery appears to include the direction of motion of a particular action (Glenberg & Kaschak 2002), it is not known whether finer details like hand-shape are also (re)created. A fine level of detail in mental simulations is critical to an account of language understanding based on imagery if imagery is to account for inference and disambiguation.

In order to flesh out these remaining questions, the research reported here first modified a study by Glenberg and Kaschak (2002) that demonstrated simulation effects in language by replacing first-person with third-person referents in the stimuli. If understanders are in fact activating the specified neural structures while processing the language, they should display the same effects with language that does not directly involve them, from which we can infer that they are indeed activating a mental simulation in order to understand the language input.

The second experiment addressed the level of detail involved in simulation. Subjects were asked to perform a slightly modified version of the same forced-choice task, which this time required the execution of a pre-assigned hand-shape, that was either compatible or incompatible with the hand-shape implied in the critical sentences. Based on the idea that simulation involves fine-motor details (e.g. Bergen & Chang 2005, Gallese & Lakoff 2005), we hypothesized that subjects would be faster at responding when the hand-shapes implied by the verb and required to respond were compatible.

Experiment 1

This study tested whether sentences that describe actions performed only by third persons yield a significant Action-Sentence Compatibility Effect - facilitatory priming of manual actions by sentences denoting similar actions.

Subjects

54 students at the University of Hawai'i Manoa participated for either course credit or five dollars. All subjects were right-handed native English speakers.

Materials

A total of 160 sentences were created, 60 meaningful critical stimuli, 20 meaningful filler stimuli, and 80 non-meaningful filler stimuli. The 60 critical stimuli were composed of 30 pairs of sentences, with one sentence denoting motion forwards, away from the body and the other denoting motion backwards, towards the body. These stimuli were of three types. One set of 20 consisted of 10 pairs of transitive sentences that differed only in terms of their object noun phrase (1a). The second set consisted of 10 pairs of transitive sentences that differed only in their main verb (1b). The final set was composed of 10 pairs of abstract caused-motion sentences that varied in their main verb and preposition in a final prepositional phrase (1c). All sentences were in the present tense with progressive aspect, and all referents were third-person. It was predicted that an Action-sentence Compatibility Effect would be observed in response to sentences denoting literal motion (1a,b), and possibly also to abstract sentences, like (1c).

- (1) a. Jane is wringing {her hands, Mary's neck.}
- b. John is {opening, closing} the drawer.
- c. Vincent is {donating, accepting} a kidney {to, from} the biology department.

Sentence pairs were drawn (with some modifications) from the stimuli used by Glenberg and Kaschak (2002), in addition to newly generated ones conforming to the above described criteria. These were then submitted to a norming study in order to choose pairs whose members encoded the appropriate direction of motion. In the norming study, 12 subjects were instructed to decide if the described action required movement of the hand toward or away from the body. To respond, they pressed buttons labeled *toward* and *away* or, *neither*. Only verb pairs each of whose members received a majority of scores in the appropriate direction and had no more than one half as many in the opposite direction were included in the critical stimuli.

Design and Procedure

Each subject saw all 160 sentences. Each critical pair was split into two blocks, as were each of the three types of stimuli. The design fully crossed the two blocks (1 and 2) with the two sentence directions (toward the body and away from the body) and the two response directions (yes is away or yes is toward). Response direction ordering was fixed with yes-is-away and no-is-toward in the first half and was reversed halfway through the experiment. Thus, half of the subjects answered each sentence in the yes-is-away condition and half in the yes-is-toward condition.

Small colored labels were created and attached to the keys on a computer keyboard such that the green "Yes" and red "No" were equidistant from a blank yellow middle button. The keyboard was also rotated such that it was perpendicular to the subject allowing these three buttons to be in a straight line with four keys separating each.

When presented with a fixation cross, subjects pressed and held the yellow button (the "h" key) to reveal the stimulus until they had decided if (yes) the sentence made

sense or (no) it did not, whereupon they released the yellow button and pressed either the “yes” or the “no.” Subjects were instructed to use only their right hand during the experiment. A training session preceded each half of the experiment.

Results

Three subjects were eliminated: two because they responded to the critical stimuli with less than 80% accuracy, and one because their mean reaction time surpassed 2.5 s.d. greater than the grand mean. One sentence item was removed from analysis for the same reason. All responses greater than 2.5 s.d. from the mean per subject were replaced with the value 2.5 s.d. from the mean for that subject. This resulted in modification of less than 1% of the data.

