When do language comprehenders mentally simulate locations?

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Abstract:

Embodied approaches to comprehension (Narayanan 1997; Zwaan 1999) propose that understanding language entails performing mental simulations of its content. The evidence, however, is mixed. Action-sentence Compatibility Effect studies (Glenberg and Kaschak 2002) report mental simulation of motor actions during processing of motion language. But the same studies find no evidence that language comprehenders perform spatial simulations of the corresponding locations. This challenges simulation-based approaches. If locations are not represented in simulation, but are still understood, then simulation may be unnecessary for understanding. We conducted a Location-sentence Compatibility experiment, to determine whether understanders mentally simulate locations. People did indeed simulate locations, but only when sentences used progressive (and not perfect) grammatical aspect. Moreover, mental simulations of locations differed for language about concrete versus abstract events. These findings substantiate the role of mental simulation in language understanding, while highlighting the importance of the grammatical form of utterances as well as their content.

Keywords:

embodiment; mental simulation; location; grammatical aspect; concreteness; abstractness.

1. Introduction

An emerging 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; Zwaan 1999, Zwaan et al. 2002). Mental simulation is the internal (re-) creation of embodied experiences (Barsalou 1999). It subjectively resembles perceptual or motor experiences that people 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 2001). The idea proposed by the various simulation-based approaches to language is that like a number of other higher human cognitive functions, like recall (Wheeler et al. 2000) and property verification (Solomon and Barsalou 2004; Pecher et al. 2003), understanding language engages perceptual and motor systems to construct modality-specific simulations of the described percepts and actions.

Key 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, Glenberg et al., 2009). 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 et al. 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 how to simulate it. For instance, grammatical person indicates what perspective to adopt in a mental simulation (Brunyé et al. 2009), 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, to simulate (Goldberg 1995).

The role of grammar in language-driven mental simulation is of substantial theoretical interest. For one, most traditional approaches treat grammar as purely structural and to all intents and purposes, meaningless (e.g., Chomsky 1957). 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 (e.g., Fodor 1983). 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 unique 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 this paper takes a modest step forward in this regard.

The grammatical structures we 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 or completed. Linguists argue that the English progressive, as in *John is opening the drawer*, highlights the internal structure of an event, while the perfect aspect, such as in *John has opened the drawer* encapsulates or shuts off access to the described process, while highlighting the resulting end-state (Comrie 1976; Dowty 1977; Langacker, 1983). Behavioral evidence supports both assertions (Carreiras et al. 1997; Magliano and Schleich 2000; Madden and Zwaan 2003; Ferretti et al. 2007; Madden and Therriault 2009; Anderson et al., 2010; Matlock, 2011). Recent work (Bergen and Wheeler 2010) 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 central part of an event (sometimes called its "nucleus"), while the perfect shuts off mental simulation of the nucleus 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 the perfect, simple past sentences, suggesting that they had not represented the internal structure of the event, so much as its resulting end-state.

These previous studies have only scratched the surface of how aspect affects mental simulation. While we know that progressive highlights the nucleus of an event, we still don't know exactly what constitutes that nucleus. Consider motor actions. What is the nucleus of an action like putting on glasses? Is it only the part of the motor action in which the hands, arms, and head are moving? Or does it also include the hands and glasses in their final location? The broader question here is whether, in mental simulation of an action, the nucleus that the progressive highlights is limited to the motor control component of the action, or whether it also includes the ending location of the action. This is an empirical question, but existing work on aspect has not yet pulled apart what's in the nucleus. If the nucleus includes just the action, and not the ending location of the action, then progressive aspect ought not to facilitate access to compatible ending locations, but perfect should. Conversely, if the final location is indeed part of the nucleus, then progressive aspect, which increases mental simulation of the nucleus of an action, should also facilitate access to the compatible ending location. When do we mentally simulate ending locations?

