Psychonomic Bulletin & Review
2002, 9 (3), 558-565

Grounding language in action

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We report a new phenomenon associated with language comprehension: the *action–sentence compatibility effect* (ACE). Participants judged whether sentences were sensible by making a response that required moving toward or away from their bodies. When a sentence implied action in one direction (e.g., "Close the drawer" implies action away from the body), the participants had difficulty making a sensibility judgment requiring a response in the opposite direction. The ACE was demonstrated for three sentences types: imperative sentences, sentences describing the transfer of concrete objects, and sentences describing the transfer of abstract entities, such as "Liz told you the story." These data are inconsistent with theories of language comprehension in which meaning is represented as a set of relations among nodes. Instead, the data support an embodied theory of meaning that relates the meaning of sentences to human action.

How language conveys meaning remains an open question. The dominant approach is to treat language as a symbol manipulation system: Language conveys meaning by using abstract, amodal, and arbitrary symbols (i.e., words) combined by syntactic rules (e.g., Burgess & Lund, 1997; Chomsky, 1980; Fodor, 2000; Kintsch, 1988; Pinker, 1994). Words are abstract in that the same word, such as "chair," is used for big chairs and little chairs, words are amodal in that the same word is used when chairs are spoken about or written about, and words are arbitrarily related to their referents in that the phonemic and orthographic characteristics of a word bear no relationship to the physical or functional characteristics of the word's referent. An alternative view is that linguistic meaning is grounded in bodily activity (e.g., Barsalou, 1999; Fincher-Kiefer, 2001; Glenberg, 1997; Glenberg & Robertson, 1999, 2000; Lakoff, 1987; McNeill, 1992; Stanfield & Zwaan, 2001). Here, we report a new phenomenon that discriminates between these approaches. We demonstrate that merely comprehending a sentence that implies action in one direction (e.g., "Close the drawer" implies action away from the body) interferes with real action in the opposite direction (e.g., movement toward the body). These data are consistent with the claim that language comprehension is grounded in bodily action, and they are inconsistent with abstract symbol theories of meaning.

Whereas some features of the linguistic signal appear to be consistent with the abstract symbol view (e.g., words appear to work as abstract symbols), Harnad's (1990) version of Searle's (1980) "Chinese Room" argument provides a compelling intuition as to why meaning cannot be conveyed solely by the syntactic relations among abstract symbols. Harnad considers a person landing at an airport in a foreign country (perhaps China) whose language she does not speak. At her disposal is a dictionary written solely in that language. Upon disembarking, she sees a sign with a sentence in logograms, and she wishes to determine the meaning of the sentence. She looks up the first logogram (an abstract symbol) in the dictionary, only to find that its definition is given by its relations to additional abstract symbols. To determine the meaning of the first symbol in the definition, she looks it up in the dictionary only to be faced with additional abstract symbols. No matter how many of these abstract symbols she relates to one another, she is never going to determine the meaning of the sentence. The lesson is that the abstract symbols of language must be grounded, or mapped, to the world if they are to convey meaning. But there are good reasons for believing that if one has only abstract symbols at one's disposal, determination of the correct mapping is impossible (Lakoff, 1987).

In contrast to meaning as an abstract symbol system, consider the possibility that meaning is embodied—that is, that it derives from the biomechanical nature of bodies and perceptual systems (Glenberg, 1997; Lakoff, 1987). One such account is provided by the *indexical hypothesis* (IH), which proposes that meaning is based on action (Glenberg & Robertson, 1999, 2000). For example, consider how a situation (e.g., a room with a chair) could be meaningful to an animal. By hypothesis, the meaning of the situation consists of the set of actions available to the animal in the situation. The set of actions results from meshing (i.e., smoothly integrating) affordances to accomplish action-based goals. Affordances are potential interactions between bodies and objects (Gibson, 1979; Tucker & Ellis, 1998). Thus, a chair affords sitting for adult hu-

This work was partially supported by a University of Wisconsin Vilas Associate Award to the first author and a National Science Foundation Graduate Fellowship to the second author. We thank Sandra Japuntich, Michelle Lenzen, Adam Nelson, Erica Ramirez, and Donald Teague for their efforts in data collection and for their discussions about these results. In addition, Immanual Barshi, Angel Fernandez, Will Langston, and Larry Shapiro helped us sharpen our ideas. Correspondence should be addressed to A. M. Glenberg, Department of Psychology, University of Wisconsin, 1202 West Johnson Street, Madison, WI 53706 (e-mail: glenberg@facstaff.wisc.edu).

mans, but not for mice or elephants, who have the wrong sorts of bodies to sit in an ordinary chair. A chair also affords standing-on for the human. If the human has the goal of changing a light bulb in a ceiling fixture, the meaning of the situation arises from meshing the affordances of a light bulb (it can be held in the hand) with the affordances of the chair (it can be stood on to raise the body) to accomplish the goal of changing the bulb.

