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The Influence of Globally Ungrammatical Local Syntactic Constraints on Real-Time Sentence Comprehension: Evidence From the Visual World Paradigm and Reading

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Abstract

We investigated the influence of globally ungrammatical local syntactic constraints on sentence comprehension, as well as the corresponding activation of global and local representations. In Experiment 1, participants viewed visual scenes with objects like a CAROUSEL and MOTORBIKE while hearing sentences with noun phrase (NP) or verb phrase (VP) modifiers like "The girl who likes the man (from London/very much) will ride the carousel." In both cases, "girl" and "ride" predicted CAROUSEL as the direct object; however, the locally coherent combination "the man from London will ride…" in NP cases alternatively predicted MOTORBIKE. During "ride," local constraints, although ruled out by the global constraints, influenced prediction as strongly as global constraints: While MOTORBIKE was fixated less than CAROUSEL in VP cases, it was fixated as much as CAROUSEL in NP cases. In Experiment 2, these local constraints likewise slowed reading times. We discuss implications for theories of sentence processing.

Keywords: Local coherence; Sentence processing; Visual world paradigm; Reading; Eye movements

1. Introduction

Comprehenders anticipate linguistic outcomes. For example, Altmann and Kamide (1999) found that comprehenders hearing "The boy will eat . . .," while viewing a visual display with a CAKE and other inedible distractor objects, fixated the edible CAKE most. These results suggest that comprehenders formed expectations about, and launched anticipatory eye movements to, likely direct objects of the verb. Comprehenders' expectations have also

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been shown to depend on multiple words and constituents. For example, Kamide, Altmann, and Haywood (2003) found that comprehenders hearing "The girl will ride. . .," while viewing a visual display with a CAROUSEL, MOTORBIKE, and other unrideable distractor objects, fixated CAROUSEL more than when hearing sentences such as "The man will ride. . ." or "The girl will taste. . .." This evidence from the visual world paradigm (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995) suggests that comprehenders are able to anticipate outcomes that optimally satisfy various linguistic constraints. However, there is also growing evidence that comprehenders' behaviors are influenced by local syntactic constraints that only indirectly relate to the global sentence constraints. Our goal in the current research was twofold: first, to address whether anticipatory behaviors depend on a globally coherent parsing of linguistic input; and second, to address the relative influence of global and local information on sentence processing.

Local coherence effects suggest that comprehenders' representations are not fully constrained by global sentence constraints. Tabor, Galantucci, and Richardson (2004) found that "locally coherent" syntactic combinations, or parses that cannot be grammatically integrated with the global syntactic constraints of an unfolding utterance, interfered with sentence processing. They compared word-by-word self-paced reading times on sentences like (1a) and (1b):

(1a)	The coach smiled at the player tossed a frisbee by the opposing team
(1b)	The coach smiled at the player thrown a frisbee by the opposing team

In (1a), "tossed" is lexically ambiguous between a passive participle and main verb. Consequently, the underlined string forms a locally coherent active clause, which cannot be grammatically integrated with "The coach smiled at. . .." In contrast, "thrown" in (1b) cannot be a main verb; consequently, there is no corresponding active clause. Tabor et al. (2004) found that reading times on "tossed" in (1a) were reliably slower than on "thrown" in (1b), and that offline grammaticality judgment ratings were lower for (1a) than (1b). Thus, although the locally coherent active clause was ruled out by the global syntactic constraints, comprehenders were nevertheless sensitive to this information. Tabor et al. suggest that local coherence effects provide evidence that the parser is constructing a "felicitous syntactic combination that is inconsistent with the current global parse" (p. 356).

Konieczny, Müller, Hachmann, Schwarzkopf, and Wolfer (2009) found that locally coherent syntactic combinations also influenced comprehenders' semantic interpretations. They compared German sentences like (2a) and (2b):

(2a)	Die Tatsache, dass die Astronautin überrascht den Außerirdischen vom Mars entdeckte, erregte Aufsehen The fact [nom], that the astronaut [nom] surprisedly/surprised the alien [acc] from Mars [dat] discovered, arose sensation [acc] "*The fact that the astronaut surprisedly discovered the alien from mars caused quite a stir*"

(continued)

(2b)	Die Tatsache, dass die Astronautin ungläubig den Außerirdischen vom Mars entdeckte, erregte Aufsehen The fact [nom], that the astronaut [nom] surprisedly the alien [acc] from Mars [dat] discovered, arose sensation [acc] "*The fact that the astronaut surprisedly discovered the alien from mars caused quite a stir*"	

In (2a), "überrascht" is lexically ambiguous between a participle-adverb ("*surprisedly*") and full verb ("*surprises*"). Consequently, the underlined string forms a locally coherent active clause, which cannot be grammatically integrated with "Die Tatsache, dass...." In contrast, "ungläubig" in (2b) cannot be a full verb; consequently, there is no corresponding active clause. Their comprehenders heard sentences like (2a) or (2b) while viewing visual displays with three scenes, which were either consistent with the global syntactic context (an alien discovered by an astronaut), the locally coherent syntactic combination (an alien surprised by an astronaut), or unrelated. Konieczny et al. found that comprehenders fixated the locally coherent scene more in (2a) than (2b), suggesting that they were forming a "felicitous" semantic interpretation based on the locally coherent syntactic combination.

Crucially, local coherence effects differ fundamentally from a closely related phenomenon in the sentence processing literature, "garden path" effects. Garden path effects arise following (disambiguation of) temporary syntactic ambiguities. For example, in "The horse raced past the barn fell," comprehenders show difficulties at "fell" (Bever, 1970). In this case, "raced" is ambiguous but biased toward a main verb interpretation; conversely, "fell" requires a reduced relative interpretation. Like garden path effects, local coherence effects stem from interactions among conflicting parses. However, while garden path effects entail conflicts among multiple (temporarily) *grammatical* analyses, local coherence effects entail conflicts among *grammatical* (global) and *ungrammatical* (local) analyses. Thus, while garden path effects are consistent with the claim that comprehenders are sensitive only to grammatical constraints, local coherence effects suggest that they must also be sensitive to globally ungrammatical locally coherent syntactic constraints.

In summary, the local coherence effects observed by Tabor et al. (2004; see also Bicknell, Levy, & Demberg, 2010) and Konieczny et al. (2009; see also Konieczny, Weldle, Wolfer, Müller, & Baumann, 2010) suggest that local syntactic constraints, although ruled out by global syntactic constraints, are influencing various aspects of sentence processing (e.g., slowing reading times, lowering judgments of grammaticality, and redirecting eye movements toward visual information consistent with local constraints). In this study, our aim was to understand their influence on prediction in sentence processing; in contrast, prior research (e.g., Tabor et al., 2004) has not addressed whether future linguistic inputs are pre-activated based on locally coherent combinations, such as "frisbee" following "the player tossed..." but before the onset of this word (e.g., "frisbee" is not unpredictable following either a relative clause or active clause interpretation, thus their effects cannot be disentangled).

