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How do people interpret implausible sentences?

Zhenguang G. Cai[1], Nan Zhao[2], Martin J. Pickering[3]

[1] Department of Linguistics and Modern Languages / Brain and Mind Institute, The Chinese University of Hong Kong, Hong Kong SAR

[2] Translation interpreting and intercultural studies, Hong Kong Baptist University, Hong Kong SAR

[3] Department of Psychology, University of Edinburgh, UK

Author notes

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Abstract

People sometimes interpret implausible sentences nonliterally, for example treating *The mother gave the candle the daughter* as meaning the daughter receiving the candle. But how do they do so? We contrasted a *nonliteral syntactic analysis* account, according to which people compute a syntactic analysis appropriate for this nonliteral meaning, with a *nonliteral semantic interpretation account*, according to which they arrive at this meaning via purely semantic processing. The former but not the latter account postulates that people consider not only a literal-but-implausible double-object (DO) analysis in comprehending *The mother gave the candle the daughter*, but also a nonliteral-but-plausible prepositional-object (PO) analysis (i.e., including *to* before *the daughter*). In three structural priming experiments, participants heard a plausible or implausible DO or PO prime sentence. They then answered a comprehension question first or described a picture of a dative event first. In accord with the nonliteral syntactic analysis account, priming was reduced following implausible sentences than following plausible sentences and following nonliterally interpreted implausible sentences than literally interpreted implausible sentences. The results suggest that comprehenders constructed a nonliteral syntactic analysis, which we argue was predicted early in the sentence.

Keywords: implausible sentences; syntactic analysis; semantic interpretation; structural priming; syntactic prediction

Sometimes, you hear something that seems implausible (e.g., *The mother gave the candle the daughter*). It may be that the speaker meant to say something highly surprising. In this case, it is appropriate for you to interpret the implausible utterance literally. But it may also be that the speaker meant to convey the plausible message that the daughter was being given the candle, and that either the speaker had a speech error or you misheard what the speaker said. In such cases, it is appropriate for you to interpret it nonliterally by adopting this plausible interpretation, and in fact you often do so (Gibson, Bergen, & Piantadosi, 2013). But how could you do so?

In this paper, we contrast two accounts of this process. First, comprehenders may consider an alternative syntactic analysis of an implausible sentence that affords a plausible meaning (e.g., revising *The mother gave the candle the daughter* into *The mother gave the candle to the daughter*), but which is inconsistent with the utterance itself. Alternatively, they may infer a plausible meaning based on the semantic relations among words/concepts (e.g., *the daughter* is a more likely recipient than theme of a giving event) without considering an alternative syntactic analysis of the sentence. Below, we report three experiments that used structural priming to test whether people consider an alternative syntactic analysis of an implausible sentence in order to arrive at a plausible (nonliteral) interpretation.

Possible mechanisms for nonliteral interpretation of implausible sentences

Much research on sentence comprehension suggests that people derive the meaning of a sentence on the basis of a syntactic analysis (or parse) of it. For instance, both modular accounts (Ferreira & Clifton, 1986; Rayner, Carlson, & Frazier, 1983) and interactive accounts (Trueswell, Tanenhaus, & Garnsey, 1994; MacDonald, Pearlmutter, & Seidenberg, 1994) assume that comprehenders assign a syntactic analysis to a sentence and read a meaning off that syntactic analysis, though they differ in how a syntactic analysis is computed (e.g., whether it draws on non-syntactic information). They focus on syntactically ambiguous sentences, where there are two (or more) grammatical analyses (e.g., *The spy saw the cop with the revolver*). According to modular accounts, comprehenders abandon the initial analysis if it has an implausible meaning and adopt an alternative analysis with a plausible meaning. According to

interactive accounts, they consider the alternatives in parallel. But both types of account are syntax-based – they assume that the interpretation of a sentence depends on how the sentence is syntactically analyzed, and therefore they consider only literal interpretations.

But how do comprehenders compute a nonliteral but plausible interpretation for an implausible sentence, for example an implausible double-object (DO) dative sentence such as *The mother gave the candle the daughter*? Syntax-based accounts assume comprehenders need a syntactic analysis to reach an interpretation, but in the exemplar sentence there is no syntactic analysis compatible with a plausible interpretation (e.g., the candle being given to the daughter). So comprehenders would have to construct a syntactic analysis that is not (entirely) compatible with the input sentence but affords a plausible interpretation. For instance, in comprehending the exemplar implausible DO sentence, comprehenders may come up with a nonliteral syntactic analysis that affords a plausible interpretation (e.g., at *the daughter*). This could be done by revising the implausible DO sentence into a plausible prepositional-object (PO) sentence such as *The mother gave the candle to the daughter* (e.g., Gibson et al., 2013) or by predicting the PO analysis early on in the sentence and maintaining it despite its incompatibility with subsequent input (e.g., *the daughter*). We will return to these mechanisms of generating a nonliteral syntactic analysis in the general discussion. For now, we refer to this account as the *nonliteral syntactic analysis account* as it stipulates that comprehenders compute a nonliteral syntactic analysis in order to arrive at a plausible interpretation for an implausible sentence.

