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# WHEN DO UNDERSTANDERS MENTALLY SIMULATE LOCATIONS?

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A leading embodied account of language processing proposes that comprehending a piece of language entails performing mental simulations of its content. Experimental studies have shown that understanders mentally simulate aspects of space, including axis of motion and location along the vertical axis. However, one widely cited study (Glenberg and Kaschak 2002) found that no evidence that processing sentences about motion towards or away from the body activated spatial representations of the corresponding locations, whether the motion was concrete or abstract. If this is true, it poses a substantial challenge to simulation-based theories of language understanding. I conducted an experiment that replicated most of Glenberg and Kaschak's method, in an attempt to determine under what conditions understanders mentally simulate the locations of described events. Results showed, first, that progressive sentences appear to induce more mental simulation, including simulation of spatial location, than perfect sentences do. And second, people mentally simulate the locations implied by concrete and abstract language differently.

**1. INTRODUCTION.** Currently, a leading hypothesis for how people understand language proposes that they do so by performing *mental simulations* of the content of utterances they encounter (Glenberg and Kaschak 2002, Feldman and Narayanan 2004, Gallese and Lakoff 2005, Bergen and Chang 2005, Zwann 1999, 2002). Mental simulation is the internal (re-)creation of embodied experiences (Barsalou 1999). It subjectively resembles perceptual or motor experiences that we experience when interacting with the real world, but it occurs in the absence of the appropriate perceptual stimuli or motor actions. When people perform mental simulation, they use neural circuitry dedicated to action and perception to envision performing actions or perceiving percepts (Kosslyn et al. 2001). The idea proposed by the various simulation-based approaches to language is that like other higher human cognitive functions, understanding language engages perceptual and motor systems to construct modality-specific simulations of the described percepts and actions.

One key type of behavioral evidence that people perform mental simulations while processing language—and the one that serves as the basis for the work reported on below—comes from one particular line of behavioral experimentation. The Action-sentence Compatibility Effect (or ACE) is the finding that processing sentences about physical actions interacts with performing bodily actions (Glenberg and Kaschak 2002). In ACE experiments, participants read or hear sentences denoting particular types of action, for instance motion away from the body, as in *You handed Andy the pizza* or toward the body, as in *Andy handed you the pizza*. Then they make sensibility judgments (deciding whether the sentence makes sense or not) by pressing a button that requires them to move their hand either toward or away from their body. The motion described by the sentence can thus be either compatible or incompatible with the one they have to perform. Participants are quicker to respond when the described action and the performed action are in the same direction, or compatible: thus an “Action-sentence Compatibility Effect.” The explanation for this recurrent finding is that both performing actions and understanding language about actions engages neural structures specific to those particular actions, and when the two processes engage the same motor structures, this results in quicker actions, as compared with the case when language processing and physical action engage competing motor control structures. Findings from ACE studies suggest that action execution and action language understanding share underlying neuro-cognitive mechanisms.

In recent years, research on the details of how language drives mental simulation has burgeoned. Empirical studies have shown that people perform mental simulations of the visual content of utterances (Stanfield and Zwaan 2001, Zwaan et al. 2002, Richardson et al. 2003, Connell 2007, Bergen et al. 2007) and their motor content (Glenberg and Kaschak 2002, Bergen et al. 2003, Bergen and Wheeler 2005, Bub et al. 2008, Taylor and Zwaan 2008). Moreover, experimental work has begun to uncover precisely what

components of language contribute in what ways to mental simulation. For instance, work has confirmed the intuitive notion that content words such as nouns and verbs contribute specific details about entities, events, and states to be simulated. For instance, both of the sentences *The chair toppled* and *The grass glistened* evoke mental simulations of events transpiring in the lower parts of the imagined visual field; the triggers for the location of the mental simulation are the main verb and the subject noun, respectively (Bergen et al. 2007). But it’s not only the content words in an utterance that contribute to language-driven mental simulation. Grammatical constructions also play a role, demonstrably providing higher-order instructions not about what to mentally simulate, but about how to simulate it. For instance, grammatical person indicates what perspective to adopt in a mental simulation (Brunyé et al. 2009, Bergen et al. Submitted), while argument structure constructions indicate how the understander should construe a described event in simulation, for example, as a transfer of possession or as motion along a path (Goldberg 1995, Bergen and Han, in preparation).

The role of grammar in language-driven mental simulation is of substantial theoretical interest. First, most traditional approaches treat grammar as purely structural, which has very limited meaning. However, to the extent that grammar serves to instruct and configure mental simulation, it can be shown to contribute, if indirectly, to meaning. Second, most theoretical schools treat grammar in particular and language in general as structurally and functionally distinct from other neuro-cognitive systems—the so-called “modularity” of syntax or of language. This thesis is difficult to hold in its strong form, however, if grammar interacts with motor and perceptual systems that support mental simulation. And finally, as a uniquely human capacity, grammar holds inherent interest for its potential to reveal characteristics of human cognition and experience. Nevertheless, the study of how grammar affects mental simulation remains in its infancy. The study described in these pages takes a modest step forward in this regard.

