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# On doing two things at once: Temporal constraints on actions in language comprehension

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In two experiments, we investigated how text comprehension is influenced by the interaction between the properties of actions and the temporal relations specified by adverbs. Participants read short narratives describing a protagonist who performed two actions that involved similar sensorimotor systems (e.g., chopping wood and painting a fence) or different ones (e.g., whistling a melody and painting a fence). The actions were described as simultaneous or successive by means of the temporal adverbs *while* and *after*, respectively. Comprehension, both in Spanish and in English, was markedly impaired (longer reading times and lower subjective coherence) for sentences including the adverb *while* and actions involving the same sensorimotor system. However, when one of the same sensorimotor system actions was described as a mental plan (e.g., chopping wood and thinking of painting a fence), comprehension was equally easy with the adverbs *while* and *after*. These results are compatible with a revised version of the indexical hypothesis that specifies how comprehension is guided by syntax and embodied constraints within multiple noninteracting mental spaces.

Time is a ubiquitous dimension of language. Discourse has a temporal structure: Words, phrases, and sentences are produced and understood serially (Saussure, 1915/1972). Like events in real-life experience, the events described by discourse are temporally organized in a reader's representation (e.g., Rinck, Gámez, Díaz, & de Vega, 2003; Zwaan & Radvansky, 1998). For instance, readers of a novel monitor the order of sequential events or the temporal overlap of simultaneous events, they may distinguish among current events, events that have already happened, and events that have not yet taken place; and they should be sensitive to event durations. In this article, we explore the understanding of temporal aspects of events in the context of the indexical hypothesis (IH; Glenberg & Robertson, 1999, 2000). We report two experiments (in Spanish, English, and German) illustrating how syntactic information and embodied information (particularly, action patterns) are integrated during the comprehension of texts that describe actions performed in time by a single character.

According to the temporal iconicity assumption, language comprehenders exploit the linearity of discourse when building their representations of temporal aspects of the situation (Chafe, 1979; Comrie, 1985; Dowty, 1986; Givón, 1992; Hopper, 1979). By default, readers assume that the order of clauses or sentences corresponds to the chronological order of the events in the situation referred to, so that successive sentences describe successive events. Thus, when *John wrote a letter and read a newspaper* is read, the writing is assumed to precede the reading. The strongest iconicity assumption proposes that readers interpret contiguous sentences as describing contiguous

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events, without any temporal break between them (Dowty, 1986; Zwaan, 1996). In some cases, however, the mapping between the discourse time and the event time is not direct, because linguistic markers may instruct readers to deviate from the default iconicity assumption. Some adverbs prompt the reader to represent the situation events as reversing the order of the text (e.g., *Before reading the newspaper, John wrote a letter*), whereas others inform the reader of time shifts or discontinuities between adjacent clauses (e.g., *John read the newspaper and one week later he wrote a letter*). Verb tense and aspect also signal a deviation from the iconicity assumption. Tense and aspect inform the reader whether, at present, an event is still developing (*The painter is working on the room*), has been completed (*The painter worked on the room*), or is yet to be done (*The painter will work on the room*).

There is some evidence that the reading of texts that conflict with the iconicity assumption requires additional cognitive resources. For instance, Münte, Schiltz, and Kutas (1998), in an event-related potential study, manipulated the adverb (*after* vs. *before*) to produce sentences matching or mismatching the iconicity assumption—for instance, *After* [*Before*] *the scientist submitted the paper, the journal changed its policy*. The results showed that *before* sentences produced a more negative signal over left frontal regions than *after* sentences did, which can be interpreted as an index of more working memory demands for the *before* sentence than for the *after* sentence.

Other studies have been conducted to examine how an event's accessibility is modulated by temporal shifts. Thus, Zwaan (1996) wrote short narratives in which adverbials were manipulated to induce time shifts of different durations—for example, *Jamie turned on his PC and started typing. A moment/An hour/A day later the telephone rang*." The latencies to a probe word (e.g., *typing*) placed at the end of the story were shorter for the adverbial *a moment later* than for the others, because it did not modify the default continuity between the events in successive sentences. In contrast, the adverbials *an hour later* or *a day later* established a temporal break overriding the iconicity assumption, thereby making the initial event less accessible.

Verb tense and aspect also modify the accessibility of described events conflicting with the iconicity assumption. Carreiras, Carriedo, Alonso, and Fernández (1997) showed that a job description remained accessible in working memory when it was made relevant to the current state of a character by means of the present tense (*Marta works as an economist*), whereas it was less accessible when it was dissociated from the present state of a character by means of the past tense (*Marta worked as an economist*). In the same vein, Magliano and Schleich (2000) demonstrated that an action (changing a tire) was more accessible when it was included in an imperfective construction (*Stephanie was changing the flat tire*) than when it was included in a perfective construction (*Stephanie changed the flat tire*).

The iconicity assumption is a good starting point for analyzing the role of temporal organization in a reader's representation of narrative worlds. Furthermore, the data mentioned above are compatible with general frameworks that consider time as one of the privileged dimensions in discourse comprehension. This is the case of the structure-building framework (Gernsbacher, 1990) and the event-indexing model (Zwaan, Langston, & Graesser, 1995; Zwaan & Radvansky, 1998). Nonetheless, there are limitations to this approach. For example, the temporal iconicity assumption treats time as an additive or independent parameter, rather than as an interactive one. That is, the temporal iconicity assumption does not describe how temporal information may constrain the interpretation of other information. Experiments performed by Radvansky and his collaborators (Radvansky, Spieler, & Zacks, 1993; Radvansky, Zwaan, Federico, & Franklin, 1998) are relevant to the claim that temporal information constrains interpretation of other information. In Radvansky et al.'s (1998) Experiment 3, participants learned one-level fan sentences (each sentence involving a unique character performing an action) or three-level fan sentences (three sentences sharing the same character, who performed three actions at the same time). There was a fan effect (interference in a speeded sentence recognition task) when the three actions could not be integrated into the same physical situation (e.g., *The teacher was reading a novel*, *The teacher was playing pinball*, *The teacher was playing piano*), whereas the fan effect was absent when the three actions could be integrated into the same physical situation (e.g., *The engineer was folding a towel*, *The engineer was biting his lip*, *The engineer was listening to the radio*). Thus, comprehension of actions proposed as simultaneous was modulated by how easily the actions could be performed in the same physical situation.

