Competition, event comprehension, and dynamic location information in sentence processing

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Abstract

Two experiments in the visual world paradigm investigated competition in sentence processing from dynamic event-related information about location. In Experiment 1, listeners viewed visual arrays with container objects like a bowl, jar, pan, and jug, while they heard sentences like "The boy will pour the sweetcorn from the bowl into the jar, and he will pour the gravy from the pan into the jug. But first/And then, he will taste the sweetcorn." While "But first" contexts referred to the "source" location of the discourse-final noun (e.g., "sweetcorn"), "And then" contexts referred to its "goal" location. In Experiment 2, listeners always heard "And then" contexts. We found that listeners rapidly fixated context-relevant locations. Crucially, they also fixated locations that were context-irrelevant, but related to the discourse-final noun, suggesting object competition, or consistent with abstract location information implied by "But first" (source) or "And then" (goal), suggesting location competition.

Keywords: Competition; Event comprehension; Location; Visual world paradigm.

Introduction

Everyday, we use language in *dynamic* real world settings that change along any number of dimensions. One such dimension is *location*: for example, objects like car keys and TV remotes are routinely involved in actions and events that result in (often frustrating!) changes of location. Findings from the Visual world paradigm (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995), which presents listeners with spoken language about a visual context, have revealed that listeners' eye movements are rapidly guided by dynamic location information (i.e., information about the multiple instantiations of an object at different locations over event time) during sentence processing.

For example, Chambers and San Juan (2008) instructed listeners to move objects around a visual array, and then they presented listeners with sentences like "Now return the…" They found that listeners anticipatorily fixated previously moved objects, consistent with "return," compared to previously unmoved objects. Similarly, Altmann and Kamide (2009) presented listeners with visual

scenes with objects like a glass (on the floor), table, and bookshelf, followed by a blank screen, and sentences like "The woman will put the glass onto the table. Then, she will pick up the bottle, and pour the wine carefully into the glass." At the discourse-final "the glass," they found that listeners were more likely to fixate the glass's new location (the prior location onscreen of the table), consistent with the sentence context, compared to its initial location on the floor.

Location-based competition?

Thus, when language comprehenders have dynamic event-related information about an object's location (i.e., information about where an object *is* and/or where it *was* and/or where it *will be*), they must resolve *which* locations are relevant to a sentence context, and *which* are not. The findings of Chambers and San Juan (2008) and Altmann and Kamide (2009) suggest that language comprehenders rapidly integrate location information with sentence context information, and rapidly retrieve context-relevant locations. Here, we ask a closely related question: do language comprehenders also retrieve context-irrelevant location information? In other words, do irrelevant locations *compete* with relevant locations?

Hoover and Richardson (2008) addressed this question in a study that used a memory recall task. Their listeners heard spoken facts from a burrowing creature at different locations in a visual display, followed by a question about one of the facts. During the question, they found that listeners were more likely to fixate the location where the queried fact had been presented (compared to distractor locations that the creature had not visited). However, listeners also fixated the location where the *non*-queried fact had been presented.

Hoover and Richardson (2008)'s findings suggest that location information drives *competition effects* in eye movements: fixations to locations that are related to target information, but context-irrelevant. This complements competition observed elsewhere: for example, Huettig and Altmann (2005) presented listeners with visual arrays with objects like a trumpet and goat, while they heard words like

"piano." They found that listeners were more likely to fixate trumpet, which was of the same category as "piano" (e.g., musical instrument), compared to distractors (e.g., goat). Hoover and Richardson's findings suggest that in addition to effects based on long-term, semantic knowledge (Huettig & Altmann, 2005), competition in language also stems from short-term, situated location information.

However, Hoover and Richardson (2008)'s findings also raise a number of new questions. First, evidence for location-based competition is mixed. For example, Altmann and Kamide (2009) observed no competition during "the glass" in their study: listeners were no more likely to fixate the glass's (context-irrelevant) initial location on the floor compared to distractors (e.g., bookshelf). Thus, it is unclear how location-based competition impacts online sentence processing.