The grammatical structures I focus on here are among the best studied in terms of their effects on mental simulation; these are constructions that encode grammatical aspect. Aspect marks the structure of an event, for instance whether it is ongoing, as in *John is opening the drawer*, or completed, as in *John has opened the drawer*. Linguists argue that the English progressive highlights the internal structure of an event, while the perfect encapsulates or shuts off access to the described process, while highlighting the resulting end-state (Comrie 1976, Dowty 1977). Behavioral evidence provides evidence supporting these two assertions. Recent work (Bergen and Wheeler, in press) has shown that progressive sentences reliably facilitate actions compatible with described motion (an ACE), but perfective sentences produce no effect on compatible or incompatible actions. This suggests that progressive aspect prompts understanders to mentally simulate the nucleus or central part of an action, while the perfect shuts off mental simulation of this core of a described event. Madden and Zwaan (2003) reported complementary findings, using a very different methodology. They had participants read either progressive or simple past sentences (*The man was opening the door* or *The man opened the door*), then presented a picture that depicted the event in an ongoing (e.g., a door being closed) or a completed state (e.g., a door completely closed). The experimenters found that participants responded to completed-state pictures faster than ongoing-state pictures following reading perfect, simple past sentences, suggesting that people do represent the resulting end-state of an event.

These previous studies, while illustrative, have only scratched the surface of how aspect affects mental simulation. For instance, do different grammatical aspects consistently highlight different parts of an event? What is the role of grammatical aspects in spatial simulation? While we know that progressive highlights the motor control component of the action (Bergen & Wheeler, in press), we still don’t know if the simulation of ending location of the action is facilitated by progressive or perfect aspect.

When do we mentally simulate ending locations? Initial indications from work with simple past tense sentences about motion towards or away from the body (*Andy handed you the pizza* or *You handed Andy the pizza*) shows that although these do activate motor representations, they do not activate spatial representations of the corresponding ending locations (Glenberg and Kaschak 2002). Two very different conclusions could be drawn from this finding. First, it could be that ending spatial locations are simply not

represented in mental simulations constructed during the processing of utterances. If true, this poses a substantial challenge to simulation-based theories of language understanding. If locations aren't represented in simulation, yet are understood, this implies that understanding can proceed in the absence of simulation. But another account is possible. Different linguistic cues may induce simulation of different parts of an event. It could be that the absence of Location-sentence Compatibility Effect in Glenberg and Kaschak's (2002) work was due to the grammatical aspect of the sentences used. Simple past aspect just not induces spatial simulation of final location of an action. The current study was designed to test the two competing hypotheses regarding the role of final location in an action, to determine under what linguistic conditions understanders mentally simulate the locations of described events.

While investigating this question using the approach described below, one more aspect was added in keeping with previous similar work (e.g., Glenberg and Kaschak 2002, Bergen and Wheeler, in press). Among the critical stimuli not only concrete sentences about hand motion was included, but also sentences about communication that have been argued to abstractly encode virtual motion toward or away from the speaker (see, e.g., Lakoff and Johnson 1980). By including not only language about concrete motion, but also language about abstract motion, we can determine whether eventual evidence of simulation of ending locations is the same for abstract and concrete language. This question, like the question of how we understand abstract language more generally, is important because abstract language poses a particular challenge for accounts of language understanding based on mental simulation. Does mental simulation occur when we process abstract language? If so, is it similar to the simulation triggered by concrete language? Varying results have been found in studies comparing abstract with concrete language. A simulation effect was found in concrete and abstract language in Glenberg and Kaschak's (2002) ACE experiment, and in a visual simulation experiment conducted by Richardson et al. (2003). However, other work on visual (Bergen et al. 2007) and motor simulation (Bergen and Wheeler, in press) has found simulation effects only in concrete sentences about space and actions, but not in sentences using abstract or metaphorical language. Clearly, the field has its work set out for it.

Based on the findings surveyed above, an experiment was designed to explore two primary questions: First, is the ending location of an action highlighted by progressive aspect, perfect aspect, both, or neither? Second, do concrete and abstract language yield similar or different mental simulations of ending location? The work sought to answer these questions using a location-sentence compatibility method, described below.

## **2. EXPERIMENT**

**2.1 PARTICIPANTS.** A total of 110 undergraduate students at the University of Hawai'i at Mānoa participated in this experiment. The participants received either extra credit in an introductory linguistics class or five dollars. All of them were right-handed native speakers of English.

