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Predicting and Priming Thematic Roles: Flexible Use of Verbal and Nonverbal Cues During Relative Clause Comprehension

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Relative-clause sentences (RCs) have been a key test case for psycholinguistic models of comprehension. While object-relative clauses (e.g., ORCs: "The bear that *the horse* . . .") are distinguished from subject-relative clauses (SRCs) after the second noun phrase (NP2; e.g., SRCs: "The bear that *pushed* . . ."), role assignments are often delayed until the embedded verb (e.g., ". . . *pushed* ate the sandwich"). This contrasts with overwhelming evidence of incremental role assignment in other garden-path sentences. The current study investigates how contextual factors modulate reliance on verbal and nonverbal cues. Using a visual-world paradigm, participants saw preceding discourse contexts that highlighted relevant roles within events (e.g., pusher, pushee). Nevertheless, role assignment for ORCs remained delayed until the embedded verb (Experiment 1). However, role assignment for ORCs occurred before the embedded verb when additional linguistic input was provided by an adverb (Experiment 2). Finally, when the likelihood of encountering RCs increased within the experimental context, role immediate assignment for ORCs was observed after NP2 (Experiment 3). Together, these findings suggest that real-time role assignment often prefers verbal cues, but can also flexibly adapt to the statistical properties of the local context.

Keywords: language processing, role assignment, statistical learning, syntactic priming, eye-tracking

Language comprehension involves identifying entities in a discourse and distinguishing between *agents* who performed the action from *patients* who receive the action. Years of psycholinguistic research offer two contrasting patterns of how these thematic roles are assigned during real-time comprehension. On the one hand, role assignment is often highly incremental, generated on a word-by-word basis (Altmann & Kamide, 1999; Levy, 2008; MacDonald, 2013; Trueswell & Tanenhaus, 1994). In classic garden-path sentences, verb biases initially lead to incorrect role assignments (e.g., interpreting "the baby" as the patient in "While Anna dressed the baby . . ."), which then lead to longer reading times when later evidence is encountered (e.g., when the sentence ends with ". . . spit up on the bed"). This demonstrates that in the face of temporary ambiguity, readers incrementally assign thematic roles via currently available information.

On the contrary, empirical research also suggests that role assignment can be delayed, notably in cases of object-relative clause sentences (ORCs) like Example 1b. Here, the first noun phrase (NP1) is the patient of the action (i.e., the one receiving the praise) and the NP2 is the agent (i.e., the one giving the praise). In contrast, these roles reverse in SRCs like Example 1a, where NP1 is now the agent and NP2 is now the patient. It is well documented that ORCs are less frequent than SRCs, leading to longer reading times and less accurate interpretation (Holmes & O'Regan, 1981; King & Just, 1991). Importantly, while the two constructions are distinguished after NP2s for ORCs (e.g., "the reporter" in Example 1b) and embedded verbs for SRCs ("praised" in Example 1a), increased reading times for ORCs are often delayed until the onset of embedded verbs (e.g., "praised" in Example 1b; Gordon, Hendrick, & Johnson, 2001, 2004; Gordon, Hendrick, Johnson, & Lee, 2006; Holmes & O'Regan, 1981; Traxler, Morris, & Seely, 2002; Traxler, Williams, Blozis, & Morris, 2005; Johnson, Lowder, & Gordon, 2011).

Example 1a. SRC: The banker that praised the reporter caused a scandal.

Example 1b. ORC: The banker that the reporter praised caused a scandal.

Thus, unlike classic garden-path sentences, comprehension of ORCs suggests that role assignments are sometimes insensitive to information that disambiguates constructions. This raises questions of *why* comprehenders fail to exploit relevant input as soon as it occurs and how malleable this tendency is across contexts. In the remainder of this introduction, we will describe two prominent frameworks for understanding RC processing and consider how

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these approaches capture distinct comprehension strategies that are adapted for varying circumstances. We will then describe three visual-world eye-tracking experiments that distinguish between contexts where role assignment for ORCs waits for the onset of verbs from ones where it exploits early information immediately.

Two Accounts of RC Processing

Asymmetries in RC comprehension are often understood through two prominent accounts of language processing. Memory-based theories (e.g., dependency locality theory, similarity interference) argue that ORC difficulties reflect the delayed onset of the embedded verb. Since comprehenders initially store arguments in memory, challenges in role assignment can emerge when NP1s and NP2s are retrieved at embedded verbs (e.g., difficulty in Example 1b since "banker" and "reporter" refer to similar occupations; Grodner & Gibson, 2005; Traxler et al., 2002). These challenges decrease when the two NPs share fewer semantic features (e.g., easier in "*The article* that the reporter praised . . ." since "article" is inanimate; Gordon et al., 2001, 2004, 2006; Mak, Vonk, & Schriefers, 2002, 2006) or when pronoun NP2s refer to accessible referents in the discourse (e.g., "The banker that *you* praised . . ."; Mak, Vonk, & Schriefers, 2008; Roland, Mauner, O'Meara, & Yun, 2012; Warren & Gibson, 2002). Manipulations of memory demands in dual-task paradigms lend converging evidence that difficulties with ORCs reflect the retrieval of NPs at the embedded verb (Fedorenko, Woodbury, & Gibson, 2013; Gordon, Hendrick, & Levine, 2002; King & Just, 1991).

In contrast, constraint-based models argue that ORC difficulties reflect its infrequency relative to SRCs (MacDonald & Christiansen, 2002). Much like classic garden-path sentences, comprehenders initially interpret NP1s as agents since most NP1s are agents in English (Bever, 1970; Ferreira, 2003). However, this bias leads to difficulties when NP2 reveals that NP1 is, in fact, a patient in ORCs. Comprehenders are sensitive to this cue in offline tasks. When presented with successive NPs (e.g., "The employee that the . . ."), they consistently completed the sentence so that NP1s are patients/themes and NP2s are agents (e.g., ". . . manager hired") (Gennari & MacDonald, 2008). Moreover, sensitivity to NP2 has also been found in online measures. In eye-tracking while reading, readers make regressive saccades at the onset of NP2 in ORCs, suggesting reanalysis of an agent-first bias (Staub, 2010). Similarly, in a sentence-continuation task, longer reaction times at NP2 onset in ORCs suggest that readers are immediately sensitive to linguistic cues that distinguish this construction from SRCs (Forster, Guerrera, & Elliot, 2009).