But other proposals instead assume that people can directly compute a semantic interpretation without having to first construct a syntactic analysis. Kuperberg (2007) argued that people use not only a parsing ("combinatorial") route that builds a syntactic analysis for an utterance and reads an interpretation off that computed syntactic analysis but also a semantic route that computes semantic relations among content words (nouns and verbs) on the basis of semantics and world knowledge. For instance, in *The hearty meal was devouring the kids*, the combinatorial route produces the literal interpretation "meal devouring kids", but the semantic route produces the nonliteral interpretation "kids devouring meal" because it is plausible that kids devour and meals are devoured. Similarly, Bornkessel-Schlesewsky and

Schlesewsky (2008) proposed that "plausibility information is processed in parallel to, but separately from prominence computation/argument linking in this processing stage" (p.66); according to their proposal, comprehenders can assign an agent role to *kids* and a patient role to *meal* based on plausibility considerations independently of syntactic analysis. Thus, according to both Kuperberg, and Bornkessel-Schlesewsky and Schlesewsky, comprehenders can compute a nonliteral plausible interpretation without having to compute a nonliteral syntactic analysis first. We refer to this account as *the nonliteral semantic interpretation account*.

Other researchers assume both nonliteral syntactic analysis and nonliteral semantic interpretation. Ferreira (2003) and Townsend and Bever (2001) proposed that comprehenders use a parsing route (which they call "algorithmic" rather than "combinatorial") together with a "heuristic" route that combines "semantic associations and syntactic habits" (Ferreira, 2003, p. 69). For example, the heuristic route assumes that the first noun is the subject of the sentence, which in turn is the agent of an action, as part of an agent-before-patient strategy. It also draws on semantic preferences, so that an agent-like entity is more likely to be treated as an agent than a patient-like entity. If the heuristic route builds up some form of syntactic analysis (however crude), then these accounts are presumably compatible with nonliteral syntactic analysis, but the mechanism involved in the "syntactic habits" needs to be specified, as do the conditions under which this heuristic route uses these habits rather than just semantic associations. We will return to this possibility in the general discussion, when we consider the revised account proposed by Karimi and Ferreira (2016).

For now, we contrast the nonliteral syntactic analysis account versus the nonliteral semantic interpretation account in the interpretation of implausible sentences. Critically, according to the nonliteral semantic interpretation account, comprehenders directly arrive at a nonliteral plausible interpretation without having to construct a syntactic analysis that is compatible with this interpretation; according to the nonliteral syntactic analysis account, they construct such a syntactic analysis. Thus, the nonliteral syntactic analysis account, but not the nonliteral semantic interpretation account, predicts that assigning a

plausible interpretation to an implausible sentence involves the construction of a nonliteral syntactic analysis compatible with that plausible interpretation.

Interpretation of implausible sentences

Some studies have used offline methods to address how people interpret implausible sentences. Ferreira (2003) had participants listen to a plausible or implausible sentence (e.g., *The cheese was eaten by the mouse* or *The mouse was eaten by the cheese*). In a role-naming task, participants were asked to name the agent or the patient in the sentence, from which Ferreira judged whether a sentence was literally interpreted (e.g., when *the cheese* was identified as the agent or *the mouse* as the patient) or nonliterally interpreted (e.g., when *the mouse* was identified as the agent or *the cheese* as the patient). Participants more often nonliterally interpreted implausible passives than implausible actives, a finding Ferreira interpreted as support for the use of heuristics (plausibility and the agent-before-patient strategy) alongside "algorithmic" parsing (for more research on the use of heuristics, see Christianson et al., 2001; Christianson et al., 2006; Lim & Christianson, 2013). Participants also more often nonliterally interpreted an implausible subject-cleft sentence (e.g., *It was the cheese that ate the mouse*) than a plausible one (e.g., *It was the mouse that ate the cheese*), despite the two sentences having the same syntactic structure, which suggests the use of a plausibility heuristic to derive an interpretation. Ferreira's plausibility heuristic is thus consistent with the nonliteral semantic interpretation account (though her agent-before-patient heuristic is consistent with the nonliteral syntactic analysis account).