The two sets of literal sentences - those in pairs that differed in terms of the just object noun (1a) or just the verb (1b), were pooled together for analysis, since the prediction that they would yield a motor compatibility effect applies to both of them. Glenberg and Kaschak (2002) found that subjects were faster to remove their finger from the button keeping the displayed sentence on the screen when the sentence and the action they had to perform to identify it as meaningful were in the same direction. In the current study, release times on the same button did not show the predicted effects. In contrast with the results reported by Glenberg and Kaschak (2002), there was no significant interaction effect between sentence direction (away, toward) and response direction (away, toward), $p=0.27$.

However, the time subjects took to press the response button indicating that the sentence was meaningful did show the predicted effects (Figure 1). A significant interaction effect was observed, in which subjects took longer to respond to sentences when the direction of their response was incompatible with the direction of described motion: in a subject repeated-measures ANOVA, $F(1,51)=4.31$; $p<0.05$. The two main effects (response direction and sentence direction) were not significant.

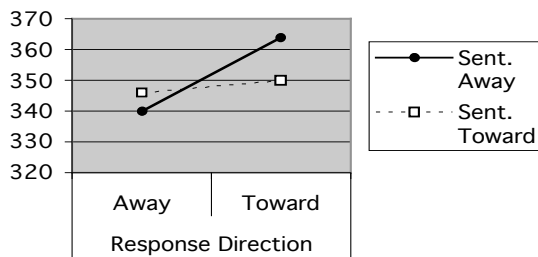


Figure 1: Response times as a product of toward and away sentences, when manual responses were toward or away from the body.

Like the sentences denoting literal motion of the hand towards or away from the body, abstract sentences yielded no significant interference effect in the button release measure, but unlike literal sentences they also displayed no interaction effect in the response measure: in a subject repeated-measures ANOVA, $F_1(1,51)=0.08$; $p=0.78$. Neither of the main effects was significant.

Discussion

As expected, sentences denoting motion away from the body were responded to faster when the subject’s physical response involved actually moving the hand away from the body, and similarly for towards sentences and toward motions. However, unexpectedly, this effect was observed not on the length of time it took subjects to read the sentence and release the button keeping the sentence on the screen, but rather on the time between release of this button and pressing of the response button – that is, in the time it took to actually execute a response. We discuss this difference in the General Discussion, below. Interestingly, the away responses show a smaller effect than the toward responses, which may be due in part to the relatively shorter response times in this condition.

A second notable finding from this experiment is that sentences denoting abstract motion did not yield a significant compatibility effect in the way that the literal motion sentences did. This stands in potential contrast with the results of Glenberg & Kaschak (2002) who found a significant compatibility effect with a set of stimuli that included abstract sentences like these. One explanation that immediately presents itself is the possibility that when processing language not about oneself, an understander performs less detailed motor imagery in general. As a consequence, the motor imagery in response to language not literally describing motion, which by all accounts would tend to be less intense than motor imagery evoked by literal language, would decrease below the level of detection by this particular instrument.

Regardless of these differences, the fact remains that reading literal sentences denoting motion towards or away from the body yielded a significant compatibility effect on the time it took subjects to press a button indicating meaningfulness of the sentence. We can conclude from this that not only sentences describing the interlocutor as a participant but also sentences describing only third persons can result in the activation of motor control functions.

Experiment 2

In order to establish the stability of this Action-sentence Compatibility Effect with third person participants, we designed another ACE experiment in which subjects once again read sentences denoting motion of one of two types. As in the previous study, the response action could be compatible or incompatible with the described action. Since sentences only involved third-person participants, the results would help assess first, whether motor activation in response to sentences not involving the understander is indeed a replicable effect, and second, whether finding the expected interaction effect on the button press, rather than release time was a reliable product of sentences like this. Moreover, we were interested in investigating the depth of motor detail contained within the motor imagery that subjects appeared to be performing, so the particular design we adopted manipulated not the direction of motion, but rather the handshape used to perform described actions.

The design of this experiment was quite similar to that of Experiment 1, described above. Subjects were asked to push

down a button to display a sentence they had to read, and decide as quickly as possible whether the sentence made sense or not. The critical sentences described an action performed either with an open palm handshape or a closed fist handshape, depending on the condition. Subjects then responded by pushing a large flat foot pedal with their hand, using either an open palm or closed fist. Response actions could thus be compatible or incompatible with the handshape of the action described in the sentence. We predicted that subjects would take longer to press the button when they had to do so with an incompatible handshape – that is, that we would observe an ACE for handshape.

Subjects

88 students at the University of Hawaii participated for either course credit or five dollars. All subjects were right-handed native English speakers. The data from four subjects were excluded for having lower than 80% accuracy, one due to experimenter error, and eighteen subjects for performing the task incorrectly. The task in this experiment proved to be difficult for subjects and incorrect performance included pressing the wrong “Enter” key on the keyboard not switching the response hand-shapes in the second half, answering with the opposite hand-shape than that assigned, or using different hands to press the “Enter” key and the response button.