The present research was designed to explore further the mechanisms through which the temporal constraints on actions provided by the text affect the ease with which language is understood. The work extends Radvansky et al.'s (1998) findings by demonstrating that felicitous comprehension requires the integration of temporal and sensorimotor parameters of the situation. Although both studies share the view that comprehension involves embodied representations or situation models, the present research differs from Radvansky et al.'s (1998) research in several respects. First, we used a comprehension task involving on-line measures, rather than a memory task. Second, our manipulation was more constrained than that used by Radvansky et al. (1998). Whereas their work focused on a variety of spatial, temporal, and motor dimensions, our work focused on a particular temporal manipulation (simultaneity vs. succession) and a particular kind of motor constraint (actions performed with the same sensorimotor system vs. actions performed with different sensorimotor systems). Finally, our hypotheses were directly inspired by a recent theory of language comprehension: the IH (Glenberg & Robertson, 2000; Kaschak & Glenberg, 2000). The IH proposes that language is understood by using syntactic constructions to develop an embodied perception–action simulation of the objects and actions described by the language. The IH is an embodied theory of cognition in the following sense. First, the representations postulated by the theory include perceptual features in sufficient detail to derive *affordances* (i.e., possibilities for interaction; Gibson, 1979),[1] and second, the process of integrating representations takes into account biological and physical (e.g., temporal) constraints on action. The syntactic constructions guide integration by specifying both the general nature of the event (e.g., someone is transferring something to someone else; e.g., Goldberg, 1995; Kaschak & Glenberg, 2000; McKoon & Ratcliff, 2003) and the role that each entity in the sentence plays in the event.

Consider the IH account of comprehending a sentence such as *She scratched her back using the 3-inch floppy disk*. First, words and phrases must be *indexed* to referents (either real-world objects or perceptual symbols; Barsalou, 1999). Thus, phrases such as *the 3-inch floppy disk* are indexed either to an object in the environment or to one's analogical memories. Second, affordances are derived from these referents (not from the words themselves). For example, a floppy disk affords grasping and back-scratching (as well as throwing as a frisbee and inserting into a slot). Third, the affordances must be integrated in a manner that produces a coherent simulation of action. The integration of affordances is guided by syntax (Kaschak & Glenberg, 2000). In the floppy disk sentence, the disk is marked by the syntax as the instrument. Because a floppy disk has the affordances that allow its use as an instrument for back-scratching, the components of the sentence can be successfully compiled into a pattern of action, and the sentence is understood. The sentence *She scratched her back using the 3-inch thread* is more difficult to understand: The components cannot be easily combined into a pattern of action as directed by the syntax unless one infers (thereby slowing comprehension) that *she* refers to a contortionist. The contrast between *3-inch disk* and *3-inch thread* sentences illustrates how biological constraints on action play a role in language comprehension.

The idea that linguistic meaning is embodied has received a good deal of support (Glenberg & Robertson, 2000; Kaschak & Glenberg, 2000; Stanfield & Zwaan, 2001; Zwaan, Stanfield, & Yaxley, 2002; Zwaan & Yaxley, 2003). Most germane to the present work is a series of experiments reported by Glenberg and Kaschak (2002). In these experiments, participants were asked to read a series of sentences and to decide whether they were sensible or not. On critical trials, the sentences described an action that required movement either toward the body (e.g., *Mark gave you a pen*) or away from the body (e.g., *You gave Mark a pen*). Half of the time, a *yes* response required an action toward the body to hit a response key, whereas the other half of the time a *yes* response required an action away from the body. The critical finding from these experiments was the action–sentence compatibility effect (ACE): When the action described in the sentence conflicted with the action required to make a response, response times were increased. Thus, comprehending language about actions appears to require a recruitment of the same motor planning systems as those needed to produce real action in the world. This conclusion is also supported by results from the neuroscience literature that demonstrate that the processing of action words (e.g., action verbs or tool names) relies partially on the same cortical generators as those used in performing actions (e.g., Damasio & Damasio, 1994; Martin, Wiggs, Ungerleider, & Haxby, 1996; Preissl, Pulvermüller, Lutzenberger, & Birbaumer, 1995; Pulvermüller, 1999). In addition, Buccino et al. (2003) reported differential activation of hand and leg muscles when reading sentences about hand actions (*He was turning the key*) and leg actions (*He was kicking the ball*).

Glenberg and Kaschak's (2002) claims provide the starting point for our exploration of the interaction between temporal and action-oriented information in language comprehension. The temporal distinction in which we are interested is that between events that occur simultaneously (signaled by the adverb *while*) and events that occur serially (signaled by the adverb *after*). According to the IH, these adverbs serve as instructions for how to simulate the events being described. *While* is an instruction to attempt a simultaneous simulation of the actions, whereas *after* is an instruction to simulate the actions in a particular temporal order. The motoric dimension in which we are interested is the distinction between actions performed with the same sensorimotor system (e.g., both painting a fence and chopping wood involve use of the hands and arms) and those performed with different sensorimotor systems (e.g., painting a fence and whistling a tune involve two distinct motor systems). If understanding language (temporal language in this case) requires constructing a perception–action simulation of the events being described, the IH makes a straightforward prediction for how the temporal and the motoric dimensions should interact. When the actions being described use different sensorimotor systems, they should be relatively easy to simulate. On the other hand, when the actions involve the same sensorimotor system, they should be easy to simulate sequentially but difficult to simulate simultaneously.

This prediction was tested in two experiments. In Experiment 1 (conducted in Spanish and English), participants read sentences, such as Sentences 1–4, that were embedded in texts:

1. While whistling a lively folk melody, he painted the fence white.
2. After whistling a lively folk melody, he painted the fence white.
3. While chopping wood with his large axe, he painted the fence white.
4. After chopping wood with his large axe, he painted the fence white.

Sentences 1 and 2 present actions using different sensorimotor systems, whereas Sentences 3 and 4 present actions using the same sensorimotor system. The IH predicts the following pattern of reading times. Participants should read Sentences 1 and 2 with relative ease, since both require simulations of events using different motor systems.

Despite requiring the simulation of actions incorporating the same motor systems, Sentence 4 should also be easy to understand, because the adverb *after* instructs the reader to simulate the actions in a particular temporal order. In contrast, Sentence 3 should be difficult to understand. This is because it is not easy to simultaneously simulate two actions in the same sensorimotor system (see Glenberg & Kaschak, 2002).

