

Constructing Meaning: The Role of Affordances and Grammatical Constructions in Sentence Comprehension

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The Indexical Hypothesis describes how sentences become meaningful through grounding their interpretation in action. We develop support for the hypothesis by examining how people understand innovative denominal verbs, that is, verbs made from nouns and first encountered by participants within the experiment (e.g., to crutch). Experiments 1 and 2 demonstrated that different syntactic constructions provide scenes or goals that influence the meaning created for the innovative verbs. Experiment 3 used reading time to demonstrate that people also consider possible interactions with the objects underlying the verbs (i.e., the affordances of the objects) when creating meaning. Experiment 4 used a property verification procedure to demonstrate that the affordances derived from the objects depend on the situation-specific actions needed to complete the goal specified by the syntactic construction. Thus the evidence supports a specific type of interaction between syntax and semantics that leads to understanding: The syntax specifies a general scene, and the affordances of objects are used to specify the scene in detail sufficient to take action. © 2000 Academic Press

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How sentences are understood is a central question. Theories of sentence comprehension can inform work on parsing (e.g., Frazier & Clifton, 1996; MacDonald, Pearlmutter, & Seidenberg, 1994; see Mitchell, 1994, for a review), lexical access (e.g., Andrews, 1992; Marlsen-Wilson, 1990), mental models (e.g., Zwaan & Radvansky, 1998; van Dijk & Kintsch, 1983; Johnson-Laird, 1983; Glenberg, Meyer, & Lindem, 1987), and meaning (e.g.,

Glenberg, 1997). In this article, we propose a model of sentence comprehension based on Glenberg and Robertson's (1999) Indexical Hypothesis. This hypothesis asserts that comprehending a sentence requires three processes: *indexing* words and phrases to referents, deriving *affordances* (Gibson, 1979) from these referents, and *meshing* (Glenberg, 1997) these affordances under the guidance of intrinsic biological and physical constraints (see Glenberg, 1997; Glenberg & Robertson, in press) as well as constraints provided by the syntax of the sentence.

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In this article, we focus on the third process (meshing) and how it is guided by syntax. We develop this account by incorporating ideas from the language development literature (e.g., Landau & Gleitman, 1985; Fisher, 1996) and linguistics (e.g., Goldberg, 1995) into the Indexical Hypothesis. In particular, we propose that the meanings associated with particular syntactic forms function to constrain the way in which sentences are interpreted. This hypothesis is investigated in four experiments that explore how adult readers understand innovative denominal verbs (Clark & Clark, 1979).

TABLE 1
Syntactic Form–Meaning Pairs^a

Form	Example	Hypothesized meaning of form
Transitive N–V–OBJ	“Mike kicked the toy”	“X acts on Y”
Double object: N–V–OBJ1–OBJ2	“Mike gave David a toy”	“X transfers Y to Z”
Caused motion N–V–OBJ–OBL	“Mike pushed the book off the table”	“X causes Y to go to Z”
Resultative N–V–OBJ–Xcomp	“Mike kissed the child unconscious”	“X causes Y to become Z”
Way construction N–V–[poss-way]–OBL	“Mike made his way across the room.”	“X creates and follows a path to OBL”

^a Adapted from Goldberg, 1995.

SYNTAX AND MEANING

The relationship between syntactic forms and meaning has been explored in terms of verb argument structures, or, roughly, the structures of simple sentences. Several sentence forms, such as the double-object, transitive, caused-motion, and others (see Table 1) have been associated with particular meanings. For example, the transitive sentence structure (N–V–OBJ) is linked with a putative meaning of “X acts on Y,” whereas the double-object sentence structure (N–V–OBJ1–OBJ2) is linked with a meaning of “X transfers Y to Z” (Pinker, 1989; Goldberg, 1992, 1995). Whereas these argument structures correspond to simple sentence forms, they are also found in more complex sentences. For instance, the transitive structure is found in the sentence, “*Mike kicked the ball* that was laying in the yard,” even though the sentence structure is complex.

The relationship between form and meaning has been explored in a number of experiments involving children (e.g., Pinker, Lebeaux, & Frost, 1987; Gropen, Pinker, Hollander, & Goldberg, 1991; Naigles, 1990; Fisher, 1996). The results from a series of paradigms (e.g., “acting out” tasks and preference looking tasks) suggests that particular syntactic forms are associated with particular meanings. In fact, children’s sensitivity to these form—meaning pairings has become a significant aspect of many theories of the child’s acquisition of verb mean-

ings (Gleitman & Gillette, 1995; Naigles, Gleitman, & Gleitman, 1992; Pinker, 1989).

Several theories have been proposed to explain this form–meaning relationship. Pinker (1989) suggests that it arises from the existence of rules that link verb semantics to argument structures. A sentence form will be associated with a particular meaning, on this account, because a cluster of verbs with similar semantics (e.g., “transfer” verbs) will commonly occur in the same sentence form. A second theory (e.g., Landau & Gleitman, 1985) suggests that there is a relationship between sentence forms and the scenes that they describe. The form–meaning linkage is thus created on the basis of this relationship between scenes and sentences. Fisher (1996) proposes a similar idea in which the relationship between a particular type of event and a particular sentence form is the basis of an analogical transfer process which allows knowledge about the old event to be transferred and applied to current events or sentences. A final hypothesis about the form–meaning linkage comes from Goldberg (1995).

Goldberg (1995) claims that certain syntactic forms exist as independent units in the language with their own meaning (called “argument structure constructions”; see Table 1). A *construction* (cf., construction grammar, Fillmore, 1988; Fillmore, Kay, & O’Connor, 1988; see Kay & Fillmore, 1999, for a discussion) is defined as a pairing of a form and meaning such

that the meaning cannot be predicted on the basis of the form alone. Argument structure constructions are believed to be lexically unfilled syntactic forms that specify both syntactic (e.g., nouns, verbs, and objects) and thematic (e.g., agents, patients, and recipients) information. For example, the transitive construction specifies reference to the “agent” and “patient” thematic roles and links these roles to specific syntactic units (the “agent” is the subject, the “patient” is the direct object). It is this hypothesis about form–meaning linkages that we incorporate into the Indexical Hypothesis.

One strength of the constructional view is that it allows for a parsimonious account of the relationship between verbs and argument structures. Consider first an alternative approach to this relationship (e.g., Pinker, 1989). According to Pinker, for a verb to appear in more than one argument structure, different senses of that verb need to be created. That is, for *toss* to appear with both a transitive argument structure (e.g., “Mike tossed the ball”) and a double-object argument structure (e.g., “Mike tossed David the ball”) requires having two senses of the verb *toss*. One sense is a transitive sense (“to X”) while the other is a transfer sense (“to transfer by X”). However, if one accepts Goldberg’s (1995) proposal about the existence of constructions that carry particular meanings, it is possible to avoid positing these additional senses of *toss*. On Goldberg’s view, *toss* can have a single, general meaning that takes on different shades (e.g., the transfer component of the double-object construction) that are supplied by the construction in which it is found.

This latter point helps understand certain innovative uses of verbs, such as:

- (1) Art sneezed the foam off his beer.

This sentence (adapted from Goldberg, 1995) is unusual in that it presents an intransitive verb (*sneeze*) in a syntactic form in which it must be interpreted transitively. As Goldberg (1995) notes, such cases are difficult to handle if one relies on the creation of different verb senses to understand how verbs can be used in different argument structures. It seems unlikely that we have in our lexicon a meaning for “to sneeze”

equivalent to “X causes Y to go to Z by sneezing.” But, if we have a construction that pairs this syntactic form with this type of meaning, then such a sentence can be readily understood (see work on syntactic bootstrapping for discussion of a similar idea; e.g., Gleitman & Gillette, 1995).

Motivating Goldberg’s (1995) analysis of constructions and their meanings is the *scene-encoding hypothesis*. According to this hypothesis, argument structure constructions encode the basic scenes of human experience (e.g., transfer, acting on, and causing motion; see Table 1). Constructions thus aid in sentence comprehension by providing the comprehender with a cue to the basic nature of the scene or event being described by the sentence. For example, the double-object construction cues the comprehender that the sentence is about a transfer situation. For the remainder of the article, we refer to the sentence forms as *constructions* and the meanings paired with these forms as *constructional meanings*.

