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Meaning in the Palm of Your Hand

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1 Introduction

An utterance like "Mom! Joshua poked me in the face!" draws from the hundreds, if not thousands, of English words pertaining to physical actions and the body. Language understanders routinely report that processing language like this brings to their mind visual images of what it looks like, and motor and haptic images of what it feels like, to observe face-poking or to participate in it, as either the poker or the pokee. The subjective experience of imagery during language understanding raises at least two questions: First, how is this the face-poking imagery achieved—what is the biological mechanism that produces it? Second, does this imagery play a role in how hearers process language about the body and action?

Addressing the first question, behavioral and neurophysiological studies alike have demonstrated that in processing language about actions, understanders rely on cognitive and neural machinery dedicated to performing the same actions. This is seen as the basis for the construction of a *mental simulation* of the described event. This idea has experienced a recent resurgence with the findings from single-cell studies in monkeys identifying so-called 'mirror neurons,' which are neural structures activated during both observation and execution of specific motor actions (Gallese et al. 1996; Rizzolatti et al. 1996). These results have subsequently been extended to the human model by neuroimaging studies showing that overlapping neural structures are activated when humans perform, perceive, or recall an action (Ehrsson et al. 2003; Kosslyn et al. 2001; Lotze et al. 1999; Porro et al.

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1996). The upshot is that the mental experience of actions, even when the individual is not performing the action in question, involves running a mental simulation of what it would be like to actually perform the action, using the neural resources that would perform the same action.

These findings on the neural basis for mental imagery have subsequently been extended from action perception and recall to address the second question above—the role of imagery in language understanding. The *simulation semantics hypothesis* proposes that this same process of mental imagery is what allows language users to understand language about scenes and events (Glenberg & Robertson 2000; Bergen & Chang 2005). In other words, the processes of *simulating*, i.e. mentally re-creating a scene or event, is at least partly constitutive of understanding the content of language. While a number of studies have demonstrated the prevalence of visual imagery in understanding language (Kosslyn et al. 2001; Stanfield & Zwaan 2001; Zwaan et al. 2002), motor imagery, perhaps due to its more covert nature, has been the subject of less language understanding research. Our focus herein will be on this less-studied side of imagery.

Several lines of behavioral work (Glenberg & Kaschak 2002; Klatzky et al. 1989; Bergen et al. 2003) have suggested that understanders engage their motor system in order to simulate various aspects of described action, including direction of motion, hand-shape, and effector used. While these studies have identified a clear role for motor structures in various linguistic tasks, several questions remain. The current research will address two such issues.

The first is the extent to which simulation is activated when the language does not directly involve the understander. Previous studies on sentence processing have focused exclusively on second person language (e.g., *Andy gave* <u>*you*</u> *the pizza*). The current study addresses this issue by including only third person referents (e.g., <u>*The waiter*</u> *carried the pizza*). The results replicate previous research (Glenberg & Kaschak 2002), showing that subjects respond more quickly when the direction of motion in the sentential semantics and actual action performance are compatible. Since even language not involving the understander still drives motor simulation, simulation is shown to be even more necessary and pervasive than formerly thought.

A second and equally crucial question pertains to the level of detail at which motor information is incorporated into a simulation. Although a few studies (Klatzky et al. 1989; Ellis & Tucker 2000; Tucker & Ellis 2001) have started to examine the interaction between language and hand-shape or grasp type, they have not determined whether a fine level of detail is also a characteristic of the motor imagery performed during <u>online</u> language processing. This second question was addressed by having subjects read sentences denoting actions performed with specific hand-shapes and subsequently physically perform a compatible or incompatible hand-shape. This task allowed us to measure the extent to which the motor systems responsible for the execution of the actions were activated by the sentence understanding task.

The results of this experiment show that subjects respond more quickly when the sentential semantics and actual hand-shape are compatible. This result provides evidence that language understanders create mental simulations of described action that includes fine motor details such as the hand-shape necessary to perform an action, even when it is described as being performed by a third person.