While memory-based and constraint-based accounts are often construed as mutually exclusive, they may together explain how role assignment varies across communicative contexts. This flexibility is consistent with noisy-channel models, which describe how certainty modulates the types of cues recruited for comprehension (Gibson, Bergen, & Piantadosi, 2013; Levy, 2008; Levy, Bicknell, Slattery, & Rayner, 2009). For example, implausible passives such as "The girl was kicked by the ball" are often misinterpreted as plausible actives (i.e., "The girl kicked the ball"), particularly when syntactic errors in filler sentences decrease certainty of what was said (e.g., missing/extra function words, scrambled word order; Gibson et al., 2013). Under these circumstances, comprehenders will recruit a canonical agent-first bias (e.g., "The girl" is the kicker) and alter their perception of the input to match the more plausible intended meaning (e.g., omitting "was" and "by" in the passive sentence to create an active one).

Role of Prediction in Real-Time Comprehension

When applied to ORC processing, noisy-channel models predict that comprehenders may delay role assignment until the embedded verb under conditions of uncertainty. However, they may just as well assign roles immediately following NP2 when this disambiguating cue reliably predicts interpretation. The current study investigates three factors that may influence when role assignment relies on canonical verbal cues versus less canonical nonverbal cues.

First, providing a discourse context that highlights two contrasting referents (e.g., agent vs. patient) may facilitate ORC interpretation by distinguishing salient roles (Fox & Thompson, 1990; Gordon & Hendrick, 2005). Since RC comprehension is typically assessed through single-sentence reading tasks (Gordon et al., 2001, 2004, 2006; Holmes & O'Regan, 1981; Johnson et al., 2011; Traxler et al., 2002, 2005), it remains unknown how interpretation unfolds when referents and actions can be predicted prior to the sentence (e.g., bears, pusher, pushee). In non-RC sentences, it is well documented that visual and discourse cues trigger prediction of role assignment. When hearing spoken utterances like "The boy will eat . . .," listeners look to the edible item in a display (e.g., a cake), demonstrating rapid use context to predict likely themes (Altmann & Kamide, 1999; Kamide, Altmann, & Haywood, 2003). Similar evidence has been found in the interpretation of prepositional phrases (Chambers, Tanenhaus, & Magnuson, 2004), determiners (Hanna, Tanenhaus, & Trueswell, 2003), and scalar adjectives (Sedivy, Tanenhaus, Chambers, & Carlson, 1999). Together, they suggest that role assignment in ORCs may be less delayed with additional discourse support.

Second, inserting manner adverbs in ORCs may increase role assignment via nonverbal cues. It has been noted that one reason why longer reading times for ORCs do not emerge at the point of construction disambiguation is because "NP1 that NP2 . . ." phrases sometimes occur in contexts where NP2s are not agents (e.g., "The director that the movie pleased received a prize . . ."). This makes NP2s less reliable cues to ORCs relative to embedded verbs. Importantly, manner adverbs reliably signal upcoming verbs, thus they may offer a more informative basis for role assignment. Consistent with this prediction, differences in reading time across ORCs and SRCs have been found on adverbs that occur before embedded verbs (e.g., "The woman who the boy had *accidentally* . . ."; Warren & Gibson, 2002). Similarly, in developmental studies of verb learning, the presence of manner adverbs in sentences increases attention to event actions (Syrett, Arunachalam, & Waxman, 2014; Syrett & Lidz, 2010). Together, these findings suggest that adverbs may provide a stronger cue to ORCs than NP2s alone.

Finally, increasing the reliability of NP2 as cue to ORCs may also promote earlier role assignment. Prior work demonstrates that expectations for an infrequent construction can vary with its occurrence within a local context (Fine & Jaeger, 2013; Fine, Jaeger, Farmer, & Qian, 2013; Jaeger & Snider, 2013). For example, when lower-frequency RC continuations were presented on 50% of trials (e.g., "The soldiers warned about the dangers conducted the raid"), delays in reading times compared to higher-frequency main-clause continuations (e.g., "The soldiers warned about the dangers *before* the raid) decreased over the 86 trials of the experiment. This suggests that syntactic expectations changed based on the likelihood of encountering the structure within the experiment. Given these findings, we may expect an analogous effect whereby less reliable cues to role assignment for ORCs (NP2s) may be exploited when its occurrence is highly predictive within the current communicative context.

Current Study

Across three experiments, we explore the comprehension strategies that listeners recruit to assign thematic roles for RC sentences. Using a visual-world eye-tracking paradigm, each trial unfolds over two phases. During the familiarization phase, listeners see animations involving three characters participating in two sequential actions. For example, a blue bear pushes a horse, which then the horse pushes a yellow bear (Figure 1). During the test phase, listeners hear an RC sentence identifying one of the characters like Example 2, while their eye movements are measured to a display like Figure 2. After each sentence, listeners select the character that ate the sandwich. Importantly, in order to determine the correct referent, they need to interpret the role of NP1 via linguistic cues in the sentence (e.g., agent in SRCs, patient in ORCs), and make corresponding eye movements to the likely referent (e.g., blue bear in SRCs, yellow bear in ORCs).

Example 2a. SRC: The bear that pushed the horse ate the sandwich.

Example 2b. ORC: The bear that the horse pushed ate the sandwich.