THE INDEXICAL HYPOTHESIS

Glenberg and Robertson’s (1999) Indexical Hypothesis proposes that three processes are used in understanding language. The first of these is indexing (e.g., mapping) the words and phrases in the sentence to (a) referents in the environment or to (b) analog mental representations (e.g., Barsalou’s, 1999, perceptual symbols; see Barsalou, Solomon, & Wu, 1999, for supporting evidence). Thus, indexing establishes the content of the language: who or what is being talked about. As evidence for this process, Glenberg and Robertson (1999) demonstrated that the opportunity to index instructions to the appropriate actions was a critical factor in determining how well participants acquired the knowledge needed to perform a task (e.g., learning to use a compass; see also Roth, 1999, for a discussion of this idea in an educational setting).

The second process proposed by the Indexical Hypothesis is the derivation of affordances (after Gibson, 1979) from the referents that were indexed. The term *affordances* refers to the ways in which individuals can interact with

things in their environment. For instance, a person can interact with a crutch in particular ways: a crutch can be used to aid one's walking when injured; to strike something; or to push something through a long, narrow crevice. All of these possibilities for interaction are the affordances that a crutch has for an adult human. The affordances that an individual derives from particular objects reflect both the ways in which the individual can interact with the object and the goals that the individual has at that particular moment (see Glenberg & Robertson, in press). If the person has an injured leg, for example, the "aid in walking" affordance will be more easily derived, whereas if the person wants to push something through a crevice, the "long and narrow" affordance will be more easily derived.

The third process proposed by the Indexical Hypothesis is that the affordances are meshed under the guidance of (a) intrinsic constraints and (b) constraints provided by the syntax of the sentence. Meshing is a process that combines affordances into coherent patterns of actions (Glenberg, 1997); that is, actions that can actually be completed to accomplish a goal. Thus, a crutch affords poking or pushing because it can be held and jabbed. This sort of poking can be combined (meshed) with other actions, such as placing an apple into a crevice and pushing the apple through the crevice. Meshing the affordances of a crutch, an apple, and a crevice allows for the understanding of, "Lyn pushed the apple through the crevice using a crutch." The meshing process is different from associating, propositionalizing, or parsing in that mesh respects intrinsic biological and physical constraints on combination. For example, it is difficult to understand, "Lyn pushed the apple through the crevice using a thread" because the usual affordances of threads do not combine (mesh) with the action of pushing (Glenberg & Robertson, in press).

The syntax of the sentence provides constraints on meshing in two ways. First, after the work on the syntactic form-meaning relationship (Goldberg, 1995; see also Gleitman & Gillette, 1995), the form of the sentence is hypothesized to provide cues to the general scene or event that is being described (e.g., a transfer

scene). This "scene" highlights certain affordances and, importantly, the syntax of the sentence (in this case, the identification of the subject, direct object, etc.) provides instructions for the meshing process such that all the objects and people are placed in the right relations to each other. From the previous example, the syntax constrains meshing such that Lyn is holding the crutch and pushing the apple rather than the crutch is manipulating Lyn in some manner.

These three processes interact dynamically, not serially. Upon reading that "Lyn pushed the apple through the crevice using a crutch," referents for Lyn, crutch, apple, and so on, are indexed and used to establish a mental model (e.g., Kintsch, 1988; Glenberg, Kruley, & Langston, 1994; Zwaan & Radvansky, 1998). As affordances are derived from Lyn and the apple, the meshing process begins. As the sentence continues, the affordances are meshed into what amounts to a mental simulation (e.g., Barsalou, 1999) of the event depicted in the sentence. The syntax of the sentence will be used at all of these stages to both aid in the indexing process (e.g., forming noun phrases) and to provide general constraints on how the mental simulation is to operate. Changes in any of these steps, such as a change in the syntactic analysis of the sentence, will result in the simulation being systematically altered to accommodate these changes. Note, however, that in real discourse, much of this work (with regard to the "Lyn" sentence) would have been done by the context in which the sentence is encountered. That is, the representations for Lyn, the crutch, and so on, would have been indexed in an earlier part of the discourse, removing the need to do that for the example sentence presented here. The discourse would also establish Lyn's goals so that the proper affordances could be derived from the crutch. It is in this way that discourse or context will operate to make the comprehension of sentences felicitous. However, if the affordances cannot be combined as directed by the syntax (e.g., pushing an apple with a thread), comprehension suffers (as demonstrated in Experiment 3).

The experiments that follow test the Indexical Hypothesis by examining how readers un-

derstand innovative denominal verbs (e.g., Clark & Clark, 1979); that is, verbs created from nouns (e.g., to *crutch*) that have no standard meaning. Denominal verbs of this sort provide an interesting arena within which to test the Indexical Hypothesis, as their meaning seems to rely almost exclusively on the context in which they are found. What it means to *crutch* something, for instance, depends on the manner in which *crutch* is being used as a verb: to *crutch* can mean to strike with a crutch, to walk with a crutch, to push with a crutch, and so on. Understanding what such a verb means, we argue, will depend on the perceptual symbol to which the noun (i.e., *crutch*) is indexed, the affordances that can be derived from that object, and the constraints that the scene being depicted in the sentence provides on how the object can be used.

This article presents four experiments to test the Indexical Hypothesis. In Experiments 1 and 2, we show that adults are sensitive to the meanings associated with particular sentence forms, that this sensitivity cannot be attributed to particular lexical items, and these meanings provide constraints on the way that sentences and innovative denominal verbs are understood. This finding is of particular interest, as it demonstrates that a mechanism that is used in language acquisition (e.g., Fisher, 1996; Gleitman & Gillette, 1995) continues to play an important role in the language comprehension of adults. Experiment 3 expands on the first two experiments to demonstrate how syntactic constraints interact with affordances in language comprehension. Finally, Experiment 4 provides evidence for the idea that specific affordances (that is, actions within specific contexts) are required to understand sentences.

EXPERIMENT 1

Experiment 1 is designed to assess a number of questions. First, it has been shown using a variety of tasks (e.g., Naigles, Gleitman, & Gleitman, 1992; Gropen, Pinker, Hollander, Goldberg, & Wilson, 1989) that children are sensitive to the meaning associated with particular syntactic forms. We aim to demonstrate here (along with Fisher, 1994; Naigles and Terrazas,

1998) that adults are also sensitive to this relationship. Second, we demonstrate that the meaning conveyed by particular syntactic forms is not due to previously learned lexical items (especially verbs) that may occur in these sentences. Finally, this experiment assesses the degree to which the meaning carried by syntactic frames can be used to constrain the interpretation of innovative denominal verbs.

To assess these claims, we presented participants with one of two tasks. In the sentence-choice task, participants saw pairs of sentences such as (1) and (2) or (3) and (4):

- (1) Lyn crutched Tom her apple so he wouldn't starve. (double-object form)
- (2) Lyn crutched her apple so Tom wouldn't starve. (transitive form)
- (3) Lindsay bought Sam a sweater to please him. (double-object form)
- (4) Lindsay bought a sweater to please Sam. (transitive form)

These sentence pairs were followed by one of two inference statements. One statement (e.g., "Tom got the apple") was consistent with the meaning of the double-object form, while the other (e.g., "Lyn acted on the apple") was consistent with the meaning of the transitive sentence form. Participants were instructed to indicate which member of the sentence pair most strongly implied that the inference statement was true. Half of the sentence pairs used conventional verbs [as in (3) and (4)], while the other half used innovative denominal verbs [as in (1) and (2)]. Note that the sentences are slightly more complex than simple double-object or transitive constructions need to be. The additional phrase was included to control for the number of participants mentioned in each sentence. The double-object sentence form requires three participants (an agent, patient, and recipient), whereas the transitive only requires two (agent and patient). The additional phrase added a motivation for the action described and allowed us to mention the same people and objects in both sentences. Equating the number of participants helps to rule out the possibility that subjects' choices in this task will be made solely on the basis of the number of participants mentioned in each sentence.

If participants are sensitive to the meaning associated with these syntactic forms, their choices should be strongly influenced by the inference statement. That is, when the inference statement is consistent with a transfer meaning, participants should choose the double-object member of the sentence pair; in contrast, when the inference statement is consistent with an “act on” meaning, participants should choose the transitive member of the pair. As the innovative denominal verbs do not have a preexisting “transfer component” to their meaning, any such meaning found in the sentence must arise from the syntactic form.