Initial indications from work with simple past tense sentences about motion toward or away from the body (*Andy handed you the pizza* or *You handed Andy the pizza*) showed 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. 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. They used the simple past, which is often interpreted as perfect (see, for instance, Madden and Zwaan 2003). As hypothesized above, it's possible that the nucleus of mentally simulated events includes ending location, in which case, simple past would shut off mental simulation of the ending location, just as it shuts off access to other aspects of the nucleus. If this is the correct interpretation of these findings, then it should be the case that progressive sentences about motor actions display a Location-sentence Compatibility Effect, even when perfect sentences do not. 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, we added one additional wrinkle in keeping with previous similar work (e.g., Glenberg and Kaschak 2002; Bergen and Wheeler 2010). We included among our critical stimuli not only concrete sentences about hand motion, but also sentences about communication (like *Dan is confessing the secret to the courtroom*) 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 2010) 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, we designed an experiment to answer two primary questions. First, is the ending location of an action highlighted by progressive aspect, perfect aspect, both, or neither? 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. If Progressive highlights not only the nucleus but also the ending location of an action, then we will observe faster reactions to ending locations with progressive sentences. However, if it is perfect aspect that accentuates the final location of an action, we should see shorter reaction times to ending locations in the perfect aspect condition.

Second, do concrete and abstract language yield similar or different mental simulations of ending location? 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.

Besides Aspect and Concreteness, we also considered another independent variable— Compatibility. If participants mentally simulated the ending location implied by a sentence, we expected 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. Our work addressed these questions using a location-sentence compatibility method, described below.

2. Experiment

2.1. Participants and design

A total of one-hundred-and-five undergraduate students at the University of Hawai‘i at Mānoa participated in this experiment. They received either extra credit in an introductory linguistics class or five dollars. All were right-handed native speakers of English.

We used a 2 (Progressive/Perfect) x 2 (Abstract/Concrete) x 2 (Compatible/Incompatible) design with Aspect as a between-subjects factor.

Aspect. Participants were randomly assigned to one of the two Aspect conditions. Participants in the Progressive condition read only progressive sentences, such as *Kimberly is hanging up the phone*. Participants in the Perfect condition read only perfect sentences, such as *Kimberly has hung up the phone*. For the Perfect condition, we used the present perfect, *has Ved*, and not the simple past or simple present for several reasons. First, unlike English simple tenses, which can be interpreted as either progressive or perfective, the present perfect unambiguously marks perfective aspect. Second, it is matched with the present progressive for length in words. And finally, it's matched with the present progressive for tense (present).

Concreteness. In order to investigate the extent to which understanders construct mental simulations in understanding abstract language, and the nature of these mental simulations, we created Abstract sentences in addition to Concrete ones. 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*. These sentences are abstract in that they do not describe actual physical motion towards or away from the agent, but do describe events that are metaphorically construed as motion towards or away from the agent. Similar stimuli have been used in other similar studies, including Glenberg & Kaschak (2002) and Bergen & Wheeler (2010).

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.

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. 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.

2.2. Materials

Based on the three independent variables described above, eighty meaningful critical sentences (in 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), or 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.*

All of the concrete sentences described hand actions. Within the concrete sentences, we 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. Nouns and verbs might engage mental simulation differently, so we included sentence type as a variable to detect any eventual differences in spatial imagery activated by different word types. The prepositional sentences were included as a length control to be compared with Abstract sentences (see more in the Discussion).

(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 80 of the nonsense sentences and all 80 sensible sentences (40 Away/Toward pairs) in his/her randomly assigned Aspect condition (Progressive or Perfect). The 40 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. In a separate norming experiment, the 80 critical sentences were rated from 0 (completely nonsense) to 7 (perfectly sensible) by twenty-five native speakers of English, who did not take part in experiment. The sentences, their average sensibility score and standard deviations are listed in the Appendix.

2.3. 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") 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.