According to the IH, three processes transform words and syntax into an action-based meaning. First, words and phrases are indexed or mapped to perceptual symbols (Barsalou, 1999; Stanfield & Zwaan, 2001). Unlike abstract symbols, perceptual symbols are modal and nonarbitrary. They are based on the brain states underlying the perception of the referent. Second, affordances are derived from the perceptual symbols (Glenberg & Robertson, 2000; Kaschak & Glenberg, 2000). Unlike the case with arbitrary symbols, new affordances can be derived from perceptual symbols because perceptual symbols are not arbitrarily related to their referents. For example, one can judge that the sentence, "Hang the coat on the upright vacuum cleaner" is sensible, because one can derive from the perceptual symbol of the vacuum cleaner the affordances that allow it to be used as a coat rack. Similarly, one can judge that the sentence "Hang the coat on the upright cup" is not sensible in most contexts, because cups do not usually have the proper affordances to serve as coat racks. Note that neither of these judgments could be based on explicit previous learning (unless you had tried to hang a coat on a cup and you failed), nor could they be based on abstract symbols; because abstract symbols are arbitrarily related to their referents, one cannot derive new affordances from them.

The third process specified by the IH is that affordances are meshed under the guidance of syntactic constructions (Kaschak & Glenberg, 2000). As will be described in greater detail later, the grammatical form of the sentence directs a cognitive simulation that combines, for example, the affordances of an upright vacuum cleaner and of a coat to accomplish the goal of hanging up the coat. If the meshed set of affordances corresponds to a doable action, the utterance is understood. If the affordances do not mesh in a way that can guide action (e.g., how could one hang a coat on a cup?), understanding is incomplete, or the sentence is judged nonsensical, even though all of the words and syntactic relations may be commonplace. In short, the IH proposes that language is made meaningful by cognitively simulating the actions implied by sentences. The experiments that will be reported next were designed to provide convincing evidence for this claim by demonstrating that the actions implied by a sentence can interfere with real action.

EXPERIMENT 1

Participants were presented with a series of sensible and nonsense sentences, and they were asked to determine as quickly as possible whether each sentence made sense. One independent variable, implied sentence direction (toward/away), was manipulated for the sensible sentences. Thus, toward sentences, such as "Open the drawer" and "Put your finger under your nose," implied action toward the body. Away sentences, such as "Close the drawer" and "Put your finger under the faucet," implied action away from the body. The nonsense sentences, such as "Boil the air," did not seem to imply any direction. Note that the participants were never instructed to consider the implied direction; their task was merely to judge sensibility. The actual response direction (yes-is-near/yes-is-far) was manipulated by using a specially constructed button box approximately $28 \times 18 \times 6$ cm. The box was held in the lap, with the longest dimension projecting outward from the body. Three critical response buttons were arrayed on the top surface (two other buttons were nonfunctional), and they differed in distance from the body: near, middle, and far. Visual presentation of a sentence was initiated by pressing the middle button with the index finger of the right hand. The sentence was displayed on a computer monitor until the middle button was released. In the yes-is-far condition, the participants responded that the sentence was sensible by moving from the middle button to the far button—that is, they moved away from the body to respond *yes*. In this condition, the participants responded *no* by moving from the middle button to the near button. The yes-is-near condition had the reverse assignment: The participants moved toward the body to respond *yes*. The major dependent variable was the time between presentation of the sentence and release of the middle button (to move to the near or the far button), corresponding to the time to read and understand the sentence and to begin to make the sensibility response.

According to the IH, meaning is action-based: Understanding a toward sentence requires meshing affordances (e.g., of a drawer and the action of opening), resulting in a simulation of actions toward the body, whereas understanding an away sentence results in a simulation of actions moving away from the body. If this simulation requires the same neural systems as the planning and guidance of real action, understanding a toward sentence should interfere with making a movement away from the body to indicate *yes* (yes-is-far), and understanding an away sentence should interfere with making a movement toward the body (yes-is-near). Because we did not control for the fine details of the sentences (e.g., length, frequency of words) or for any intrinsic differences in ease of response direction, the prediction was for a statistical interaction between implied sentence direction and actual response direction. This interaction will be referred to as the *action–sentence compatibility effect* (ACE).

We also manipulated the sentence type. Half of the 80 sensible sentence pairs (i.e., 40 toward/away pairs) were in the imperative, such as the examples above. The other half of the sensible sentence pairs described a type of transfer. The concrete transfer pairs (20 toward/away pairs) described transfer of a physical object between "you" and another person. Half of these used the double-object con-

struction (e.g., "Courtney handed you the notebook/You handed Courtney the notebook") and half used the dative form (e.g., "Andy delivered the pizza to you/You delivered the pizza to Andy"). The 20 abstract transfer pairs described a nonphysical transfer, such as "Liz told you the story/You told Liz the story" and "The policeman radioed the message to you/You radioed the message to the policeman."