The second task is a meaning-choice task which addresses the question of whether constructional meanings can provide constraints on the interpretation of innovative denominal verbs. Clark and Clark (1979) note that the meaning of these denominal verbs is unprincipled (i.e., that it changes greatly depending on the context in which it is used). As Pinker (1989) notes, however, this lack of principle in meaning is detrimental to communication; ideally, a language system should provide enough constraints on meaning that comprehension is less a function of individual interpretation and more a function of general principles. The Indexical Hypothesis describes some of these principles: the affordances of the noun that is named in the denominal verb provide one set of constraints on verb meaning (an issue to be addressed in Experiments 3 and 4). Another set of constraints may be provided by the construction in which the verb appears (a point which is also made in Clark & Clark, 1979).

To explore this idea, we presented participants with the denominal verb sentences from the sentence-choice task. Each sentence was presented individually, and the participants were asked to indicate which of two meanings provided (e.g., “to act on using a crutch” or “to transfer using a crutch”) more closely matched the meaning of the verb in the sentence. If the argument structure helps to constrain the meaning of these innovative denominal verbs, participants should be more likely to select the transfer definition for verbs in the double-object construction and more likely to select the “act

on” meaning for the same verbs in the transitive construction.

Note that the two tasks used in this experiment address different issues. In the sentence-choice task, we probe participants’ interpretation of sentences. These interpretations (especially in the case of denominal verbs) may be orthogonal to the interpretation of the verbs in these sentences. For example, “Lyn crutched Tom her apple to prove her point” can be interpreted as conveying a transfer meaning regardless of whether *to crutch* means “to act on using a crutch” or “to transfer using a crutch.” In contrast, the verb-choice task addresses the degree to which the constructions will impose some structure on the meaning of the denominal verbs.

Method

Participants. The 34 participants were students enrolled by introductory psychology classes at the University of Wisconsin—Madison. Seventeen participants were used in each task. They received extra credit in exchange for their participation.

Materials. Twenty pairs of critical sentences (double-object and transitive) using innovative denominal verbs and 20 pairs of sentences (double-object and transitive) using conventional verbs were written for this experiment. The conventional verbs were taken from Pinker’s (1989) list of verbs that participate in the double-object construction. Twenty additional pairs of sentences in different constructions (the way construction, the caused-motion construction, and the resultative construction; see Table 1), some of which contained denominal verbs, were generated as filler items. See Appendix 1 for a list of all critical sentences for this experiment.

For the sentence-choice task, two inference statements were generated for each sentence pair. One statement was consistent with the meaning of the double-object construction and was presented in the form “OBJ1 got the OBJ2” (e.g., “Tom got the apple”). The other was consistent with the meaning of the transitive construction and was presented in the form “N acted on the OBJ1” (e.g., “Lyn acted on the apple”). Four forms were created to counterbal-

ance the order of the sentences in the pair (double-object first or transitive first) and the type of inference statement (transfer or act-on). A sentence pair appeared once on each form and over the course of the experiment appeared equally often in all combinations. Participants in this task saw 20 pairs of sentences using denominal verbs, 20 pairs of sentences using conventional verbs, and 20 filler items.

For the meaning-choice task, two verb definitions were generated for each of the innovative denominal verbs used in the sentence-choice task. One definition read "to transfer using an X" (consistent with the double object) while the other read "to act on using an X" (consistent with the transitive). Each participant saw 10 double-object sentences, 10 transitive sentences, and 10 filler sentences selected from the fillers generated for the sentence-choice task. Each of the 30 sentences was followed by two definitions of the verb. Four forms were generated to counterbalance (a) whether a particular innovative denominal verb appeared in the double-object or transitive construction and (b) the order of the transfer and act-on definitions.

Procedure. After signing consent forms, each participant was given one form. Participants given the sentence-choice task were told that they were going to read a series of pairs of sentences followed by an inference. They were to choose (with a pencil mark) which member of the pair of sentences most strongly implied that the inference was true. Participants given the meaning-choice task were informed that they were going to read a series of sentences. For each sentence, they were to determine what the verb in the sentence meant by choosing one of the two definitions.

Results

Sentence-choice task. The data of interest are in Table 2. When participants were asked to choose a sentence consistent with the transfer meaning, they overwhelmingly chose the double-object construction for both conventional and innovative denominal verbs. In contrast, when participants were asked to choose a sentence consistent with the act-on inference, they

TABLE 2
Results of Experiment 1

Verb type	Inference type	
	Transfer inference	Act-on inference
Sentence-choice task: Proportion of double-object sentences chosen ^a		
Conventional	.92 (.17)	.06 (.06)
Innovative denominal	.80 (.19)	.04 (.07)
Sentence type	Proportion	
Meaning-choice task: Proportion of transfer definitions chosen ^a		
Double object	.61 (.23)	
Transitive	.42 (.18)	

^a Standard deviations in parentheses. For this and all tables, standard deviations were computed across subjects.

overwhelmingly chose the transitive construction for both verb types. Given that the innovative denominal verbs have no preestablished meaning, these results demonstrate how the construction can determine the meaning of a sentence.

Statistical support for these conclusions comes from a two-factor within-subjects ANOVA in which the independent variables are construction type and verb type and the dependent variable is the proportion of double-object sentences chosen.¹ Analyses with subjects as a random factor will be denoted with the subscript 1; analyses using texts or sentences as a random factor will be denoted with the subscript 2. Participants were much more likely to choose the double-object sentence when the "transfer" statement was used than when the act-on statement was used [$F(1,16) = 250.66, p < .001$; $F(1,19) = 504.85, p < .001$]. Participants

¹ Two participants left one of the items on the form blank (a different item for each participant). Their data were included in this analysis after we calculated their proportion of double-object sentences chosen of 9 (rather than of 10). Removing these subjects from the data pool had no effect on the pattern of results observed.

were also more likely to choose the double object sentence when the sentences contained a conventional verb [$F1(1,16) = 12.96, p < .01$; $F2(1,19) = 7.51, p < .025$]. This effect is qualified by a significant verb type by inference statement interaction [$F1(1,16) = 20.44, p < .001$; $F2(1,19) = 4.61, p < .05$]. When the inference statement was of the act-on form, participants did not differ in the percentage of trials on which they chose the double-object sentence (6% for the conventional verbs, 4% for the denominal verbs; $F1$ and $F2$ both < 1). When the statement was in the “got” form, though, participants did differ in their choices [92% for conventional verbs, 80% for denominal verbs; $F1(1,16) = 20.91$; $F2(1,19) = 6.92$].

Meaning-choice task. The results from this task are presented in the bottom of Table 2. After reading the double-object sentence, participants preferred the transfer definition for the verb. In contrast, after reading the transitive sentence, participants preferred the act-on meaning of the verb. Statistically, participants were more likely to select the transfer definition after having read the double-object sentence [$F1(1,16) = 8.78, p < .01$; $F2(1,19) = 7.37, p < .025$].

Discussion

The data from these two tasks support the hypothesis that particular syntactic forms are associated with particular meanings. When the inference statement implied transfer, participants were far more likely to choose the double-object sentence than the transitive sentence. This was true for both conventional and denominal verbs. These data demonstrate that the meaning of the construction is not purely tied to the semantics of the verb. First, the innovative denominal verbs (e.g., “to crutch”) have no meaning outside of the sentence frame. Second, the meaning of these verbs changes depending on the sentence frame. When an innovative denominal verb (e.g., *crutch*) is presented in the double-object construction, 80% of the participants agree that it implies transfer; when the same verb is presented in the transitive construction, however, 95% of the people agree that it implies “acted on.” Thus, syntactic forms can

be used to constrain the interpretation of innovative denominal verbs.

There are two minor qualifications to our conclusions. The first arises from the significant difference between the verb types observed with the “transfer” statements in the sentence-choice task. One possible explanation for this effect is that the conventional verbs used in this experiment occurred fairly frequently with the double-object construction (e.g., give, send, bring), and many of them have a transfer component to their meaning (e.g., give). The denominal verbs, however, lacked both the frequency of use in the double-object construction and the transfer component of meaning.

The second qualification arises from the low proportion of construction-consistent definitions selected in the meaning-choice task (e.g., 61% for verbs in the double-object sentences). While this proportion is different from chance [$t(16) = 2.14, p < .05$], it is lower than one might expect given the hypothesized relationship between sentence forms and meaning. We believe that this low proportion is a function of the fact that neither definition presented to the subjects was “wrong” in any sense. Acting on something is one component of transfer, just as transfer is one way of acting on something. This ambiguity may have led to the proportion of construction-consistent definitions being lower than expected.