2 Background

Over the past five years, lines of research in the embodied cognitive psychology, cognitive linguistics, and narrative processing paradigms have converged on the notion that processing language (as well as performing other higher cognitive functions) engages neural structures involved in perception and motor control (Barsalou 1999; Glenberg & Robertson 2000; Stanfield & Zwaan 2001; Glenberg & Kaschak 2002; Zwaan et al. 2002; Bergen et al. 2003, 2004; Richardson et al. 2003). Performing a motor action like grabbing or running requires the activation of appropriate neural circuitry in the motor system. Neuroimaging evidence suggests that the same brain areas are also selectively activated while processing words (Pulvermüller et al. 2001; Hauk et al. 2004) or sentences (Tettamanti et al. ms.) describing the same actions.

One proposed interpretation of this activation of modal brain systems during language processing is that understanders may be engaging in mental imagery. The reasoning is that since mental imagery is known to selectively engage perceptual and motor systems, and since language seems to do the same, perhaps the understanding of motor and perceptual language engages imagery of the appropriate type. In other words, perhaps hearing language about an event or action leads an understander to imagine what it would be like to perform the described action or observe the described event.

The concept of mental imagery is usually interpreted as referring primarily to visual imagery, and indeed a great deal of imagery work has focused on this sense (see Kosslyn et al. 2001). Behavioral studies of visual imagery during language comprehension have shown that understanders not only construct a global mental image of a scene, but do so in relatively fine detail, including such components as object locations, orientations, and shapes (Stanfield & Zwaan 2001; Zwaan et al. 2002).

By contrast with visual imagery, however, motor imagery entails imagining performing a particular action. Various brain imaging studies have shown that mentally imagining performing an action engages those motor circuits involved in actually performing the same action (Ehrsson et al. 2003; Kosslyn et al. 2001; Lotze et al. 1999; Porro et al. 1996). Behavioral research has also demonstrated that processing words involving actions performed using a given part of the body (hand, mouth, leg) and visually categorizing images of the same actions causes interference (Bergen et al. 2003, 2004), which indicates that the two processes recruit the same neural structures. Other work has demonstrated that a primed hand-shape can cause facilitation effects during language comprehension tasks (Klatzky 1989).

The work providing the greatest insights into the use of motor imagery during online language understanding, by Glenberg & Kaschak (2002), tests whether processing a sentence that denotes a particular type of action facilitates performing a similar action. This method has been used to show that sentences denoting physical or abstract motion toward or away from the body interfere with actually performing a real action in the incompatible direction (e.g. *Open the drawer*, encoding motion toward the body, interferes with moving one's arm away from the body). This Action-Sentence Compatibility Effect (ACE) is interpreted as indicating that processing sentences about action yields motor imagery.

Within the scope of behavioral linguistic research, this Action-Sentence (or Action-language) Compatibility Effect (ACE) is rapidly becoming a reliable and well-documented method for evaluating the interaction between language processing and imagery (Glenberg & Kaschak 2002; Borghi et al. 2004; Kaschak et al. 2005; Tseng & Bergen 2005; Havas et al., to appear). Although it is difficult to directly observe online language processing, this interaction effect allows researchers to more closely examine what understanders are doing when they hear or read language by looking at their performance on physical tasks while they are processing linguistic input. Their behavior is instructive for issues of language structure, meaning, and other cognitive processes (e.g. emotion, conceptual knowledge) involved in comprehension.