Method

The 44 right-handed, native English-speaking participants were recruited from introductory psychology classes at the University of Wisconsin, Madison, and earned extra credit points for participation. Each participant judged the sensibility of 160 sentences, half of which were intended to be sensible and half of which were intended to be nonsense. Each participant was initially randomly assigned to the yes-is-near or yes-is-far condition. Midway through the experiment, the participant was instructed to reverse the assignment of response to button and was given additional practice with the new assignment. Of the sensible sentences, 40 were randomly chosen from pairs of toward/away imperative sentences, 20 were chosen from pairs of toward/away concrete transfer sentences, and 20 were chosen from pairs of toward/away abstract transfer sentences. For both the concrete and the abstract transfer sentences, half were in the double-object form, and half were in the dative form. Forty of the nonsense sentences were in an imperative form but described actions that could not (except under some highly metaphorical readings) take place. The other 40 nonsense sentences were in double-object and dative forms. Some examples are "You gave the earring Susan" and "Joe sang the cards to you." The presentation of the 160 sentences was divided into 10 blocks of 16 sentences, in which each block contained a random mix of 8 nonsense sentences, 4 imperative sentences (2 toward and 2 away), 2 concrete transfer sentences (1 toward and 1 away), and 2 abstract transfer sentences (1 toward and 1 away).

Results

Analyses were conducted on the proportion of correct judgments, as well as on the reading times (time between presentation of the sentence and when the participant released the middle button). To reduce practice effects, the first block of 16 trials was discarded for both the yes-is-near and the yes-is-far conditions. To reduce the effect of outliers, for each participant, for each of the 12 conditions (defined by combinations of two response directions, two implied sentence directions, and three sentence types), both the fastest and the slowest reading times were discarded. The mean of the remaining reading times is referred to as the *trimmed mean reading time*. In addition, 9 participants were eliminated because of failure to maintain a constant error rate across conditions—that is, the within-subjects range in their error rates was at least .5. (The results of the analyses were substantially the same with and without these 9 participants.) A Type 1 error rate of .05 was adopted.

The data of major interest are illustrated in Figure 1. The interaction between response direction and implied sentence direction—that is, the ACE—is significant [$F(1,34) = 7.75$, $MS_e = 47{,}013$]. Although the effect seems to be stronger for the two types of transfer sentences, as compared with the imperative sentences, the three-factor interaction was not significant ($F < 1$).[1] This result confirms the prediction from the IH and is inconsistent with abstract symbol theories of meaning. In fact, the result is quite amazing: Merely understanding a sentence can facilitate or interfere with a physical response.

There were several other significant effects in the analyses of the trimmed mean reading times. There was a large main effect of sentence type [$F(2,68) = 72.41$, $MS_e = 111{,}207$], reflecting the fact that the shorter imperative sentences were read much faster than the longer transfer sentences. There was also a significant interaction between sentence direction and sentence type [$F(2,68) = 3.97$, $MS_e = 63{,}887$]. That is, the away sentences were read more

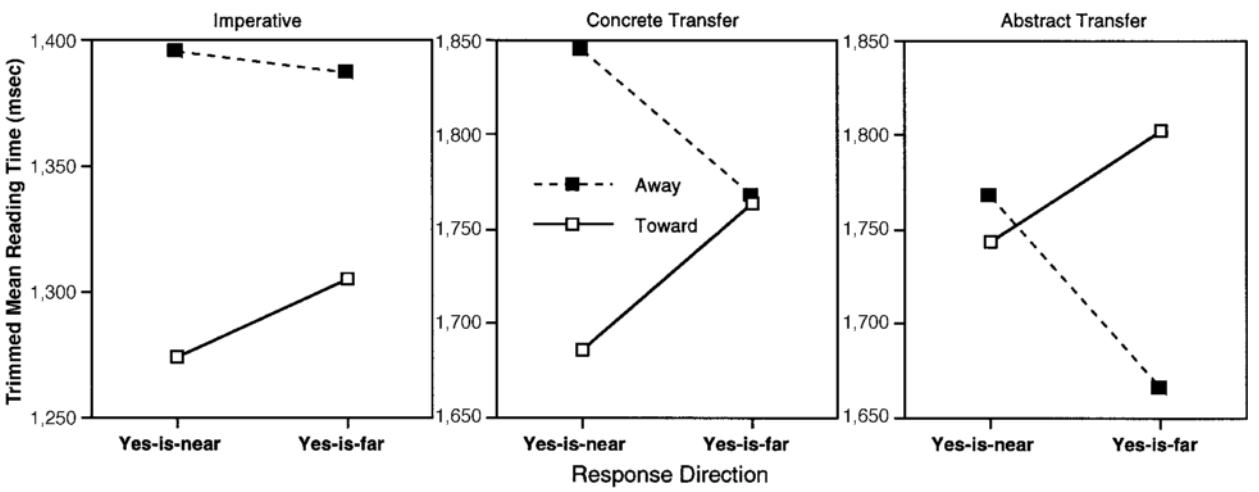

Figure 1. Data from Experiment 1 illustrating the action–sentence compatibility effect (that is, the interaction between implied sentence direction and actual response direction) for imperative sentences, concrete transfer sentences, and abstract transfer sentences.

quickly than the toward sentences for both the imperative and the concrete transfer sentences, but the opposite held for the abstract transfer sentences.