Critically, the familiarization phase allows listeners to preencode many event details, even before hearing the RC sentences in the test phase. This includes the object categories (e.g., bear, horse), target action (e.g., push), and likely roles within the event (e.g., pusher, pushee). Thus, if delays in exploiting nonverbal cues in prior studies (Gordon et al., 2001, 2004, 2006; Holmes & O'Regan, 1981; Johnson et al., 2011; Traxler et al., 2002, 2005) reflect the inaccessibility of events or actors, then providing this context should lead to immediate role assignment following NP2s in ORCs and embedded verbs in SRCs. Nevertheless, if verbal cues are necessary to assign grammatical roles in ORCs, then role assignment will be delayed until after this point, even in a context with strong discourse support.

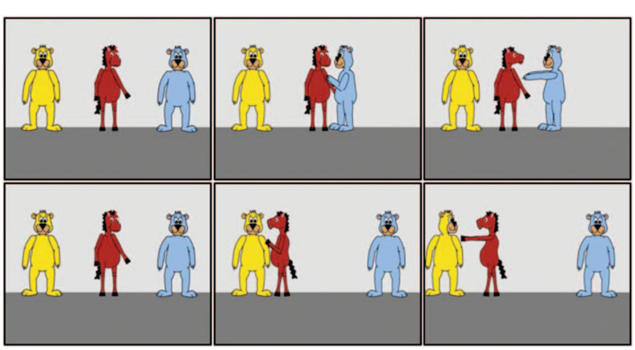

Figure 1. During the familiarization phase, participants viewed an animation of two transitive actions involving three characters. In the top panel, the blue bear (2-referent agent) pushes the horse. In the bottom panel, the horse pushes the yellow bear (2-referent patient). See the online article for the color version of this figure.

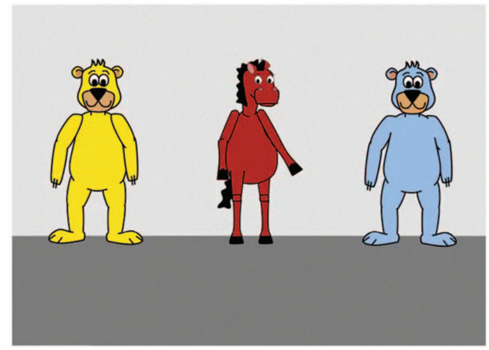

Figure 2. During the test phase, participant heard critical sentences identifying a target character using either a subject-relative clause or object-relative clause. In this sample display, the two-referent characters are the yellow and blue bears. The one-referent character is the horse. See the online article for the color version of this figure.

Experiment 1

Method

Participants. Thirty-two undergraduate students from the University of Maryland were recruited for this study. They received either $5 or course credit for their participation. All participants were native English speakers.

Procedures and materials. Participants sat in front of a computer monitor, and their eye movements were measured to the display using an Eyelink 1000 (2012) desktop eye-tracker. They were told that they would see a series of animations and descriptions of the characters. Their task was to use this description to identify the character who ate the sandwich. Each trial featured two phases. During the familiarization phase, participants saw a brief animation involving three characters (see Figure 1). Two of the characters were from the same category (2-referent: e.g., yellow bear and blue bear). One was from a unique category (1-referent: e.g., horse). Events were transitive actions involving an agent from the 2-referent category acting upon the one-referent character (e.g., *yellow bear* pushes *horse*), who in turn acts upon the other two-referent character (e.g., *horse* pushes *blue bear*). Thus, each event included one agent and one patient from the two-referent category. During the test phase, critical sentences identified a target character using either a SRC or ORC (see Example 2). All sentences finished with the main-clause phrase "ate the sandwich." After each sentence, participants saw still images of the characters side-by-side (see Figure 2) and were asked to click on that target referent using the mouse cursor (i.e., "Who ate the sandwich?"). Once they did this, the trial ended, and the next trial began.

Four versions of each of the 12 critical items were counterbalanced and presented across four between-subjects lists. Critical trials were also randomly presented with 24 additional filler trials. Filler trials served two primary purposes. First, they prevented listeners from predicting the target character prior to the sentence by referring to the one-referent character on one third of the trials (e.g., "The horse was in the middle, then ate the sandwich"). Second, they prevented listeners from predicting the RC construction by using actives (e.g., "The horse pushed the bear, then ate the sandwich"), passives (e.g., "The bear was pushed by the horse, then ate the sandwich"), and resultative sentences (e.g., "The bear fell, then ate the sandwich"). Across all trials, there were 54 unique characters: 18 characters in the one-referent category and 36 characters in the two-referent category. Each character was a participant in one of 18 unique transitive actions (e.g., push, bite, kick, etc.). Each event type was used two times for a total of 36 trials.

Results

During the critical sentence, fixations to the display were coded based on their relation to the two-referent characters. In the familiarization phase, the character that acted on the one-referent character was coded as the agent, and the one that was acted upon by the one-referent character was coded as the patient. Eye movements were analyzed over four regions of interest (Table 1):

1. *Ambiguous region*: this region starts at sentence onset and ends after the onset of the complementizer (e.g., "The bear that . . ."). During this region, SRCs are indistinguishable from ORCs. Thus, we predict equal fixations to the agent and patient characters.

2. *Disambiguation region*: this region starts at the onset of the embedded clause and ends at the onset of the main clause (e.g., "pushed" for SRC and "the horse" for ORC). During this region, SRCs and ORCs are linguistically disambiguated. If this nonverbal cue can be used immediately, then looks during this region will increase to the agent in SRCs and the patient in ORCs. If, however, encountering the embedded verb is necessary to assign roles in ORCs, then we expect looks to the agent and patient to remain equal across constructions.

3. *Spillover region*: this region starts at the onset of the embedded verb in ORCs and the onset of NP2 in SRCs and ends at the onset of the main clause (e.g., "the horse" for SRC and "pushed" for ORC). If verbal cues are necessary for assigning roles for ORCs, then this will be the *earliest* point at which agent/patient looks are distinguished across constructions.

4. *Main clause region*: this region starts at the onset of the main clause and ends at the offset of the sentence. This region is the same in both SRCs and ORCs (e.g., ". . . ate the sandwich"). Both accounts predict that participants will be looking at the appropriate referent.