Second, and more importantly, Hoover and Richardson (2008)'s findings seem to depend more precisely on *object*, rather than *location*, competition. In a second condition in which two different creatures presented their facts, they found no competition effects (i.e., listeners did not fixate the location where the non-queried fact had been presented). Thus, perhaps a more precise way of thinking about their results is that the *creature* was competing with itself, insomuch as it had to be represented at two locations, rather than that the associated *locations* were competing. Indeed, this claim is compatible with recent work by Hindy, Altmann, Kalenik, & Thomspon-Schill (2012): they found that conflict-associated brain regions were activated during sentences that described a state change (e.g., "The squirrel will crack the acorn"). They suggest that event-related changes activate multiple instantiations of an object, and that the representation of the object before the change competes with (and engenders conflict with) the representation of the object after the change.

Current experiments

In the current study, we tested for location-based and object-based competition effects in sentence processing. In two experiments, we addressed a critical difference between Altmann and Kamide (2009) and Hoover and Richardson (2008): the predictability of the context-relevant location information. In Altmann and Kamide, the discourse contexts were highly predictable (e.g., the discourse-final "the glass" could be anticipated based on the verb selectional restrictions of "pour"), and consequently they observed strong anticipatory effects (e.g., listeners fixated context-relevant locations *prior* to the discourse-final noun). By contrast, Hoover and Richardson (2008) queried facts (and their associated locations) at random. Here, we used discourse contexts that were closely related to Altmann and Kamide (2009), but that did not allow for anticipation. Listeners viewed visual arrays with container objects like a bowl, jar, pan, and jug (Figure 1), while they heard sentence pairs like (1a,b).

(1a) The boy will pour the sweetcorn from the bowl into the jar, and he will pour the gravy from the pan into the jug.

(1b) But first/And then, he will taste the sweetcorn.

Two critical referents (e.g., "sweetcorn" and "gravy") were described in (1a), so that listeners could not anticipate the discourse-final noun in (1b) (half of trials re-referred to the first critical referent ["sweetcorn"], and half to the second critical referent ["gravy"]). In Experiment 1, listeners heard both "But first" contexts, which referred to the "source" location (e.g., bowl) of the discourse-final noun (e.g., "sweetcorn"), and "And then" contexts, which referred to its "goal" location (e.g., jar). In Experiment 2, listeners only heard "And then" contexts, which always referred to the "goal" location.

Crucially, our design allowed us to disentangle location-based and object-based competition. In both experiments, we tested for object-based competition (e.g., competition between sweetcorn and itself) by examining fixations to container objects that were related to the discourse-final noun but inconsistent with "But first/And then" (e.g., jar, the goal location of "sweetcorn," following "But first, he will taste the sweetcorn"). On the other hand, we tested for location-based competition (e.g., competition between source/goal locations, which were not linked via an object) by examining fixations to container objects that were consistent with "But first" (source location) or "And then" (goal location) but unrelated to the discourse-final noun (e.g., pan, the source location of "gravy," following "But first, he will taste the sweetcorn").
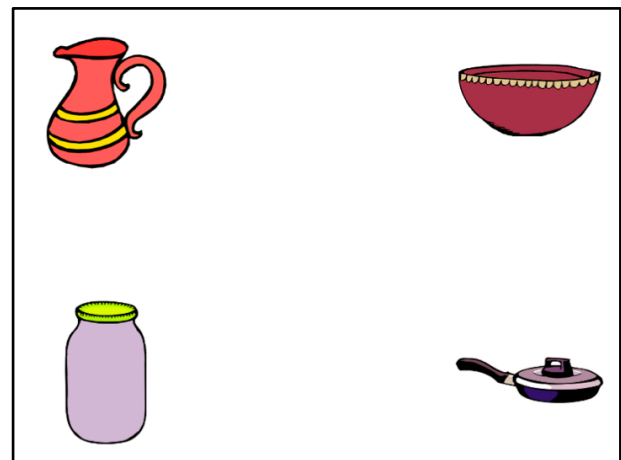
Experiment 1

Figure 1: Example visual array from Experiments 1 and 2.