While great strides have been made in the areas of language processing and imagery, two outstanding issues remain that are of some consequence in interpreting the significance of motor processing in language comprehension. The first issue is whether language understanders perform motor imagery when processing language that does not include them as participants in described actions (e.g., *<u>John</u> opened the door*, as contrasted with Glenberg & Kaschak's *Open the door*). 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 (as argued, e.g. by MacWhinney 1999; Feldman & Narayanan 2004; Gallese and Lakoff 2005; Bergen and Chang 2005). This approach views the internal (re)creation of motor control events as critical to processing language about actions since modal motor control knowledge, being dynamic and detailed, can provide the basis for the rapid disambiguation and inference generation required for online language processing. This claim cannot be evaluated solely on the basis of language involving the interlocutor as a participant (as is used in experiments like Glenberg & Kaschak 2002) 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. The present study will resolve the problem by performing an ACE experiment similar to the Glenberg and Kaschak design, using stimuli that include only third person participants; a stronger test case for proposed mental simulation.

In addition to the question of perspective, the level of detail involved in simulation also begs more in-depth exploration. While both motor and perceptual imagery have been shown in various experiments to be automatically and unconsciously activated by language, the degree of fine-motor detail remains unspecified. Motor imagery appears to include general motor information such as the direction of motion of a particular action, but it is not known whether finer details about the action such as the amount of applied force, angle of the foot, or hand-shape necessary to perform an action are also (re)created in the simulation performed in response to a sentence. For example, if exposed to a sentence like the complaint about face-poking illustrated above, an understander might know that the poking probably took place with the index finger, that this finger was rigid, and that it probably exerted a low level of force on the victim's face. But it is, as of yet, unclear which of these pieces of information are automatically and unconsciously included in a simulation of the sentence's content during language understanding.

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 aspects of language like inference and disambiguation. This study investigates the level of fine-motor detail in imagery during language understanding by analyzing whether hand-shape constitutes part of language-driven simulation, specifically a closed fist versus an open, flat palm hand-shape.

As in other Action-sentence Compatibility Effect experiments, we tested whether language understanders mentally simulate the fine motor details involved in action performance by comparing response times from sentence-response pairs where the hand-shape responses and sentential semantics match and those where they do not. If subjects are simulating the implied hand-shape (open palm or closed fist), as argued by Bailey (1997), we predicted they should take longer to respond when the actual physical response requires them to perform an action incompatible with the one they have just simulated.

3 Method

3.1 Participants

Eighty-eight students at the University of Hawaii participated for either course credit or five dollars. All subjects were right-handed native English speakers.

3.2 Task

Subjects read sentences that were either meaningful or not (e.g., *The bride dieted* versus *The branch swarmed*.) and made 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 grip types.) The response pattern (either with fist meaning YES and palm meaning NO; or the reverse) was randomly assigned to each participant and reversed midway through the experiment. Subjects were presented with a sample picture of hand-shapes during the instructions (Fig. 2).

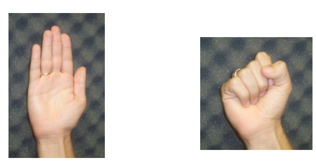

Figure 1. Fist and palm hand-shape images in the instructions

3.3 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, also centered. 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.

In order to check response accuracy, 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 too quickly to make an informed judgment, the response was noted and eliminated from analysis.

3.4 Stimuli

16 critical sentences were created, half with verbs encoding a palm hand-shape and half encoding a fist hand-shape (1a). Another 16 critical sentences were created using 8 verbs that variably encoded actions performed with either a fist or palm hand-shape, depending on the direct object (1b). In order to mask any possible relation between the physical responses that subjects had to perform and the semantics of the critical verbs, a large number of fillers were also created to make the number of sentences total 160. All critical trials were sensible and necessarily transitive (since they encoded hand actions on objects) but fillers were balanced such that half of all stimuli were non-sensible and, orthogonally, half of all stimuli were intransitive (See Appendix B).

(1)	PALM	FIST
a.	*The waiter is smoothing the tablecloth.*	*The tourist is punching the wall.*
b.	*The waitress is carrying the platter.*	*The lawyer is carrying the briefcase.*

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 <u>patted</u> the cushion*; *The singer <u>gripped</u> the microphone*). 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 <u>lifted</u> the plate*; *The bartender <u>lifted</u> the bottle*). Our motivation for using these two types of stimuli was 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.