**2.2 PROCEDURE.** The participants were asked to sit in front of a personal computer and were told that their task was to read sentences and to indicate as quickly and accurately as possible whether each sentence made sense by pressing the appropriate button on a keyboard. The response-collecting keyboard was rotated 90 degrees from its normal orientation so that the long dimension projected outward from the body. Participants first saw a fixation cross in the center of the screen for 500 milliseconds, then a sentence. They read it and pressed the {'} key (labeled "yes") or the {A} key (labeled "no") on the keyboard to indicate if the sentence was meaningful or not. They had to hold their right index finger over the "yes" button and their left index finger over the "no" button throughout the experiment. Halfway through the experiment, an experimenter swapped the locations of the "yes" and "no" labels, so that the "yes" button was now closer to their body and the "no" button farther. Sixteen practice trials preceded each half of the experiment, and there was a short break between the two halves. The experiment took about 20 minutes for each participant.

**2.3 DESIGN.** I manipulated three factors: Compatibility, Aspect, and Concreteness.

**2.3.1 COMPATIBILITY.** Each sensible sentence denoted (abstract or concrete) motion either away from or toward the body. Thus, “toward” sentences, such as *Louis is grabbing his nose*, implied an ending location close to the body, while “away” sentences, such as *Kimberly is hanging up the phone*, implied an ending location far from the body. The sentence-implied location was either compatible or incompatible with the location of the “yes” response button (close/far) on the keyboard. If participants mentally simulated the ending location implied by a sentence, I expected that they would respond faster when the location of the button they pressed was Compatible with the ending location implied by the sentence they had just read, and slower when the two were Incompatible. Each participant saw the same number of “away” and “toward” sentences and responded by pressing the “yes” button when it was either far from or close to the body, making Compatibility a within-participants factor.

**2.3.2 ASPECT.** There are two levels of the aspect condition. Participants in the Progressive group read progressive sentences, such as *Kimberly is hanging up the phone*. Participants in the Perfect group read perfect sentences, such as *Kimberly has hung up the phone*. Either of these groups might show significant effects of Compatibility; either progressive or perfect sentences might drive participants to focus more on the ending location of an action by triggering stronger spatial imagery of it. The Perfect condition used the present participle, *has Ved*, because it is an unambiguous marker of perfective aspect, unlike the simple past, *Ved*, and also because it is matched for tense (present) with the present progressive, *is Ving*.

**2.3.3 CONCRETENESS.** The final independent variable was the Concreteness of critical stimuli. Concrete sentences described manual actions toward or away from the body. Abstract sentences described transfers of abstract possession, as in *Ronnie has sold the land to a corporation*, and transfers of information, as in *Darlene has transmitted the orders to the front line*. If abstract language yields mental simulation similar to that performed in understanding literal language, then grammatical elements such as aspect markers should have the same effect on both types of language. This factor was between items, i.e. two different item sets for abstract and concrete sentences.

Each critical sentence pair (away/toward) was split between two halves of the experiment. The design fully crossed the two halves (1 and 2) with the two response locations (Yes-is-Far or Yes-is-Near). Response location ordering was fixed with Yes-is-Far and No-is-near in the first half, and was reversed halfway through the experiment.

**2.4 MATERIALS.** Based on the three independent variables described above, forty meaningful critical sentences pairs (of away/toward versions) and eighty non-meaningful filler sentences (e.g., *The potato mumbled the lamp*) were created for each aspect condition. The only difference between the Progressive condition (2) and the Perfect condition (3) was the grammatical aspect of sentences.

Critical sentences denoted either a concrete action away from the body such as (2a, 3a), or toward the body such as (2b, 3b), and abstract motion away from (2c, 3c) or toward the body (2d, 3d). All sentences mentioned only third persons.

- (2) a. Kimberly *is hanging up* the phone.
- b. Louis *is grabbing* his nose.
- c. Alicia *is transferring* responsibility to a law firm.
- d. Michele *is withdrawing* her proposal from the running.
- (3) a. Kimberly *has hung up* the phone.
- b. Louis *has grabbed* his nose.
- c. Alicia *has transferred* responsibility to a law firm.
- d. Michele *has withdrawn* her proposal from the running.

There were in total ten pairs of abstract sentences and thirty pairs of concrete ones. All of the concrete sentences described hand actions. Within the concrete sentences, I also manipulated how the sentence contributed to the directional meaning. There were three types of sentence, each consisting of ten pairs

whose directions were determined by verbs (4a, 4b), nouns (5a, 5b), and prepositional phrases (6a, 6b), respectively. I included this variable to detect any eventual differences in spatial imagery activated by different word types.

- (4) a. Betty is *pushing* the door. (Away)
- b. Cheryl is *pulling* the door. (Toward)
- (5) a. Rebecca is adjusting *the thermostat*. (Away)
- b. Lisa is adjusting *her glasses*. (Toward)
- (6) a. Christina is pouring the water *into the sink*. (Away)
- b. Tammy is pouring the water *on her head*. (Toward)

In total, each participant saw all eighty of the nonsense sentences and all eighty sensible sentences (40 Away/Toward pairs) in his/her randomly assigned Aspect condition (Progressive or Perfect). The forty critical sentence pairs consisted of ten pairs of the four sentence types: the Verb-different, the Noun-different, the Prepositional-phrase different sentences and the abstract sentences.