These predictions contrast with the predictions derived from different versions of the iconicity hypothesis described earlier. The strongest version of the iconicity hypothesis straightforwardly predicts that sentences involving the adverb *while* should be read more slowly than those using the adverb *after*. This is because the *while* sentences violate the iconicity assumption, whereas the *after* sentences do not. Other possibilities beyond a strong iconicity hypothesis also exist. For instance, *while* sentences might be read more slowly than *after* sentences because they involve integrating old and new information into a single structure, thereby demanding more cognitive resources. Conversely, it is also possible to predict that *after* sentences would be read slightly more slowly than *while* sentences because the former involve a temporal shift and the latter do not. Finally, it is possible that both integration effort and temporal shift counterbalance each other across readers and/or materials. If so, no systematic difference between *while* sentences and *after* sentences would be expected.[2]

The data from Experiment 1 were complemented with a norming study to rule out the possibility that background knowledge, rather than a perception–action simulation, could account for the results. According to the background knowledge hypothesis, the relative difficulty in understanding Sentence 3 with respect to Sentence 1 might be related to the fact that participants know that the conjunction of *chopping wood* and *painting a fence* occurs less frequently than *whistling a melody* and *painting a fence*. We asked participants to rate how frequently the pairs of actions occur, and then we partialed out these estimates from the on-line comprehension data. Our expectation was that the basic results would remain the same, thereby demonstrating that differential frequency of pairs of actions cannot be the sole basis of the effect.

In Experiment 2, we introduced a more subtle manipulation to demonstrate that *while* sentences involving the same motor system do not show any difficulty when they are not required to be simulated as part of the same action pattern. In that experiment, we described one of the actions as an epistemic state, rather than as a real action—for instance, *While chopping wood with his large axe, he* thought of *painting the fence white*. If the actions of painting are not integrated with the actions of chopping wood, there should be little difficulty in comprehending this type of sentence.

## EXPERIMENT 1

The experiment was performed with Spanish materials (Experiment 1A) and with English materials (Experiment 1B). Both data sets were complemented with a norming study to obtain co-occurrence ratings of actions and to test the role of background knowledge on the reading time results. In Experiments 1A and 1B, the same design, experimental procedure, and materials were used. The materials first were written in Spanish and then were translated into English. However, literal translation was impossible, because Spanish and English adverbial sentences differ in verb tenses. The critical adverbial sentence included two clauses sharing the grammatical subject and including an action verb in each clause. In Spanish, this kind of adverbial construction with a coreferent subject differs slightly for *while* (*mientras*) and *after* (*después de*) clauses. Specifically, *while* clauses involve an imperfective aspect mark in the verb (e.g., Spanish imperfect past tense), whereas *after* clauses demand a verb in infinitive with a perfective meaning (e.g., García-Fernández, 1999; Hernanz, 1999). For instance,

5. Mientras charlaba con su marido, la mujer se peinó con la raya en medio. [While (she) was chatting with her husband, the woman used a comb to part her hair.]

6. Después de charlar con su marido, la mujer se peinó con la raya en medio. [After chatting with her husband, the woman used a comb to part her hair.]

In Spanish, the simultaneity marked by *while* and the succession marked by *after* are considerably reinforced by their respective aspectual marking in the verb. This is not the case in English, where the marking on the verb is not dependent on the choice of adverb. Thus, in English, the manipulation can be restricted to a single word.

Our use of the same sensorimotor system actions to produce conflicting actions and different sensorimotor system actions to produce nonconflicting actions is only approximate, for several reasons. First, actions involving the same sensorimotor system do not necessarily conflict. For example, one can talk and chew gum, snap one's fingers while conducting a band, and so on. Second, although language may assert simultaneity, there are instances in which the events may be understood as interruptable and, hence, not strictly simultaneous. For example, *While painting the wall, Mike adjusted the lights*. It seems that Mike may have interrupted his painting in order to adjust the lights, and then he returned to painting. Third, some actions involving different motor systems will conflict. For instance, *painting the fence* and *skipping* conflict because one of them involves body displacement and the other requires being still. When people infer these relations between events, the inferences may well depend on event durations, their interruptability, and their implicit displacement, as well as on whether or not the actions share the same motor system. Thus, same sensorimotor systems and different sensorimotor systems can only be rough stand-ins for determining which actions will conflict during a simulation.

We did not strictly control all of the possible factors that could modulate the comprehension of simultaneous and successive actions, for two reasons. First, nonstandard interpretations of the temporal sentences work against the predictions from the IH, thus making for a stronger test of the hypothesis. Consider again, *While painting the wall, Mike adjusted the lights*. If the reader infers that *painting the wall* is momentarily interrupted to perform *adjusting the lights*, the comprehension should be facile (fast reading and high sensibility ratings), in conflict with the predictions of the IH. If the predictions of the IH are confirmed in the face of this possible variability in the interpretation of the sentences, it indicates the robustness of the phenomenon under study. Second, we asked our participants to estimate whether the stories were coherent. These estimates indicate the extent to which readers' interpretations of the sentences matched with the experimenter's intuitions (and they did, as we will see).

## General Method

**Participants**. The participants were 46 students (32 females) from the University of La Laguna (Spain) and 24 students from the University of Wisconsin. The La Laguna students were all native speakers of Spanish, and the Wisconsin students were all native speakers of English. All the students were enrolled in introductory psychology courses and received extra credit in exchange for their participation. Data from 2 Spanish and 1 American participant were discarded from the analysis because their coherence responses were apparently random.

**Design and Materials**. A factorial 2 (adverb: *while*/*after*) × 2 (motor system: same/different) experimental design was run. All factors were within subjects. The experimental materials consisted of 40 stories, as illustrated in Table 1.

Each text contained one or two initial sentences introducing the character and his/her general goal, the adverbial sentence, including two clauses, and one or two final sentences. Four different versions of each story were written, one for each of the cells created by crossing the adverb and the motor system implicit in the action verbs. In all versions of the stories, the second clause of the adverbial sentence was the same. If the IH is correct, all *after* sentences in the experimental set should be judged (by the participants) as coherent, whereas some of the *while* sentences should be judged as odd. In order to correct this possible bias associated with the adverb, two sets of control stories were created. Ten additional *while* stories were written to be sensible. They typically included a hand–arm action in the adverbial clause and a mouth or perceptual action in the second clause—for instance, *Mientras cortaba la tela en dos piezas, el sastre escuchó el canto de los pájaros* (*While he was cutting the cloth*

**Table 1**
**Examples of the Materials Used in Experiment 1A (Spanish), Experiment 1B (English), and Experiment 2 (German)**

**Experiment 1A: Spanish Materials**
El artista estaba deseando empezar a trabajar en un retrato./
Mientras abría [Después de abrir] la puerta del estudio,/*pintó cuidadosamente un rostro de mujer*./
Mientras sujetaba [Después de sujetar] una pipa entre los dientes,/*pintó cuidadosamente un rostro de mujer*./
COHERENCE JUDGMENT
El retrato quedó terminado/y era muy hermoso.
TEST: retrato