Methods

Participants Forty-eight individuals from the University of Dundee community participated for course credit or £4.

Materials We constructed 48 sentence pairs like (1a,b). The first sentence described the critical contents of two containers moving either from their initial locations into two new locations (1a), or into two new locations from their initial locations. The second sentence referred to either the
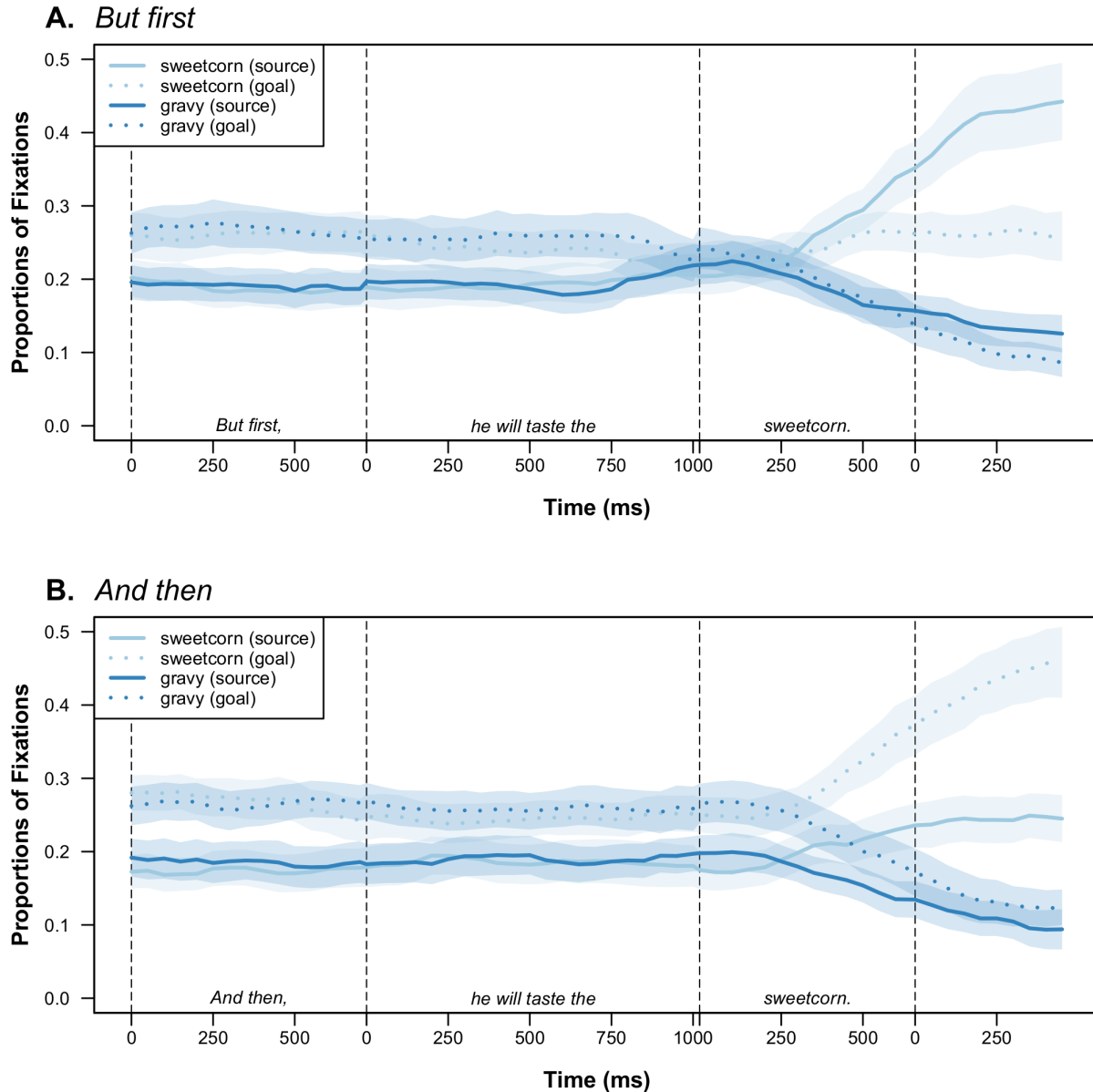
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A. *But first*