Materials

16 critical sentences were created, half with verbs encoding a palm hand-shape (2a) and half with a fist hand-shape (2b). Another 16 critical sentences were created using 8 verbs that variably encoded actions performed with either a fist (3a) or palm hand-shape (3b), depending on the direct object. In order to mask any possible relation between the physical responses subjects had to perform and the semantics of the critical verbs, a large number of fillers were also created to make the total number of sentences 160. All critical trials were sensible and transitive (since they encoded hand actions on objects) but fillers were divided such that half of all stimuli were non-sensible, and orthogonally, half of all stimuli were intransitive.

As mentioned above, we used critical stimuli of two types. The first (fixed) type had a verb strongly implying the use of a fixed hand-shape (e.g. *The nanny patted the cushion*; *The singer gripped the microphone*) – see also the examples in (2). The second (variable) type contained a verb whose action could be performed with one hand-shape or the other depending on the sentential context (e.g. *The busboy lifted the plate*; *The bartender lifted the bottle*), as seen as well in (3). The use of these two types of stimuli was meant to evaluate whether any action compatibility effects resulted just from the lexical semantics of the verbs, or whether they resulted from the generation of a mental simulation of the event described by the entire sentence.

- (2) a. The waiter smoothed the tablecloth.
b. The tourist punched the wall.
- (3) a. The waitress carried the platter.
b. The lawyer carried the briefcase.

Design and Procedure

Each trial began with a fixation cross in the center of the computer screen that remained until the subject pressed the “Enter” key in order to initiate the visual presentation of the stimulus sentence. The sentence remained until the subject released the “Enter” key in order to press the response button with either of the pre-assigned hand shapes (closed fist or open palm). Once the subject had responded by pressing the button, the fixation cross would appear in preparation for the next trial. Subjects were instructed to use only their right hand during the experiment. Subjects had a training session before each half of the experiment (16 and 20 trials, respectively) in order to familiarize them with the task.

Subjects read sentences that were either meaningful or not, and were asked to make a sensibility judgment – ‘yes, it makes sense, or ‘no, it does not make sense’. They indicated their judgment by pressing a button, using a pre-assigned hand-shape, either a flat, open palm or a clenched fist. (This methodology is similar to Ellis and Tucker 2000 and Tucker and Ellis 2001, which required responses using different types of grip.) The response pattern (fist means ‘yes’ and palm means ‘no; or fist means ‘no’ and palm means ‘yes’) was randomly assigned to each participant and was reversed midway through the experiment.

In order to check accuracy of response, subjects were video-recorded and answers (palm or fist) were coded by a naïve assistant with no knowledge of which condition was assigned to each half for a given subject. If a subject failed to respond to a trial, or didn’t hold down the Enter key such that the sentence stimulus flashed on the screen and the subject chose to guess the answer, the response was noted and eliminated from analysis.

Results

As discussed earlier, previous work with sentences describing actions involving the understander (Glenberg and Kaschak 2002) has shown that subjects are faster to read a sentence when it is compatible with the action they have to perform. In the current study, just as in Experiment 1, release times on the same button indicating reading time did not show the predicted interaction effect. A three-way (sentence type [fixed, variable] by handshape [fist, palm] by sentence shape [fist, palm]) repeated-measured subjects ANOVA showed a main effect of sentence type (fixed or variable): $F_1(1,65)=7.473$; $p<.01$, and a strong two-way interaction between sentence type and sentence hand-shape (fist or palm): $F_1(1,65)=27.698$, $p<.001$. However, the critical interaction between the response hand-shape and the sentence hand-shape was not significant: $F_1(1,65)=.011$, $p=.916$.

Instead, as in Experiment 1, the time subjects took to press the response button indicating that the sentence was meaningful did show the predicted effect. With response button press times, there was a main effect of sentence hand-shape (fist or palm), $F_1(1,65)=9.189$; $p<.01$, which is not unexpected since the palm and fist sentences were different and not intended to be matched for response latency. There was also a two-way effect between sentence

type (fixed or variable) and sentence hand-shape, $F_1(1,65)=5.903$; $p<.05$, which we did not predict.

Critically, the interaction effect between response hand-shape (fist or palm) and sentence hand-shape (the ACE) is significant, and in the predicted direction: $F_1(1,65)=6.294$; $p<.05$ (Fig. 2). A repeated-measures item analysis also confirmed the significance of the ACE for these sentences: $F_2(1,30)=6.35$, $p<0.05$. As expected, subjects were much quicker to press the response button when the hand-shape required to respond was compatible with the hand-shape implied by the sentence. This can be interpreted as evidence that action language comprehension has an effect on action performance to the level of fine motor detail, despite the fact that the effect was much stronger for fist than palm sentences.