The onset of each region is shifted by 200 ms to take into account the time that is necessary to program a saccadic eye movement (Allopenna, Magnuson, & Tanenhaus, 1998). Figure 3 illustrates average fixations to the three characters for each condition. At the start of the critical sentence, listeners often fixated on the one-referent character (e.g., horse) since it was located at the center of the display. There was no significant difference in looks to the one-referent character across constructions during any regions of interest (ps > 0.20). Also as expected, looks to the agent increased for SRCs, and looks to the patient for ORCs by sentence offset. To directly compare across conditions, our primary dependent measure calculated agent preference as the natural log ratio of looks to the agent over looks to the patient (see Brown-Schmidt (2012) and Huang, Zheng, Meng, and Snedeker (2013) for similar approaches). Positive values indicated a preference for the likely agent while negative values indicated a preference for the likely patient. These values were analyzed in a linear mixed-effects model using the lme4 software package in R (Bates, 2007). Subjects and items were included as random intercepts. Across all analyses, final models were selected by adding predictors to a null model until the fit of the larger model was not significantly better than the fit of the smaller model (ps > 0.05).

Omnibus analyses confirmed that agent preference varied across constructions over regions of the instruction, leading to a significant interaction between the two, $\chi^2(4, N = 32) = 174.24$, $p < .001$. To pinpoint when agent preference diverged, we separately assessed the effect of construction during each time window. There were no differences in agent preference between SRC and ORC constructions in the ambiguous region (0.16 vs. 0.18, $p > .60$). Figure 4 illustrates that even in the disambiguating region, there was no effect of construction (0.11 vs. 0.08, $p > .20$). Finally, in the spillover region, agent preference was greater for SRCs compared with ORCs, leading to a main effect of construction (0.23

Table 1
Duration of Time Windows (in Milliseconds) in Critical Sentences for Experiments 1–3

		Ambiguous	Disambiguation		Spillover	Main clause
Experiment	SRC ORC	The bear that	(quickly) the horse	pushed (quickly)	the horse pushed	ate the sandwich.
Exp. 1	SRC	909	380		757	1,017
	ORC	918	588		675	1,023
Exp. 2	SRC	882	578	366	730	1,097
	ORC	820	588	592	582	1,076
Exp. 3	SRC	692	477		774	1,121
	ORC	752	613		704	1,134

Note. SRC = subject-relative clause; ORC = object-relative clause; Exp. = Experiment.

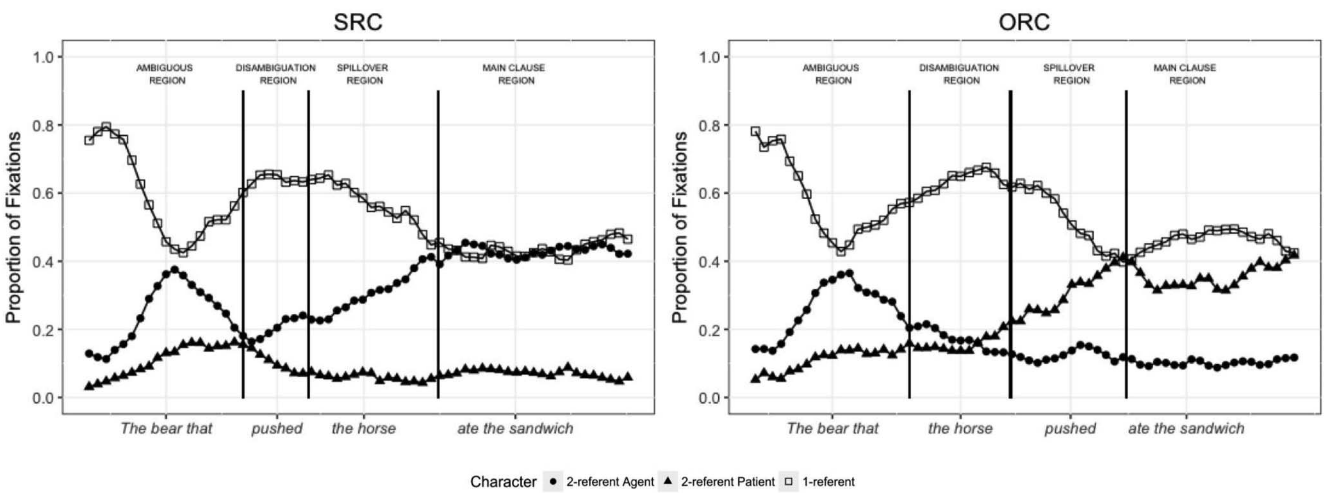

Figure 3. In Experiment 1, the proportion of fixations to each character during regions within the instruction. SRC = subject-relative clause; ORC = object-relative clause.

vs. −0.04; $\chi^2(1, N = 32) = 80.38$, $p < .001$). This effect of construction remained significant during the main clause (0.33 vs. −0.09; $\chi^2(1, N = 32) = 147.65$, $p < .001$). These results suggest that even with prior discourse context, verbal information is strongly preferred for assigning roles in ORCs.

Discussion

Experiment 1 examined the source of delays in real-time role assignment by providing a relevant discourse context prior to hearing RC sentences. If discourse context facilitates use of nonverbal cues, then role assignment for ORCs should occur immediately after NP2 onset. Nevertheless, we found that even when object categories (e.g., bear, horse), target action (e.g., push), and likely roles within the event (e.g., pusher, pushee) were available before sentences, role assignments were delayed beyond the point of linguistic disambiguation. Thus, despite striking differences in tasks and materials, our results are consistent with prior studies showing increased reading times at the embedded verb for ORCs (Gibson, Desmet, Grodner, Watson, & Ko, 2005; Gordon et al., 2001, 2004, 2006; Grodner & Gibson, 2005; Johnson et al., 2011; King & Just, 1991; Reali & Christiansen, 2007; Traxler et al., 2002, 2005; Warren & Gibson, 2002; Wells, Christiansen, Race, Acheson, & MacDonald, 2009).