B. *And then*

Figure 2: Average (95% CI) proportions of fixations to source and goal locations of the sweetcorn (target referent) and gravy (competitor referent) during "But first…" (A) and "And then…" (B) "he will taste the sweetcorn" in Experiment 1.

first (e.g., "sweetcorn") or second (e.g., "gravy") of the critical contents, and either its initial ("But first") or new ("And then") location (1b). Each item had eight forms, reflecting the crossing of movement description (from-into and into-from), conjunction ("But first" and "And then"), and discourse-final noun ("sweetcorn" and "gravy"), which were rotated across participants (see Appendix A). Visual arrays (Figure 1) depicted the container objects in the four corners of the display, but not their contents.

For each critical referent, the "source" location was the location of the object before the described movement (e.g., sweetcorn: bowl; gravy: pan), and the "goal" location was

the location of the object after the described movement (e.g., sweetcorn: jar; gravy: jug).

Procedure We used an SR Research EyeLink II head-mounted eye tracker, sampling at 500 Hz from one eye (viewing was binocular). The experiments involved a look-and-listen task: participants were instructed to look carefully at the visual arrays, and to listen carefully to the sentences. The onset of the visual stimulus preceded the onset of the spoken stimulus by 1,000 ms. A trial ended 3,000 ms after the offset of the sentence.

The eye tracker was recalibrated after every eighth trial. The experiment began with four practice trials, and included

12 filler trials (which described a single critical object, rather than two). The experiment was approximately 40 minutes in length.

Results

Average proportions of fixations to source and goal locations of the sweetcorn (target referent) and gravy (competitor referent) in the visual array are plotted during "But first, he will taste the sweetcorn" in Figure 2A and during "And then, he will taste the sweetcorn" in Figure 2B. Eye movements were resynchronized at the onset of each of the plotted windows ("But first/And then," "he will taste the," "sweetcorn").

We analyzed eye movements during three time windows: during "But first/And then, he will taste the," at the offset of "sweetcorn," and between sentence offset and 500 ms following sentence offset. These windows directly precede, and follow, the critical discourse-final noun. Average proportions of fixations to each region of interest (ROI) are reported within each time window in Table 1 ("But first…") and Table 2 ("And then…"). We submitted proportions of fixations to planned pairwise comparisons (using paired t-tests).

Table 1: Average (SD) proportions of fixations to source and goal locations of the sweetcorn (target referent) and gravy (competitor referent) during "But first, he will taste the," at the offset of "sweetcorn," and between sentence offset and 500 ms past sentence offset in Experiment 1.

ROI	"But"	"sweetcorn"	+500
sweetcorn (source)	.19 (.07)	.35 (.13)	.41 (.16)
sweetcorn (goal)	.25 (.08)	.26 (.09)	.26 (.10)
gravy (source)	.20 (.06)	.16 (.08)	.14 (.07)
gravy (goal)	.26 (.08)	.14 (.10)	.11 (.07)

Table 2: Average (SD) proportions of fixations to source and goal locations of the sweetcorn (target referent) and gravy (competitor referent) during "And then, he will taste the," at the offset of "sweetcorn," and between sentence offset and 500 ms past sentence offset in Experiment 1.