Self-organizing cognitive architectures (e.g., Kukona, Cho, Magnuson, & Tabor, 2014; Tabor et al., 2004) hypothesize that (e.g., linguistic) structure forms from the bottom up. Consequently, these frameworks predict that representations that satisfy local but not global constraints will emerge simultaneously with representations that optimally satisfy global constraints; at the same time, they predict that the latter will tend to inhibit the former in time due to greater support from global constraints. Crucially, these frameworks predict that local coherence effects are a general property of the language system—whether in the case of Tabor et al. (2004) and Konieczny et al. (2009), or even during anticipation, when comprehenders must generate expectations about future linguistic input based on both global and local information. Here, we addressed two questions: First, what are the sources of information that constrain predictive processes and to what extent do anticipatory behaviors rely on locally coherent syntactic combinations; and second, how influential are local syntactic constraints and to what extent do comprehenders activate global and local outcomes? Although both of these questions have significant theoretical implications (elaborated on in the General Discussion), and such effects are explicitly predicted by self-organization, neither has been addressed previously.

We report two eye-tracking experiments. In Experiment 1, our participants heard sentences like (3a) and (3b), while viewing visual displays like Fig. 1:

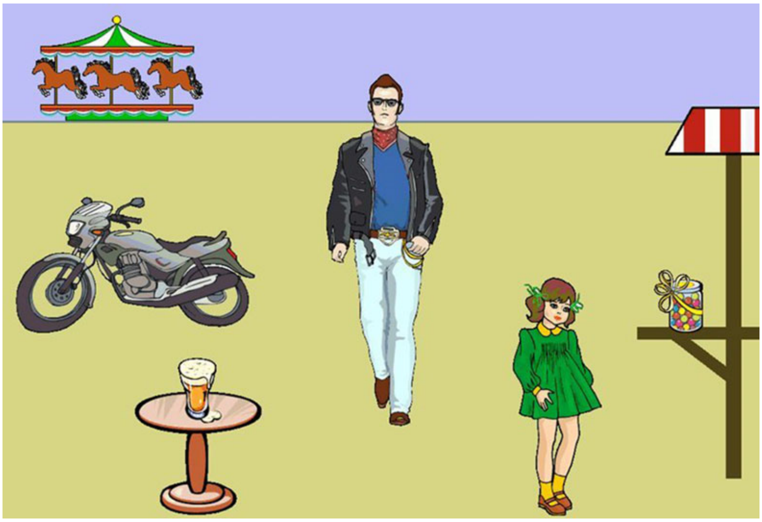

Fig. 1. Example visual display from Experiment 1. Participants heard NP modifier sentences like "The girl who likes the man from London will ride the carousel" or VP modifier sentences like "The girl who likes the man very much will ride the carousel." For these example sentences, the carousel was the Global object, the predictable direct object of the main clause subject and verb (e.g. "The girl ... will ride..."), and the motorbike was the Local object, the predictable direct object of the locally coherent syntactic combination in NP modifier sentences (e.g., "the man... will ride...").

(3a)	*NP modifier (local coherence):* The girl who likes the man from London will ride the carousel
(3b)	*VP modifier (non-local coherence):* The girl who likes the man very much will ride the carousel

Sentence (3a) contains a noun phrase (NP) modifier (e.g., "from London"), whereas (3b) contains a verb phrase (VP) modifier (e.g., "very much"). In (3a), the underlined string forms a locally coherent active clause, which cannot be grammatically integrated with "The girl who likes...." In contrast, "very much" blocks similar noun-verb attachment in (3b). Similar to Kamide et al. (2003), we tested for anticipatory eye movements to direct objects before the direct object noun (i.e., during the main verb).

Crucially, the global sentence constraints in (3a,b) support a very different direct object than the locally coherent syntactic combination in (3a). While "The girl... will ride..." supports CAROUSEL as a direct object, "the man... will ride..." supports MOTORBIKE as a direct object. For these example sentences, we call the CAROUSEL the Global object, or the predictable direct object of the main clause subject and verb, and the MOTORBIKE the Local object, or the predictable direct object of the locally coherent syntactic combination in NP modifier sentences. Critically, we can address the influence of local information on anticipatory behaviors by comparing fixation patterns between sentences: If anticipatory eye movements depend on a globally coherent parsing of linguistic input, we predict no difference between (3a) and (3b); if anticipatory eye movements are influenced by globally ungrammatical local syntactic constraints, we predict more fixations to Local objects in (3a) than (3b).

In addition, we used a design in which Global and Local objects rotated across conditions. For example, "carousel" and "motorbike" (and the animate nouns "girl" and "man") were rotated between sentences (3a,b) and (3c,d), such that in the latter case, MOTORBIKE was now the Global object and CAROUSEL the Local object:

(3c)	*NP modifier (local coherence):* The man who likes the girl from London will ride the motorbike
(3d)	*VP modifier (non-local coherence):* The man who likes the girl very much will ride the motorbike

Thus, we can also address the *relative* influence of global and local information on sentence processing by comparing fixation patterns between objects (i.e., which cannot be accounted for by extraneous object-based properties because objects were used as both Global and Local objects across lists): If globally ungrammatical local syntactic constraints have a weak influence, we expect more fixations to Global than Local objects in (3a,c; although not as big a difference as in 3b,d); if these local syntactic constraints have a strong influence, we expect at least as many fixations to Local objects as Global objects in (3a,c). In this regard, our design addresses a limitation of previous findings: In Tabor et al. (2004), the reading time and grammaticality judgment data did not address the relative activation of globally and locally coherent parses; and in Konieczny et al. (2009, 2010), the visually distinct stimuli made comparisons between (e.g., global vs. local) scenes difficult to interpret.

In addition, our design also addressed a number of concerns that have been raised in the literature. First, our locally coherent syntactic combinations did not involve lexical ambiguities (e.g., "tossed," Tabor et al., 2004; "überrascht," Konieczny et al., 2009). The use of lexical ambiguities in previous studies has raised questions about the extent to which local coherence effects reflect lexical rather than syntactic processes (e.g., see Gibson, 2006). Second, our auditory stimuli were recorded as globally coherent forms. In previous studies, Konieczny and colleagues have recorded locally coherent clauses in isolation and spliced these into sentences; consequently, their sentences may include additional speech cues that conflict with the global syntactic constraints and influence eye movements.

Finally, in Experiment 2, we examined the influence of locally coherent syntactic forms on reading. We used a similar manipulation to Experiment 1 (e.g., 3a and 3b) with an eye-tracking during reading paradigm, which enabled us to relate the current findings directly to prior reading-based research (e.g., Tabor et al., 2004). In contrast to Experiment 1, plausible direct objects of the locally coherent structures (e.g., "motorbike" in 3a) were not made explicit (e.g., they were not visually depicted), addressing a potential limitation of Experiment 1 (i.e., in which their depiction may have encouraged locally coherent interpretations).

Again, self-organization, which assumes bottom-up activation of (e.g., linguistic) structure, predicts pre-activation of representations that satisfy local but not global constraints (in addition to representations that optimally satisfy global constraints) in both experiments.

2. Experiment 1

2.1. Method

2.1.1. Participants

Thirty-two individuals from the University of Dundee community participated for course credit. All participants were native speakers of English with self-reported normal or corrected-to-normal vision. All participants also reported that they did not have a known cognitive, linguistic or perceptual deficit.