Discussion

Several aspects of the results are notable. First, the ACE is strong evidence that at least some language understanding taps into an action-based system. Second, we have demonstrated the ACE for multiple sentence constructions—namely, imperative sentences, double-object sentences, and dative constructions. Third, the ACE is found for sentences that describe concrete actions (the imperative and the concrete transfer sentences), as well as for sentences that describe more abstract actions (the abstract transfer sentences). This finding is important for ruling out an alternative explanation of the effect. According to the IH, understanding a sentence calls upon the same cognitive mechanisms as those used in planning and taking action. Hence, when the implied direction of the sentence contrasts with the actual response direction, there is interference. The alternative is that understanding reflects the manipulation of abstract symbols. However, once a sentence is understood, sentences that imply action are translated into an action pattern, and it is this postunderstanding translation that interferes with the response. This alternative can account for the data from the imperative and concrete transfer sentences. These sentences either demand actions (imperatives) or describe actions (concrete transfer) that may be contrary to the actions needed to make the sensibility response. The alternative cannot account for the ACE observed with the abstract transfer sentences. For these sentences, the actions required to effect the transfer (e.g., talking, singing, radioing) do not directly contrast with the actions needed to make the response (moving the arm and hand to the yes button). Thus, even if there were a postunderstanding translation into an action pattern, there would be no reason to suspect that that pattern would interfere with the manual response.

EXPERIMENTS 2A AND 2B

Experiment 2A was designed to replicate and modestly extend the major effects from Experiment 1. In Experiment 2A, the response direction variable was manipulated between subjects. In addition, the participants responded with their left hands. Thus, we could determine whether the ACE reflects action-planning specific for the dominant hand in these right-handed subjects. Otherwise, the experiment was substantially identical to Experiment 1.

Experiment 2B was designed to test a spatial location alternative to the IH. Confounded with the *actions* required in the yes-is-near and yes-is-far conditions, however, was *location* of the yes response buttons: closer or farther from the body, respectively. In Experiment 2B, the participant in the yes-is-near or yes-is-far condition did not move the hand. Instead, the left index finger was poised over the yes button (either near to or far from the body), and the right index finger was poised over the no button (either far from or near to the body). The prediction derived from the IH is that the ACE will be eliminated in this experiment because there is no relevant interfering action when the response is made.

Method

There were 70 participants in Experiment 2A and 72 participants in Experiment 2B from the same source as in Experiment 1. The participants were randomly assigned to Experiment 2A or 2B after reporting to the laboratory. After signing a consent form, the participants were instructed about the operation of the button box and practiced the appropriate response method. As in Experiment 1, all the participants judged 160 sentences, consisting of 10 blocks of 16 sentences.

Results

The first block of 16 trials was treated as practice and was discarded. No participant showed a range of error rates greater than or equal to .5, and hence none was eliminated. Trimmed mean reading times were computed from the remaining trials, and the data of most interest are presented in Figure 2 (for Experiment 2A) and Figure 3 (for Experiment 2B).

Experiment 2A. The ACE interaction of implied sentence direction and actual response direction was significant [$F(1,68) = 3.72$, $MS_e = 91{,}069$]. The only other significant finding for the reading times was a main effect of sentence type [$F(2,68) = 191.71$, $MS_e = 46{,}871$], indicating that the shorter imperative sentences were read more quickly than the longer transfer sentences. There were two main effects in the analysis of error rates. First, there were fewer errors on the toward sentences (4%) than on the away sentences [7%; $F(1,68) = 6.99$, $MS_e = 76.87$]. Second, there were fewer errors for the imperative sentences (4%) than for the concrete (6.5%) or the abstract (7%) transfer sentences [$F(2,136) = 10.99$, $MS_e = 38.87$].

Experiment 2B. There was very little evidence for an ACE interaction [$F(1,70) = 0.20$, $MS_e = 43{,}935$]. Thus, the contrast between the results of Experiments 2A and 2B indicate that the interference arises from action, rather than from the spatial location of the response buttons.