4 Results

The data from four subjects were excluded for lower than 80% accuracy, from one due to experimenter error, and from eighteen for incorrect task performance. The task in this experiment proved to be difficult for subjects and incorrect performance included various mistakes: pressing the wrong ENTER key on the keyboard (the ENTER key on the number pad was later concealed to prevent this), 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.

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 showed none of the predicted effects. There was a main effect of sentence type (fixed or variable): $F1(1,65)=7.473$; $p<.01$, and a strong two-way interaction between sentence type and sentence hand-shape (fist or palm): $F1(1,65)=27.698$, $p<.001$. However, the critical interaction between the response hand-shape and the sentence hand-shape was not significant: $F1(1,65)=.011$, $p=.916$.

Contrarily, the time subjects took to press the response button indicating that the sentence was meaningful did show the predicted effects. With response button press times, there was a main effect of sentence hand-shape (fist or palm), $F_1(1,65)=9.189$; $p<.01$ such that subjects were faster to respond to sentences describing a fist action than a palm. This is not particularly surprising since the palm and fist sentences were not intended to be matched for response latency. There was also a two-way interaction 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 between response hand-shape (fist or palm) and sentence hand-shape (the ACE) was significant and in the predicted direction: $F_1(1,65)=6.294$; $p<.05$ (See Fig. 2). 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 this level of fine motor detail.

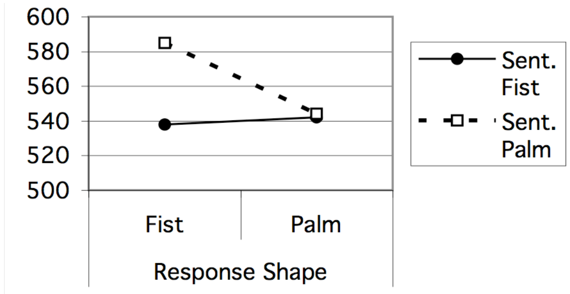

Figure 2: Response Hand-shape by Sentence Hand-shape (mean RTs)

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 (fixed or variable), response hand-shape (fist or palm), and sentence hand-shape (fist or palm). There was, however, no such significant effect, which fails to disconfirm the null hypothesis that these two sentence types yield the same effect: $F_1(1,65)=.346$, $p=.559$

5 Discussion

As expected, subjects responded significantly faster when the response hand-shape was compatible with the hand-shape encoded in the sentence, whether the verb strongly entailed this hand-shape or not. This result indicates that understanders are incorporating fine motor detail into their internal simulations of motor events when understanding action language.

Beyond greater general interest, these results also broaden the range of linguistic phenomena known to engage motor imagery to include language involving only third person referents. This is quite a remarkable finding, in fact, that reading language describing someone else performing an action leads an understander to internally imagine what it would be like to perform that same action, to a fine level of motor detail.

This work compares intriguingly with its predecessor. Although the facilitatory compatibility effect found in the current study is consistent with the findings of Glenberg and Kaschak (2002), it was the response button press rather than the release of the sentence display button that proved significant in this experiment. Let us outline two possible explanations for this difference. The first involves the timeline for processing different levels of detail in the simulation. Since Glenberg and Kaschak (2002) were evaluating more general aspects of motor actions like direction of motion, whereas the current study manipulated the more fine-grained parameter of hand-shape, it is possible that broader action information gets integrated earlier into a constructed simulation, while more detailed information, such as hand-shape, being often less critical to the interpretation, enters later into the creation of imagery. This kind of informational timeline might make general and specific aspects of the action affect response times differently as the information gets integrated at different points in the simulation. As a result, more general aspects would demonstrate compatibility effects earlier in the response process—at the reading button release, while finer detail would appear later on, at the response button press.