2.1.2. Materials

We constructed 24 sentences based on the materials used in Kamide et al. (2003). Each sentence had a NP modifier (e.g., 3a,c) and VP modifier (e.g., 3b,d) form. NP modifier forms contained a locally coherent syntactic combination (e.g., "the man/girl from London will ride…"), whereas VP modifier forms contained an adverb that blocked similar noun-verb attachment (e.g., "the man/girl very much will ride …"). Each sentence was associated with a visual display (see Fig. 1) that depicted both the Global object, which was the predictable direct object of the main clause subject and verb, and the Local object, which was the predictable direct object of the locally coherent syntactic combination in NP modifier sentences. Nevertheless, Global objects were always the direct objects of our sentences, and Local objects were never mentioned. Main clause subjects and direct objects were also rotated (e.g., 3a,b vs. 3c,d), so that critical visual objects (e.g., CAROUSEL, MOTORBIKE) occurred as both the Global and Local objects across forms (allowing for direct comparison of fixations). Scenes also depicted the Global and Local agents (e.g., GIRL, MAN) and two distractors (e.g., SWEETS, BEER) that were, respectively, associated with these agents but did not meet the selectional restrictions of the verbs. All experimental sentences used in Experiment 1 are reported in the Supplementary Material.

A male native speaker of British English recorded sentences in Praat with a sampling rate of 44.1 kHz and 16-bit resolution. The speaker was instructed to produce each form (e.g., 3a–d), with natural prosody. In order to carefully balance the temporal lag between our relative clause nouns and main verbs, we selected one recording of each main verb phrase (e.g., "will ride the…") and spliced this across all forms (nevertheless, locally coherent clauses were never recorded in isolation as a main clause).

Participants heard 12 sentences of each Modifier type (NP and VP) across the experiment. We also constructed 12 filler sentences, in which its direct object was modified by a relative clause (e.g., "The bear irritates the clown that will twirl the hula-hoop"). All our visual displays used clip-art scenes. We created four lists by rotating each sentence across its four forms (e.g., 3a–d) in a Latin Square, and we used a pseudorandom ordering of sentences.

2.1.3. Procedure

We used an SR Research EyeLink II head-mounted eye tracker sampling at 500 Hz from one eye (viewing was binocular). We used a look-and-listen task: Listeners were instructed to look carefully at the visual display while they listened 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 was approximately 20 min in length.

3. Results

Mean (*SE*) proportions of fixations to Global and Local objects and distractors are plotted by Modifier type between auxiliary verb onset and mean sentence offset in Fig. 2A–D. We analyzed eye movements between main verb onset and mean direct object onset (e.g., "ride the_"; duration $M = 890$ ms), where we expected anticipatory effects to emerge. Our dependent measure was the mean proportions of fixations to each object within the analysis window by participants or items; we computed the proportion of samples that an object was fixated within the window on each trial as a continuous value between zero and one, then averaged these values across trials by participants or items (alternatively, trial-level data were not analyzed because trial-level values tended to cluster at zero and one). Means and standard deviations are reported in Table 1.

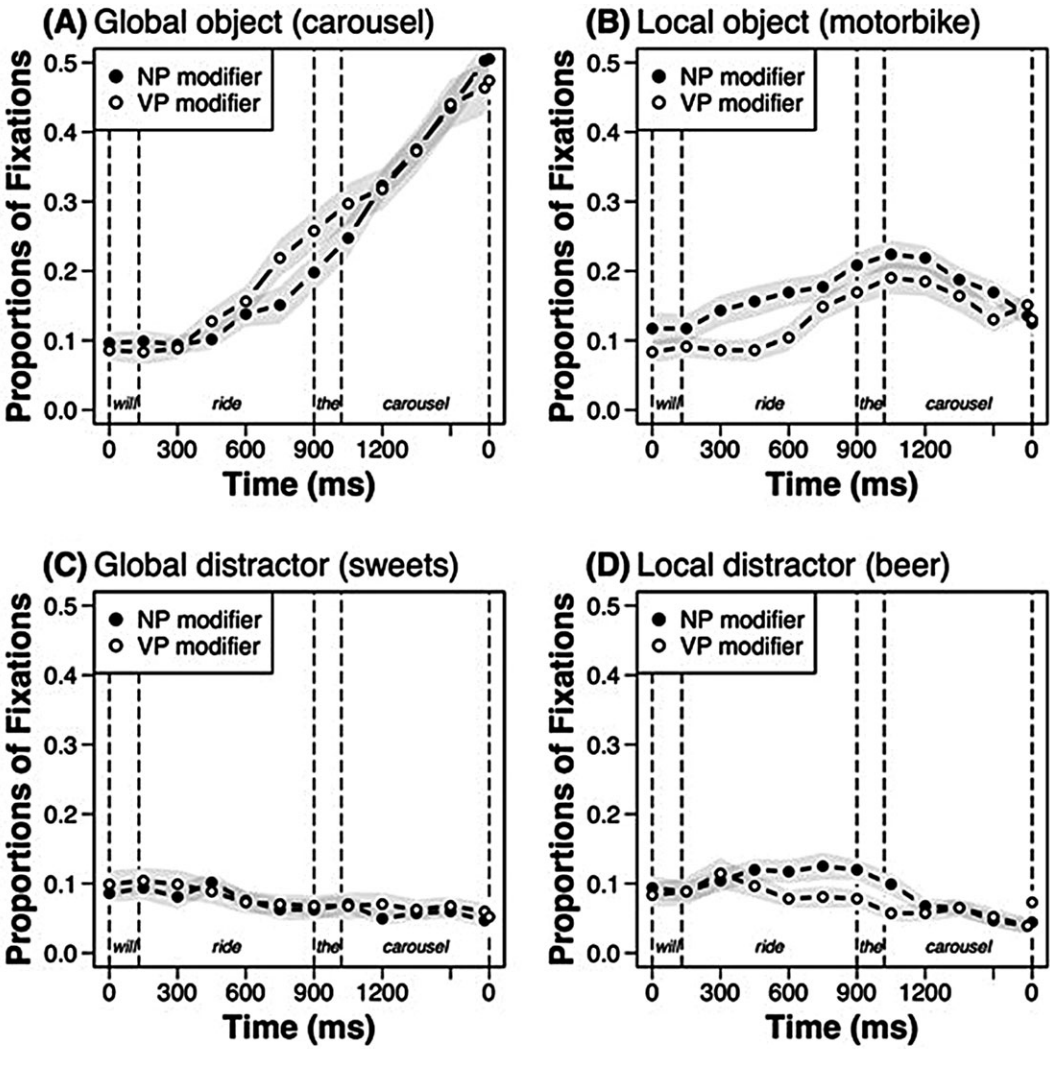

Fig. 2. Experiment 1: Mean (*SE*) proportions of fixations to the Global (A) and Local (B) objects and Global (C) and Local (D) distractors by modifier type between auxiliary verb onset and sentence offset (the objects described are for the example sentences, "The girl who likes the man from London/very much will ride the...")

Our analyses used linear mixed effects models (lme4 in *R*), with deviation-coded fixed effects and random intercepts by participants or items (random slopes were not included because trial-level data was not analyzed). Our models included the following fixed effects: *Modifier type* (NP and VP); *Agent association* (Global and Local); and *Verb consistency* (consistent and inconsistent). While Agent association captured whether an object was associated with the Global (e.g., Global object or distractor) or Local (e.g., Local object or distractor) agent, Verb consistency captured whether an object was consistent

Table 1
Experiment 1: Mean (SD; $\times 10^{-2}$) proportions of trials with fixations to the Global and Local objects and Global and Local distractors between main verb onset and mean noun onset (the objects described are for the example sentences, "The girl who likes the man from London/very much will ride the…")

Object	Agent Association	Verb Consistency	NP Modifier (Local Coherence) *M* (*SD*)	VP Modifier (Non-Local Coherence) *M* (*SD*)
Global object (carousel)	Global	Consistent	13.84 (9.05)	16.30 (9.99)
Local object (motorbike)	Local	Consistent	16.56 (8.76)	11.93 (7.51)
Global distractor (sweets)	Global	Inconsistent	7.88 (6.07)	8.23 (7.91)
Local distractor (beer)	Local	Inconsistent	11.19 (6.17)	8.80 (6.53)

(e.g., Global or Local object) or inconsistent (e.g., Global or Local distractor) with the main verb. We assume that t-values greater than 2.00 are significant at $p < .05$.