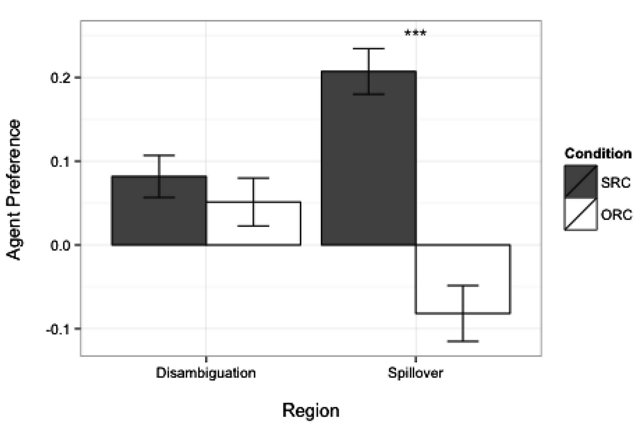

Figure 4. In Experiment 1, agent preference within the disambiguation and spillover regions. Error bars represent standard errors. SRC = subject-relative clause; ORC = object-relative clause. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < 0.001$.

In Experiment 2, we examined whether early role assignment for ORCs emerge when an additional cue reliably signals an upcoming embedded verb. Following prior work (Warren & Gibson, 2002), we inserted manner adverbs between NP2s and embedded verbs for ORCs and complementizers and embedded verbs for SRCs (see Example 3). If role assignment exploits reliable nonverbal cue, then role assignment in ORCs may emerge on the adverb, but *before* the embedded verb. However, if role assignment relies on the verb, then fixations across constructions should again remain indistinguishable until the embedded verb, even when additional time is available.

Example 3a. SRC: The bear that *quickly* pushed the horse ate the sandwich.

Example 3b. ORC: The bear that the horse *quickly* pushed ate the sandwich.

Experiment 2

Method

Participants. Thirty-two undergraduate students from the University of Maryland were recruited for this study. They received either $5 or course credit for their participation. All participants were native English speakers.

Procedures and materials. The procedures and materials were similar to Experiment 1 with one key change: an adverb was embedded into each critical sentence (see Example 3). In SRCs, the adverb was placed in between the complementizer and the verb (e.g., ". . . that *quickly* pushed the horse . . ."). In ORCs, the adverb was placed in between NP2 and the verb (e.g., ". . . that the horse *quickly* pushed . . ."). Across trials, there were 36 unique two- or three-syllable adverbs used (e.g., "rudely," "foolishly," "eagerly"). This manipulation lengthened instructions by an average of 590 ms (see Table 1). Four versions of each of the 12 critical items were counterbalanced and presented across four between-subjects lists. Similar to Experiment 1, 12 filler trials were included to prevent early predictions of (a) the target character, and (b) the construction. To avoid early predictions of trial type, adverbs were also inserted in filler items, prior to the main clause (e.g., "The bear fell then *quickly* ate the sandwich").

Results

Eye-movements in Experiment 2 were analyzed in a linear mixed-effects model with subjects and items included as random intercepts. To isolate possible effects of the adverb, the early disambiguation region corresponded to adverbs for SRCs and NP2s for ORCs, and the late disambiguation region corresponded to embedded verbs for SRCs and adverbs for ORCs. Figure 5 illustrates fixations to the three characters for each condition. As in Experiment 1, looks to agents increased for SRCs while looks to patients increased for ORCs. Unlike Experiment 1, looks to one-referent characters (e.g., horse) varied across conditions. We believe this reflects the inclusion of adverbs in the critical sentences. In the early disambiguation region, listeners sensibly looked more to one-referent characters following NP2s in ORCs (0.62, "the horse") compared to adverbs in SRCs (0.49, "quickly"), $\chi^2(1, N = 32) = 16.1$, $p < .001$. This effect persists into the late disambiguation region (0.62 vs. 0.54, $\chi^2(1, N = 32) = 5.09$, $p < .05$).

As in Experiment 1, our primary analyses focused on agent preference, calculated as the natural log ratio of looks to the agent over looks to the patient. Here, omnibus analyses revealed a significant interaction between construction and region, $\chi^2(5, N = 32) = 153.55$, $p < .001$. Importantly, unlike looks to one-referent characters, there were no differences across conditions during the ambiguous (0.16 vs. 0.16; $p > .80$) and early disambiguation regions (0.09 vs. 0.05; $p > .20$). Critically, Figure 6 illustrates that in the late disambiguation region, agent preference for SRCs was greater than ORCs (0.14 vs. −0.07; $\chi^2(1, N = 32) = 40.70$, $p < .001$). In ORCs, this region corresponds to the onset of the adverb and before the embedded verb. Effects of construction remained significant in the spillover (0.22 vs. −0.14; $\chi^2(1, N = 32) = 110.24$, $p < .001$) and main clause regions (0.25 vs. −0.10; $\chi^2(1, N = 32) = 111.34$, $p < .001$). These results suggest that nonverbal cues were used to assign roles for ORCs.

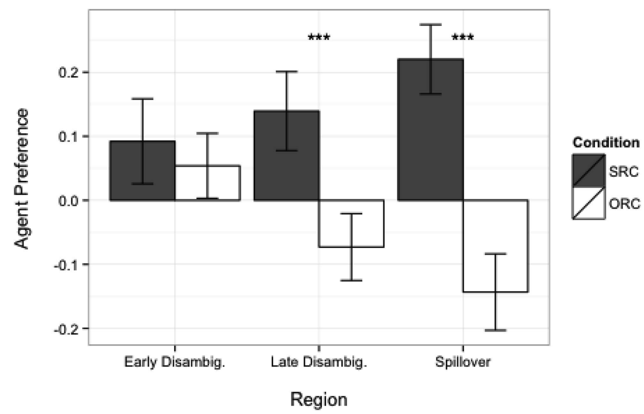

Figure 6. In Experiment 2, agent preference within the early disambiguation, late disambiguation, and spillover regions. Error bars represent standard errors. SRC = subject-relative clause; ORC = object-relative clause. * $p < .05$. ** $p < .01$. *** $p < 0.001$.