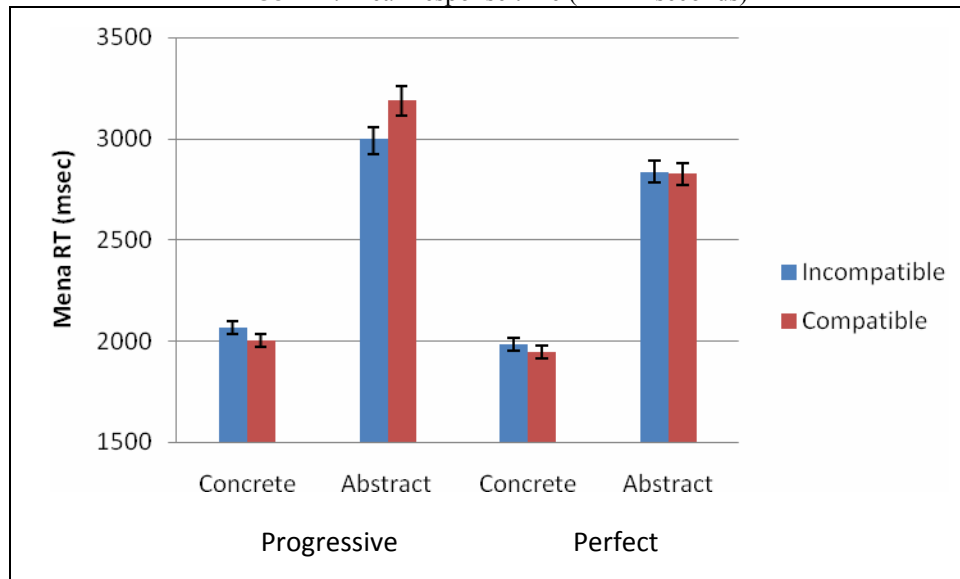
**3. RESULTS.** One participant who did not finish the experiment was excluded from the analysis. In addition, all participants who had accuracy lower than 85% were excluded; this eliminated ten participants. Two other participants were excluded for having mean response times more than 2.5 standard deviations from the mean for all participants. I also excluded all trials with incorrect responses and all responses shorter than 500 milliseconds or slower than 16 seconds. As a result, 12% of the data was eliminated. No items were removed for reasons of accuracy or outlying SD. This yielded the results reported in table 1, and presented graphically in figure 1.

TABLE 1. Results—mean RT and s.d. in each condition

Aspect	Concreteness	Compatibility	mean RT (ms)	s.d. (ms)
<b>Progressive</b>	Abstract	No	3012	877
		Yes	3203	1047
	Concrete	No	2073	497
		Yes	2011	448
<b>Perfect</b>	Abstract	No	2822	728
		Yes	2814	721
	Concrete	No	1973	453
		Yes	1940	431

Two three-way repeated-measures ANOVAs were performed, one each with participants and items as random factors. These three-way analyses showed a large main effect for Concreteness by participants and by  $F_1(1, 95) = 399.64, p < 0.001, F_2(1, 78) = 108.06, p < 0.001$ ; it should not be surprising to find that concrete sentences are processed faster than their abstract counterparts. I also found a significant interaction between Aspect and Concreteness  $F_1(1, 95) = 14.12, p = 0.037, F_2(1, 78) = 14.12, p < 0.001$ ; abstract sentences were processed slightly more slowly in the progressive aspect than the perfect, while concrete sentences showed no such effect. There was a significant interaction between Compatibility and Concreteness both by participants and by items  $F_1(1, 95) = 6.76, p = 0.011, F_2(1, 78) = 4.79, p = 0.032$ —Compatible actions were performed more quickly than Incompatible ones when following Concrete sentences, but the reverse was true following Abstract sentences. I also found a 3-way interaction among Compatibility, Aspect, and Concreteness  $F_1(1, 95) = 4.49, p = 0.037, F_2(1, 78) = 5.31, p = 0.024$ ; this complex interaction is perhaps best seen in figure 1. There was no overall Compatibility effect, and no other effects approached significance.

FIGURE 1. Mean response time (in milliseconds)



In order to look independently at Compatibility and Concreteness effects in the two aspects, I performed two (Compatibility) by two (Concreteness) repeated-measures ANOVAs separately for each of the two aspects.

Within perfect aspect only, a two-way Repeated-Measures ANOVA showed a main effect of Concreteness, significant both by participants,  $F_1(1, 44) = 253.73, p < 0.001$ , and items  $F_2(1, 78) = 94.88, p < 0.001$ . Again, the abstract sentences were processed much more slowly than the concrete ones. Neither a Compatibility effect nor an interaction between Compatibility and Concreteness was found, suggesting that perfect aspect does not focus simulation on final location of an event<sup>1</sup>.