First, we compared anticipatory eye movements to the (verb consistent) Global and Local objects with both NP and VP modifiers. We submitted the mean proportions of fixations to Global and Local objects to a model with fixed effects of Agent association (Global object = −0.5 and Local object = 0.5), Modifier type (NP = −0.5 and VP = 0.5) and their interaction. The analysis revealed a reliable interaction of Agent association and Modifier type ($Est._p = 0.07$, $SE = 0.03$, $t_p = 2.54$; $Est._i = 0.07$, $SE = 0.03$, $t_i = 2.60$), and non-reliable effects of Agent association and Modifier type (ts < 1).

In order to unpack this interaction, we submitted the mean proportions of fixations to the (verb consistent) Global and Local objects to four planned pairwise comparisons, with fixed effects of Modifier type or Agent association. The analysis revealed reliably more eye movements to Local objects with NP versus VP modifiers ($Est._p = -0.05$, $SE = 0.02$, $t_p = -2.41$; $Est._i = -0.05$, $SE = 0.02$, $t_i = -2.46$), but no such difference for Global objects ($Est._p = 0.02$, $SE = 0.02$, $t_p = 1.24$; $Est._i = 0.02$, $SE = 0.02$, $t_i = 1.53$). In addition, the analysis revealed reliably more eye movements to Global versus Local objects with VP modifiers ($Est._p = 0.04$, $SE = 0.02$, $t_p = 2.08$; $Est._i = 0.04$, $SE = 0.02$, $t_i = 2.28$), but no such difference for NP modifiers ($Est._p = -0.03$, $SE = 0.02$, $t_p = -1.35$; $Est._i = -0.03$, $SE = 0.02$, $t_i = -1.22$).

A further 2 × 2 analysis of fixations to Local objects with fixed effects of Modifier type (NP = −0.5 and VP = 0.5) and Region ("ride the" = −0.5 and "PP/Adv + will" = 0.5) found a reliable interaction ($Est._p = 0.05$, $SE = 0.02$, $t_p = -2.20$, $Est._i = 0.04$, $SE = 0.02$, $t_i = 2.06$), with no difference between NP and VP modifiers in the pre-"ride the" region (pairwise: $Est._p = -0.00$, $SE = 0.01$, $t_p = -0.05$; $Est._i = -0.00$, $SE = 0.01$, $t_i = -0.11$), suggesting effects emerged from "ride the," not before.

Second, in order to explore whether these patterns were specific to the (verb consistent) Global and Local objects, we also submitted the mean proportions of fixations to the (verb inconsistent) Global and Local distractors to a similar model with fixed effects of Agent association (Global distractor = −0.5 and Local distractor = 0.5), Modifier type, and their interaction. The analysis revealed non-reliable effects of Agent association ($Est._p = -0.02$, $SE = 0.01$, $t_p = -1.85$; $Est._i = -0.02$, $SE = 0.01$, $t_i = -1.93$), Modifier type (ts < 1) and their interaction ($Est._p = 0.03$, $SE = 0.02$, $t_p = 1.30$; $Est._i = 0.03$, $SE = 0.02$, $t_i = 1.45$). Planned pairwise comparisons revealed no difference in eye movements with NP versus VP modifiers for Global (ts < 1) or Local ($Est._p = -0.02$, $SE = 0.01$, $t_p = -1.52$; $Est._i = -0.02$, $SE = 0.01$, $t_i = -1.81$) distractors. However, planned pairwise comparisons revealed reliably more eye movements to Local versus Global distractors with NP modifiers ($Est._p = -0.03$, $SE = 0.01$, $t_p = -2.52$; $Est._i = -0.03$, $SE = 0.02$, $t_i = -2.01$), but no such difference for VP modifiers (ts < 1).

Finally, we tested for anticipatory eye movements to Global objects versus a baseline by comparing Global objects versus distractors with both NP and VP modifiers. However, because the object versus distractor status of a given referent was not rotated across lists (e.g., the carousel was never a Global distractor, and the sweets were never a Global object), these results should be interpreted with caution (e.g., in contrast to the previous analyses); for example, these effects could reflect extraneous object-based properties. We submitted the mean proportions of fixations to Global objects and distractors to a model with fixed effects of Verb consistency (Global object = −0.5 and Global distractor = 0.5), Modifier type, and their interaction. The analysis revealed a reliable effect of Verb consistency ($Est._p = 0.07$, $SE = 0.01$, $t_p = 5.22$; $Est._i = 0.07$, $SE = 0.01$, $t_i = 5.33$; with more eye movements to Global objects than distractors), a non-reliable effect of Modifier type ($Est._p = 0.01$, $SE = 0.01$, $t_p = 1.05$; $Est._p = 0.01$, $SE = 0.01$, $t_p = 1.07$), and a non-reliable interaction (ts < 1). Thus, participants fixated Global objects more than Global distractors irrespective of Modifier type.

Similarly, we tested for anticipatory eye movements to Local objects versus a baseline by comparing Local objects versus Local distractors with both NP and VP modifiers. Again, because the object versus distractor status of a given referent was not rotated across lists (e.g., the motorbike was never a Local distractor, and the beer as never a Local object), these results should be interpreted with caution. We submitted the mean proportions of fixations to Local objects and distractors to a model with fixed effects of Verb consistency (Local object = −0.5 and Local distractor = 0.5), Modifier type and their interaction. The analysis revealed a reliable effect of Verb consistency ($Est._p = -0.04$, $SE = 0.01$, $t_p = -3.65$; $Est._i = -0.04$, $SE = 0.01$, $t_i = -3.13$; with more eye movements to Local objects than distractors), a reliable effect of Modifier type ($Est._p = -0.04$, $SE = 0.01$, $t_p = -3.02$; $Est._i = -0.03$, $SE = 0.01$, $t_i = -2.63$; with more eye movements with NP than VP modifiers), and a non-reliable interaction (ts < 1). Thus, cumulatively fixations were greatest to Local objects with NP modifiers (i.e., vs. the remaining comparisons).

4. Discussion

We found that anticipatory eye movements following the main verb were modulated by local syntactic constraints that only indirectly related to the global syntactic constraints, such that comprehenders formed expectations about, and anticipatorily launched eye movements to, objects that were predicted by globally ungrammatical local constraints. During "ride the_," comprehenders fixated Local objects (e.g., MOTORBIKE) more with NP modifier sentences (e.g., 3a), in which the Local object was a predictable direct object of the locally coherent syntactic combination (e.g., "the man will ride..."), as compared to VP modifier sentences (e.g., 3b), in which an adverb (e.g., "very much") blocked similar (locally coherent) noun-verb attachment. Moreover, while comprehenders fixated Global objects reliably more than Local objects with VP modifier sentences (e.g., consistent with Kamide et al., 2003), they fixated Local objects as much as Global objects with NP modifier sentences. Finally, while effects of the modifier manipulation robustly centered on the Local objects, we did observe some influence on Local distractors as well.