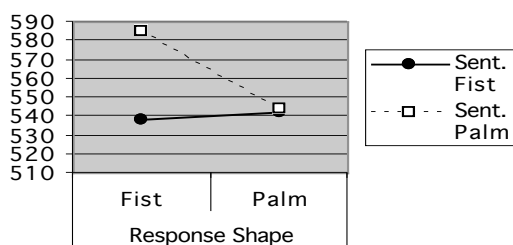


Figure 2: Response Hand-shape by Sentence Hand-shape

If there was a significantly different effect for fixed hand-shape verbs versus variable hand-shape verbs, we should expect a three-way interaction between sentence type, response hand-shape, and sentence hand-shape. However, there was no such significant effect, which fails to disconfirm the null hypothesis that these two sentence types yield the same effect: $F_1(1,65)=.346$, $p=.559$.

Discussion

These results demonstrate that sentences denoting actions performed using a particular handshape prime the performance of a physical response using the same handshape. This effect is produced by processing sentences denoting actions performed by third persons, confirming the finding reported in Experiment 1 that a sentence need not involve the understander for it to yield motor activity. This level of motor detail has not been previously demonstrated in sentence processing research on language not involving the understander. Finally, the observed effect here measured the time it took subjects to respond by pressing a button using the target response handshape, further reinforcing the finding in Experiment 1 that response time, and not reading time, is the critical measure of motor activity in third-person-participant sentence comprehension.

General Discussion

Previous studies have shown that language about a hearer leads them to perform motor imagery about the described actions. It has been argued that this motor activation arises due to the need on the part of the language understander to prepare for situated action (Glenberg & Kaschak 2002). While this may be correct, results from the current studies

demonstrate that motor action is facilitated even when language describes actions involving only third-person participants, in which case they are less likely to be preparing to perform the described actions. This finding demonstrates that motor imagery is much more pervasive than previously known. An interpretation of this effect is that language comprehension in general engages cognitive mechanisms responsible for motor performance in order to perform a mental simulation of language content (Feldman & Narayanan 2004, Bergen & Chang 2005, Lakoff & Gallese 2005).

Not only have we seen that language not about an understander will nevertheless lead them to perform mental motor imagery, but in addition, Experiment 2 showed that this simulation includes detail as to the handshapes that would be required to perform the described action. By demonstrating that subjects found it easier to respond when sentential semantics and an executed handshape were compatible, Experiment 2 provides behavioral evidence that this kind of mental simulation of action performance in language understanding includes detailed motor information.

Both of these findings serve to strengthen an embodied theory of meaning wherein experiences of action and perception provide the basis for the subsequent mental recreation of these experiences such that they can be recruited for the purposes of interpreting and acting on the basis of upon linguistic input.

One interesting sidenote relates to the measurement on which the Action-sentence Compatibility Effect was observed. As noted above, in their original work, Glenberg & Kaschak (2002) found a significant compatibility effect on the time it took subjects to read the sentence and release the button keeping it on the screen. By contrast, in each of the studies described above (like in Tseng & Bergen 2005), the effect was observed instead on the time it took subjects to perform the compatible or incompatible action that indicated their meaningfulness judgment.

Here is a possible explanation. The main difference between the two experiments was in whether the sentence stimuli described actions involving the experimental subject or not. It could thus be the case that when language is about an understander (compared with when it only pertains to third persons), they more immediately engage motor imagery, as they are preparing for situated action. This would explain why in Glenberg & Kaschak's (2002) study, which used second-person participants in sentences, the motor compatibility effect was observed as early as the release time - when subjects are still planning their motor response. By contrast, in the current studies, where sentences did not involve the experimental subject, motor activation occurred later, and therefore showed up on the motor response times, rather than the reading button release times. If this explanation is correct, such a difference in timecourse of simulation would constitute a dramatic demonstration of the intricate nature of mental access to semantic content during language processing, and would highlight the importance of attending to the details of linguistic stimuli in language processing.

Conclusion

The body, and our experiences in it, matter to language in a trivial and a non-trivial way. Trivially, without a body, we could obviously not produce or perceive language, nor for that matter would we have much of interest to talk about. But less trivially, it seems that the act of communicating through language about action uses the ability to call up mental representations of how one moves one's body. The integration of language processing with the mental simulation of motor action is yet another in an increasingly long list of important ways in which the embodiment of human beings critically structures the higher-order cognitive behaviors they engage in.

Acknowledgments

Our thanks to Art Glenberg for invaluable consultation throughout, to Kristin Ciano for her help coding the data and running subjects, as well as to Meylysa Tseng and other members of the Cognitive Linguistics Research Group at the University of Hawai'i for feedback on the design. All errors and omissions are of course our own.

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