EXPERIMENT 2

Experiment 1 demonstrated that participants are sensitive to the meaning of the double-object construction and that this meaning cannot be solely a product of verb semantics. It also demonstrated that syntactic forms constrain the meaning ascribed to innovative denominal verbs. Nonetheless, for both tasks the constructional meaning was presented explicitly to the participants. In Experiment 2, we ask if the participants would come up with these meanings on their own.

We presented the denominal verb sentences from Experiment 1 with a context that sets up a potential transfer scene (see Table 3). After reading these contexts and the denominal verb sentences, the participants were asked to per-

TABLE 3

Example Pair of Passages from Experiment 2

(1) Tom and Lyn competed on different baseball teams. After the game, Tom, who had been pitching, was kidding her about striking out three times. Lyn said, "It was an aberration! I was distracted by your ugly face. I can hit anything to any field using anything!" To prove it, she took her apple over to manager who was recovering from a twisted ankle, and she grabbed his crutch.

Critical sentences

Lyn crutched Tom her apple to prove her point. (double object)

Lyn crutched her apple to prove her point to Tom (transitive)

Probes (used in Experiment 4)

The crutch is sturdy. (Most Important affordance)

The crutch is long. (Not Important affordance)

The crutch an help with injuries. (Most Frequent Associate)

(2) Tom and Lyn had made a bad miscalculation. Because they are U.S. citizens they thought they could protest civil rights abuses in the dictatorship. But now they were being held incommunicado in a prison dungeon. Lyn was beaten so badly that she needed a crutch to help her to walk. Because the mortar between the bricks was crumbling, Tom and Lyn were able to create a long, narrow crevice in the three-foot wall separating the cells. Lyn learned that Tom was being deprived of food in an effort to get him to reveal other members of their human rights group. Lyn tried shove a piece of apple through the crevice, but the wall was too wide, and her arm couldn't reach through it. Then she got an idea.

Critical sentences

Lyn crutched Tom the apple so he wouldn't starve. (double object)

Lyn crutched the apple so Tom wouldn't starve. (transitive)

Probes (used in Experiment 4)

The crutch is sturdy. (Not Important affordance)

The crutch is long. (Most Important affordance)

The crutch can help with injuries. (Most Frequent Associate)

form one of two tasks, either to paraphrase the critical sentence or to define the innovative denominal verb.

Method

Participants. The participants were 64 introductory psychology students from the University of Wisconsin—Madison. Thirty-two participants were used in each task. The participants received extra credit in exchange for their participation.

Materials. A pair of contexts was generated to introduce each of the 20 denominal verb sentences used in Experiment 1 (see Appendix 1 for critical sentences; passages available upon request from the authors). Pairs of contexts were generated to fit the needs of Experiment 4. Each member of the pair presented a potential transfer situation, and each of these situations proposed using the object that was named by the

denominal verb in a different way. As an example, consider the passages in Table 3. In the first passage, the transfer is accomplished by using the crutch to hit the apple; in the second passage, the transfer is accomplished by pushing the apple through a crack with the crutch.

For both the sentence-paraphrase and verb-definition tasks, eight forms were constructed to counterbalance (a) version of the passage, (b) double-object and transitive concluding sentence, and (c) two random orders of the passages. Each form presented the participant with 10 passages that ended with double-object sentences and 10 passages that ended with transitive sentences.

Procedure. Participants were told that they were going to read a series of passages. They were informed that some of the concluding sentences would contain unusual verbs and that they should try their best to understand what the

passages and sentences mean. The participants in the sentence-paraphrase task were then instructed to write a paraphrase for each of the concluding sentences. The participants in the verb-definition task were instructed to write definitions that best matched their sense of what the verb meant in the context of the passage.

Scoring. The paraphrases were scored twice using two criteria. The transfer score (0 or 1) indicated whether the paraphrase conveyed transfer by explicitly indicating that the object to be transferred was received by the intended recipient. Thus, the paraphrase, "Lyn pushed the apple through the crack" would be scored as 0 because it does not explicitly state that Tom got the apple.

The verb score (0 or 1) was based solely on the verb used in the paraphrase. The verb score was 1 if the verb appeared on Pinker's (1989) list of verbs that take the double-object construction. If two verbs were used in the paraphrase (e.g., "Lyn found a crutch and used it to give Tom the apple"), the verb score was 1 if either verb was on Pinker's list.

The definitions were also scored using two criteria. The transfer score was 1 if the definition included both a transfer of an object and that the means of the transfer was the noun named in the denominal verb (e.g., "to crutch means to hit something to someone using a crutch"). The second scoring was identical to the verb score for the sentence-paraphrase task: in defining the innovative denominal verbs, did the participant use a verb from Pinker's (1989) list?

Results

Sentence-paraphrase task. The transfer score was assigned by M.P.K. One-third of the paraphrases were scored by an independent rater. The agreement between the two was 95%.

Table 4 presents the proportion of transfer paraphrases (of 10) for double-object and transitive sentences for each participant. Because it had an F ratio of greater than 1, counterbalance condition was included as a factor in this analysis. For the transfer score, there was a main effect of construction type [$F(1,24) = 16.43, p < .001; F(1,19) = 26.2, p < .001$]. Partici-

TABLE 4
Results from Experiment 2

Construction	Transfer score	Verb score
Sentence-paraphrase task ^a		
Double object	.65 (.14)	.49 (.15)
Transitive	.52 (.17)	.43 (.12)
Verb-definition task ^a		
Double object	.50 (.24)	.49 (.23)
Transitive	.35 (.21)	.32 (.21)

^a Standard deviations in parentheses.

pants were more likely to give a transfer paraphrase for the sentence when it was in the double-object form. This effect was also significant for the verb score in the subject analysis [$F(1,24) = 4.40, p < .05$], but not in the analysis by items [$F(1,19) = 3.39, p = .08$].

Verb-definition task. The transfer score was assigned by M.P.K. One-third of the definitions were also scored by an independent rater. The agreement between the raters was 94%. The data are shown in Table 4. For the transfer score, participants were more likely to give a transfer definition for the innovative denominal verbs when they were presented in the double-object construction [$F(1,24) = 18.36, p < .001; F(1,19) = 9.78, p < .01$]. This result also showed up in the analysis of the verb score [$F(1,24) = 13.38, p < .01; F(1,19) = 6.18, p < .025$].

Discussion

The data from both tasks complement the results of Experiment 1. Participants demonstrated sensitivity to constructional meanings in their paraphrases, and they showed that this meaning shapes the definition imposed on the innovative denominal verbs. One might object to our interpretation on the grounds that the passage, not the construction, was providing the "transfer" meaning. On this view, the construction would not in fact be providing any constraints on the interpretation of these sentences and verbs. This hypothesis is supported by the

TABLE 5

Example Passage from Experiment 3

Rachel worked for a scientist in a research firm. As part of her duties, she was required to bring the scientist's mail to his office so he could open it after lunch. On this particular day, Rachel encountered three large boxes among the mail addressed to the scientist. The boxes were way too big for her to carry.

Affordance manipulating sentence:

In the corner of the room, though, Rachel noticed an office chair with four *good/missing* wheels

Critical sentence

Rachel *brought/chaired* the scientist his mail.

presence of the large number of transfer paraphrases for the transitive sentences. Nonetheless, this objection cannot explain why the double-object sentences and verbs were paraphrased as meaning "transfer" more often than the transitive sentences and verbs. Thus, an explanation of these data on the basis of the passage alone is not justified.

EXPERIMENT 3

Experiments 1 and 2 demonstrated how constructions can provide constraints on the interpretation of sentences and innovative denominal verbs. In Experiments 3 and 4, we demonstrate how the constraints provided by constructions (again, the double-object construction) interact with the embodied constraints on meshing. We do this by demonstrating that the constraints provided by the constructional scene (i.e., the general scene specified by the meaning of the construction) are not enough to ensure comprehension (i.e., successful meshing) of sentences. Rather, it is these constraints in combination with the embodied constraints that determine whether a sentence will be understood. As we demonstrate, when the affordances of a situation do not support the scene provided by the construction, comprehension suffers.