Overall, the current results are consistent with prior evidence for local coherence effects (e.g., Tabor et al., 2014). Three novel aspects of these results also invite further discussion. First, in VP modifier sentences (i.e., which blocked the locally coherent structure), comprehenders' expectations were *dominated* by the globally grammatical parse (i.e., as reflected in fixations to the Global object), consistent with prior research (e.g., Kamide et al., 2003). In contrast, in NP modifier sentences, comprehenders' expectations were not alternatively dominated by the locally coherent parse (i.e., as reflected in fixations to the Local object); rather, the globally grammatical and locally coherent parses were activated to a similar degree, suggesting considerable but not overriding influence of the locally coherent structure.

Second, the reliably greater fixations to Local versus Global distractors with NP modifiers (as well as the reliable main effect of Verb type in the 2×2 analysis of Local objects versus distractors with NP and VP modifiers, although this result should be interpreted cautiously) is consistent with lexically based activation (e.g., via semantic associations) of Local objects *and* distractors by the Local agent *alongside* our local coherence effects. In fact, such lexical effects are consistent with prior research (e.g., Kukona et al., 2014); we return to this issue and related findings in the literature in the General Discussion. Nevertheless, the Local distractor effects were less robust than the Local object effects (e.g., see the non-reliable effects in the 2×2 analysis of Global versus Local distractors with NP and VP modifiers).

Finally, one side effect of our NP versus VP modifier manipulation was that the relative clause noun phrases in NP modifiers were systematically longer than in VP modifiers, both in terms of number of words and duration (e.g., "the man from London" in 3A vs. "the man" in 3B). Thus, one alternative explanation of our results is that NP modifiers may have primed Local objects and distractors more than VP modifiers due to their longer relative clause noun phrases. On the one hand, the simplest version of this explanation is not compatible with our results; rather, Local objects were fixated more than distractors with NP modifiers, suggesting that these objects were not equivalently primed by longer relative clause noun phrases. On the other hand, these results may be compatible with an explanation that assumes sentence-level combinational *interactions* between noun phrases (i.e., whether long vs. short) and verbs; however, such an explanation likewise depends on globally ungrammatical (i.e., NP-verb) interactions. Moreover, such length-related effects may be consistent with self-organization (e.g., see “digging in effects”; Tabor & Hutchins, 2004).

In contrast to Experiment 1, which made use of the visual world paradigm, prior research has largely used reading-based methods to investigate local coherence effects. Potentially, by visually depicting plausible direct objects of our locally coherent structures (e.g., “motorbike” in 3a), Experiment 1 may have encouraged such effects. Thus, Experiment 2 investigated reading-based processing costs of these structures. If readers are forming the globally ungrammatical local structure in (3a), we predict slower reading times on the critical direct object in (3a) than in (3b) because “carousel” is an implausible outcome of the locally coherent structure. Alternatively, if readers are not forming the local structure, we predict no such difference between (3a) and (3b). Consistent with Levy, Bicknell, Slattery, and Rayner (2009), we predicted that local coherence effects would impact both early and later reading time measures.

5. Experiment 2

5.1. Method

5.1.1. Participants

Fifty-five individuals from the University of Dundee community participated for course credit. All participants were native speakers of English with self-reported normal or corrected-to-normal vision. All participants also reported that they did not have a known cognitive, linguistic, or perceptual deficit. None of the participants had taken part in Experiment 1.

5.1.2. Materials

We constructed 24 sentences based on the materials used in Experiment 1. Each sentence had a NP modifier form (e.g., 4a), which contained a locally coherent syntactic combination (e.g., “the old man from Rome will ride...”), and a VP modifier form (e.g., 4b), which contained an adverb that blocked similar noun-verb attachment (e.g., “the old man very much will ride...”). Unlike Experiment 1, main clause subjects and direct objects were not rotated (i.e., given that the study did not use Global/Local visual objects):

(4a) *NP modifier (local coherence):* The little girl who adores the old man from Rome will ride the tricycle in the schoolyard

(4b) *VP modifier (non-local coherence):* The little girl who adores the old man very much will ride the tricycle in the schoolyard

The sentences used in Experiment 1 were modified to suit the reading paradigm in the following ways: (i) a prepositional phrase ending (e.g., “in the schoolyard” in 4a,b) was added to all sentences so that the critical direct object noun (e.g., “the carousel” in 4a,b) was not the final word of the sentence to avoid wrap-up effects on this region; (ii) given there was no prior context (cf. visual contexts in Experiment 1), some agents and objects were changed in such a way that the global attachment clearly described a more plausible outcome than the local attachment (e.g., “the girl” in 3a,b was replaced with “the little girl” in 4a,b); and (iii) the modifiers used in the two conditions (e.g., “from Rome” & “very much”) were matched for their mean number of words (*NP Modifier*—2.29; *VP Modifier*—2.29; $p = 1.00$), mean total number of characters (*NP Modifier*—10.58; *VP Modifier*—11.38; $p = .10$), and mean total lexical decision times (based on the British Lexicon Project: Keuleers, Lacey, Rastle & Brysbaert, 2012; *NP Modifier*—1,314.46 ms; *VP Modifier*—1,274.20 ms; $p = .54$). Due to the high-frequency word “from” in the NP Modifier condition, the mean lexical frequency (per word) was significantly higher with NP than VP modifiers (based on the British National Corpus; *NP Modifier*—697,677; *VP Modifier*—247,237; $p < .05$). However, this frequency difference was not expected to be problematic for our hypotheses because it predicted the opposite reading time pattern (i.e., faster rather than slower reading times in the higher frequency NP modifier condition). All experimental sentences used in Experiment 2 are shown in the Supplementary Material.

Again, the global sentence constraints in (4a,b; “The little girl… will ride…”) support a very different direct object than the locally coherent syntactic combination in (4a; “the old man… will ride…”). If readers only activate a globally coherent parsing of linguistic input, we predict no difference between (4a) and (4b); if readers are influenced by globally ungrammatical local syntactic constraints, we predict greater reading difficulty (e.g., slower reading times) in (4a) than (4b).

Participants read 12 sentences of each Modifier type (NP and VP) across the experiment. We also constructed 12 filler sentences based on the materials used in Experiment 1. We created two lists by rotating each sentence across its two forms (e.g., 4a,b) in a Latin Square, and we used a pseudorandom ordering of sentences.

5.1.3. Procedure

We used an SR Research EyeLink 1,000 head-mounted eye tracker sampling at 1,000 Hz from one eye (viewing was binocular). The eye tracker was used in desktop setup with chin and forehead rests. The background of the screen was light gray and the screen resolution was 1,024 × 768 pixels. Sentences were presented on a single line in the center of the screen in black Courier New 16-point font. To begin each trial, participants fixated a point in the center of the screen. Next, a cross appeared on the left side of the screen where the sentence would begin. When a fixation was detected on the cross, it disappeared and the sentence appeared. Sentences appeared onscreen until participants pressed the spacebar. Twelve of the sentences were followed by a comprehension question (true-false statement)[1] (including four of the fillers); participants pressed “p” for “yes” and “q” for “no,” and did not receive feedback. Comprehension questions focused on the relationship between direct objects and other sentence referents (e.g., “The zookeeper will wash the zebra near the gate” as a false comprehension question following “The zookeeper who dislikes the tourist … will wash the elephant near the enclosure.”).

The eye tracker was recalibrated after every twelfth trial. The experiment began with three practice trials and was approximately 20 min in length.