**Experiment 1B: English Materials**
The artist was looking forward to getting to work on a portrait./
While [After] unlocking the studio door,/*he carefully painted a woman's face*./
While [After] holding a pipe between his teeth,/*he carefully painted a woman's face*./
COHERENCE JUDGMENT
The portrait was finished/and it was beautiful
TEST: portrait

**Experiment 2: German Materials**
Die Verkäuferin hatte einen freien Tag,/den sie zu Hause verbrachte./
Während sie einen Brief schrieb,/*begann sie, einen Nagel in die Wand zu schlagen*./
Nachdem sie einen Brief geschrieben hatte,/*begann sie, einen Nagel in die Wand zu schlagen*./
Während sie einen Brief schrieb,/*dachte sie daran, einen Nagel in die Wand zu schlagen*./
Nachdem sie einen Brief geschrieben hatte,/*dachte sie daran, einen Nagel in die Wand zu schlagen*./
COHERENCE JUDGMENT
Danach hängte sie ein selbst gemaltes Bild an den Nagel./
TEST: Supermarkt

*English translation:*
The shop assistant had a day off,/which she spent at home./
While she wrote a letter,/*she started to drive a nail into the wall.*/
After she had written a letter,/*she started to drive a nail into the wall.*/
While she wrote a letter,/*she thought of driving a nail into the wall.*/
After she had written a letter,/*she thought of driving a nail into the wall.*/
COHERENCE JUDGMENT
Then she hung a self-painted picture on the nail./
TEST: supermarket

Note—Self-paced segments are separated by a slash (/), and the critical clause is written in italics.

*into two pieces, the tailor attended to the birds' songs*). Another 10 stories were formed with *after* sentences whose clauses established an order for the actions that was impossible or very unlikely—for instance, *Después de apretarse el cinturón de seguridad, entró en el coche* (*After fastening her seat belt, she went into the car*). Thus, the total number of sensible stories (20) should be the same for *while* and for *after* sentences. Six stories were also written for training, and finally, a set of 60 filler stories was created. The filler stories used varying numbers of sentences and grammatical structures.

Four sets of experimental sentences were formed to counterbalance the four versions of the stories. Each set included 10 same motor system stories with *while*, 10 same motor system stories with *after*, 10 different motor system stories with *while*, and 10 different motor system stories with *after*.

**Procedure**. Each participant was randomly assigned to one of the four counterbalanced conditions. At the beginning of the experimental session, the participants were given instructions on the computer screen. Then they received a set of 6 training stories in order to become familiar with the task. Finally, they were given the 120 stories (40 experimental, 20 control, and 60 filler) in a random order. The participants were asked to read for comprehension. At the beginning of a story, the message NEW STORY was shown on the screen. The participants pressed the space bar to erase the screen and present the next text unit. The unit was ordinarily a sentence, except that the critical sentence was presented in two clauses.

The participants also made two speeded judgments. First, a coherence judgment immediately followed the adverbial sentence. The coherence judgment was prompted by the computer message: "Is this coherent?" and the participants had to press one of the two keys assigned to the *yes* and the *no* responses, respectively. The coherence judgment was required for the whole antecedent text (three or four sentences), and the instructions were intentionally vague. A coherent story was explained as one that makes sense, whereas a noncoherent story was described as one that sounds odd. The second speeded judgment was to a probe word. The participants indicated whether or not the probe word had appeared in the story by pressing the corresponding *yes* or *no* key. The response to the probe test was followed by feedback. The purpose of the probe task was to encourage the participants to read carefully by having an objective measure that could be scored for feedback. Speed and accuracy were emphasized equally for the two speeded tasks.

In this and the following experiment, analyses of variance (ANOVAs) were conducted on reading times of the critical clause, response latencies to test probes, errors to test probes, and coherence judgments. These analyses were performed both for participants ($F_1$) and for items ($F_2$). The alpha level was set at .05, unless otherwise indicated. Effects that are not mentioned are not significant.

Reading time data corresponding to stories in which the participants made errors in the test probe were dropped from the analyses. In addition, clauses that were read in less than 300 msec were discarded. This resulted in the loss of 10% of the trials in the Spanish sample and the loss of slightly less than 6% in the American sample. In addition, data from five English items were excluded because fewer than 33% of the participants correctly indicated that the scenario was sensible (even though it was intended to be). We suspect that the problems with these items arose from cultural differences between the Spanish and the American students or from nonidiomatic translations.

**Norming study**. Thirty-two Spanish-speaking and 30 English-speaking participants (none of whom had participated in the main experiment) were asked to estimate how often same motor and different motor system actions occur together. We used these estimates as a covariate for the reading times and the sensibility ratings we obtained in Experiment 1A and Experiment 1B, respectively.

The norming study was done with two sets of materials formed with the pairs of actions used in the adverbial sentences of Experiments 1A and 1B, although the character names and the adverbs *while* and *after* were removed. No other connective was introduced between the two action clauses. Each set included 40 pairs of actions, 20 in the same motor system version (flossing teeth–using a comb to part hair), and 20 in the different motor system (e.g., breathlessly chatting with a husband–using a comb to part hair). Half of the participants were assigned to each of the counterbalanced sets, and they were asked to judge the percentage of times that the two actions in a pair occur at about the same time. The same materials and procedure were used with the Spanish and the American participants, differing, obviously, in the language in which the booklets were written.

## Experiment 1A: Spanish Results

**Reading time for the critical adverbial clause**. The results are displayed in Table 2. The only significant effect was an adverb × motor system interaction [$F_1(1,40) = 6.65$, $MS_e = 60{,}415$, $p < .01$; $F_2(1,39) = 12.92$, $MS_e = 113{,}685$, $p < .01$]. Same motor system sentences were read 288 msec more slowly if the adverb was *while* than if the adverb was *after*. In contrast, different motor system sentences were read 95 msec more quickly if the adverb was *while* than if the adverb was *after*. This pattern of reading times is generally consistent with the predictions of the IH (discrepancies are addressed in the Discussion section).

**Coherence judgments**. Analysis of the coherence ratings revealed a strong interaction between motor system and adverb [$F_1(1,43) = 84.7$, $MS_e = 0.027$, $p < .00001$; $F_2(1,39) = 58.5$, $MS_e = 0.038$, $p < .00001$]. Passages containing sentences describing two actions using the same motor system were rated as much less sensible than passages in which the sentences contained the adverb *while* (see Table 3).

No significant effects were obtained when coherence judgment latency, probe test latency, and probe test errors were used as dependent measures.