Discussion

In Experiment 2, we tested the hypothesis that adverbs would be a more reliable cue to role assignment for ORCs relative to NP2s (e.g., "The bear that the horse quickly pushed . . ."). Similar to Experiment 1, we found no evidence of immediate role assignment at NP2 onset in ORCs. However, unlike Experiment 1, we saw

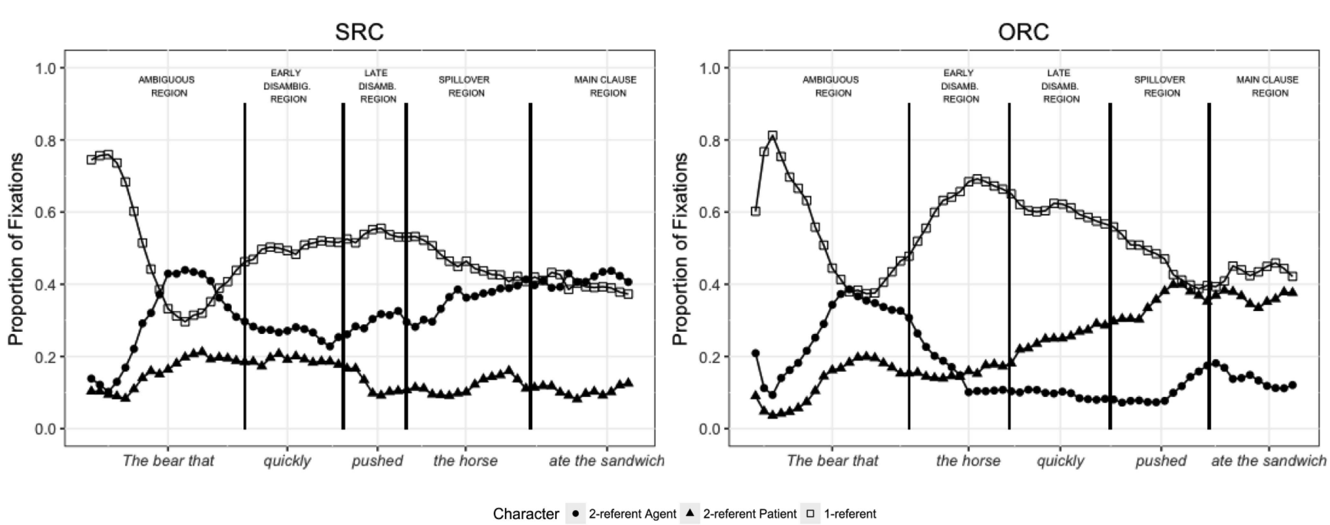

Figure 5. In Experiment 2, the proportion of fixations to each character during regions within the instruction. SRC = subject-relative clause; ORC = object-relative clause.

increased looks to the patient at adverb onset and prior to the embedded verb. This suggests that verbal information, while strongly preferred, may not always be necessary for role assignment. Instead, sufficiently reliable nonverbal cues can also be recruited to assign thematic roles. Interestingly, comparisons of agent preference across constructions provide converging evidence that while adverbs are more reliable than NP2s, they are still less reliable than verbs. Figure 6 illustrates that for SRCs, a significant agent preference emerges during early disambiguation (following adverb onset) and further increases during late disambiguation (following verb onset). Similarly, for ORCs, a significant patient preference emerges during late disambiguation (following adverb onset) and further increases during the spillover region (following verb onset).

In Experiment 3, we examined whether the statistics of the experimental context can lead to *immediate* role assignment after NP2 for ORCs. Consistent with noisy-channel models (Gibson et al., 2013; Levy, 2008; Levy et al., 2009), listeners may recruit this cue when it reliably predicts interpretation within the local context. Prior research demonstrates these effects for other syntactic constructions (Fine & Jaeger, 2013; Fine et al., 2013; Jaeger & Snider, 2013). Thus, we took a similar approach and increased the likelihood of RCs from 33% in Experiments 1 and 2 to 50% in Experiment 3. Moreover, since RCs distinguish salient entities in the discourse (Fox & Thompson, 1990; Gordon & Hendrick, 2005), we increased the likelihood of referring to two-referent characters from 67% in Experiments 1 and 2 to 100% in Experiment 3. If recruiting nonverbal cues to role assignment depends on their reliability within a communicative context, then listeners should now infer NP1s as patients immediately following NP2s in ORCs. If, however, listeners strongly prefer verbal cues to role assignment, then reference restriction may remain delayed until embedded verbs even when earlier cues are reliable in the local context.

Experiment 3

Method

Participants. Thirty-two undergraduate students from the University of Maryland were recruited for this study. They received either $5 or course credit for their participation. All participants were native English speakers.

Procedures. Participants were presented with procedures and materials similar to Experiment 1 with two key changes. First, we decreased the number of filler items from 24 to 12 trials. Thus, while RCs comprised 33% of trials in Experiments 1 and 2, they now accounted for 50% of trials in Experiment 3. All filler trials were active and passive sentences. Second, unlike Experiments 1 and 2, filler trials no longer referred to the one-referent character (e.g., horse). Thus, across all trials, potential targets were always two-referent characters (e.g., blue bear, yellow bear). Importantly, each character had an equal likelihood of being mentioned. The order presentation was randomized across trials such that items from the same construction were not presented consecutively more than twice.

Results

Eye-movements in Experiment 3 were analyzed in a linear mixed-effects model with subjects and items included as random intercepts. Figure 7 illustrates fixations to the three characters over the course of the critical sentence. Once again, looks appropriately increased to agents for SRCs and patients for ORCs. There was no significant difference in looks to one-referent characters (e.g., horse) across constructions, $\chi^2(1, N = 32) = 1.15, p > .20$.