Table 5 presents an example of the texts used in this experiment. As in the passages from previous experiments, these texts are designed to set up a potential transfer situation. Each text has two versions: one that easily affords the transfer by means of some object (the *afforded* version) and one that does not easily afford transfer by means of that same object, but does

not rule out transfer altogether (the *nonafforded* version). This manipulation was achieved by changing a property of the object that is to be used in the transfer. In the example in Table 5, when the chair has four good wheels, it affords transferring the mail by means of the chair. However, when the chair has four missing wheels, transfer via the chair is no longer easily afforded, although it is still possible that Rachel could somehow get the mail to the scientist. The passage ended with a critical sentence in the double-object form containing a conventional verb or an innovative denominal verb. Predictions focus on the reading time for these critical sentences.

According to the Indexical Hypothesis, meaning arises from the mesh of affordances guided by intrinsic biological and physical constraints and the scene or goal specified by the construction. Thus, when the affordances of a chair with wheels (it can easily be pushed even when stacked with items) can be meshed with the affordances of large boxes (they can be stacked on a chair) to accomplish transfer (as specified by the construction), comprehension should be easy and fast. However, when the affordances cannot be easily meshed to accomplish transfer (a chair without wheels does not easily afford pushing), comprehension should be difficult and slow. This prediction parallels the data reported in Glenberg and Robertson (in press) that shows that lack of proper affordances for the action described by a sentence will produce comprehension difficulties.

The Indexical Hypothesis also predicts an affordance by verb-type interaction. When the critical sentence contains a conventional verb,

we expect the difference between the afforded and nonafforded conditions to be relatively small. This is because the meaning of the construction and the semantics of the conventional verb should allow the reader to infer that the transfer took place even though he or she may not be sure how it occurred (e.g., by bringing). When the critical sentence contains a denominal verb, however, we expect this difference to be much larger. In this case, the noun underlying the denominal verb either can or cannot easily effect the transfer, and the reader will experience greater difficulty in determining a meaning for the sentence.

Method

Participants. The participants were 36 students from the University of Wisconsin—Madison. The students received extra credit in exchange for their participation.

Materials. Twelve passages were generated for this experiment. The passages were written to suggest a potential transfer scene using a particular object as a potential means of transfer. The penultimate sentence of each passage was manipulated to produce afforded and nonafforded versions of the text. Afforded versions described the object as having affordances that supported use of the object in the transfer; nonafforded versions presented affordances that did not support the use of the object in the transfer. For each passage, two critical sentences (one with a conventional verb and one with a denominal verb) were written (see Appendix 2 for a list of critical sentences). Four counterbalance conditions were created to ensure that the afforded and nonafforded version of each passage was presented equally often with critical sentences containing conventional and innovative denominal verbs.

Procedure. Participants were randomly assigned to one of the four counterbalance conditions. The participants were told that they would read each paragraph sentence by sentence on the screen of a computer and that they should try to understand each sentence fully. To advance to the next sentence, the participant needed to press the space bar on the computer keyboard.

After reading the instructions and going

TABLE 6
Reading Time (in Seconds) for Critical Sentences in Experiment 3^a

Verb type	Passage type		(Nonafforded – afforded) difference
	Afforded	Nonafforded	
Conventional	2.37 (.90)	2.83 (.85)	.46
Denominal	3.21 (1.09)	4.31 (1.33)	1.10

^a Standard deviations in parentheses.

through a practice text, each participant read 12 passages [3 passages in each of 4 conditions formed by crossing the two types of texts (afforded and nonafforded) with the two types of verbs (conventional and innovative denominal)]. The passages were presented in random order with the constraint that in each block of 4 trials, 1 passage from each condition would be presented. Following each passage, participants answered a “yes/no” question about details from various points in the text.

Results

Reading times greater than 3 standard deviations from their respective mean were removed from the dataset as outliers. This involved the loss of less than 1% of the responses. In addition, we checked for accuracy on the yes/no questions that followed each text. Performance was quite good on these questions (average performance across participants was 96.8%), and no participants missed more than two questions, indicating that they were following our instructions.

The dependent variable of interest was the time to read the critical sentence as measured by the time between key presses. These data are presented in Table 6. The data are in agreement with the predictions of the Indexical Hypothesis. Participants read the afforded sentences more quickly than the nonafforded sentences. In addition, this difference was more than twice as large for the innovative denominal verb sentences as for the conventional verb sentences.

A within-subjects ANOVA demonstrated main effects of both verb type and affordances.

Participants read critical sentences with conventional verbs faster than sentences with denominal verbs [$F(1,35) = 120.04, p < .001$; $F(2,11) = 28.30, p < .001$]. Participants also read the critical sentences faster following the afforded version of the passages than when the sentences followed the nonafforded passage [$F(1,35) = 24.74, p < .001$; $F(2,11) = 20.61, p < .001$]. Finally, there was an interaction of affordance and verb type [$F(1,35) = 4.63, p < .05$; $F(2,35) = 3.80, p = .077$].²

Discussion

When the context does not provide affordances needed to understand how the transfer implied by the critical sentence was carried out, participants had a much more difficult time understanding the sentences (as evidenced by the longer reading times). Thus, we have shown that affordances are important to the comprehension of sentences and particularly important to the manner in which innovative denominal verbs are understood.

The effect of verb type is only of minor interest. The slower reading times of sentences with denominal verbs may be attributed to factors such as their novelty, the relatively low frequency with which they are used as verbs (i.e., zero), or other similar factors. The crucial finding in these data is that affordances are considered in understanding the critical sentences. When affordances are proportionately important for understanding (i.e., when reading the innovative denominal verbs), the affordance manipulation is proportionately large.

EXPERIMENT 4

Experiment 3 demonstrated that affordances are important to the comprehension of sentences. In this experiment, we demonstrate that particular affordances are derived to carry out the action specified by the constructional scene.

Participants were presented with the passages and critical sentences from Experiment 2. These

passages were generated in pairs such that both members of the pair involved the use of the same object to transfer something to someone else (see Table 3), and each passage portrayed the object as being used in a unique manner. We asked the participants to read the passages, after which we presented a probe for verification. The participants answered “yes” or “no” to these probes (see Table 3).

The probes were of three types. For each passage, there was a probe that described the affordance of the noun underlying the denominal verb that was Most Important to the comprehension of the critical sentence. For example, in the first passage in Table 3, the fact that “the crutch is sturdy” is important to understanding how Tom got the apple. There was also a probe that named an affordance of the noun that was Not Important to the comprehension of the critical sentence. For the first passage in Table 3, the fact that the “crutch is long” is not particularly important to understanding how Tom got the apple. Note that the materials are constructed so that the Most Important affordance from version 1 was a Not Important affordance in version 2 and vice versa. The third probe type was named the Most Frequent Associate to the noun. It was determined by a norming study.

According to the Indexical Hypothesis, participants should be faster to verify the Important Affordance than the Not Important affordance because, in understanding the critical sentence, the Most Important affordance will have been derived. The Most Frequent Associate probe is intended as a control to provide a standard against which to compare the reaction time to the other probes. If the Most Important affordance is truly being highlighted, responses to these probes should be as fast or faster than responses to the Most Frequent Associate probes.

Method

Participants. The participants were 50 introductory psychology students from the University of Wisconsin—Madison. They received extra credit in exchange for their participation.

² The data were also analyzed including outliers. The data produced the same pattern of results as reported in the text, save for the fact that the interaction of verb and affordance was significant in the analysis by items in this case ($p = .05$).

Materials. Eighteen pairs of passages from Experiment 2 were used in this experiment. For each passage, there were three probe types: a Most Frequent Associate probe, a Most Important affordance probe, and a Not Important affordance probe (see Appendix 3 for a list of probe items). Probes were generally of the form “the [noun] is/can [affordance]” (see Table 3). Of the 54 probes used in this study (3 probes each for 18 denominal verbs), 33 were of the “can” form, 16 of the “is” form, and 5 used another form (e.g., “the [noun] has [affordance]”). All three probe types were of approximately the same length; the mean number of characters in each probe type ranged from 25 to 26.4. In addition, 20 distractor passages that were similar to the original passages were constructed. For each passage, a probe that was not true was generated (e.g., “crayons can fly”).

To increase the number of observations on each probe type, the type of probe contrasted with the Most Important affordance probe was manipulated between subjects. In one condition (i.e., the Most Important affordance vs Most Frequent Associate condition), four counterbalanced sets of items were generated to present both versions of each passage equally often with the Most Frequent Associate and Most Important affordance probes. Here, the “affordance”-based probes (i.e., the probes based on the affordances of the object used to effect the transfer) were presented equally often as the “Most Important” probes, and the “associate”-based probes (i.e., the probes based on the most frequent associate to the object used to effect the transfer) were presented as the “Most Frequent Associate” probes. In the other condition (i.e., the Most Important affordance vs Not Important affordance conditions), four counterbalanced sets of items were created to present both versions of each passage equally often with the Most Important affordance and the Not Important affordance probes. Each “affordance”-based probe was presented equally often as the Most Important and the Not Important probe. Any one participant saw only two of the three probe types in the experiment.