Several other effects were significant in the analysis of trimmed mean reading times and error rates. For the reading times, there was a main effect of implied sentence direction, in that toward sentences (trimmed mean reading time of 1,742 msec) were read faster than away sentences [1,800 msec; $F(1,70) = 8.27$, $MS_e = 43{,}935$]. Also, the imperative sentences were read much faster than the longer transfer sentences [$F(2,140) = 425.66$, $MS_e = 25{,}902$]. Finally, there was a significant interaction of sentence direction and sentence type [$F(2,140) = 3.88$, $MS_e = 23{,}299$]. There were corresponding effects in the error rates that were positively correlated with the reading times, precluding speed–accuracy tradeoffs. There was a main effect of implied sentence direction in that there were fewer errors on toward sentences (6%) than on away sentences [7%; $F(1,70) = 3.65$, $MS_e = 39.64$]. There was a main effect of sentence type, so that there were fewer er-

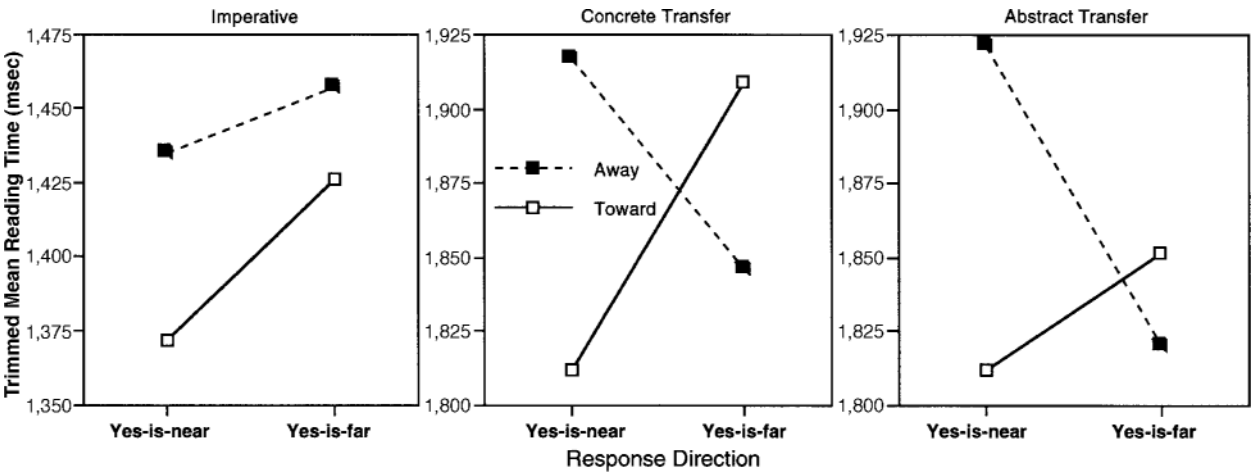

Figure 2. Data from Experiment 2A illustrating the action–sentence compatibility effect for imperative sentences, concrete transfer sentences, and abstract transfer sentences.

rors on the imperative sentences (5%) than on the concrete (7%) or the abstract (7%) transfer sentences [$F(2,140) = 4.76$, $MS_e = 41.10$]. Finally, there was an interaction between these factors, in that the difference between the toward and the away imperative sentences (4%) was greater than the corresponding differences for the concrete (0.5%) and the abstract (2.5%) transfer sentences [$F(2,140) = 4.23$, $MS_e = 38.78$].

Discussion

The results from Experiments 2A and 2B accomplished three goals. First, they demonstrated replicability of the ACE. Second, they extended the phenomenon to a between-subjects design in which the participants responded using the nondominant hand. Thus, the ACE is unlikely to reflect detailed action planning at the level of particular muscles. Third, the contrast between Experiments 2A and 2B indicate that the ACE depends on action, and not solely on spatial location of the responses.

GENERAL DISCUSSION

The ACE is consistent with the prediction derived from the IH and supports the notion that language understanding is grounded in bodily action. That is, the meaning of a sentence is given by an understanding of (1) how the actions described by the sentence can be accomplished or (2) how the sentence changes the possibilities for action (as will be described later). The ACE demonstrates that this description of language understanding is