ROI	"And"	"sweetcorn"	+500
sweetcorn (source)	.18 (.08)	.23 (.10)	.24 (.10)
sweetcorn (goal)	.26 (.08)	.36 (.14)	.42 (.14)
gravy (source)	.19 (.08)	.14 (.08)	.11 (.08)
gravy (goal)	.26 (.08)	.18 (.11)	.14 (.09)

"But first."[1] During "But first, he will taste the," fixations to goal locations were reliably greater than to source locations (p's < .001). However, fixations to sweetcorn and gravy source locations did not differ reliably

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[1] "But first" was ambiguous because it could refer either to the time period before the first or the second movement. Thus, we also performed analyses only on target referents that were mentioned second, for whom the ambiguity did not apply, which showed a similar pattern of results.

(p = .68), and fixations to sweetcorn and gravy goal locations did not differ reliably (p = .60).

At the offset of "sweetcorn," fixations to the (context-relevant) sweetcorn source location were reliably greater than to the sweetcorn goal location (p < .01), gravy source location (p < .001), and gravy goal location (p < .001); fixations to the sweetcorn goal location were reliably greater than to the gravy source location (p < .001) and gravy goal location (p < .001), capturing object competition; and fixations to the gravy source location were not reliably different from the gravy goal location (p = .49).

Finally, during the 500 ms time window following sentence offset, fixations to the sweetcorn source location were reliably greater than to the sweetcorn goal location (p < .001), gravy source location (p < .001), and gravy goal location (p < .001); fixations to the sweetcorn goal location were reliably greater than to the gravy source location (p < .001) and gravy goal location (p < .001), capturing object competition; and fixations to the gravy source location were reliably greater than to the gravy goal location (p < .05), capturing location competition.

"And then." During "And then, he will taste the," fixations to goal locations were reliably greater than to source locations (p's < .001). However, fixations to sweetcorn and gravy source locations did not differ reliably (p = .66), and fixations to sweetcorn and gravy goal locations did not differ reliably (p = .81).

At the offset of "sweetcorn," fixations to the (context-relevant) sweetcorn goal location were reliably greater than to the sweetcorn source location (p < .001), gravy goal location (p < .001), and gravy source location (p < .001); fixations to the sweetcorn source location were reliably greater than to the gravy goal location (p = .05) and gravy source location (p < .001), capturing object competition; and fixations to the gravy goal location were marginally greater than to the gravy source location (p = .08), capturing location competition.

Finally, during the 500 ms time window following sentence offset, fixations to the sweetcorn goal location were reliably greater than to the sweetcorn source location (p < .001), gravy goal location (p < .001), and gravy source location (p < .001); fixations to the sweetcorn source location were reliably greater than to the gravy goal location (p < .001) and gravy source location (p < .001), capturing object competition; and fixations to the gravy goal location were marginally greater than to the gravy source location (p = .08), capturing location competition.