Also using a role-naming task, Bader and Meng (2018) replicated Ferreira's (2003) observations, using German implausible sentences, by showing that German speakers' role naming was sensitive to plausibility and other heuristics. For instance, compared to "canonical" active sentences with subject-before-object word order, people more often nonliterally interpreted "non-canonical" object-before-subject active sentences (by using an agent-before-patient heuristic) and passive sentences (by using a heuristic treating a nominative noun as the agent). But when they asked participants to judge whether a sentence was plausible or not (instead of recalling a thematic role), the differences among the three types

of sentences disappeared. Bader and Meng argued that people use "algorithmic" parsing to interpret both canonical and non-canonical sentences, and the greater frequency of nonliteral interpretations (as reflected in role naming) for non-canonical than canonical sentences in both their study and in Ferreira (2003) probably reflects post-interpretation decision processes (see also Cutter, Paterson, & Filik, 2022; Paolazzi et al., 2019). In particular, they argued that mistakes in role naming arise from a memory representation of a sentence that includes both its meaning and a representation encoding the words, their linear order, and the syntactic structure of the sentence. To determine the agent or patient of a sentence, they retrieve, from the memory representation, cues that encode typical properties of agents or patients, for example whether they are animate or not, their linear position, their phrasal category, or their syntactic function. For example, an early noun phrase will tend to be interpreted as the agent, whether or not this is (literally) correct.

Meng and Bader (2021) largely replicated the results of Bader and Meng (2018) in a study in which participants judged a sentence's plausibility and performed role naming for the same sentences. Moreover, participants sometimes made role naming mistakes when they had correctly assessed sentence plausibility, thus suggesting that the role naming task is not closely related to the parsing process. In addition, findings were identical regardless of the order in which participants performed role naming and plausibility judgements. It is therefore unclear whether Ferreira's (2003) results provide evidence for the use of heuristics in parsing, and specifically for a semantic route to interpretation.

Instead of using a metalinguistic task such as role naming or plausibility judgment, Gibson et al. (2013) had participants read plausible and implausible sentences involving a variety of structures – for example, an implausible DO dative sentence such as *The mother gave the candle the daughter* or an implausible PO dative sentence such as *The mother gave the daughter to the candle*. Participants then answered a comprehension question (e.g., *Did the daughter receive someone/something?*). Gibson et al. observed that implausible DO sentences were more often nonliterally interpreted than implausible PO sentences. They argued that the likelihood of nonliteral interpretations reflects people's belief about the likelihood of an otherwise plausible sentence being corrupted (via misproduction or misperception) into

an implausible sentence (see also Gibson et al., 2017; Frazier & Clifton, 2015; Levy et al., 2009). In particular, Gibson et al. (2013) assumed that it is more likely for a plausible PO sentence (e.g., *The mother gave the candle to the daughter*) to be corrupted into an implausible DO (*The mother gave the candle the daughter* via the omission of *to*) than for a plausible DO sentence (e.g., *The mother gave the daughter the candle*) to be corrupted into an implausible PO sentence (e.g., *The mother gave the daughter the candle* via the insertion of *to*) (see General Discussion). Therefore, people are more likely to nonliterally interpret implausible DO than PO sentences. In sum, Gibson et al. argued that people syntactically edit implausible sentences into a form that they assume was intended by the speaker, in a manner consistent with the nonliteral syntactic analysis account.

However, the experiments in Gibson et al. (2013) are concerned with interpretation and do not provide direct evidence about how comprehenders syntactically analyze implausible sentences. The same is the case for Ferreira (2003) and subsequent studies such as Meng and Bader (2018). We therefore turn to structural priming, a method that is concerned with syntactic analysis itself.

Structural priming following implausible sentences

Structural priming is the tendency for people to repeat a syntactic structure (e.g., active vs. passive, or DO vs. PO dative) they have produced or comprehended (see Pickering & Ferreira, 2008, for a review). For instance, people are more likely to describe a dative event using a DO dative (e.g., *The girl is handing the man a paintbrush*) instead of a PO dative (e.g., *The girl is handing a paintbrush to the man*) after hearing a DO sentence (e.g., *The rock star sold the undercover agent some drugs*) than after hearing a PO sentence (e.g., *The rock star sold some drugs to the undercover agent*) (Bock, 1986). Such priming is not primarily due to lexical or prosodic repetition from the prime sentence and instead reflects the abstract syntactic structure of the prime sentence (Bock, 1989; Bock & Loebell, 1990). There is evidence for structural priming arising from non-syntactic representations, for example relating to the order of thematic roles (Chang et al., 2003) or their prominence (Bernolet et al., 2009), but there are considerably larger syntactic effects (e.g., Cai et al., 2012), as discussed by Branigan and Pickering (2017).