As in Experiment 1, our primary analyses focused on agent preference over four periods of interest during the critical sentences: ambiguous, disambiguation, spillover, and main clause. Omnibus analyses revealed a significant interaction between construction and region, $\chi^2(4, N = 32) = 108.28, p < .001$. In the

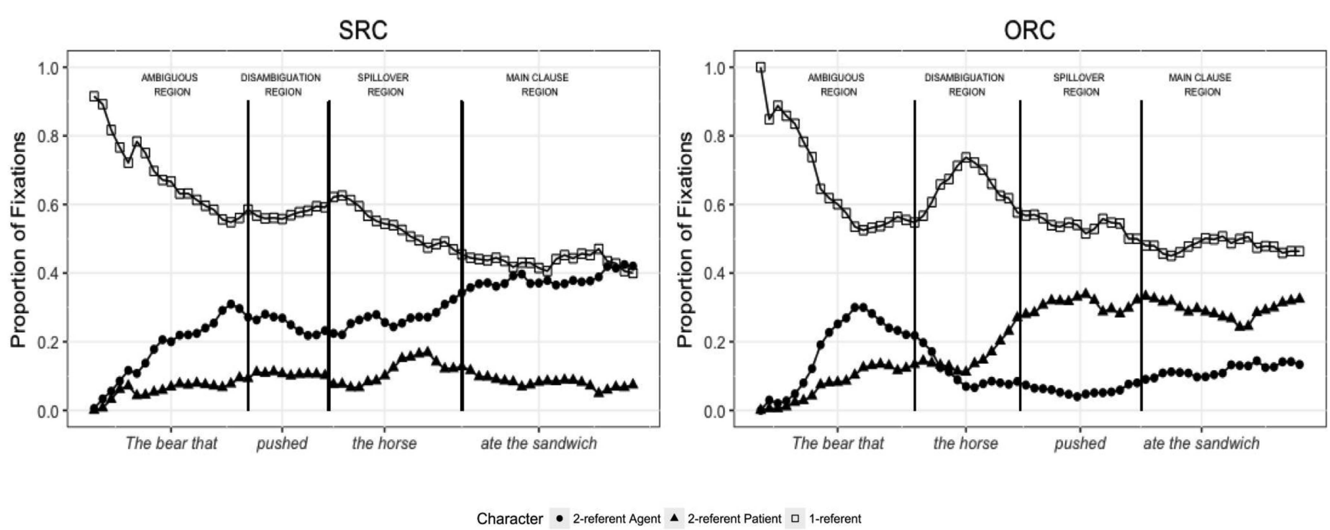

Figure 7. In Experiment 3, the proportion of fixations to each character during regions within the instruction. SRC = subject-relative clause; ORC = object-relative clause.

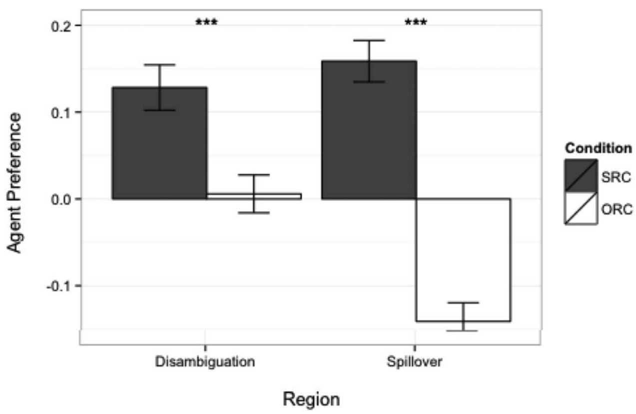

Figure 8. In Experiment 3, agent preference within the disambiguation and spillover regions. Error bars represent standard errors. SRC = subject-relative clause; ORC = object-relative clause. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < 0.001$.

ambiguous region, there was no effect of construction (0.14 vs. 0.12; $p > .40$). Critically, Figure 8 illustrates that unlike Experiments 1 and 2, agent preference for SRCs was significantly greater than in ORCs during the disambiguation region, $\chi^2(1, N = 32) = 18.10$, $p < .001$. The effect of construction continued through the spillover, $\chi^2(1, N = 32) = 92.99$, $p < .001$ and main clause regions, $\chi^2(1, N = 32) = 113.63$, $p < .001$. This suggests that NP2 was immediately used to assign roles for ORCs.

The briefness of the current study illustrates that learning effects can emerge with minimal experience. Over the course of 12 critical trials, listeners shifted from disambiguating ORCs via embedded verbs in Experiment 1 to NP2s in Experiment 3. Statistical comparisons demonstrate an experiment by construction interaction during the disambiguation region, $\chi^2(N = 32) = 6.33$, $p < .05$. While agent preference for SRCs was similar across Experiments 1 and 3 (0.08 vs. 0.14; $t(62) = 1.34$, $p > .10$), agent preference was significantly lower (and correct patient looks higher) in Experiment 3 compared with Experiment 1 (−0.01 vs. 0.08; $t(62) = 2.20$, $p < .05$). This suggests that the local statistics of an experimental context can alter listeners' comprehension strategies and lead to rapid adaptation to previously less informative cues.[1]

Discussion

In Experiment 3, we increased the reliability of NP2 as a cue to assigning roles for ORCs by restricting the range of constructions and referents. Similar to Experiment 2, role assignment was observed before the onset of the embedded verb for ORCs. However, unlike Experiments 1 and 2, this effect occurred immediately following NP2. This suggests that within 12 critical trials, listeners rapidly adjusted to the statistics of the local context and converged on the earliest cue to thematic role assignment. These findings are consistent with noisy-channel models where comprehension strategies exploit reliable cues under conditions of certainty (Gibson et al., 2013; Levy, 2008; Levy et al., 2009). They are also consistent with prior studies showing rapid adaptation to local statistics over an experimental context (Fine & Jaeger, 2013; Fine et al., 2013; Jaeger & Snider, 2013). However, while prior studies focused on decreasing the magnitude of reading difficulty within a region (e.g., shorter time for reading the main clause), our findings demonstrates that comprehender can actively shift the type of linguistic cues used for interpretation (e.g., using NPs rather than embedded verbs).