**Norming results**. The participants rated pairs of actions of different motor systems as occurring more frequently ($M = 64\%$, $SD = 13$) than pairs of actions involving the same motor system ($M = 19\%$; $SD = 13$). This difference was statistically significant [$t(39) = 15$, $p < .0001$]. The frequency estimates did not correlate significantly with the reading times from Experiment 1A, and hence, that variable would not be an effective covariate. There was, however, a small correlation between reading time and the difference between the same motor system and different motor system frequency estimates [$r = .21$, $p < .01$]. Consequently, we used these differences

**Table 2**
**Mean Reading Times (in Milliseconds) and Standard Deviations of the Critical Clauses as a Function of Adverb and Motor System in Experiments 1A (Spanish) and 1B (English)**

| | | Adverb | | | |
|---|---|---|---|---|---|
| | | While | | After | |
| Experiment | Motor System | *M* | *SD* | *M* | *SD* |
| 1A | Same | 2,445 | 395 | 2,157 | 372 |
| | Different | 2,241 | 458 | 2,336 | 468 |
| 1B | Same | 1,880 | 507 | 1,797 | 435 |
| | Different | 1,768 | 383 | 1,843 | 402 |

**Table 3**
**Coherence Ratings as a Function of Adverb and Motor System, Reported as the Proportion of Participants Responding Affirmatively, in Experiments 1A (Spanish) and 1B (English)**

| | | Adverb | |
|---|---|---|---|
| Experiment | Motor System | While | After |
| 1A | Same | .33 | .78 |
| | Different | .83 | .79 |
| 1B | Same | .45 | .86 |
| | Different | .89 | .81 |

as a covariate. In the analysis of covariance for the reading times, the critical interaction between adverb and same or different motor systems remained highly significant [$F_2(1,37) = 12.26$, $MS_e = 119{,}831$, $p < .001$]. Similarly, in the analysis of covariance for the coherence ratings, the critical interaction remained significant [$F_2(1,37) = 55.53$, $MS_e = 482$, $p < .0001$].

## Experiment 1B: English Results

**Reading time for the critical adverbial clause**. The only significant effect was an interaction between adverb and motor system [$F_1(1,22) = 4.94$, $MS_e = 44{,}710$, $p < .04$; $F_2(1,34) = 4.38$, $MS_e = 49{,}910$, $p < .05$]. For sentences describing actions using the same motor system, reading times were 83 msec longer if the adverb was *while* than if the adverb was *after*. For sentences describing actions using different motor systems, the reading time pattern was reversed, with times being 75 msec shorter for *while* than for *after* (Table 2).

**Coherence judgments**. Analysis of the ratings revealed a strong interaction between motor system and adverb [$F_1(1,22) = 61.83$, $MS_e = 0.022$, $p < .0001$; $F_2(1,34) = 68.26$, $p < .0001$]. Passages containing sentences describing two actions using the same motor system were rated as much less sensible than other passages when the sentences contained the adverb *while* (Table 3).

**Norming results**. The participants rated pairs of actions involving different motor systems as occurring more frequently ($M = 34\%$, $SD = 17$) than pairs of actions involving the same motor system ($M = 14\%$; $SD = 10$). This difference was statistically significant ($t = 5.89$, $p < .0001$). As for the Spanish data, the difference between same and different motor system estimates of co-occurrence was introduced as a covariate. In the analysis of the critical second-clause reading times, after accounting for the co-occurrence estimates, the adverb × motor system interaction was marginally significant [$F(1,31) = 3.89$, $MS_e = 264{,}823$, $p = .058$] for the reading times. The covariate did not have a significant relationship with the coherence ratings of Experiment 1B ($p > .12$), and therefore, the adverb × motor system interaction was again highly significant [$F(1,31) = 11.69$, $MS_e = 2.86$, $p < .002$].

## Discussion

*While* and *after* sentences did not differ significantly in reading times for the critical clause. The lack of a main effect of adverb is contrary to the prediction of a strong iconicity assumption; it predicts longer reading times for *while* sentences than for *after* sentences. Nonetheless, the null effect of adverb is not very informative, because it might be just a consequence of the variability in the materials and/or the participants' strategies (e.g., integration/shifting balance).

The most important finding from this experiment is the crossover interaction between adverb and motor system. For the same sensorimotor system, *while* sentences produced longer reading of the critical clause than *after* sentences did. However, the pattern is reversed when the two actions of the adverbial sentence tag different motor systems. The adverb × motor system interaction obtained on the coherence judgment task indicates that the participants' metacognitive appraisals of coherence correspond to the reading time data. Specifically, sentences involving simultaneous actions with the same sensorimotor system are considered much less sensible. Thus, comprehension depends on the particular combination of temporal features (prompted by the adverb) and motor features (implicit in the action phrases) of the actions. The same patterns of effects were observed in the data in both Experiments 1A and 1B, despite the different languages. Recall that in Spanish, the contrast between *while* and *after* is carried by both the adverb and the verb tense. The replication of the effects in English allows us to attribute the bulk of the effects to the adverb.

One aspect of the results can be easily explained by the IH: Performing actions that use similar motor activities is possible when the actions are described as successive, but simulating the same two actions becomes difficult when they are described as simultaneous. It is less clear why comprehension of two actions described as taking place in succession should be slower when they involve different sensorimotor systems than when they involve the same sensorimotor system. One possibility is that there is a cost when the simulation must switch from simulating one sensorimotor system to simulating another. As an example, consider the results of Pecher, Zeelenberg, and Barsalou (2003). They had people verify that objects had particular properties—for example, that a blender is loud. If the preceding verification trial probed the same modality (e.g., *Do leaves rustle?*), responding was faster than when the preceding trial probed a different modality (e.g., *Are cranberries tart?*). Pecher et al. attributed this conceptual slowing to the same processes that contribute to the slowing of perceptual processing upon the switching of modalities (cf. Spence, Nicholls, & Driver, 2001). This notion of a switching cost in simulation can be applied to the present data as follows. In comprehending the *after* sentences, the simulation process is able to integrate both same motor system and different motor system actions. However, the switch required by the different motor system simulation produces a small cost. In comprehending the *while* sentences, the simulation process is able to mesh the different motor system actions, albeit with a small cost due to switching. This small cost is overwhelmed, however, in comparison with the massive disruption caused by the inability to integrate the same motor system actions.

The norming data showed that different motor system actions were judged as occurring at the same time more frequently than same motor system actions. But even if we assume that these estimates reflect background knowledge of action co-occurrence, they do not show any systematic relation with the reading times or with the coherence judgment data from the experiment. Thus, the norming data, statistically combined with the reading data, support our interpretation of the results in terms of a simulation mechanism. This support comes about by ruling out the alternative hypothesis that knowledge of frequencies of co-occurrence is a sufficient explanation of the observed data.