In contrast, Progressive aspect showed a significant interaction between Compatibility and Concreteness, in both the participants  $F_1(1, 51) = 11.219, p = 0.002$ , and items  $F_2(1, 19) = 8.627, p = 0.004$  analyses, showing that for progressives, the abstract and concrete sentences interact with the compatibility of sentence direction and response location. The two-way ANOVA also showed a large main effect of Concreteness, again, in both the participants  $F_1(1, 51) = 194.22, p < 0.001$ , and items  $F_2(1, 59) = 106.84, p < 0.001$  analyses, showing that the concrete sentences were processed much faster than the abstract ones, as found within the perfect aspect. But there was no overall Compatibility effect. The abstract and concrete sentences displayed opposite Compatibility directions, as seen in figure 1. This suggests a closer look at progressives.

In order to uncover where the interaction effect was coming from within the progressive, I performed one-way repeated measure ANOVAs separately for Abstract and Concrete sentences for only the participants who were exposed to the progressive, with Compatibility as the only independent variable. For abstract sentences, they showed a main *incompatibility* effect  $F_1(1, 51) = 6.17, p = 0.016$ ,  $F_2(1, 19) = 4.61, p = 0.045$ , with faster responses when the response location and the sentence direction did NOT match (that is, when sentence direction was away while the response button was near the body, or when sentence direction was toward while the response button was far from the body). By contrast, a *compatibility* effect was found within concrete sentences. The effect was significant by participants  $F_1(1, 51) = 6.56, p = 0.013$ ,

<sup>1</sup> No significant interaction of sentence type and compatibility was found in pairwise comparisons among the four different types of concrete and abstract sentences within perfect aspect. Abstract vs. PP-different  $F_1(1, 44) = 0.007, p = 0.935$ ; Abstract vs. Noun-different  $F_1(1, 44) = 0.003, p = 0.958$ ; Abstract vs. Verb-different  $F_1(1, 44) = 0.172, p = 0.681$ .



and marginally significant by items  $F_2(1, 59) = 2.77, p=0.1$ . The opposite effect of Compatibility in abstract and concrete language suggests that people perform mental simulation differently when processing abstract and concrete sentences.

To summarize thus far, different Location-sentence Compatibility Effects for abstract and concrete sentences were found when they were presented in progressive aspect, but not with perfect aspect. More specifically, within progressive sentences that showed the LCE, concrete sentences showed a strong *compatibility* effect, while their abstract counterparts acted differently, showing an *incompatibility* effect.

**4. DISCUSSION.** This experiment yielded two key findings: one pertaining to grammatical aspect and the other to differences in processing of abstract and concrete language. I will address each of these.

Regarding simulation of the ending location of an action, two competing hypotheses can be outlined. The ending location could be understood as part of the end-state, thus focused on by perfect aspect, or as part of the nucleus of an action, thus highlighted by the progressive aspect. What the current study found were significant effects of Compatibility with progressive sentences, though in different directions for abstract and concrete language. This Location-sentence Compatibility Effect with progressive aspect, but not perfect aspect, is consistent with the interpretation that, at least for the purposes of simulation, the ending location of an action is represented as part of the action, rather than part of the resulting end-state.

While this study and some previous work (Bergen & Wheeler, in press) might be interpreted as indicating that progressive language induces more detailed mental simulation overall than perfect language does, this conclusion is not necessarily licensed. Previous work (Madden & Zwaan, 2003) has shown that perfect aspect highlights the end-states of events. What is clear is that language understanders are more likely to actively engage in spatial imagery about the final location of an action when that action is described by progressive aspect than by perfect aspect. This finding may provide an explanation for a previously mysterious finding. In Madden and Zwaan's (2003) first experiment, participants were more likely to choose pictures showing completed events than the ones showing ongoing events when they read perfective sentences, but chose either picture after reading imperfective sentences<sup>2</sup> (they chose the matching picture (in-progress picture) on only 56% of the imperfective trials). The authors concluded that the absence of an effect on imperfective sentences and pictures suggests that "each reader represents an in-progress event at varying stages of completion." This is a reasonable interpretation, given the picture identification paradigm they employed. However, considering the current study, another interpretation is possible. It could be that progressive aspect not only highlights the internal structure of an event, but also the final physical state (as it does the final spatial location in the sentences used in the current experiment). As a result, participants might find that depictions of the ongoing states of events and their final physical states equally match the content of the participants' mental simulations when they process progressive sentences.