Discussion

During the discourse-final noun, we found that listeners were more likely to fixate context-relevant locations compared to all other locations (e.g., see fixations to the sweetcorn source location in Figure 2A and sweetcorn goal location in Figure 2B). Consistent with Chambers and San Juan (2008) and Altmann and Kamide (2009), these results suggest that listeners rapidly integrate location and sentence
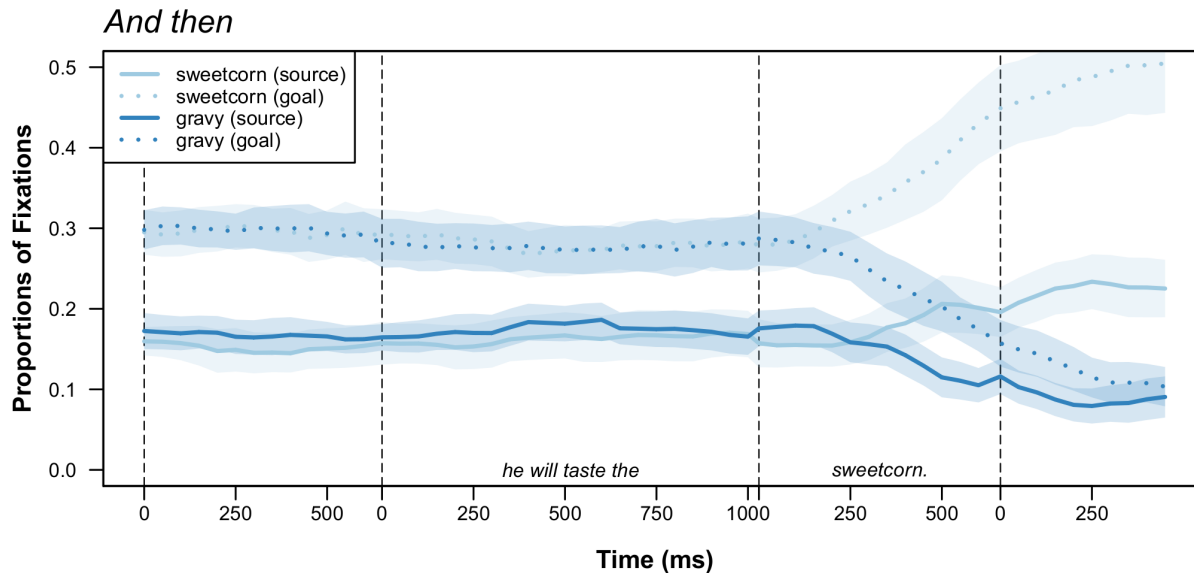
And then

Figure 3: Average (95% CI) proportions of fixations to source and goal locations of the sweetcorn (target referent) and gravy (competitor referent) during "And then, he will taste the sweetcorn" in Experiment 2.

context information. We also found that listeners had a strong bias to fixate goal locations prior to the discourse-final noun for both "And then" (in which goal information was relevant) and "But first" (in which source information was relevant) contexts. This result suggests that listeners may be biased to track "current" location information: indeed, by the end of the second sentence, the "current" location corresponds to the goal location if one assumes that the description of the events in the language, and the events themselves, are closely time locked.

Crucially, we also found evidence for object-based competition: listeners were more likely to fixate locations that were related to the discourse-final noun but inconsistent with "But first/And then" compared to completely unrelated locations (e.g., see fixations to the sweetcorn goal location vs. gravy goal location in Figure 2A and sweetcorn source location vs. gravy source location in Figure 2B). This result suggests that representations of the sweetcorn at context-irrelevant locations were competing with representations of the sweetcorn at context relevant locations.

Finally, we also found evidence for location-based competition that was independent of object-based competition. Following "sweetcorn," listeners were more likely to fixate the gravy source location compared to the gravy goal location with "But first," which was consistent with source locations, although *both* gravy locations were unrelated to "sweetcorn." The opposite pattern was also observed with "And then," although the effect was marginal. These results suggest that source locations were competing, based on abstract information about whether a location was a source or a goal of an event, even though no object was present at two source locations.

Next, we asked: can location-based competition be reduced in a setting in which there is less uncertainty about

which referents are relevant? Thus, in Experiment 2 listeners always heard "And then" contexts, in which goal locations were relevant.

Experiment 2

Methods

Participants Twenty-four individuals from the University of Dundee community participated for course credit or £4.

Materials Materials were identical to Experiment 1, except that the second sentence always referred to the goal location ("And then…").

Procedure The procedure was identical to Experiment 1.

Results

Average proportions of fixations to source and goal locations of the sweetcorn (target referent) and gravy (competitor referent) in the visual array are plotted during "And then, he will taste the sweetcorn" in Figure 3. We performed identical analyses to Experiment 1. Average proportions of fixations by ROI are reported in Table 3.