Three phases of norming were used in this experiment. First, the nouns named by the de-

nominal verbs were presented (out of context) to 46 participants who were asked to write down the first three words that came to mind after reading each noun. For each noun, the most frequent response was used to generate the Most Frequent Associate probe. In no cases did the Most Frequent Associate overlap with either the Most Important or Not Important affordances.

In the second norming phase, we presented the passages to 40 participants, along with both the Most Important and Not Important affordance probes. We asked the participants to rate (on a scale from 1 to 7) how important each affordance was to understanding the action of the critical sentence. Passages that did not demonstrate a mean difference of at least 2 rating points between each probe type were excluded from the experiment. Two pairs of passages were excluded by this criterion, which is why we used only 18 of the 20 pairs from Experiment 2.

Note that in this experiment, the Most Important affordance probe is determined by the preceding context. Thus, there is a possibility that differences in reaction times to the probe is due to direct associations between words in the context and words in the probe rather than affordances. The final phase of norming was intended to counter this association alternative. The passages and probes were submitted to three analyses using Latent Semantic Analysis (LSA; see Landauer, 1999, Landauer & Dumais, 1997, and Landauer, Foltz, & Laham, 1998, for a discussion). LSA is a computer program that computes an index of the relatedness between sets of words on the basis of occurrences in similar contexts. Words are related, on this view, to the degree that they occur in similar texts (see Landauer, Foltz, & Laham, 1998). We used LSA to compare the probe concepts to (a) the whole passage that preceded it, (b) the noun named by the denominal verb, and (c) the last sentence of the passage. These comparisons yield a metric of the relatedness of the two concepts: the cosine between the vectors representing the stimuli being compared. If the cosine is low (i.e., close to zero), the two concepts appear in nearly orthogonal contexts and hence are not likely to be associatively

related. A cosine of 1.0 indicates that the two stimuli appear in identical contexts.³

In the first analysis, we calculated the cosine between the main concept from each probe (e.g., “sturdy”) and the accompanying passage. The average cosine for the Most Important affordance probes (.06) and the Not Important affordance probes (.05) did not differ from each other ($F < 1$), but they did differ from the average cosine of the Most Frequent Associate (.14) [$F(1,53) = 12.33, p < .01$; and $F(1,53) = 17.08, p < .01$, respectively]. This indicates that the Most Frequent Associate is more closely related to the passage (in the sense that the associate and words in the passage tend to appear in similar texts) than were either of the affordance probes.

In the second LSA analysis, the probe concepts (e.g., “sturdy” and “long”) were compared to the noun named by their accompanying denominal verb (e.g., “crutch”). The mean cosine for the Most Frequent Associate (.36) was more related to the noun named by the denominal verb than were the mean of the cosines for the two affordances (.16), [$F(1,33) = 38.70, p < .001$]. These analyses do not differentiate between Most Important and Not Important affordances because importance is determined relative to the context presented by the passage. The third LSA analysis compared the probe concepts to the last sentence of their accompanying passage (i.e., the sentence containing the innovative denominal verb). The mean cosine for the Most Frequent Associate (.01) did not differ from the mean cosine for the affordances (.02) [$F(1,35) = 1.57, p = .22$].

The LSA analyses demonstrate either no difference between probe types or an advantage for the Most Frequent Associate probes.

Procedure. Participants were told that they were to read passages line by line, advancing from one sentence to the next by pressing the space bar. At the end of each passage, three asterisks were presented on the screen for 1 s, and this was followed by one of the three probes

³The analyses were conducted using the LSA TASA-WK space. In this space, the corpus of language used by LSA in computing relatedness come from novels, newspapers, and other types of texts.

for the passage. The participants were told to respond as to whether the probe statement was true by pressing a “yes” or “no” key. They were told to answer as quickly and accurately as possible.

Participants were randomly assigned to a condition that presented two of the three probe types. All participants received Most Important affordance probes. Approximately half of the participants also saw the Not Important affordance probes (24 participants), whereas the other half saw the Most Frequent Associate probes (26 participants). In all, each participant saw 18 critical probes (9 Most Important Affordance probes and either 9 Not Important Affordance or 9 Most Frequent Associate probes) and 18 distractor probes to which the appropriate answer was “no.” The dependent variable of interest was the response time to the probe items.

Results

Analysis of response times for all texts. The response times greater than 3 standard deviations from the mean in each condition were removed from the data as outliers. This resulted in a loss of less than 2% of the responses. Additionally, participants who made greater than 22% errors across all of the trials were excluded from the analysis. This resulted in the loss of one participant from the Most Important affordance vs Not Important affordance conditions. Finally, all trials on which an error was made was excluded from the analysis of response times. The data of interest are presented in Table 7.

In the Most Important affordance vs Not Important affordance conditions, participants were faster to verify the Important Affordance than the Not Important affordance [$F_1(1,23) = 6.25, p < .025$; $F_2(1,35) = 8.69, p < .01$]. In the Most Important affordance vs Most Frequent Associate conditions, participants were also faster to verify the Most Important affordance [$F_1(1,25) = 14.03, p < .001$; $F_2(1,35) = 7.14, p < .025$].

Further analysis demonstrated significant differences in the number of errors made in each condition. Participants made more errors on the

TABLE 7

Response Times in Seconds and Error Proportions (with Standard Deviations in Parentheses) for Experiment 4

Probe Type	Most Important affordance	Not Important affordance	Most Frequent Associate
All texts			
Condition			
MIA vs NIA ^a			
Response time	2.37 (.53)	2.74 (.92)	—
Error rate	.08 (.10)	.31 (.19)	—
MIA vs MFA ^a			
Response time	2.38 (.61)	—	2.96 (1.05)
Error rate	.14 (.12)	—	.28 (.19)
Excluding texts			
Condition			
MIA vs NIA			
Response time	2.26 (.56)	2.85 (1.26)	—
Error rate	.03 (.08)	.25 (.22)	—
MIA vs MFA			
Response time	2.35 (.63)	—	2.76 (1.15)
Error rate	.06 (.10)	—	.13 (.18)

^a IA, Most Important affordance; NIA, Not Important affordance; MFA, Most Frequent Associate.

Not Important affordance (31%) and Most Frequent Associate (28%) probes than on the Most Important affordance probes (8 and 14%, respectively). This difference was significant in both the Most Importance affordance vs Not Important affordance condition [$F1(1,25) = 31.50, p < .001; F2(1,35) = 18.78, p < .001$] and the Most Important affordance vs Most Frequent Associate condition [$F1(1,25) = 17.41, p < .001; F2(1,35) = 5.55, p < .025$]. The direction of the difference in error rates precludes a speed accuracy trade-off because the higher error rates were associated with longer response times.

Analysis of Response Times for Low-Error Rate Texts

It appeared as if the difference in error rates was due to difficulties with specific passages. For example, the Most Frequent Associate probe for a passage involving the denominal verb “to mouse” was “the mouse can eat cheese.” This was true for one version of the passage, in which the mouse was a live animal; however, it was false of the other version, in

which the mouse was a toy. In the latter case, the correct response (i.e., “no”) would have been scored as an error. Of the 36 texts used in this experiment, 18 showed this type of asymmetry and displayed error rates in excess of 25%. The passages that did not show these types of problems had much smaller error rates. To ensure that our conclusions are not affected by odd passages, we performed analyses on texts with low error rates. We examined the error rates for each passage across all participants and excluded from analysis those pairs of passages that produced an error rate of greater than 25%. This resulted in the loss of 9 pairs of passages (of 18). After this step, all participants with an error rate of greater than 22% were also eliminated. This resulted in the loss of one participant from the Most Important affordance vs Not Important affordance condition (the same participant who was excluded from the analysis for all texts). Finally, all incorrect responses and outliers were excluded from the analysis (outliers defined as above).