If my interpretation of the current findings is correct—if progressive aspect highlights not only the action but also the final location of a described event—this does narrow the scope of what perfect aspect highlights in simulation about actions. Perfective aspect might well evoke more general simulation about the impact or consequences of an action, but not the action itself. This imagery may be quite idiosyncratic, and based heavily on personal experiences. For example, when hearing the sentence *The boy has lit the fire*, some people may imagine a house getting warm, with condensation appearing on the window. Others may project the picture of a leaping flame, and others may see the boy's hand covered with ashes. Likewise, upon processing the sentence *The stock market has crashed*, people who spend a lot of time looking at charts might imagine a line slanting downwards from left to right, while people sensitive to color may see a whole screen of figures in red, and old movie lovers who have a dramatic imaginations might see a desperate brokers jumping out of windows. These various types of imagery, triggered by perfect aspect,

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<sup>2</sup> The imperfective sentences in their experiment were past progressive, while ours were present progressive, but critically they were both progressive.

are likely to be more heterogeneous than those that depict the actual performance of an action and its location, and might as a result be harder to measure experimentally. This view of how the perfect functions actually coincides quite nicely with Comrie's (1976) argument regarding perfect aspect, that "perfect indicates the continuing present relevance of a past situation."

The findings on aspect also build off of those reported by Glenberg & Kaschak (2002). Their work on spatial location (their experiment 2B), using a method almost identical to ours, produced no effect of language on rates to respond when the response buttons were placed close to or far from the body. Our work replicated their finding with perfect sentences, but not with progressive sentences, which successfully focused simulation on the entire described event, including the ending location. The perfect sentences in our perfect aspect condition, and their simple past tense sentences, appear to have evoked no measurable spatial imagery about the ending locations of actions. The findings of current study do, however, call for a more textured interpretation of findings from experiments like these. Glenberg & Kaschak (2002) found a compatibility effect of their simple past tense sentences when they had participants move their hands towards or away from their body to respond, but not when they had participants hold their hands above keys close to or far from their bodies. They reasoned that the mental simulation effects they found when people performed motions towards or away from their bodies were due to action itself, and not just to the spatial location of the response buttons. But my findings—a Location-sentence Compatibility Effect with progressive sentences—suggest that spatial location can be a represented component of a mental simulation, given the right linguistic cues.

To sum up the findings on aspect, progressive sentences, but not perfect ones, appear to promote mental simulation not only of the motor control involved in performing a described action, but also of the ending location of that action. This confirms not only the previously reported effects of grammatical aspect, highlighting certain parts of a described event for mental simulation, but the role more broadly of grammatical structures in exerting higher-order effects on mental simulation.

Now let us turn to the second interesting finding to come out of the experiment — people mentally simulate the ending locations implied by both concrete and abstract language, but those simulations are different. Within progressive aspect, which induces simulation of ending location, concrete sentences showed a Location-sentence Compatibility Effect, and abstract sentences showed a Location-sentence Incompatibility Effect. This is an intriguing finding because, to date, as discussed in the introduction, the jury is still out on whether the mental simulation activated by abstract language is the same as that activated by literal language. Our results support the position that the two are indeed different. But in exactly what way? Why would concrete language produce a compatibility effect, while abstract language generates an incompatibility effect?

The literature on language-induced mental simulation is replete with examples of both compatibility and incompatibility effects. The broad outlines of an explanation for when you get which have been articulated by several authors (Kaschak et al., 2005; Bergen, 2007). When a task requires language users to engage the same neuro-cognitive systems to do two similar but non-integratable things at the same time (for instance, simulating motion of the hand away from the body to punch a wall and away from the body to press a button might be similar but non-integratable), this produces an incompatibility effect. By contrast, compatibility effects arise when two tasks are either simultaneous and integratable (e.g. simulating pressing a button in a particular place, and actually pressing a button in that same place), or temporally separated and similar (even if they are non-integratable). The Action-sentence Compatibility Effect is usually interpreted as a compatibility effect of the last kind—people perform their manual response several seconds after the end of the sentence, and because the two tasks are sequential, we find compatibility effects for sentences and actions going in the same direction, even when the actions are slightly different. Compatibility effects like this one can be seen as a type of priming—a set of neural structures is activated by one activity (motor imagery) and this speeds performance of a subsequent, similar activity.

In this way, the literature points us in the direction of an explanation for the difference between the effects of abstract and concrete sentences. It could be that the difference is one in the timing of the proc-

essing of the respective sentences. Namely, it could be that people processing concrete sentences have fully understood the content by the time they make a manual response, which in turn leaves enough temporal separation between the sentence understanding and action-planning tasks to generate a compatibility effect even when the two actions are merely similar but non-integratable. However, abstract sentences might by contrast take longer to process, meaning that their meaning is still being processed at the time when the response action is being planned and executed. In this case, previous work suggests that simultaneously engaging two similar but non-identical mental simulations should produce an incompatibility effect. As for why spatial processing might last longer for abstract language than for concrete language, there are a number of possible explanations. For instance, it could be that the spatial components of mental simulation are engaged only late in the comprehension process for abstract language about communication and transfer of abstract possessions—in something like the two-stage model of processing suggested for figurative and other complex language (Kaup et al., 2007; Giora et al., 2004). Or it could be that abstract language is just harder to understand, and as a result, meaning processing continues even after the understanders has made a judgment about whether or not the sentence is meaningful.