During "And then, he will taste the," fixations to goal locations were reliably greater than to source locations (p's < .001). However, fixations to sweetcorn and gravy source locations did not differ reliably ($p = .19$), and fixations to sweetcorn and gravy goal locations did not differ reliably ($p = .50$).

At the offset of "sweetcorn," fixations to the (context-relevant) sweetcorn goal location were reliably greater than to the sweetcorn source location ($p < .001$), gravy goal location ($p < .001$), and gravy source location ($p < .001$);

fixations to the sweetcorn source location were reliably greater than to the gravy source location ($p < .001$), capturing object competition, but not the gravy goal location ($p = .21$); and fixations to the gravy goal location were reliably greater than to the gravy source location ($p < .05$), capturing location competition.

Finally, during the 500 ms time window following sentence offset, fixations to the sweetcorn goal location were reliably greater than to the sweetcorn source location ($p < .001$), gravy goal location ($p < .001$), and gravy source location ($p < .001$); fixations to the sweetcorn source location were reliably greater than to the gravy goal location ($p < .001$) and gravy source location ($p < .001$), capturing object competition; and fixations to the gravy goal location were reliably greater than to the gravy source location ($p < .05$), capturing location competition.

Table 3: Average (SD) proportions of fixations to source and goal locations of the sweetcorn (target referent) and gravy (competitor referent) during "And then, he will taste the," at the offset of "sweetcorn," and between sentence offset and 500 ms past sentence offset in Experiment 2.

ROI	"And"	"sweetcorn"	+500
sweetcorn (source)	.16 (.06)	.19 (.07)	.22 (.08)
sweetcorn (goal)	.29 (.06)	.44 (.13)	.48 (.14)
gravy (source)	.17 (.04)	.12 (.05)	.09 (.05)
gravy (goal)	.28 (.05)	.17 (.07)	.13 (.06)

Discussion

The pattern of results in Experiment 2 was similar to Experiment 1. We found that listeners were more likely to fixate the context-relevant sweetcorn goal location compared to all other locations. Similarly, listeners also fixated the sweetcorn source location based on object competition, and the gravy goal location based on location competition. Further, these results suggest that competition does not depend on mentioning both source/goal locations.

General Discussion

In two experiments, we found evidence for both location-based and objects-based competition in sentence processing. While our sentence contexts *modulated* fixations to contextually-relevant locations, they did not fully *inhibit* fixations to contextually-irrelevant "competitor" locations. Consistent with Hoover and Richardson (2008) and Hindy et al. (2012), our results suggest that representations of an object (e.g., sweetcorn) before an event-related change compete with representations of the object after the change. In our case, the crucial event-related change was one of location, and the impact of this competition was reflected in eye movements to context-irrelevant locations. Critically, we also found evidence for object-independent location competition (e.g., between goal locations, although they corresponded to different objects [i.e., sweetcorn vs. gravy]). Taken together, these findings suggest that these

two sources of competition – objects and abstract location information – are separable, and have differential effects on sentence processing.

But our findings also diverged from the results of Altmann and Kamide (2009), who did not observe competition during "the glass" (see the Introduction). As we have suggested, a critical difference between the current experiments and their study was the predictability of the context-relevant location. Indeed, they *did* observe *anticipatory* competition effects: just prior to "the glass" (i.e., during "the wine carefully into"), listeners were reliably more likely to fixate competitor locations than distractors. Taken together, these findings suggest that location information *does* compete, and that this competition can precede the mention of the critical referent.

Appendix A

1a. The boy will pour the sweetcorn from the bowl into the jar, and he will pour the gravy from the pan into the jug.

1b. The boy will pour the sweetcorn into the jar from the bowl, and he will pour the gravy into the jug from the pan.

2a. But first, he will taste the sweetcorn.

2b. And then, he will taste the sweetcorn.

2c. But first, he will taste the gravy.

2d. And then, he will taste the gravy.

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