## EXPERIMENT 2

The results of Experiment 1 were largely consistent with the claim that the understanding of language involves the creation of a perception–action simulation of the events described. Comprehension difficulties arose when the described temporal structure of the events required the reader to simulate two actions by using the same sensorimotor system at the same time. Experiment 2 extended this result by asking what happens when one of the actions mentioned in the text is considered by the actor but is not actually performed.

In most languages, there are constructions that describe mental states rather than factual states or events. For instance, expressions such as *I am thinking of*, *Mary believes that*, and *she decided to* (among others) refer to propositional attitudes of the speaker or other person. Even though the predicates in these sentences could involve physical actions or events, they do not have to be interpreted as actually occurring. For instance, the sentence *Mary believes that John is painting the fence* does not mean that John is really painting the fence. One way to describe the comprehension of propositional attitudes is to use the theoretical framework of mental spaces (Fauconnier, 1994, 1998). Thus, in the sentence above, *believes* can be considered as a *mental space builder*. The mental space builder prompts the reader to build a mental model that operates with information that can be taken as true for *Mary*, even though this information might be actually false in another space that defines the real world (e.g., actually John had gone to the cinema) or another individual's perspective (e.g., Peter knows that John will never paint the fence).

In this experiment, we manipulated two verbal periphrases in the critical clause: *thought of* and *began to*. The phrase *thought of* is a mental space builder that cancels the reality of the predicate, putting its action/event in an epistemic mental space. In contrast, the phrase *began to* does not cancel the reality status of the predicate; it just signals that the event/action is at an initial stage of development.

We used the materials of previous experiments, with some modifications. First, we selected only the same motor system version of the texts, although we maintained the *while/after* manipulation. Second, the critical clause was preceded either by the verbal phrase *thought of* or by *began to* (see Table 1).

We predicted that the critical clause with *thought of* would be understood equally well following the adverbs *while* and *after*. By contrast, we expected that the critical clause with *began to* would be poorly understood following the adverb *while*, replicating the pattern we had obtained for same motor system texts. The rationale is that the space builder *thought of* in the critical clause triggers the construction of a mental space separated from the mental space corresponding to the action of the first clause. Consequently, the reader would not try to concatenate the motor action of the first clause (*real*) and the motor action of the second clause (*epistemic*) into a single action sequence. In the *began to* sentences, however, the actions of the first and the second clauses have the same status (they share the same mental space), and readers would attempt to merge them into the same action plan, being more successful when the actions were described as successive than when they were described as simultaneous.

### Method

**Participants**. Sixty students of psychology at the Dresden University of Technology (Germany) received course credit in exchange for their participation in the experiment. All the students had German as their first language. Half of the participants were randomly assigned to each of the verb conditions. Data from 1 participant were discarded because his responses to the test probe were apparently random.

**Design and Materials**. The materials of Experiment 1B were translated into German and modified to accomplish the aims of the experiment. Thirty same motor system stories were used as experimental materials in a 2 (adverb: *while/after*) × 2 (verb: *thought of/began to*) experimental design. Adverb was a within-subjects and verb was a between-subjects factor. In addition, 30 stimuli were adapted as control materials for both the *thought of* and the *began to* sets of materials, to balance the sensibility values across conditions. Thus, in the *thought of* condition, both the *while* and the *after* control items were made inconsistent (e.g., *While/After fastening the seat belt, he thought of going into the car*). In contrast, in the *began to* condition, the *while* control items were made consistent (e.g., *While the actress was going onto the stage, she began to notice her heart beating*), and the *after* control items were inconsistent (e.g., *After the bride went into the church full of people, she began to put on her white clothes*). Finally, there were 60 filler texts and 6 training texts. Thus, each participant received a total of 126 texts (30 experimental, 30 control, 60 filler, and 6 for training).

**Procedure**. The procedure was exactly the same as that in Experiments 1A and 1B. The instructions were translated and adapted from English into German.

### Results

The same data trimming procedures and statistics as those in Experiment 1 were used. In addition, students' *t* tests between the *while* and the *after* conditions were calculated separately for each verb.

**Reading time for the critical adverbial clause**. The mean reading times are shown in Table 4. In addition to a significant effect of adverb [$F_1(1,57) = 15.8$, $MS_e =$

**Table 4**
**Mean Reading Times (in Milliseconds) and Standard Deviations of the Critical Clauses as a Function of Adverb and Verb in Experiment 2 (German)**

| | Adverb | | | |
|---|---|---|---|---|
| | While | | After | |
| Verb | *M* | *SD* | *M* | *SD* |
| Thought of | 2,360 | 213 | 2,297 | 212 |
| Began to | 2,543 | 194 | 2,308 | 238 |

41,502, $p < .001$; $F_2(1,29) = 13.4$, $MS_e = 49.754$, $p < .01$], the expected verb × adverb interaction was significant [$F_1(1,57) = 5.23$, $MS_e = 41{,}502$, $p < .05$; $F_2(1,29) = 2.98$, $MS_e = 74{,}826$, $p < .10$]. The Student's *t* tests conducted separately for each verb were also informative. For the *began to* sentences, the effect of adverb was significant [$t_1(29) = 4.76$, $SE = 49.4$, $p < .001$; $t_2(29) = 3.4$, $SE = 68.9$, $p < .01$]. In particular, the critical clause was read 235 msec more quickly in the *after* than in the *while* version, replicating the effect obtained in Experiment 1 with same motor system materials. In contrast, for the *thought of* sentences, the *while–after* difference was considerably smaller (63 msec) and nonsignificant [$t_1(29) = 1.11$, $SE = 56.7$, n.s.; $t_2(29) = 1.05$, $SE = 59.7$, n.s.].

**Coherence judgments**. The mean coherence ratings are shown in Table 5. The analysis revealed a strong interaction between verb and adverb [$F_1(1,57) = 404$, $MS_e = 0.0086$, $p < .0001$; $F_2(1,29) = 496$, $MS_e = 0.0071$, $p < .0001$]. Passages containing the space builder *thought of* were rated as equally coherent in both the *while* and the *after* versions [$t_1(28) = 0.12$, $SE = 1.92$, n.s.]. By contrast, passages containing the verbal periphrasis *began to* were rated as appropriate much more frequently in the *after* than in the *while* version of the story [$t_1(29) = 24.5$, $SE = 2.81$, $p < .001$; $t_2(29) = 21.5$, $SE = 3.2$, $p < .0001$].

### Discussion

In Experiment 2, same motor system texts were used exclusively. Critical sentences were read more slowly in the *while* than in the *after* version of the texts, suggesting that trying to understand two simultaneous actions, even if one of them is only thought about, involves more cognitive resources. Nevertheless, this *while–after* effect was strongly modulated by the verbal periphrasis included in the second clause. When the second clause included *began to,* the adverb effect was obtained: The participants read the second clause slowly and rated the passage as less coherent in the *while* than in the *after* version of the texts. In contrast, the presence of the epistemic space builder *thought of* produced similar performance in the *while* and the *after* conditions.