3. Results

Six participants who had accuracy lower than 85% were excluded from the analysis. In addition, two other partipants were excluded for having mean response times more than 2.5 standard deviations from the mean for all participants. We also removed all trials with incorrect responses and all responses shorter than 500 milliseconds or greater than 2.5 standard deviations from the mean of the responses in each condition. 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 Mean RT and SD in each condition

Aspect	Concreteness	Compatibility	Mean RT (ms)	SD (ms)
Progressive	Abstract	No	3011	876
		Yes	3203	894
	Concrete	No	2061	481
		Yes	2004	439
Perfect	Abstract	No	2822	728
		Yes	2814	721
	Concrete	No	1963	430
		Yes	1936	424

We performed two three-way repeated-measures ANOVAs, one each with participants and items as random factors. These three-way analyses showed a large main effect for Concreteness by participants and by items F_1 (1, 95) = 397.46, p < .001, F_2 (1, 78) = 112.37, p < .001; it should not be surprising to find that concrete sentences are processed faster than their abstract counterparts. We also found a significant interaction between Aspect and Concreteness F_1 (1, 95) = 4.49, p= .037, F_2 (1, 78) = 14.52, p < .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) = 6.26, p = .014, F_2 (1, 78) = 4.583, p = .035—Compatible actions were performed more quickly than Incompatible ones when following Concrete sentences, but the reverse was true following Abstract sentences. We also found a three–way interaction among Compatibility, Aspect, and Concreteness F_1 (1, 95) = 4.65, p = .034, F_2 (1, 78) = 5.73, p = .019; this complex interaction is perhaps best understood visually, as in Figure 1, below. There was no overall Compatibility effect, and no other effects approached significance.

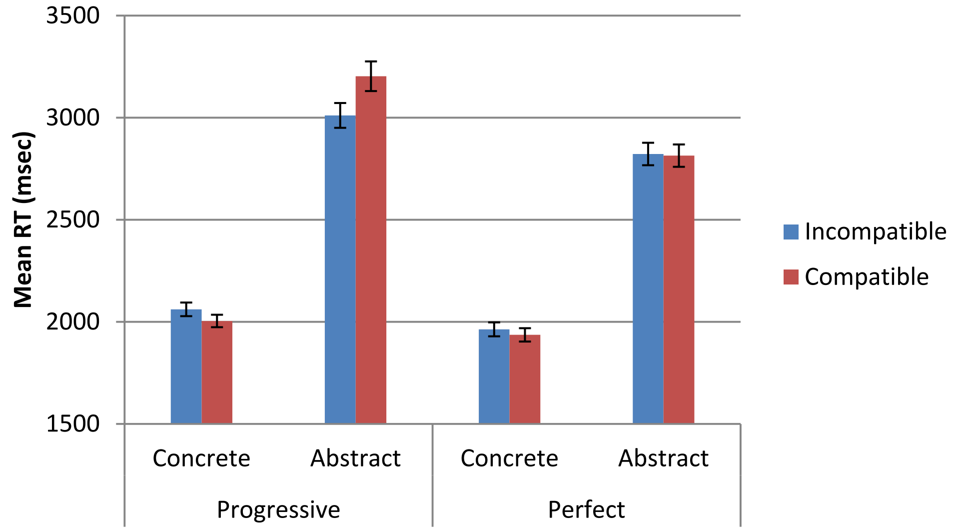

Figure 1 Mean response time (in milliseconds) showing a main effect of Concreteness, a compatibility effect for concrete sentences, and an incompatibility effect for abstract sentences.

In order to look independently at Compatibility and Concreteness effects in the two aspects, we performed 2 (Compatibility) x 2 (Concreteness) repeated-measures ANOVAs separately for each of the two aspects. First, we looked only at the perfect.

Within Perfect aspect only, a two-way Repeated-Measures ANOVA showed a main effect of Concreteness, significant both by participants, F_1 (1, 44) = 251.55, p < .001, and items F_2 (1, 78) = 99.02, p < .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 the final location of an event.

In contrast, Progressive aspect showed a significant interaction between Compatibility and Concreteness, in both the participants F_1 (1, 51) = 11.16, p = .002, and items F_2 (1, 78) = 8.79, p = .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) = 193.46, p < .001, and items F_2 (1, 78) = 110.81, p < .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, we 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 = .016, F_2 (1, 19) = 4.61, p = .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) = 5.48, p = .023, and marginally significant by items F_2 (1, 59) = 2.51, p = .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, we found different Location-sentence Compatibility Effects for abstract and concrete sentences 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 compatibility effect while their abstract counterparts acted differently, showing an incompatibility effect.