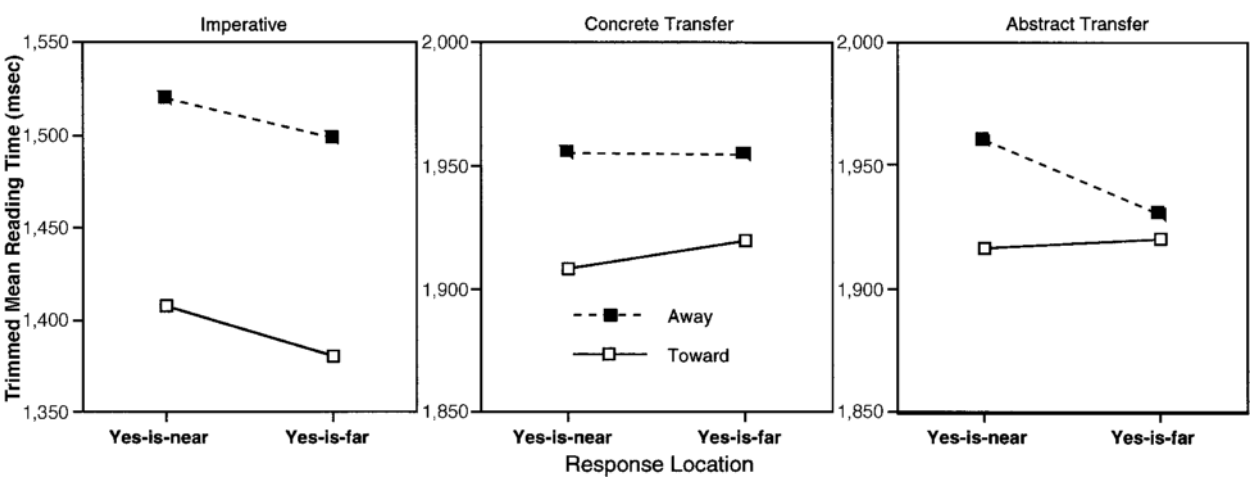

Figure 3. Data from Experiment 2B. In this experiment, responding did not require movement to the response buttons, and the action–sentence compatibility effect was eliminated.

not metaphorical—that is, it is not simply a way to describe understanding. Instead, real bodily action is at the root of meaning conveyed by language.

This rest of the discussion will be focused on two topics. First, we will discuss how the IH proposes that affordances are combined with grammatical information to result in a meshed or integrated understanding. This discussion will lead to an explanation for the ACE found with the abstract transfer sentences. Second, we will briefly discuss whether the claim that language is grounded in action can be extended to forms of language that seem far removed from action.

To review, the IH proposes that words and phrases are indexed to analogical perceptual symbols (Barsalou, 1999) based on the brain states underlying the perception of the referent. Second, affordances are derived from the perceptual symbols. Third, affordances are meshed under the guidance of syntactic constructions (Kaschak & Glenberg, 2000). Meshing is the smooth integration or combination of action or action plans. Thus, one can literally combine the actions of sitting in a chair and eating (those actions mesh), whereas one cannot combine the actions of sitting in a chair and jumping rope.

How does grammatical information guide the meshing of affordances? According to construction grammarians (e.g., Goldberg, 1995; Kay & Fillmore, 1999; Michaelis & Lambrecht, 1996), constructions[2] carry a general meaning that is not dependent on the particular lexical items in the sentence. For example, the double-object construction, "Subject–verb–object$_1$–object$_2$" carries the meaning that the subject transfers object$_2$ to object$_1$. That the sentence form carries meaning can be demonstrated by using innovative denominal verbs—that is, verbs made up anew from nouns (Kaschak & Glenberg, 2000). For example, upon watching an injured woman who is hobbling past a soccer field return an errant ball to the goalie, one might remark, "The woman crutched the goalie the ball." In this sentence, the innovative denominal verb "to crutch" seems to mean "use a crutch to transfer an object." However, the meaning must be coming from the construction, because the verb "to crutch" has no (dictionary) meaning. In this example, the construction coerces a new perspective on "crutch" from something used to support the body to an instrument of transfer. Importantly, this coercion will be successful only if the object (the crutch, in this case) has the proper affordances to effect the transfer of object$_2$ (Kaschak & Glenberg, 2000). For example, it would be difficult to understand how a woman in the park who had just finished eating a lunch of hard-boiled eggs might "eggshell" the goalie the ball: Ordinary eggshells do not have the right affordances to effect the transfer of soccer balls. Thus, according to the IH, the meaning associated with the construction (e.g., transfer) is used to guide the meshing of affordances derived from the perceptual symbols. When the affordances can be smoothly combined (e.g., we can envision how a human can use a crutch to transfer a soccer ball to a goalie), the sentence is understood.

How are these constructional meanings learned? It is likely that young children learn the actions associated with frequently heard verbs, such as "to give," by being rewarded for correct responses when a parent makes such utterances as "Give me the bottle" (Tomasello, 2000). The actions then become associated with the double-object construction because of the frequent pairing of the verb "to give" and the double-object construction, as in "You give Liz the toy." Thus, the double object construction comes to be treated as an instruction to mesh affordances of the referents of "you," "Liz," and "toy" in order to accomplish the goal of giving. Over development, the double-object instructions for meshing are applied to other actions that can effect transfer, such as "to hand," "to send," "to bicycle," and "to crutch." The final step is to apply the double-object instructions when the transfer is not of a physical object but of information, as in "You told Liz the story." That is, we come to understand the sentence as a physical movement from "you" to "Liz." To say it differently, over the course of learning the English double-object construction, we learn to treat the construction as an instruction to simulate a literal transfer of an object from one entity to another even when the object being transferred is not a physical object. This simulation is consistent with the claim that people understand communication as a type of transfer in which words act as containers of information (Lakoff, 1987).