**Table 5**
**Coherence Ratings as a Function of Adverb and Verb, Reported as the Proportion of Participants Responding Affirmatively, in Experiment 2 (German)**

| | Adverb | |
|---|---|---|
| Verb | While | After |
| Thought of | .74 | .74 |
| Began to | .14 | .83 |

A possible concern in interpreting these data is that, in German, there is a slight difference between the two verbal periphrases: *Thought of* involves an additional particle (*daran*) that is absent in *began to*. (In English, the two sentence types are syntactically identical.) This superficial difference in sentence lengths might explain longer reading times for *thought of* clauses than for *began to* clauses, but in fact, we did not observe such a difference. There is no reason to suspect that the additional particle might underlie the interaction effect of interest—namely, that with *thought of* there was no difference in reading time following *while* and *after*, whereas with *began to* the *while–after* effect was robust. This result is most easily explained by the semantics of the verbal constructions. Apparently, *thought of* triggers the construction of a separate mental space that does not interact strongly with the factual space provided by the first clause. Consequently, readers do not try to integrate the motor actions belonging to these separated mental spaces, and thus, any difficulty with *while* is obviated. In contrast, *began to* triggers integration of actions in the same mental space. In this case, the difficulty of integrating the actions becomes apparent to the reader, and the reader is forced either to consider a reinterpretation of the text (e.g., indexing the words to different perceptual symbols, deriving different affordances from the symbols, or considering new syntactic analyses) or to conclude that the text is incoherent.

## GENERAL DISCUSSION

Experiment 1 demonstrated that when actions were described as being performed at the same time (by using the adverb *while*), they were easier to comprehend when they involved different sensorimotor systems than when they involved the same sensorimotor system. The opposite pattern held when actions were described as taking place in succession (by using the adverb *after*). The results of the norming study suggest that this pattern of reading times was not based exclusively on knowledge about the differential frequency with which actions occur together. Rather, it appears that readers are constructing a perception–action simulation of the events described in the text and that the simulation is difficult or impossible when the adverb *while* directs that the simulation be of incompatible actions. Experiment 2 extended these results by showing that when the simulation of incompatible actions is avoided (by using the verbal periphrasis *thought of* ), any difficulty with the comprehension of *while* is also avoided. These data are largely consistent with a revised version of the IH (as will be discussed later).

Have we only demonstrated the obvious? Of course, people find it difficult to imagine chopping wood and painting a fence at the same time! Indeed, we think that many of our results seem obvious because people do engage in these sorts of perception–action simulations while comprehending. However, the point of our demonstrations reaches further. First, we demonstrate the extent to which these simulations take into account specific components of action—namely, whether or not two actions can be integrated as a consequence of their underlying motor programs. Second, this integration process is sensitive to temporal parameters, as prompted by adverbs. Third, it seems unlikely that simple associative factors can account for the data. That is, the norming study ruled out the possibility that knowledge of differential frequencies of co-occurrence could account for our data. Finally, our data provide two new constraints on embodied theories of language comprehension, and we turn to these now.

According to the IH, language at many levels consists of instructions for constructing an embodied mental simulation of what the language is about (i.e., an embodied mental model). Thus, noun phrases are instructions for retrieving (indexing) representations from which affordances can be derived (Glenberg & Robertson, 2000), verbs of manner are instructions for retrieving motor programs or plans that can potentially select and act on those affordances (Glenberg & Kaschak, 2002), and verb-argument constructions (e.g., the double-object construction) provide a general framework (e.g., transfer) that must be accomplished when simulating the effect of the verb (Kaschak & Glenberg, 2000). The first new constraint is that temporal adverbs provide instructions for controlling the manner in which multiple models are combined. Thus, *while* is an instruction to simulate how two actions can be performed simultaneously, *after* is an instruction to simulate the current clause and then the next, and *before* is an instruction to simulate the first clause, simulate the second clause, and then to check that the simulation of the first clause (temporally, the second event) will mesh with the end-state of the simulation of the second clause (temporally, the first event). This general approach of considering language as instructions for simulation can be applied to other components of language as well, such as negation (Glenberg, Robertson, Jansen, & Johnson-Glenberg, 1999), specificity of articles (Robertson, Gernsbacher, & Guidotti, 2000), and locative prepositions (de Vega, Rodrigo, Ato, Dehn, & Barquero, 2002).

Second, Experiment 2 provides another constraint on the IH by introducing the notion of separate epistemic mental spaces. Our results suggest that nominally incompatible actions (those sharing the same motor system) that are described as simultaneous (by means of the adverb *while*) were easily understood when one of the actions was further described as a mental plan. Thus, the mental simulation of the integration of motor actions is constrained to those texts that describe the actions as factual, rather than as imaginary or hypothetical. A reformulation of the IH can deal with this constraint. Syntactic constructions with mentalist verbs trigger a partition of the situation model into an epistemic model that is separated from other factual mental models. Our data do not inform us as to whether, in the epistemic model, the sensorimotor affordances of the represented entities are suppressed or whether they are still activated and used to create a simulation within that model. What seems clear from our data is that the affordances of actions and events in this epistemic space do not strongly interact with the actions and events in the factual space. Future research could be undertaken to explore how mental spaces (especially epistemic ones) work. Perhaps the whole set of processes (indexing, activation of affordances, and computing action patterns) takes place separately in each particular mental space. Another possibility is that mentalist verbs determine a special kind of indexing process addressed to more cognitive states (e.g., beliefs, emotions, or intentions), rather than to sensorimotor entities or their perceptual symbols. This indexing process for cognitive states is compatible with Barsalou's (1999) proposal that some perceptual symbols refer to introspective states, rather than to external entities.

The notion of mental spaces has remained largely speculative up to now, since it has not had empirical support derived from the performance of naive participants. A significant exception has been a study by Traxler, Sanford, Aked, & Moxey (1997). They demonstrated the functionality of mental spaces in noncanonical causal expressions, such as *It is raining because John took the umbrella*. An expression such as this is understood when the reader realizes that it has an implicit space-builder: *(I think) that it is raining because John took the umbrella*. What we propose here is that some space-builders determine the partition of situation models into separate functional spaces and that simulations do not merge across spaces. This is an important constraint for the construction of simulations that might prevent the computational explosion that computer scientists refer to as the frame problem.