In the Most Important affordance vs Not Important affordance conditions see Table 7), par-

ticipants were faster to verify the Important Affordance than the Not Important affordances [$F1(1,23) = 8.20, p < .01$; $F2(1,17) = 7.86, p < .025$]. In the Most Important affordance vs Most Frequent Associate condition, participants were faster to verify the Most Important affordances, although the difference was only marginally significant [$F1(1,25) = 3.81, p = .06$; $F2(1,17) = 3.17, p = .09$].

Discussion

The data are in accord with the predictions derived from the Indexical Hypothesis. Participants were faster to verify the affordance important for the understanding of the critical sentence than to verify either the Not Important affordance or the Most Frequent Associate. This result held across both analyses that we performed (the weaker effects in the second analysis were likely due to the dramatic loss in power that resulted from excluding so many observations).

One might object to our characterization of these data as a demonstration of the role of affordances in sentence comprehension on the grounds that our task was simply a property-verification task. There are a number of reasons why we believe this objection to be misguided. First, the faster response times for the Most Important affordance probes is context dependent. That is, the affordance that was responded to more quickly was determined by the nature of the transfer action that needed to be taken and by the goals of the characters in the passages, not by a simple association between the passage and the property named in the probe. Also, a simple associative account of this context specificity is ruled out by the LSA analyses conducted on the probes and passages. In two of the three LSA analyses, the Most Frequent Associate was more strongly related to the preceding context than were either of the two affordance types. If the reaction time data were only reflecting associative priming by the context, we should have seen the fastest response times to the Most Frequent Associate probes, but we did not. Further, if associative priming was the source of this observed pattern of data, there should have been no difference between the

response times to the Most Important and the Not Important affordances, as both were related (in the LSA analyses) equally to the preceding context.

GENERAL DISCUSSION

The experiments reported here have accomplished several goals. First, Experiments 1 and 2 demonstrate that adult participants are sensitive to the meanings associated with particular syntactic forms and that these meanings are not due to previously established meanings of verbs. Second, these same experiments demonstrate that constructional meanings can be used to constrain the meaning of innovative denominal verbs. Finally, Experiments 3 and 4 show that constructional meanings are not enough to ensure felicitous understanding of sentences and denominal verbs. Rather, affordances play a role in sentence comprehension as well. Each of these is discussed in turn.

In Experiments 1 and 2, we replicated the finding (Fisher, 1994; Naigles & Terrazas, 1998) that adults are sensitive to the meaning associated with particular sentence forms and expanded on the existing literature in two ways. First, we demonstrated that constructional meanings are not tied to the semantics of particular verbs. Participants were sensitive to differences in constructional meanings even when differential cues to this meaning could not have come from the verbs and nouns in the sentences. Second, we have shown that constructional meanings provide constraints on the interpretation of innovative denominal verbs.

The relationship between syntactic form and meaning discussed here and elsewhere (Goldberg, 1995; Pinker, 1989; Fisher, 1996) appears to be an important aspect of language acquisition, language comprehension, and, ostensibly, language production (see Goldberg, 1999, and Tomasello & Brooks, 1999, for more specific constructional approaches to language development). A large body of work on verb acquisition (e.g., Pinker, 1989, 1984; Landau & Gleitman, 1985) has demonstrated that the cues provided by such form–meaning links (i.e., constructions) may be vital to learning the meaning of new verbs. As the work of Fisher (1994; see

also Naigles & Terrazas, 1998) and the experiments reported here demonstrate, this link may be important for adults' understanding of novel utterances as well. These findings are of particular interest, for they suggest that a mechanism that is used in the acquisition of language continues to play an important role in the language processing of adults. This idea has strong implications for the study of language in both adults and children (see MacDonald, 1999, for a discussion of some ways to relate adult and child language research).

While we consider our experiments a success in providing basic support for Goldberg's (1995) approach to the relationship between sentence forms and meaning, this success might be qualified by two limitations. First, the present experiments examined only two constructions: the double object and the transitive. Second, our data do not, in and of themselves, rule out alternative approaches to form-meaning links (e.g., Fisher, 1996; Landau & Gleitman, 1985; Pinker, 1989). These limitations lead to the criticism that our experiments have not demonstrated sensitivity to constructional meanings, but, rather, that they demonstrate sensitivity to the presence or absence of particular thematic roles. Participants may have decided that the double-object sentences meant transfer when the denominal verbs were present because they detected the "recipient" role in this sentence form and not in the transitive form. We would argue, however, that this alternative explanation is not much different from the one offered by the constructional approach. Recall that constructions carry both syntactic information and information about the thematic roles linked to each syntactic category. Part of what it is to recognize these constructions and access their meaning may well be the recognition of the pattern of thematic roles that they specify.

This criticism does raise an issue regarding the linguistic knowledge to which an individual has access. The type of linguistic knowledge at work in these experiments is knowledge of constructions, or knowledge of some other principle, such as that specified by the Universal Theta Assignment Hypothesis (UTAH; Baker, 1988). Unfortunately, our data do not distin-

guish among these alternatives, although Goldberg (1995) presents a series of arguments in favor of adopting a constructional approach.

The experiments reported here also show how the Indexical Hypothesis provides an account of the comprehension of innovative denominal verbs. The syntactic form in which these verbs were encountered was shown to play a large role in determining the meaning that was ascribed to them. In addition, it was shown that particular affordances (e.g., the specific actions required to use the object to effect a transfer) were necessary for the participants to understand sentences with these verbs. Such constraints are important to the comprehension of denominal verbs, as, on the whole, their meaning cannot be well predicted outside of the context in which they appear (Clark & Clark, 1979; but see Kelly, 1998). Note that our appeal to the concept of affordances does not amount to saying that in using an innovative denominal verb, we employ the object named by the noun in a stereotypic manner. Clark and Clark (1979) argue that this characterization is wrong. In addition, the results from Experiment 4 demonstrate that unusual uses of the objects named by the denominal verbs were more important to understanding sentences than were stereotypical uses. We believe that the computation of affordances for the noun is perhaps the only way to determine the use of an object in context.

Experiments 3 and 4 build on the work of Glenberg and Robertson (in press), and help us to answer the question that we started with: how are sentences understood? Our basic claim is that meaning is not achieved solely through the combination of words and other abstract symbols (e.g., nodes) by syntactic and probabilistic manipulations. Instead, the symbols must be grounded, and we propose that the meaning of situations and of sentences is grounded in action.

But just as language is not a concatenation of words, meaning is not a concatenation of affordances. The affordances must be combined (or, meshed) into a coherent pattern, that is, one that supports action. Experiments 3 and 4 provide the first evidence for how this is done: constructional meanings provide a framework for the

selection (Experiment 4) and combination of (Experiment 3) affordances. That is, the basic scene specified by the construction constrains the mesh of affordances so that the goals specified by the scene are achieved. If the affordances cannot be meshed, comprehension is slow and unsuccessful (Experiment 3).

Work on the combination of lexical and contextual information in the comprehension of sentences (e.g., Swinney, 1979) has dealt with similar issues, as has work in linguistics (e.g., Fauconnier's, 1999, "mental spaces" analysis). The novel contribution of this work is to specify that a particular type of knowledge about the world (i.e., affordances) interacts with a specific type of linguistic knowledge (i.e., constructions) to produce meaning. There are clearly many questions that need to be answered about our approach. One important question is whether the idea of affordances can be extended to abstract concepts. There are at least three mechanisms for doing so. First, Lakoff (1987) discusses how image schemas can be metaphorically extended to abstract domains. For example, Lakoff suggests that human understanding of a container is a structured image schema based on direct experience. The schema includes the information that a container has an inside and an outside and that another object can be inside or outside, but not both. This concrete understanding of containers forms the basis, Lakoff asserts, for our understanding of an abstract logical principle that has a related structure, namely "p or not-p, but not both." Barsalou (1999) offers another approach to understanding abstract ideas. As an example, consider Barsalou's analysis of the concept of truth. He suggests that truth arises from a multistep comparison process. First, one forms a simulation of a situation. This simulation is often prompted by language, such as the assertion, "The airplane is in the sky." Second, because the simulation makes use of perceptual (i.e., analogical) symbols, it can be compared with an actual situation that is being perceived. Third, the language is judged as "true" when the simulation substantially matches the perceived situation. Fourth, the concept of truth emerges as a conscious application of this procedure.