4. Discussion

This experiment yielded two key findings that we will discuss in detail, one pertaining to grammatical aspect and the other to differences in processing of abstract and concrete language. We will address these in turn.

In the introduction, we outlined two competing hypotheses regarding simulation of the ending location of an action. People might understand the ending location as part of the end-state, thus focusing on it when processing language that uses perfect aspect. Alternatively, they could understand it as part of the nucleus of an action, thus highlighted by the progressive aspect. What we found were significant effects of Compatibility with progressive sentences, though in different directions for abstract and concrete language, as we will discuss below. 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 nucleus of an action, rather than part of the resulting end-state.

While this study and some previous work (Anderson et al., 2010; Bergen and Wheeler 2010) 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 and Zwaan 2003) has shown that perfect aspect highlights the end-states of events, so the progressive doesn't increase simulation overall.

However, the finding that language understanders are more likely to activate the ending location of an action when that action is described by progressive aspect than by perfect aspect 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[1] (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, the results from the current study suggest another possible interpretation. 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 this interpretation is correct—if progressive aspect profiles 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. Perfect aspect might well evoke more general simulation about the impact or consequences of an action, but not the action itself. The content of these mental representations may be quite idiosyncratic, relying 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*

[1] The imperfective sentences in their experiment were past progressive, while ours were present progressive, but critically they were both progressive.

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 dramatic imaginations might see desperate stock brokers jumping out of windows. These various types of imagery, triggered by perfect aspect, 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 coincides quite nicely with Comrie's (1976: 52) argument regarding perfect aspect that "perfect indicates the continuing present relevance of a past situation."

Our findings on aspect also build off of those reported by Glenberg and 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 condition, and their simple past tense sentences, appear to have evoked no measurable spatial imagery about the ending locations of actions. Our findings do, however, call for a more textured interpretation of findings from experiments like these. Glenberg and 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 our findings—a Location-sentence Compatibility Effect with progressive sentences—suggests that spatial location can be a represented component of a mental simulation, given the right linguistic cues.

To sum up our 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 novel 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 how mental simulation activated by abstract language relates to the simulation 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 simulation) 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 in the timing of the processing 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. The idea that the time course of processing could underlie the differential responding is actually supported by the experimental data, in that the pattern of results observed is stronger for slower responses, or for those sentences which generally tended to be processed relatively slowly—time course significantly predicts effect size $\beta = 0.11$, t (79) =2.65, $p = .009$.

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.

To this last point, 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, less interestingly, it could be due to 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 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 isn't 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 $F_1(1, 51) = 10.52$, $p = 0.002$, $F_2(1, 38) = 5.04$, $p = .031$[2], 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. Thus, time course of processing, but not sentence length, is the likely cause for the differences in simulation between the two aspects.

[2] In pairwise comparisons, Abstract sentences are also significantly different in their compatibility effects from the other sentence types, namely Noun-different $F_1(1, 51) = 6.56$, $p = .013$, $F_2(1, 38) = 5.27$, $p = .027$, and Verb-different $F_1(1, 51) = 9.31$, $p = .004$, $F_2(1, 38) = 5.15$, $p = .035$. 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.

Table 2 Results from Progressive Aspect—mean RT and SD for each sentence type

Concreteness	*Sentence Type*	*Compatibility*	*mean RT (ms)*	*SD (ms)*
Abstract	Abstract	No	3011	876
		Yes	3203	894
Concrete	Noun-diff	No	1849	477
		Yes	1796	425
	Verb-diff	No	1884	453
		Yes	1816	444
	Pp-diff	No	2449	636
		Yes	2398	554