In conclusion, we have demonstrated that temporal adverbs cannot be treated as additive or independent of other components of language—in particular, the motoric programs underlying the meaning of some verbs. Adverbial constructions are invitations to consider how events or actions fit together in time. Because language can be used to describe novel events and novel combinations, determining how events fit together requires flexible analogical knowledge, such as the embodied representations described by the IH. In addition, some syntactic phrases or constructions prompt the partition of situation models into functionally separable spaces across which readers do not consider the fit of components.

## REFERENCES

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

Buccino, G., Riggio, L., Melli, G., Patteri, I., Lagravinese, G., Nanetti, L., & Rizzolatti, G. (2003, September). *Listening to action related sentences modulates the activity of primary motor cortex*. Poster presented at the 13th Conference of the European Society for Cognitive Psychology, Granada, Spain.

Carreiras, M., Carriedo, N., Alonso, M. A., & Fernández, A. (1997). The role of verb tense and verb aspect in the foregrounding of information during reading. *Memory & Cognition*, **25**, 438-446.

Chafe, W. L. (1979). The flow of thought and the flow of language. In T. Givón (Ed.), *Syntax and semantics: Vol. 12. Discourse and syntax* (pp. 159-181). New York: Academic Press.

Comrie, B. (1985). *Tense*. Cambridge: Cambridge University Press.

Damasio, A., & Damasio, H. (1994). Cortical systems for retrieval of concrete knowledge: The convergence zone framework. In C. Koch & J. L. Davis (Eds.), *Large-scale neuronal theories of the brain* (pp. 61-74). Cambridge, MA: MIT Press.

de Vega, M., Rodrigo, M. J., Ato, M., Dehn, D. M., & Barquero, B. (2002). How nouns and prepositions fit together: An exploration of the semantics of locative sentences. *Discourse Processes*, **34**, 117-143.

Dowty, D. (1986). The effects of aspectual class on the temporal structure of discourse: Semantics or pragmatics? *Linguistics & Philosophy*, **9**, 37-61.

Fauconnier, G. (1994). *Mental spaces: Aspects of meaning construction in natural language*. New York: Cambridge University Press.

Fauconnier, G. (1998). Mental spaces, language modalities, and conceptual integration. In M. Tomasello (Ed.), *The new psychology of language: Cognitive and functional approaches to language structure* (pp. 251-280). Mahwah, NJ: Erlbaum.

García-Fernández, L. (1999). *Los complementos adverbiales temporales: La subordinación temporal* [The temporal adverbial complements: The temporal subordination]. In I. Bosque & V. de Monte (Eds.), *Gramática descriptiva de la lengua española* [Descriptive grammar of the Spanish language] (Vol. 2, pp. 3129-3208). Madrid: Espasa.

Gernsbacher, M. A. (1990). *Language comprehension as structure building*. Hillsdale, NJ: Erlbaum.

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

Givón, T. (1992). The grammar of referential coherence as mental processing instructions. *Linguistics*, **30**, 5-55.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin &Review*, **9**, 558-565.

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.

Glenberg, A. M., Robertson, D. A., Jansen, J. L., & Johnson-Glenberg, M. C. (1999). Not propositions. *Journal of Cognitive Systems Research*, **1**, 19-33.

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

Hernanz, M. L. (1999). El infinitivo [The infinitive]. In I. Bosque & V. de Monte (Eds.), *Gramática descriptiva de la lengua española* [Descriptive grammar of the Spanish language] (Vol. 2, pp. 2197-2356). Madrid: Espasa.

Hopper, P. J. (1979). Aspect and foregrounding in discourse. In T. Givón (Ed.), *Syntax and semantics: Vol. 12. Discourse and syntax* (pp. 213-241). New York: Academic Press.

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.

Magliano, J. P., & Schleich, M. C. (2000). Verb aspect and situation models. *Discourse Processes*, **29**, 83-112.

Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature*, **379**, 649-652.

McKoon, G., & Ratcliff, R. (2003). Meaning through syntax: Language comprehension and the reduced relative clause construction. *Psychological Review*, **110**, 490-525.

Münte, T. F., Schiltz, K., & Kutas, M. (1998). When temporal terms belie conceptual order. *Nature*, **395**, 71-73.

Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2003). Verifying different-modality properties for concepts produces switching costs. *Psychological Science*, **14**, 119-124.

Preissl, H., Pulvermüller, F., Lutzenberger, W., & Birbaumer, N. (1995). Evoked potentials distinguish between nouns and verbs. *Neuroscience Letters*, **197**, 81-83.

Pulvermüller, F. (1999). Words in the brain's language. *Behavioral & Brain Sciences*, **22**, 253-336.

Radvansky, G. S., Spieler, D. H., & Zacks, R. T. (1993). Mental model organization. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **19**, 95-114.

Radvansky, G. S., Zwaan, R. A., Federico, T., & Franklin, N. (1998). Retrieval from temporally organized situation models. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **24**, 1224-1237.

Rinck, M., Gámez, E., Díaz, J. M., & de Vega, M. (2003). Processing of temporal information: Evidence from eye movements. *Memory & Cognition*, **31**, 77-86.

Robertson, D. A., Gernsbacher, M. A., & Guidotti, S. J. (2000). Functional neuroanatomy of the cognitive process of mapping during discourse comprehension. *Psychological Science*, **11**, 255-260.

Saussure, F. (1972). *Curso de lingüistica general* [Course of general linguistics; original French: Cours de linguistique generale]. Madrid: Alianza Editorial. (Original work published 1915)

Spence, C., Nicholls, M. E. R., & Driver, J. (2001). The cost of expecting events in the wrong sensory modality. *Perception & Psychophysics*, **63**, 330-336.

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

Traxler, M. J., Sanford, A. J., Aked, J. P., & Moxey, L. M. (1997). Processing causal and diagnostic statement in discourse. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **23**, 88-101.

Zwaan, R. A. (1996). Processing narrative time shifts. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **22**, 1196-1207.

Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The construction of situation models in narrative comprehension: An event-indexing model. *Psychological Science*, **6**, 292-297.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin*, **123**, 162-185.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Do language comprehenders routinely represent the shapes of objects? *Psychological Science*, **13**, 168-171.

Zwaan, R. A., & Yaxley, R. H. (2003). Spatial iconicity affects semantic relatedness judgments. *Psychonomic Bulletin & Review*, **10**, 954-958.

## NOTES

1. Affordances of an object are properties that support interaction with an animal having a particular type of body. Thus, affordances depend on the physics of the object and the biology of the interacting animal. For example, a 3-in. disk affords back-scratching for an adult human (or simian) who has arms and fingers that are appropriately articulated. The disk would not afford back-scratching for a newborn human or, say, a bear. A tree trunk, however, might well afford back-scratching for both the human and the bear.

2. We thank Gabriel Radvansky for suggesting these alternatives.

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