The final approach to understanding abstract ideas within an embodied system is illustrated in the previous paragraphs: we understand abstract ideas from concrete examples. Thus, our understanding of containment may well arise from experience with specific examples of containers, just as our understanding of a theory (e.g., about how language works) may well arise from specific examples (e.g., sentences about crutches). Importantly, the individual examples use language about concrete situations from which affordances can be derived. It may be that abstract symbols emerge from the multiple examples, but it is by no means necessary. For instance, an understanding of the abstract concept of democracy may well be based on specific experiences and actions such as observing a parent casting a ballot. A sophisticated understanding of the notion of democracy is more than this, but that sophisticated understanding may well be based on multiple exemplars, just as a sophisticated understanding of the notion of a chair must include dining chairs, stuffed chairs, beanbag chairs, and balans chairs. This approach to understanding abstract ideas is consonant with the use of concrete examples at all levels of pedagogy to explicate abstractions.

In this article we have demonstrated support both for the hypothesis that particular syntactic forms (i.e., constructions) carry particular meanings and for the Indexical Hypothesis that affordances are meshed under the guidance of constructions. Whereas the focus of this work has been on deriving meaning from sentences, the broad scope of language use indicates that the communication of meaning is opportunistic. In addition to the devices discussed here, language takes advantage of gesture (MacNeill, 1998), common ground (Clark, 1996), and the real people and objects in the environment (see Roth, 1999). We believe that these components of meaning making can be interpreted within the Indexical framework. At the very least, the success of this project demonstrates how a focus on meaning can profitably constrain our theorizing about language processing.

APPENDIX 1

Critical Sentences from Experiments 1 and 2

Denominal verb sentences used in Experiments 1 and 2. Alternative versions of the sentences refer to changes made in the sentences so they would fit better with the passages used in Experiment 2. The sentence on top is the double-object sentence; the sentence on bottom is the transitive sentence.

(1) Mike ballooned David the toy to help him out. Mike ballooned the toy to help David out. (Alternative: Mike ballooned David the toy to continue the game. Mike ballooned the toy to continue the game with David.)

(2) Pauline spatulaed Mary the cookie dough to meet her request. Pauline spatulaed the cookie dough to meet Mary's request.

(3) The old man cupped the boy some popcorn to calm him down. The old man cupped the popcorn to calm the boy down.

(4) Lois blanketed the neighbors her baby to save him. Lois blanketed her baby so the neighbors could save him.

(5) Maureen postcarded her sister the news to keep her informed. Maureen postcarded the news to keep her sister informed.

(6) Paul rocked Bill the lure to give him luck. Paul rocked the lure to give Bill luck.

(7) Adam booked Jareb his request to stop the guitar playing. Adam booked his request that Jareb stop the guitar playing.

(8) George bindered Lydia the note so he could ask for a date. George bindered the note so he could ask Lydia for a date.

(9) Blind Willie saxophoned John a happy story to cheer him up. Blind Willie saxophoned a happy story to cheer John up.

(10) Jeb tractored Gwenda a message to reassure her. Jeb tractored a message to reassure Gwenda.

(11) Doug bottled the rescuers a message so they could find him. Doug bottled a message to the rescuers could find him.

(12) Sally pursed Pete the fish to keep him company. Sally pursed the fish to keep Pete company.

(13) Duncan Tonkaed mom his laundry to appease her. Duncan Tonkaed his laundry to appease his mom.

(14) Todd branched Rick a scratch to get back at him. Todd branched a scratch to get back at Rick.

(15) Rachel chaired the scientist the mail so he could open his packages. Rachel chaired the mail so the scientist could open his packages.

(16) Lyn crutched Tom her apple so he wouldn't starve. Lyn crutched the apple so Tom wouldn't starve. (Alternative: Lyn crutched Tom her apple to prove her point. Lyn crutched her apple to prove her point to Tom.)

(17) Mina enveloped Larry some chocolate to make him smile. Mina enveloped some chocolate to make Larry smile.

(18) The operator craned the mason the cement to help him. The operator craned the cement to help the mason.

(19) Erik fanned his cat the ball to satisfy him. Erik fanned the ball to satisfy his cat.

(20) Art moused Jim a greeting to make him laugh. Art moused a greeting to make Jim laugh. (Alternative: Art moused Jim a joke to make him laugh. Art moused a joke to make Jim laugh.)

Conventional Verb sentence pairs used in Experiment 1:

(21) Vince cooked Frank a meal for his retirement. Vince cooked a meal for Frank's retirement.

(22) Peter baked John a cake to surprise him. Peter baked a cake to surprise John.

(23) Josh faxed his boss a letter to satisfy him. Josh faxed a letter to satisfy his boss.

(24) Wendy sent Kyle a card to apologize. Wendy sent a card to apologize to Kyle.

(25) Thomas flung his girlfriend his coat to keep her warm. Thomas flung his coat to keep his girlfriend warm.

(26) Mark painted Sally a portrait for her birthday. Mark painted a portrait for Sally's birthday.

(27) Bruce bought Seline a present during his visit. Bruce bought a present during his visit to Seline.

(28) Jack won his little sister a stuffed animal to make her smile. Jack won a stuffed animal to make his little sister smile.

(29) Lindsay purchased Sam a sweater to make him happy. Lindsay purchased a sweater to make Sam happy.

(30) Kevin blasted Simon the rocket ship to impress him. Kevin blasted the rocket ship to impress Simon.

(31) Max poured Luke a drink to please him. Max poured a drink to please Luke.

(32) Julie fixed Ivor a dinner to surprise him. Julie fixed a dinner to surprise Ivor.

(33) Fred tossed Bob a rotten egg to get back at him. Fred tossed a rotten egg to get back at Bob.

(34) Paul recorded Marge a song to show his love. Paul recorded a song to show Marge his love.

(35) The scout radioed Mandy a message to save her life. The scout radioed a message to save Mandy's life.

(36) Bertha mailed Betty a letter to make amends. Bertha mailed a letter to make amends to Betty.

(37) The woman gave the fire victims ten dollars to aid them. The woman gave ten dollars to aid the fire victims.

(38) Liz tossed Brain a salad so he wouldn't be hungry. Liz tossed a salad so Brian wouldn't be hungry.

(39) Tony shipped his wife a souvenir to placate her. Tony shipped a souvenir to placate his wife.

(40) The mother made her daughter a dress for the prom. The mother made a dress for her daughter's prom.

APPENDIX 2

Critical Sentences from Experiment 3

(1) David gave/flasked John some juice.

(2) Art dropped/ballooned Mina the paper.

(3) Joan sent/belled the hikers a warning.

(4) Jeb brought/minivanned Gwenda the sculpture.

(5) Patty played/guitarred the judges her song.

- (6) Rachel brought/chaired the scientist his mail.
- (7) Kate got/dumb waited June some water.
- (8) Keith brought/glassed his mother-in-law the flowers.
- (9) Lindsay and Sam sent/flashlighted the farmhands a message.
- (10) Fred sent/moused Bob a message.
- (11) Brian presented/Applied Jen his marriage proposal.
- (12) Tom gave/oranged his grandmother her medicine.

APPENDIX 3

Probe Statements from Experiment 4

The top two probes in each set of three are the “affordance-based” probes. The third probe is the “Most Frequent Associate” probe.

- (1) The mouse can be heard. The mouse can be seen. The mouse can eat cheese.
- (2) The blanket is long and sturdy. The blanket is soft. The blanket is warm.
- (3) The book can be thrown. The book can slide. The book can be read.
- (4) The saxophone is tube-like. The saxophone can be heard. The saxophone can play music.
- (5) The crutch is sturdy. The crutch is long. The crutch is used for an injury.
- (6) The bottle can reflect light. The bottle can float. The bottle can hold beer.
- (7) The spatula can carry things. The spatula can be used as a catapult. The spatula can be used for cooking.
- (8) The binder can open. The binder can hold things in place. The binder holds paper.
- (9) The postcard is flat. The postcard can be mailed. The postcard depicts vacations.
- (10) The purse can carry things. The purse can conceal things. The purse can hold money.
- (11) The cup can float. The cup can contain things. The cup is used for drinking.
- (12) The branch has whippy ends. The branch is long and firm. The branch is from a tree.
- (13) The tractor can hold things. The tractor can overturn earth. The tractor is used for farming.
- (14) The chair can roll. The chair can hold things. The chair is used for sitting.
- (15) The balloon is buoyant. The balloon is hollow. The balloon holds air.
- (16) The envelope is firm. The envelope can hold things. The envelope can hold letters.
- (17) The Tonka can carry things. The Tonka can drive over things. The Tonka is a truck.
- (18) The fan can rotate. The fan can blow things. The fan cools things.

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