6. Results

We focused our analyses on four regions: pre-verb (“from Rome/very much”); verb (“will ride”); direct object (“the tricycle); and prepositional phrase (“in the schoolyard”—spill-over region). We analyzed four standard reading time measures (Rayner, 1998): (a) *first fixation duration*, the duration of the first fixation in a region; (b) *gaze duration*, the sum of the durations of all fixations in a region until it was exited; (c) *go-past time*, the sum of the durations of all fixations in a region including re-readings of earlier regions until it was exited to the right; and (d) *total time*, the sum of the durations of all fixations in a region including re-readings. We also analyzed first-pass *regression proportions*, the proportion of trials in which a region was exited to the left rather than right (i.e., to an earlier rather than later region). Fixations less than 80 ms in duration were combined with a previous or subsequent fixation if they were within 11 pixels of each other or were eliminated (3% of data points). Fixations more than 800 ms in duration were also eliminated (<1% of data points). Finally, data points on each reading time measure that were more than 2.5 standard deviations from each participant’s mean were eliminated (3% of data points on average).

We compared eye movements with NP versus VP modifiers by performing separate pairwise comparisons for each region and eye movement measure. We submitted eye movements to linear mixed-effects models with maximal random effects structure (i.e., participants and items random intercepts and slopes; Barr, Levy, Scheepers, & Tily, 2013). Regressions were submitted to mixed logit models with a binomial outcome (regression = 1). Models included fixed effects of Modifier type (NP = −0.5 vs. VP = 0.5) and random intercepts and slopes by participants and items. We report regression coefficients (*Est.*), which estimate the effect size of the NP versus VP modifier comparison in ms for reading time measures. Where models failed to converge, we simplified their random effects structure by removing random correlations (i.e., independent intercepts and slopes). Again, we assume that t-values greater than 2.00 are significant at $p < .05$, and greater than 2.58 are significant at $p < .01$. The most crucial analyses concern the direct object and prepositional phrase regions, where we expected Global and Local direct objects to conflict.

Mean (*SD*) reading times (ms) by measure and proportions of regressions are reported in Table 2 for the four regions, along with the results of the pairwise NP versus VP modifier comparisons (the numbers for the regression measure are proportions).

We observed no reliable effects in the verb region on any measure. In contrast, we observed reliable effects of Modifier type on total times in the direct object region, and on first fixation and go-past times in the prepositional phrase region, such that reading times were reliably faster with VP than NP modifiers in both regions. There was no significant difference between the two modifier types on other measures in these regions. In addition, we observed reliable effects of Modifier type on first fixation and go-past times in the pre-verb region, such that reading times were reliably slower with VP than NP

Table 2
Experiment 2: Mean (SD) reading times (ms) by measure and proportions of regressions for the pre-verb, verb, direct object, and prepositional phrase regions, and results of the pairwise NP versus VP modifier comparisons

Region	Measure	NP Modifier (Local Coherence) *M* (*SD*)	VP Modifier (Non-local Coherence) *M* (*SD*)	NP Versus VP Modifier *Est* (*SE*)	*t*
Pre-Verb (*"from Rome/very much"*)	First	218 (31)	231 (40)	12 (4)	2.85**
	Gaze	437 (109)	476 (131)	42 (27)	1.58
	Go-past	523 (192)	590 (246)	71 (35)	2.00*
	Total	701 (261)	763 (274)	65 (36)	1.80
	Regressions	0.12 (0.11)	0.14 (0.12)	0.33 (0.25)	1.30
Verb (*"will ride"*)	First	214 (35)	216 (30)	2 (4)	0.59
	Gaze	345 (90)	340 (80)	−5 (8)	−0.56
	Go-past	397 (110)	420 (134)	25 (20)	1.24
	Total	544 (176)	532 (163)	−13 (16)	−0.83
	Regressions	0.10 (0.08)	0.14 (0.11)	0.33 (0.27)	1.23
Direct Object (*"the tricycle"*)	First	221 (31)	215 (27)	−6 (3)	−1.79
	Gaze	333 (75)	328 (66)	−5 (8)	−0.58
	Go-past	420 (160)	403 (123)	−11 (17)	−0.67
	Total	539 (162)	504 (144)	−33 (15)	−2.19*
	Regressions	0.18 (0.14)	0.16 (0.14)	−0.14 (0.20)	−0.73
Prepositional Phrase (*"in the schoolyard"*)	First	234 (40)	225 (35)	−10 (4)	−2.21*
	Gaze	543 (158)	536 (158)	−9 (15)	−0.63
	Go-past	1778 (1006)	1621 (840)	−155 (77)	−2.00*
	Total	743 (224)	710 (208)	−32 (19)	−1.72
	Regressions	0.80 (0.22)	0.77 (0.22)	−0.25 (0.21)	−1.17

Note. $^{*}p < .05$; $^{**}p < .01$. *R* formula syntax: "outcome ~ modifier type + (modifier type | participant) + (modifier type | item)."

modifiers on both measures (closely mirroring the higher lexical frequencies in the later in this region).

7. Discussion

We found that total reading times on the direct object and first fixation and go-past reading times on the prepositional phrase were modulated by local syntactic constraints that only indirectly related to the global syntactic constraints. Comprehenders were slower to read the direct object and prepositional phrase ("the tricycle in the schoolyard") with NP modifier sentences (e.g., 4a), in which the direct object of the sentence was not a predictable direct object of the locally coherent syntactic combination (e.g., "the old man from Rome will ride ..."), as compared to VP modifier sentences (e.g., 4b), in which an adverb (e.g., "very much") blocked similar (locally coherent) noun-verb attachment.

Overall, the current results are again consistent with prior evidence for local coherence effects (e.g., Tabor et al., 2014). It is worth noting that post-verb, the NP versus VP modifier difference was only reliable on the total time measure in the direct object region. This result suggests that the locally coherent structure in our NP modifier sentences only impacted later stages of processing (i.e., during the direct object, which likely spilled over onto the subsequent region), which may reflect a number of factors. First, it might be the case that locally coherent structures inherently impact later stages of processing; however, the results of Levy et al. (2009), who observed local coherence effects on first-pass reading times, suggest otherwise. Second, it might reflect our use of (im)plausibility (i.e., a man riding a carousel is implausible in 4a). In our materials, the degree of implausibility might not have been sufficient to trigger immediate "reanalysis" of the locally coherent structure (i.e., de-activation of this structure, given its inability to fit grammatically with the global structure); previous eye-tracking studies have likewise shown that comprehenders use real-world knowledge later in processing (e.g., Garrod & Terras, 2000; Staub & Clifton, 2006).[2] In addition, this later effect during the direct object region appeared to carry over to the subsequent "spill-over" region (i.e., prepositional phrase region), manifesting in both earlier and later measures.

On the other hand, we did not observe a reliable NP versus VP modifier difference in the verb region. This result could indicate that (a) the verb region ("will ride") itself did not trigger "reanalysis" (e.g., in contrast to Experiment 1, where we observed differences between NP versus VP modifiers during the verb); and (b) during the "reanalysis" that was triggered at the later regions, readers did not revisit the verb region, which may have been attached incorrectly (which is likewise supported by our analysis of regressions). As for (a), we speculate that locally coherent analyses (or, at least, of the kind we consider here) may need a further external cue to trigger "reanalysis" (e.g., a conflicting direct object). As for (b), it could be argued that our readers simply did not need to revisit the source of the difficulty when "reanalysis" was triggered and pursued. Such eye movement patterns are not uncommon in the eye-tracking literature (e.g., Ferreira & Clifton, 1986).