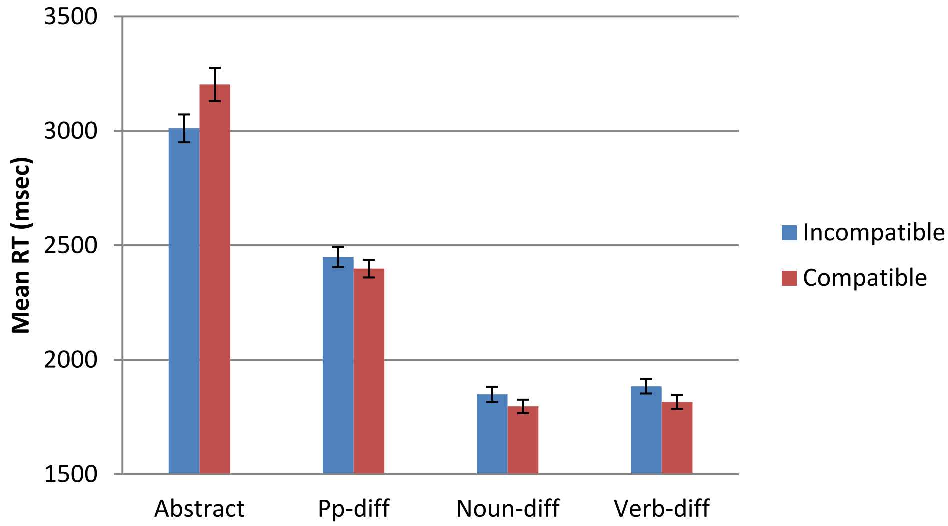

Figure 2 Mean response times in all sentence types in Progressive Aspect. Error bars indicate standard error.

To summarize our 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 varied mental simulations, including simulation of spatial location, than perfect sentences do. And for the purpose of simulation, the final location is not represented 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 Madden and Zwaan 2003; Bergen and Chang 2005; and Bergen and Wheeler 2010). We also found that abstract and concrete language evoke different simulation effects, although we only found this difference 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 and Wiemer-Hastings 2005; Bergen et al. 2007). Results from our work 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. The number shows the average and standard deviation of its sensibility score.

	Mean	SD		Mean	SD
Noun-differing pairs	*6.5*	*0.9*			
AWAY	6.3	1.2	TOWARDS	6.7	0.7
Shirley is brushing the couch.	5.0	2.0	Brian is pinching his chin.	6.2	1.6
Mildred is squeezing the mustard bottle.	6.7	0.9	Willie is lighting his cigarette.	7.0	0.0
Ben is feeding his child.	6.8	0.6	Kelly is scratching her head.	7.0	0.0
Melissa is grabbing the doorknob.	6.2	1.4	Jonathan is tucking in his shirt.	7.0	0.2
Chris is patting the cat.	5.7	1.8	Fred is putting in his contact lens.	6.5	1.4
Mary is rubbing the magic lamp.	6.8	0.7	Joan is washing her face.	6.9	0.3
Helen is wiping the counter.	6.8	1.0	Louis is grabbing his nose.	6.7	0.9
Terry is pushing the elevator button.	7.0	0.0	Lisa is adjusting her glasses.	6.0	1.8
Pamela is beating the drum.	6.6	1.1	Virginia is brushing her teeth.	7.0	0.2
Eric is washing his desk.	5.5	2.0	Jean is cleaning her ear.	6.4	1.0

	Mean	SD		Mean	SD
Verb-differing pairs	*6.3*	*1.3*			
AWAY	6.3	1.4	TOWARDS	6.3	1.2
Judith is closing the cupboard.	6.3	1.5	Cheryl is pulling the door.	5.6	1.9
Bruce is tossing out the water.	5.9	1.8	Dennis is picking up the toys.	6.7	0.9
Beverly is closing the drawer.	6.5	1.3	James is eating the pie.	6.4	1.2
Ashley is stretching her arms.	6.6	1.1	Stephen is dragging in a fish.	5.0	1.8
Maria is spitting out the water.	6.2	1.6	Janice is snatching the ring.	5.8	1.8
Joshua is tossing a Q-tip.	5.8	1.9	Donald is biting his fingernails.	6.8	0.9
Kimberly is hanging up the phone.	6.6	1.1	Stephanie is rubbing her belly.	6.9	0.4
George is taking off the jacket.	5.5	1.9	Harry is smoking a cigarette.	7.0	0.0
Carol is taking off her glasses.	6.5	1.4	Edward is putting in the earplugs.	6.3	1.3
Carl is flipping the burger.	6.7	0.7	Joyce is stealing a marshmallow.	6.3	1.4