General Discussion

In three experiments, we investigated various cues to role assignment during real-time comprehension. Even when relevant information about likely referents, roles, and actions was present in the discourse, we found that role assignment remained delayed until embedded verbs for ORCs (Experiment 1). Yet, role assignment can occur before the verb, when the reliability of nonverbal cues increases (Experiment 2) or when a local context restricts likely constructions and referents (Experiment 3). Thus, consistent with prior reading-time studies (Gibson et al., 2005; Gordon et al., 2001, 2004, 2006; Grodner & Gibson, 2005; Johnson et al., 2011; King & Just, 1991; Reali & Christiansen, 2007; Traxler et al., 2002, 2005; Warren & Gibson, 2002; Wells et al., 2009), our results suggest that embedded verbs are very reliable cues to role assignment for ORCs. Yet, consistent with other prior studies (Forster et al., 2009; Staub, 2010), our results suggest that NP2 is used as a cue to role assignment under some circumstances: when contextual properties increase the reliability of NP2s, comprehenders will use this cue to immediately distinguish ORCs from SRCs.

More broadly speaking, our findings contribute to evidence of surprising limits to role assignment during comprehension (Chow & Phillips, 2013; Chow, Smith, Lau, & Phillips, 2016; Kim, Oines, & Sikos, 2016; Kukona, Fang, Aicher, Chen, & Magnuson, 2011). For example, Kukona and colleagues (2011) presented listeners with passive sentences ("Toby was arrested by the policeman") while eye movements were measured to displays featuring agents (e.g., policeman) and patients (e.g., crook). If passives cues (i.e., "arrest*ed by*") are used to identify upcoming NPs, then there should be more agent looks before NP2 onset. Instead, listeners were just as likely to look to patients, suggesting that early expectations may be based on semantic priming (e.g., "policeman" and "crook" are related to "arrest"), rather than structurally derived role assignment. Similarly, Chow and colleagues (Chow, Wang, Lau, & Phillips, 2017) found evidence of slow role assignment via the *ba* particle in Mandarin Chinese. Using an EEG paradigm, readers saw sentences featuring implausible (e.g., suspect *ba* policeman arrest → "The suspect arrested the policeman") and plausible verbs (e.g., policeman *ba* suspect arrest → "The policeman arrested the suspect"). Yet, N400 effects only emerged when additional linguistic material extended the time between arguments and the onset of the implausible verb (e.g., suspect *ba* policeman *zai last week* arrest → "The suspect arrested the policeman last week"). This suggests that structure-based predictions of role

[1] We also analyzed agent preference during Experiment 3 for differences across half and third blocks, as well as with trial number as a fixed-effects factor. However, we did not find a significant Block × Construction interaction ($ps > 0.10$). We believe that this reflects the small number of trials that were used. Prior studies that reveal significant interactions with block typically include 24--36 critical trials (Fine & Jaeger, 2013; Fine et al., 2013; Jaeger & Snider, 2013). Since the current study only included 12 critical trials, statistical comparisons of block effects have far less power to detect significant effects.

assignment are slower compared with role assignment via semantic priming.

Importantly, our findings also demonstrate that listeners adopt strategies to maximize quick and accurate comprehension. Within the local context, increasing the reliability of NP2 for ORCs led to role assignment on this basis. The malleability of real-time comprehension has been demonstrated over multiple experimental sessions (Wells et al., 2009) and within a single session (Fine & Jaeger, 2013; Fine et al., 2013; Jaeger & Snider, 2013). Adjustments of local statistics may increase trial-to-trial priming of linguistic representations and enhance expectations for upcoming input. In this respect, malleable expectations ease the burden inherent to incremental interpretation by allowing listeners to exploit reliable cues with continuous speech. Similar effects are well documented in language production, where speakers often produce syntactic structures that they have recently uttered (Bock, 1986; Bock, Dell, Chang, & Onishi, 2007; Bock & Griffin, 2000; Chang, Dell, & Bock, 2006). Flexible expectations are also found at other levels of representations (Dell, Reed, Adams, & Meyer, 2000; Goldrick & Larson, 2008; Taylor & Houghton, 2005; Warker & Dell, 2006; Warker, Dell, Whalen, & Gereg, 2008). When asked to repeat syllables that conform to unstated phonological rules (e.g., [f] in onset position), speakers' errors overwhelmingly adhere to experiment-specific rules (Dell et al., 2000).

Finally, over the course of language development, malleable strategies for comprehension may also benefit learning since children have to acquire language-specific properties by way of understanding caregiver input. As such, many accounts have argued for an inherent link between the input statistics that inform comprehension and learning (Chang et al., 2006; Huang & Arnold, 2016; MacDonald, 2013). In the production-distribution-comprehension model, both processes are directly supported by speakers' tendency to recruit syntactic structures that reduce the demands of language production (MacDonald, 2013). In the dual-path model, a developing comprehension system predicts upcoming words as sentences unfold and updates linguistic representations when prediction errors occur (Chang et al., 2006). Importantly, error-based learning continues to operate in a mature system, and may support adults' rapid sensitivity to novel syntactic dependencies in artificial learning tasks (Culbertson, Smolensky, & Legendre, 2012; Fedzechkina, Jaeger, & Newport, 2012; Kam & Newport, 2009; Misyak & Christiansen, 2012; Wonnacott, Newport, & Tanenhaus, 2008).

In conclusion, we investigated the conditions under which listeners recruit verbal and nonverbal cues to assign roles for RC sentences. Even when a discourse context provide salient information supporting interpretation (e.g., likely referents, roles, and actions), role assignment for ORCs did not occur until the onset of the embedded verb. This suggests that a supporting discourse alone did not increase the reliability of NP2s for assigning roles in ORCs. Importantly, listeners spontaneously recruited adverbs for role assignment, suggesting that nonverbal cues can be used when they reliably signal upcoming verbs. Moreover, NP2s were adopted when the likelihood of encountering ORCs increased within the current linguistic context. Altogether, our findings suggest that the language processing system flexibly recruits different cues based on how reliably they predict structurally mediate role assignment.

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