Finally, we observed a reliable NP versus VP modifier difference in the pre-verb region. This effect likely depended on two factors: (a) the higher lexical frequencies of NP versus VP modifiers (i.e., "from") (and note that this difference disappeared by the verb); and (b) a clause wrap-up process in VP modifier sentences. Based on the past eye-tracking reading literature, it seems reasonable to consider (a) to be a main cause of the effects in the first fixation duration, and (b) as a main cause of the effects in the go-past time.

In sum, as with Experiment 1, Experiment 2 aimed to investigate the process by which an ungrammatical local coherence is formed during sentence processing. However, unlike the previous experiment, the current reading experiment offered an opportunity to examine (a) whether locally coherent structure is formed even when there is no explicit context to support this structure (other than the subordinate clause of the sentence; cf. the motorbike in the visual context in Experiment 1); and (b) how and when detection of, and recovery from, the local coherent structure is achieved. We observed processing costs in NP modifier sentences that contained locally coherent structures. However, the effects were obtained only in total times during the direct object, which suggests that, once established, a locally coherent structure is maintained for some time and is not "reanalyzed" until a later stage of processing.

8. General discussion

In two experiments, we found that comprehenders' eye movements were modulated by local syntactic constraints that only indirectly related to the global syntactic constraints. In the visual world paradigm, participants fixated Local objects (e.g., MOTORBIKE) more during "ride the_" with NP modifier sentences (e.g., 3a), in which the Local object was a predictable direct object of the locally coherent syntactic combination (e.g., "the man from London will ride…"), as compared to VP modifier sentences (e.g., 3b). Similarly, when reading, comprehenders were slower to read the critical direct object with NP modifier sentences (e.g., 4a), in which the direct object of the sentence was not a plausible direct object of the locally coherent syntactic combination (e.g., "the old man from Rome will ride…"), as compared to VP modifier sentences (e.g., 4b).

The current results are consistent with previous evidence for local coherence effects (e.g., Bicknell et al., 2010; Konieczny et al., 2009, 2010; Tabor et al., 2004), which reveal that locally coherent syntactic combinations interfere with sentence processing in a number of ways, slowing reading times, lowering judgments of grammaticality, and redirecting eye movements. However, the current results also extend this evidence in two key, novel ways. First, our findings in Experiment 1 reveal that locally coherent syntactic combinations influence anticipatory behaviors. In previous research, comprehenders were shown to anticipate outcomes that optimally satisfied the global sentence constraints (e.g., CAROUSEL rather than MOTORBIKE following "The girl will ride…"; Kamide et al., 2003). Kamide et al. (2003) suggest that "the processor uses accruing constraints to compute the likely thematic relationships among the entities already referred to in the linguistic input, among the entities concurrently available in the visual context, and between the two" (p. 152). This account implies that comprehenders are anticipating outcomes that *optimally* satisfy the "accruing constraints." However, our findings reveal that the "accruing constraints" are not being applied sufficiently quickly or strongly to block local syntactic constraints that only indirectly relate to the "accruing constraints." Rather, our comprehenders showed sensitivity to both global *and* local information, which both impacted anticipatory aspects of sentence processing. These anticipatory results build on local coherence effects observed in prior research (e.g., Tabor et al., 2004), which have not addressed whether comprehenders use locally coherent combinations to generate expectations about future linguistic inputs.

Second, our findings in Experiment 1 also reveal that locally coherent syntactic combinations can have a *powerful* influence on sentence processing. Despite the fact that our locally coherent syntactic combinations did not satisfy the global syntactic constraints (i.e., syntactic well-formedness at the sentence level), they were nevertheless as strongly activated, and influenced anticipatory eye movements as strongly, as globally coherent parses. In contrast, many sentence comprehension models, including the classic Garden

Path model (e.g., Frazier, 1987), assume that the parser aims to form syntactically well-formed structures at each moment in time because syntactic well-formedness is an overriding constraint on processing. According to such models, grammatical structures should always override ungrammatical competitors (i.e., ungrammatical structures should not be activated, let alone as strongly as grammatical ones). Thus, to our knowledge this study is the first to provide evidence that these local syntactic constraints can have as strong an influence on sentence processing as global syntactic constraints. In contrast, Konieczny et al.'s (2009) comprehenders overwhelmingly preferred global to local scenes, and their sentences only weakly modulated fixations to local scenes. Thus, not only can globally ungrammatical local syntactic constraints influence anticipatory aspects of sentence processing, but they can also nearly override global constraints. This result is particularly surprising because it suggests a dramatic divergence between "online" and "offline" performance, such that despite the powerful interference from the locally coherent combination, comprehenders nevertheless appeared to be able to recover the meaning of the sentence (e.g., as suggested by eye movements to the Global object by sentence offset in Experiment 1 and hinted by the comprehension question accuracies in Experiment 2).

The current results also build on previous findings showing lexical interference effects in anticipation (e.g., Kukona et al., 2014). For example, comprehenders hearing "The boy will eat the white..." fixated WHITE CAR more than BROWN CAR based on local lexical constraints from the adjective (e.g., "white"; Kukona et al., 2014), and comprehenders hearing "Toby will arrest..." fixated *policeman* more than distractors based on local lexical constraints from the verb (e.g., "arrest"; Kukona, Fang, Aicher, Chen, & Magnuson, 2011; see also "verb effects" in Kamide et al., 2003). In line with these findings, the current results suggest that comprehenders are anticipating outcomes that satisfy local (e.g., lexical or syntactic) constraints that only indirectly relate to the global sentence constraints. Indeed, an alternative explanation of our local coherence effects is that they could reflect lexical (semantic) associations between the Local agent and object (e.g., "man"—"motorbike"), rather than syntactic constraints. However, this predicts a similar pattern in NP and VP conditions, which we did not observe. A variant of this explanation is that NP modifiers could make the Local agent more prominent, thus enhancing lexical effects only in the NP condition (see also the discussion for Experiment 1). However, this predicts that Global and Local distractors should show the same pattern as Global and Local objects, which we did not observe. These results suggest that our local coherence effects depended at least in part on sentence-level, rather than lexical-level, processing. On the other hand, our 2×2 analysis of Modifier type (NP vs. VP) and Verb consistency (Local object vs. Local distractor) did not reveal a reliable interaction of these factors. On balance, these findings suggest that there is likely some "local" activation of Local distractors, but that this activation is modulated by the locally coherent structure, such that these (i.e., lexical and sentential) processes work closely in concert. Moreover, the results of Experiment 2 show closely related differences between NP versus VP modifier conditions, even though plausible direct objects of our locally coherent structures (e.g., "motorbike" in 3a) were not made explicit (e.g., they were not visually depicted) in the reading experiment.

Alternatively, the longer relative clause noun phrases in NP versus VP modifiers may have played a role, potentially "priming" Local objects and distractors more. On the one hand, such an explanation does not require that comprehenders were sensitive to locally coherent combinations. On the other hand, the differential effects observed for Local objects versus distractors with NP modifiers suggest sentence-level combinational *interactions* between noun phrases (i.e., whether long vs. short) and verbs, which here reflected globally ungrammatical (i.e., locally coherent) sentence-level combinations. While the current results do not distinguish these explanations, future research might address this issue by systematically manipulating length-related factors.