	Mean	SD		Mean	SD
PP-differing pairs	*6.2*	*1.5*			
AWAY	6.4	1.3	TOWARDS	6.0	1.6
Andrew is dumping the coffee into the sink.	6.4	1.8	Nancy is tossing the cracker past her lips.	5.9	2.4
Rose is putting the ear-plugs on the table.	6.9	1.4	Patrick is putting a tissue to his nose.	6.5	1.7
Christina is pouring the water into the sink.	6.5	0.3	Nicole is spreading the lotion on her back.	6.7	1.2
Sharon is putting the pencil in the pencil sharpener.	6.6	1.1	Walter is putting money in his pocket.	6.8	0.5
Jeffrey is throwing the pills onto the floor.	4.2	1.1	Jessica is shoving her finger into her ear.	6.4	1.1
Sandra is running her hands through the dog's hair.	6.4	1.3	Adam is placing a dime on his shoulder.	5.7	2.2
Ruth is squeezing the drops into the bowl.	5.9	1.7	Debra is putting a grape in her mouth.	6.6	1.2
Mark is slapping the sticker on the refrigerator.	6.2	1.8	Jose is sticking tape on his nose.	6.0	1.8
Samuel is putting a ring in the jewelry box.	6.5	1.0	Kenneth is driving his knuckles into his ribs.	5.4	2.3
Charles is wiping the sweat off the bench.	6.6	0.9	Jane is putting her finger under her nose.	6.0	1.6

	Mean	SD		Mean	SD
Abstract pairs	*5.9*	*1.7*			
AWAY	6.4	1.2	TOWARDS	5.3	2.1
Darlene is transmitting the orders to the front lines.	6.6	1.0	Bill is tearing his heart out of the relationship.	4.0	2.4
Bertha is posting her wedding date to the newsgroup.	6.1	1.6	Oscar is receiving the message from headquarters.	6.4	1.5
Lloyd is donating a kidney to the biology department.	6.7	1.0	Michele is withdrawing her proposal from the running.	5.4	2.1
Dan is confessing his secret to the courtroom.	6.5	1.0	Jill is withdrawing her time from charity.	4.9	2.0
Andy is pitching the idea to the publishing firm.	6.9	0.4	Jane is collecting praise from the children.	4.9	2.3
Alicia is transferring responsibility to a lav firm.	5.8	2.0	Jim is receiving the honor from the teacher.	5.4	2.1
Jeff is encoding the information on a computer disk.	6.4	1.4	Megan is removing her true name from her diary.	5.9	1.7
Calvin is submitting the request to the committee.	6.7	1.0	Juan is extracting state secrets from the enemy.	5.8	1.9
Bonnie is returning a sense of decorum to the proceedings.	5.7	2.0	Darlene is taking the idea away from the conversation.	4.6	2.5
Ronnie is selling the land to a corporation.	6.8	0.6	Tom is stealing the match from his opponent.	5.1	2.3

Sample Filler sentences. Only progressive version is shown below. Perfect versions were identical except for aspect marking.

Louise is stretching the apple.
Vincent is blowing a lesson to Liz.
Crystal is scratching us a clock.
Stanley is grabbing him to the vase.
Jesse is teaching his time to Anna.
Diana is devoting the song Jenni.
Peggy is eating Sally the tea cup.
Allen is drinking the house to Joe.
Annie is pouring the horse to him.
Jimmy is thinking him the ice cream.

Dawn is typing her dinner.
Nathan is opening the plate.
Sherry is mowing the drum.
Leonard is washing the air.
Grace is pouring the moon.
Jeffery is fertilizing his clips.
Emily is plugging the railing.
Norman is turning on the candy.
Tiffany is bicycling the steel using the keyboard.
Tracy is drinking the backpack throughout the calendar.