What is the scope of this analysis? Clearly, our data illustrate an action-based understanding for only a limited set of English constructions. Furthermore, the constructions we examined are closely associated with explicit action. Even the abstract transfer sentences are not far removed from literal action. Although we have not attempted a formal or an experimental analysis of how to extend the scope of the IH, we provide three sketches that illustrate how it may be possible to do so.

Consider first how we might understand such sentences as "The dog is growling" or "That is a beautiful sunset." We propose that language is used and understood in rich contexts and that, in those rich contexts, some statements are understood as providing new perspectives—that is, as highlighting new affordances for action. Thus, while taking a walk in a neighborhood, one person may remark that an approaching dog is quite friendly. A companion might note, "The dog is growling." This statement is meant to draw attention to a new aspect of the situation (i.e., a changing perspective), thereby revealing new affordances. These new affordances change the possibilities for action and, thus, change the meaning of the situation. A similar analysis applies to such sentences as "That is a beautiful sunset." The statement is meant to change the meaning of a situation by calling attention to an affordance: The sunset affords looking at, and acting on this affordance results in the goal of a pleasurable experience.

As a second sketch, consider the notion of cause. Causal reasoning is important for our everyday and scientific understanding of the physical world, for our under-

standing of social relations, and for our understanding of discourse (Keenan, Baillet, & Brown, 1984; Singer, 1994; van den Broek, 1994). Many analyses of causal reasoning and causal language revolve around abstract ideas, what Novick and Cheng (in press) refer to as "purely covariational" approaches, in which the inference of causality is based on an analysis of the covariation of events. In contrast, a simple, embodied analysis of causal language is possible. Infants may learn about the causal power of their own actions early in development (Piaget, 1954). For example, infants learn how adjusting their sensory apparatus brings new views of the world (O'Regan & Noe, 2001). Similarly, from moving body parts with sufficient force, infants can learn how forceful changes in body parts can affect both their bodies and other objects (Meltzoff & Moore, 1997). From these basic experience, infants learn to conceptualize causes as the application of a bodily force to effect a change or resist a change. Furthermore, we propose that this notion of cause is used to ground causal language. That is, even as adults, we understand language about physical, social, and psychological causation in terms of the pushes and pulls of our bodily experience.

This proposal is consistent with the force dynamics analysis of causal language developed by Talmy (1988). According to Talmy, causal constructions portray causal events as simple contrasts between agonists and antagonists, acting against one another to produce change or stasis. Thus, on Talmy's analysis, the sentence "The shed fell because of the wind blowing on it" portrays the weaker agonist, the shed, succumbing to the stronger antagonist, the wind. On our embodied analysis, we propose that people conceptualize the wind as pushing against the shed, much as one might push over a house of cards. On Talmy's analysis, the sentence "The speaker refused to stop despite the fact that time ran out" portrays a stronger agonist (the speaker) overcoming the weaker antagonist, the social norm of stopping when time runs out. We propose that understanding this sort of situation requires an embodied notion of forceful action akin to pushing (by the social norm) and resisting the push. This analysis presupposes a type of identification or projection process. That is, the language comprehender can project onto the wind (or the social norm) his or her experiences of forceful action.

The final sketch is based on research reported by Ochs, Gonzales, and Jacoby (1996). They studied interactions among scientists participating in a high-energy physics laboratory. The physicists' discussions were about how changes in the temperature of a substance result in phase transitions among three magnetic states, one of which is termed a domain state. Ochs et al. reported that while trying to understand the relations depicted in a graph of magnetic field strength (y-axis) as a function of temperature (x-axis), the laboratory director gesturally simulated changes in temperature by moving his hand across the graph parallel to the x-axis. While doing so he said, "When I come down [in temperature] I'm in the domain state." Apparently, in attempting to understand the graph and the underlying hypothesis, the director identified with the substance ("When *I* come down . . .") and used his arm gestures to simulate changes in temperature. Ochs et al. noted that this sort of explicit bodily identification was used just when the scientists were having a difficult time understanding a new hypothesis. Similarly, Roth (1999) noted that students in a high school physics laboratory grounded their language about the dynamics of a chaotic system by using their bodies (e.g., moving a chin back and forth to correspond to changes in the system). The point of this sketch is to demonstrate that both professional scientists and naive students attempt to ground language about abstract phenomena in bodily experience.

In summary, our results demonstrate that the understanding of imperative, double-object, and dative constructions is grounded in action. Given that language almost certainly arose to facilitate coordination of action, it is not surprising that there is an observable remnant of that history. The results also raise the intriguing possibility that much, if not all, language comprehension is similarly grounded. Although substantial work needs to be done to secure that possibility, that work may well be rewarded by an account of language and meaning firmly anchored in human experience.