A second explanation for this difference in where the effect shows up might stem from the level of interlocutor involvement in the sentence stimuli. Since second-person language directly involves the understander (e.g., *Andy handed you the pizza*), sentences that include the interlocutor as participant may initiate preparation for situated action earlier in processing than when the sentence does not involve the interlocutor (e.g., *Andy handed the doctor the pizza*). Since the current experiment used only third-person sentences, as compared with the original work by Glenberg and Kaschak (2002), we might interpret the observation of an effect later on in the response process as resulting from understanders not being immediately involved in the sentence and therefore not immediately preparing to perform the action. The validity of this idea of variance can be addressed by replicating Glenberg and Kaschak's original work using sentences distinguished on a broader scale, for example, by only varying the participants such that all sentences use only third-person participants. A study is currently underway which implements this manipulation. The demonstration of such variation in the processing time-course reinforces the sensitivity of the simulation involved in interpreting language content and meaning.

Biologist Thomas Huxley (1879) observed that "Science is simply common sense at its best". Upon reflection, not as language researchers, but as lay-people, there is hardly a more commonsensical idea of how language about action should be understood, than that it should engage the understander's own bodily systems for controlling action. Thus, if we have poked people in the face, and then hear a child recount an experience of poking someone in the face, it is intuitive that we would draw upon our direct experiences to interpret information from others. After all, an understander already has a motor system similar to that of the speaker, so why shouldn't this existing resource be put to good use? And good use there is, if one is able to engage one's motor system in a simulation mode wherein the system is activated, but only to the level of imagery, not to the level of action execution. This could allow one to perform all sorts of minute and productive inferences quickly and at low cost, while at the same time preparing to perform appropriate actions. If there ever were a common sense way to make use of one's experience in one's body to facilitate higher cognitive functions like language comprehension, then engaging motor control systems to understand language certainly is one.

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Appendix A: Critical Stimuli

Fixed-Palm

(1) The nanny patted the cushion
(2) The uncle petted the dog
(3) The chef slapped the counter
(4) The waiter smoothed the tablecloth
(5) The father spanked the boy
(6) The girl stroked the cat
(7) The actor swatted the mosquito
(8) The teacher smacked the desk

Fixed-Fist

(1) The secretary clutched the coffee mug
(2) The student grabbed the telephone
(3) The woman grasped the tennis racket
(4) The singer gripped the microphone
(5) The tourist punched the wall
(6) The robber slugged the cop
(7) The shopper squeezed the tomato
(8) The housewife wrung the dishrag

Variable (a = Palm; b = Fist)

(1) a. The busboy lifted the plate
b. The bartender lifted the bottle

(2) a. The waitress carried the platter
b. The lawyer carried the briefcase

(3) a. The maid rubbed the countertop
b. The archaeologist rubbed the coin

(4) a. The grocer held the watermelon
b. The professor held the wine glass

(5) a. The jogger pushed the car
b. The auntie pushed the stroller

(6) a. The volunteer caught the sandbag
b. The cashier caught the tennis ball

(7) a. The musician played the bongo drums
b. The president played the saxophone

(8) a. The butler polished the serving dish
b. The servant polished the spoon

Appendix B: Sample Filler Stimuli

Fillers -- Sensible, intransitive

(1) The bride dieted
(2) The twig snapped
(3) The doctor golfed
(4) The puppies played
(5) The cooks slaved
(6) The runner limped
(7) The vase broke
(8) The guests feasted

Fillers -- Non-sensible, intransitive

(1) The moose blossomed
(2) The ink split
(3) The honey sang
(4) The water whistled
(5) The tuna stole
(6) The cigarette fled
(7) The favorites rioted
(8) The coffee labored

Fillers -- Non-sensible, transitive

(1) The ambassador plucked the cement
(2) The banker pinched the mountain
(3) The blacksmith whacked the rain
(4) The butcher massaged the window
(5) The builder scrunched the potato
(6) The coach bounced the rug
(7) The referee smashed the pond
(8) The husband kneaded the bookshelf