Indeed, there's good reason to believe that the abstract sentences we used were harder to process than the concrete ones. The most telling evidence is that abstract sentences took much longer to be processed than their concrete counterparts, as shown by the main effect of Concreteness observed above. To be clear, this difficulty in processing abstract sentences could be due to one of several causes. It could be a product of some aspect of the intrinsic character of abstract, as compared with concrete, language. Or, least interestingly, it could be due differences in the lengths of the sentences. As it turns out, our abstract sentences (average length = 7.35 words) are slightly longer than our concrete sentences (average length = 6.28 words).

However, we can easily reject the uninteresting length explanation, in the following way. We had three types of concrete sentence, those differing in verbs (4), in object nouns (5), and in prepositional phrases (6). These had different mean lengths: noun-differing averaged 5.43 words, verb-differing averaged 5.3 words and PP-differing averaged 8.1 words. If sentence length was the only reason for the incompatibility effect, then the longer, PP-differing sentences should induce an incompatibility effect, just as the longer abstract sentences do. But that is not what we found. In a pairwise comparison within progressive aspect, with Sentence-Type (Abstract or PP-Differing) and Compatibility as independent variables, there was a significant interaction between Sentence-Type and Compatibility  $F_1(1, 51) = 8.86, p < .01, F_2(1, 76) = 2.85, p = .043^3$ , where Abstract sentences displayed an incompatibility effect, but PP-differing sentences showed a small compatibility effect (see Figure 2, below). Thus it is not merely sentence length that produces an incompatibility effect in processing abstract sentences, at least within progressive aspect.

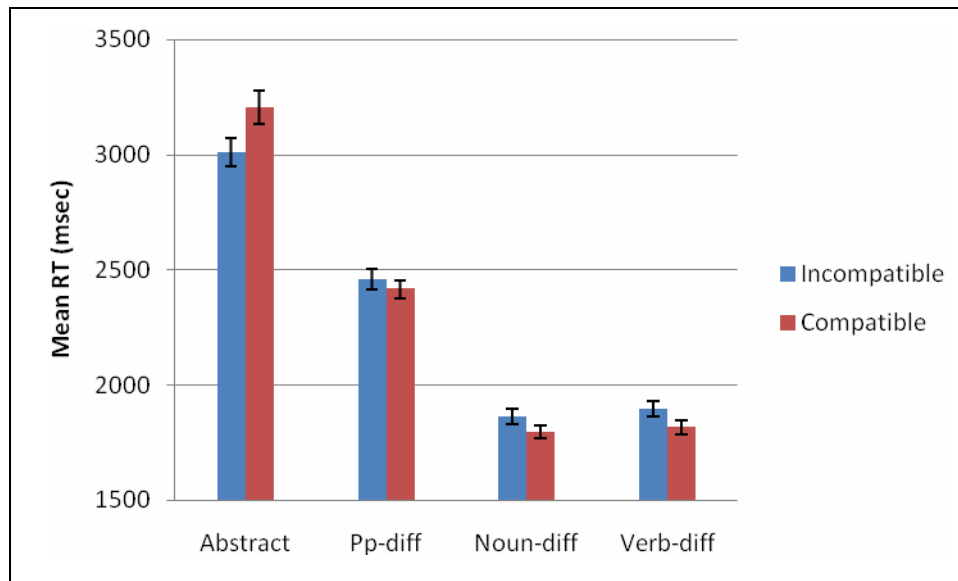
TABLE 2 Results from progressive aspect—mean RT and SD for each sentence type

<i>Concreteness</i>	<i>Sentence Type</i>	<i>Compatibility</i>	<i>mean RT (ms)</i>	<i>SD (ms)</i>
Abstract	Abstract	No	3012	877
		Yes	3204	1047
Concrete	Noun-diff	No	1862	499
		Yes	1796	425
	Verb-diff	No	1897	476

<sup>3</sup> In pairwise comparisons within progressive aspect, Abstract sentences are also significantly different in their compatibility effects from the other sentence types, namely Noun-different  $F_1(1, 51) = 7.62, p < .01, F_2(1, 38) = 5.88, p = .02$ , and Verb-different  $F_1(1, 51) = 9.53, p < .01, F_2(1, 38) = 5.15, p = .029$ . However, no interaction of compatibility and sentence type was found among the three concrete sentence types, which suggests that reading these three types of concrete sentences yields similar simulation patterns.

	Yes	1816	444
Pp-diff	No	2460	652
	Yes	2417	574

FIGURE 2 Mean response times in all sentence types in Progressive Aspect. Error bars indicate standard error.



To summarize the findings on concreteness, concrete language facilitated compatible action in a compatible location, while abstract language inhibited it. We've argued that this might result from differences in the time-course of processing of these different types of sentence. The spatial components of simulation performed in processing abstract sentences might take longer, and as a result, the participants might have still been simulating a location while planning and executing their physical response. The simultaneous use of the same brain mechanisms to perform two slightly different tasks would thus produce interference for abstract sentences. However, concrete sentences, which are processed more quickly, leave participants done with their spatial simulations by the time they perform their responses.