REFERENCES

Barsalou, L. W. (1999). Perceptual symbols systems. *Behavioral & Brain Sciences*, **22**, 577-660.

Burgess, C., & Lund, K. (1997). Modelling parsing constraints with high-dimensional context space. *Language & Cognitive Processes*, **12**, 177-210.

Chomsky, N. (1980). *Rules and representations*. New York: Columbia University Press.

Fillmore, C. J., Kay, P., & O'Connor, M. C. (1988). Regularity and idiomaticity in grammatical constructions: The case of *let alone*. *Language*, **64**, 501-538.

Fincher-Kiefer, R. (2001). Perceptual components of situation models. *Memory & Cognition*, **29**, 336-343.

Fodor, J. (2000). *The mind doesn't work that way*. Cambridge, MA: MIT Press.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Glenberg, A. M. (1997). What memory is for. *Behavioral & Brain Sciences*, **20**, 1-55.

Glenberg, A. M., & Robertson, D. A. (1999). Indexical understanding of instructions. *Discourse Processes*, **28**, 1-26.

Glenberg, A. M., & Robertson, D. A. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory & Language*, **43**, 379-401.

Goldberg, A. E. (1995). *A construction grammar approach to argument structure*. Chicago: University of Chicago Press.

Harnad, S. (1990). The symbol grounding problem. *Physica D*, **42**, 335-346.

Kaschak, M. P., & Glenberg, A. M. (2000). Constructing meaning: The role of affordances and grammatical constructions in sentence comprehension. *Journal of Memory & Language*, **43**, 508-529.

Kay, P., & Fillmore, C. J. (1999). Grammatical constructions and linguistic generalizations: The *What's X doing Y?* construction. *Language*, **75**, 1-33.

Keenan, J. M., Baillet, S. D., & Brown, P. (1984). The effects of causal cohesion on comprehension and memory. *Journal of Verbal Learning & Verbal Behavior*, **23**, 115-126.

Kintsch, W. (1988). The role of knowledge in discourse comprehen-

sion: A construction-integration model. *Psychological Review*, **95**, 163-182.

Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind.* Chicago: University of Chicago Press.

McNeill, D. (1992). *Hand and mind.* Chicago: University of Chicago Press.

Meltzoff, A. N., & Moore, M. K. (1997). Explaining facial imitation: A theoretical model. *Early Development & Parenting*, **6**, 179-192.

Michaelis, L., & Lambrecht, K. (1996). Toward a construction-based model of language function: The case of nominal extraposition. *Language*, **72**, 215-247.

Novick, L. R., & Cheng, P. W. (in press). Assessing interactive causal influence. *Psychological Review*.

Ochs, E., Gonzales, P., & Jacoby, S. (1996). "When I come down I'm in the domain state": Grammar and graphic representation in the interpretive activity of physicists. In E. Ochs, E. A. Schegloff, & S. A. Thompson (Eds.), *Interaction and grammar* (pp. 328-369). New York: Cambridge University Press.

O'Regan, J. K., & Noe, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral & Brain Sciences*, **24**, 939-1031.

Piaget, J. (1954). *The construction of reality in the child.* New York: Basic Books.

Pinker, S. (1994). *The language instinct.* New York: HarperCollins.

Roth, W.-M. (1999). Discourse and agency in school science laboratories. *Discourse Processes*, **28**, 27-60.

Searle, J. R. (1980). Minds, brains and programs. *Behavioral & Brain Sciences*, **3**, 417-424.

Singer, M. (1994). Discourse inference processes. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 479-517). San Diego: Academic Press.

Stanfield, R. A., & Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science*, **12**, 153-156.

Talmy, L. (1988). Force dynamics in language and cognition. *Cognitive Science*, **12**, 49-100.

Tomasello, M. (2000). Do young children have adult syntactic competence? *Cognition*, **74**, 209-253.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception & Performance*, **24**, 830-846.

van den Broek, P. (1994). Comprehension and memory of narrative texts: Inferences and coherence. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 539-589). San Diego: Academic Press.

NOTES

1. In a separate experiment not reported here, we used only the imperative sentences and manipulated response direction between subjects. The ACE was significant [$F(1,54) = 12.33, MS_e = 11{,}251$].

2. In general, a construction is a pairing of a form and a meaning, in which the meaning cannot be deduced from the components of the form (e.g., Goldberg, 1995). Thus, monomorphemic words (e.g., "book") and some phrases (e.g., "all of a sudden" and "by and large"; see Fillmore, Kay, & O'Connor, 1988) are constructions, in that the meaning cannot be deduced from the letters, individual sounds, or individual words. Here, we restrict the meaning of construction to verb-argument constructions, such as the double-object construction, in which a meaning (e.g., transfer) is paired with a syntactic form (e.g., the abstract form of the double object construction).

(Manuscript received August 3, 2001;
accepted for publication November 12, 2001.)