These findings complement a variety of findings from the sentence processing literature, including related evidence for retrieval interference. Van Dyke (2007) compared sentences such as (5a) and (5b):

(5a) The worker was surprised that the resident who said that the neighbor was dangerous was complaining about the investigation

(5b) The worker was surprised that the resident who was living near the dangerous neighbor was complaining about the investigation

She found that reading times on "was complaining" were reliably slower in (5b), in which "neighbor," the intervening noun between "was complaining" and its subject (e.g., "resident"), was also a subject (e.g., "the neighbor was…"), than in (5a), in which "neighbor" was a non-subject (e.g., "living near the…neighbor"). Critically, when "neighbor" was a non-subject (i.e., in 5b), it also formed a local coherence (e.g., "the dangerous neighbor was complaining about the investigation"); thus, Van Dyke found less interference from "the neighbor" during "was complaining" in sentences that contained a locally coherent structure. These results at "was complaining" suggest that interference from grammatical overlap was more prominent than potential interference from locally coherent structures, in contrast to the current and prior findings (i.e., showing that locally coherent structures tend to impede processing). However, the pattern reversed during "about the" (i.e., the spillover region) in Van Dyke's study. Together, these findings support a complex interplay between local coherences and (e.g., retrieval) cues to grammatical role.

Again, our findings also differ fundamentally from "garden path" effects. The critical difference between garden path and local coherence effects is that the former is concerned with conflicts between multiple (temporarily) grammatical analyses (e.g., main verb vs. reduced relative attachment in "The horse raced past the barn fell"; Bever, 1970), whereas the latter is concerned with conflicts between grammatical (global) and ungrammatical (local) analyses. Our data suggested that, as in many (legitimate) syntactically ambiguous structures, a domain of semantics of a forthcoming object can be predicted based on a locally coherent structure (Experiment 1). However, unlike temporarily grammatical structures that turn out to be incorrect later in the sentence, our data seemed to indicate that once-established (never grammatical) locally coherent structures can require robust evidence and a relatively long time to initiate "reanalysis" (Experiment 2) (although this is currently a speculation, and we need more evidence based on a wider variety of types of locally coherent structures and reanalysis cues).

Finally, we turn to theoretical implications of the current results. Three very different accounts of local coherence effects, which follow from three very different theoretical perspectives, are prominent in the literature. Again, the first is self-organization (e.g., Konieczny et al., 2009, 2010; Kukona et al., 2014; Tabor et al., 2004). Because self-organization assumes that the formation of (e.g., linguistic) structure is *highly* bottom up (i.e., such that bottom-up interactions tend to occur even where they conflict with top-down constraints), it predicts that representations that satisfy local but not global constraints will emerge simultaneously with representations that optimally satisfy global constraints. Moreover, these emerging representations can entail expectations about linguistic outcomes. Recently, Kukona et al. (2014) implemented a self-organizing artificial neural network framework that modeled anticipatory eye movements in the visual world paradigm. Consistent with human comprehenders, the network showed lexical interference effects, anticipatorily fixating WHITE CAR more than BROWN CAR on hearing "The boy will eat the white...." Simulations based on more complex linguistic input are needed, but it is plausible that the network would show similar sensitivity to globally ungrammatical local *syntactic* constraints, like *lexical* constraints, thus predicting more fixations to Local objects with NP than VP modifier sentences.

The second is the "good enough" approach (e.g., Ferreira & Patson, 2007). The crucial assumption of the "good enough" approach is that language comprehenders employ heuristics and cobble together parses that are merely "good enough" for the task at hand. Underlying this approach is the assumption that the language processor's resources are severely limited (e.g., memory capacity, processing bandwidth, time, etc.). Consequently, the processor commits itself to efficient structural analyses, even though this sometimes produces ungrammatical results. Thus, language comprehenders show local coherence effects because the language system depends on "heuristics that allow it to do the least amount of work necessary to arrive at a meaning for a sentence" (p. 81; Ferreira & Patson, 2007). Specifying the nature of these heuristics is beyond the scope of this study. However, our results offer further evidence for the potential "short sightedness" of the language system (i.e., in that it constructs locally coherent parse structures based on the most recently heard words) and they provide a further challenge to theories that assume that parsing is fully constrained by the global syntactic context.

The third perspective is Bayesian belief update and related noisy-channel approaches (see also Traxler, 2014 for comparisons with "good enough" approaches). The crucial assumption of Bayesian models is that comprehenders distribute probabilities over grammatical parses, and update these probabilities as an utterance unfolds. Models by Hale (2001) and Levy (2008b) assume that comprehenders only distribute probabilities over grammatical parses that are compatible with the global syntactic constraints; thus, they do not predict the effects observed here. However, more recent models (e.g., Gibson, Bergen, & Piantadosi, 2013; Levy, 2008a) assume that linguistic input (i.e., including global information) is transmitted via a "noisy channel" that comprehenders maintain uncertainty about; consequently, they do allow probabilities to be distributed over grammatical parses that are incompatible with the (input-based) global information. Thus, while self-organization assumes that comprehenders activate globally incompatible parses because there is locally coherent, bottom-up support, uncertainty-based Bayesian models assume that comprehenders do so because there is uncertainty about the global information. Indeed, results from Levy et al. (2009) suggest that what comprehenders may be doing in Tabor et al.'s (2004) study is re-interpreting sentences like (1a) as orthographically similar, but more frequent sentences (e.g., "The coach smiled *and* the player tossed the frisbee") as a consequence of uncertainty about the linguistic input (e.g., about whether the word was "at" or "and"). In fact, when Levy et al. replaced "at" in (1a), which has many orthographic neighbors (e.g., "and") that support an alternative grammatical parse, with "toward," which has few such neighbors, the local coherence effects diminished. Similarly, comprehenders in this study may be re-interpreting (3a) as a phonologically similar sentence that supports MOTORBIKE as a direct object (e.g., such as "the man from London *that* will ride...," which is not unlike our fillers). Nevertheless, the particularly *powerful* influence of local information that we observed in this study (e.g., Experiment 1) also provides a new challenge for all three of these perspectives: Our findings suggest that what also needs to be accounted for is the *degree* of interference, which in contexts like those investigated here, was as influential as the global sentence constraints (see also Bicknell & Levy, 2009; for another version of a belief-updating model of Tabor et al., 2004, results).

Finally, it is useful to discuss the "nature" of locally coherent analyses. An extremely crucial yet difficult question is whether locally coherent analyses have the same properties as globally correct analyses. It is possible to hypothesize that locally coherent analyses involve less developed, more tentative structural connections across constituents. As a consequence, such analyses might be predicted to be more easily reanalyzed when counter-evidence becomes available in a sentence. This hypothesis is straightforwardly reflected in the good-enough processing account. Although our current data do not offer a definitive answer to this question, the strong activation of the Local object in Experiment 1 and the lack of early effects in Experiment 2 suggest some "robustness" in locally coherent analyses. Nevertheless, a variety of locally coherent structures should be examined across an array of experimental and linguistic settings to more fully address this question.

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Notes

1. Comprehension questions were included to motivate careful reading, rather than as an outcome variable. (Due to a scripting error, responses were also not recorded for all participants.) Nevertheless, accuracies for participants with recorded

responses were near identical across Modifier types: NP, *M* = 82%, *SD* = 15%; VP, *M* = 82%, *SD* = 25%.

2. Alternatively, we could hypothesize that the longer reading times only reflect anomaly detection, and reanalysis from the locally coherent analysis to the global analysis does not happen. Our data do not rule out this possibility, and such an operation would be in line with a "good enough" processor (as discussed in the General Discussion). Importantly, we take the processing cost at the critical noun in the NP modifier (local coherence) condition as evidence for a locally formed analysis.

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Supplementary Material