In general, the findings reported here are instructive in two ways. First, progressive sentences appear to induce more mental simulation, including simulation of spatial location, than perfect sentences do. And for the purpose of simulation, the final location is not understood as part of the resulting state of an action, but rather as part of the core of the action itself, highlighted by the progressive aspect. These results once again give support to those simulation-based models of language understanding arguing that grammatical structures, such as grammatical aspect constructions, guide understanders to construct mental simulations that focus on different parts of a described action (such as Bergen & Chang, 2005). The current study also found that abstract and concrete language evoke different simulation effects, although only in progressive sentences. Abstract language generally refers to actions or events that are neither purely physically nor spatially constrained, and remains a serious issue for embodied theories of language processing (Richardson et al., 2003; Barsalou & Wiemer-Hastings, 2005; Bergen et al., 2007). Results from this study may provide some clues, in that abstract language engages spatial simulation, and is generally more difficult to process compared to concrete language because the two are conceptually different. However, a number of questions about exactly how abstract language is processed, and how it differs from concrete language, remain unanswered. Does the understanding of abstract language depend on concrete concepts, making it more complex and requiring more steps in the simulation process? Or can it be that abstract language is conceptually more general or vague compared to concrete language, thus evoking more varied and longer-lasting simulation? Definitive answers must await further empirical investigation.

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## Appendix

Critical stimuli. Only progressive version is shown below. Perfect versions were identical except for aspect marking.

### *Noun-differing pairs*

#### AWAY

Shirley is brushing the couch.  
Mildred is squeezing the mustard bottle.  
Ben is feeding his child.  
Melissa is grabbing the doorknob.  
Chris is patting the cat.  
Mary is rubbing the magic lamp.  
Helen is wiping the counter.  
Terry is pushing the elevator button.  
Pamela is beating the drum.  
Eric is washing his desk.

#### TOWARDS

Brian is pinching his chin.  
Willie is lighting his cigarette.  
Kelly is scratching her head.  
Jonathan is tucking in his shirt.  
Fred is putting in his contact lens.  
Joan is washing her face.  
Lisa is adjusting her glasses.  
Louis is grabbing his nose.  
Virginia is brushing her teeth.  
Jean is cleaning her ear.

### *Verb-differing pairs*

#### AWAY

Judith is closing the cupboard.  
Bruce is tossing out the water.  
Beverly is closing the drawer.  
Ashley is stretching her arms.  
Maria is spitting out the water.  
Joshua is tossing a Q-tip.  
Kimberly is hanging up the phone.  
George is taking off the jacket.  
Carol is taking off her glasses.  
Carl is flipping the burger.

#### TOWARDS

Cheryl is pulling the door.  
Dennis is picking up the toys.  
James is eating the pie.  
Stephen is dragging in a fish.  
Janice is snatching the ring.  
Donald is biting his fingernails.  
Stephanie is rubbing her belly.  
Harry is smoking a cigarette.  
Edward is putting in the earplugs.  
Joyce is stealing a marshmallow.

### *PP-differing pair*

#### AWAY

Andrew is dumping the coffee into the sink.  
Rose is putting the ear-plugs on the table.  
Christina is pouring the water into the sink.  
Sharon is putting the pencil in the pencil sharpener.  
Jeffrey is throwing the pills onto the floor.  
Nancy is tossing the cracker past her lips.  
Patrick is putting a tissue to his nose.  
Nicole is spreading the lotion on her back.  
Walter is putting money in his pocket.  
Jessica is shoving her finger into her ear.

#### TOWARDS

Sandra is running her hands through the dog's hair.  
Ruth is squeezing the drops into the bowl.  
Mark is slapping the sticker on the refrigerator.  
Samuel is putting a ring in the jewelry box.  
Charles is wiping the sweat off the bench.  
Adam is placing a dime on his shoulder.  
Debra is putting a grape in her mouth.  
Jose is sticking tape on his nose.  
Kenneth is driving his knuckles into his ribs.  
Jane is putting her finger under her nose.

*Abstract pairs*

AWAY

Darlene is transmitting the orders to the front lines.

Bertha is posting her wedding date to the news-group.

Lloyd is donating a kidney to the biology department.

Dan is confessing his secret to the courtroom.

Andy is pitching the idea to the publishing firm.

Alicia is transferring responsibility to a law firm.

Jeff is encoding the information on a computer disk.

Calvin is submitting the request to the committee.

Bonnie is returning a sense of decorum to the proceedings.

Ronnie is selling the land to a corporation.

TOWARDS

Bill is tearing his heart out of the relationship.

Oscar is receiving the message from headquarters.

Michele is withdrawing her proposal from the running.

Jill is withdrawing her time from charity.

Jane is collecting praise from the children.

Jim is receiving the honor from the teacher.

Megan is removing her true name from her diary.

Juan is extracting state secrets from the enemy.

Darlene is taking the idea away from the conversation.

Tom is stealing the match from his opponent.