For the above reasons, structural priming has been extensively used to map out syntactic representations and processes underlying sentence comprehension (Arai et al., 2007; Cai et al., 2013, 2015; Ivanova et al. 2012; van Gompel et al., 2006; Ziegler, Snedeker, & Wittenberg, 2018; see Branigan & Pickering, 2017). For instance, Cai et al. (2015) used structural priming to show that, when comprehending Chinese sentences with a missing object argument that can be contextually recovered (e.g., in *Niuzai mai-le yiben shu hou song-gei-le shuishou naben shu*, lit, "cowboy bought a book then gave sailor", the word *naben shu* "the book" is omitted after *shuishou* "sailor"), people reconstruct the missing argument in syntax. In the study, participants listened to a missing-argument or full-form dative (DO or PO) sentence and then described a dative event. They were structurally primed to the same extent following a missing-argument DO sentence and its full-form counterpart, and also to the same extent following a missing-argument PO sentence and its full-form counterpart, suggesting that they syntactically reconstructed the missing argument (e.g., *naben shu*, "the book") in comprehension.

Structural priming has also been used to examine how people understand anomalous sentences. For instance, Ivanova et al. (2017) presented comprehenders with sentences missing a verb (i.e., the verb was replaced with hash-marks or was simply excluded). Participants tended to repeat the structure of the prime sentence as though a verb had been included. Ivanova et al. interpreted the results as suggesting that comprehenders determine the most likely syntactic structure for the sentence, which then serves as the source of priming. Such an account is of course compatible with the nonliteral syntactic analysis account, though what comprehenders do with ungrammatical sentences does not necessarily reflect what they do with implausible-but-grammatical sentences.

In addition, Van Gompel et al. (2006) had participants read a prime sentence such as *While the man was visiting(,) the children who were surprisingly pleasant and funny played outside* and then complete a written target preamble, here *When the doctor was visiti*…. When the prime sentence did not contain a comma, it was temporally ambiguous at *visiting the children* and reading-time data suggested that participants often initially interpreted the verb *visiting* transitively, but after revision interpreted it intransitively. Importantly, participants completed the target preamble transitively (e.g., *When the doctor*

was visiting the patient) to a greater extent following an ambiguous prime (i.e., without a common) than following an unambiguous one (i.e., with the comma). Thus, people sometimes retain a record of an abandoned transitive analysis.

Structural priming is thus ideal for investigating how people arrive at a plausible nonliteral interpretation for an implausible sentence. Let us consider the implausible DO sentence *The mother gave the candle the daughter* and the implausible PO sentence *The mother gave the daughter to the candle*. Under the nonliteral semantic interpretation account, people can use plausibility information to arrive at the plausible nonliteral interpretation in which the candle is the patient and the daughter is the recipient, without any revision to the structure of the implausible sentences. Given that structural priming mainly reflects syntactic representations, the nonliteral semantic interpretation account predicts that priming effects should be similar following an implausible prime and a plausible prime. In contrast, under the nonliteral syntactic analysis account, people revise an implausible DO sentence into a PO sentence and an implausible PO sentence into a DO sentence in order to arrive at a plausible nonliteral interpretation. As the DO and PO representations would be both available in an implausible dative prime, but not in a plausible prime, the nonliteral syntactic analysis account predicts reduced structural priming following an implausible prime than a plausible prime. In addition, this account predicts that people adopt the nonliteral analysis to a greater extent (and hence there should be a further reduction in structural priming) if they turn out to nonliterally than literally interpret an implausible sentence.

In a highly relevant study, Christianson, Luke, and Ferreira (2010) had participants listen to an active or passive prime sentence that was either plausible (e.g., *The angler caught the fish* or *The fish was caught by the angler*) or implausible (e.g., *The fish caught the angler* or *The angler was caught by the fish*) and then decided whether a noun phrase acted as the agent/patient of the described event (e.g., *catcher = fish?*). Participants then described a drawing of a transitive event (e.g., a boy pinching a girl). Plausible primes led to standard structural priming, with more passive picture descriptions following a plausible passive prime sentence compared to an active prime sentence. In contrast, implausible primes led to reversed structural priming, with more passive picture descriptions following an implausible active

prime sentence compared to a passive prime sentence. These results appear to support the nonliteral syntactic analysis account, though the question remains how they relate to the account proposed in Ferreira (2003). We will return to this issue in the General Discussion.

The current study

Below, we report three structural priming experiments (with the third experiment preregistered) that investigated how comprehenders compute a nonliteral interpretation (via nonliteral syntactic analysis or nonliteral semantic interpretation). In Experiment 1, participants first heard a DO/PO prime sentence that was either plausible (e.g., *The mother gave the daughter the candle* / *The mother gave the candle to the daughter*) or implausible (e.g., *The mother gave the candle the daughter* / *The mother gave the daughter to the candle*); they then answered a comprehension question about the sentence (e.g., *Did the daughter receive something/someone?*), according to which we could determine whether they literally or nonliterally interpreted the prime sentence. Finally, they described a dative event (e.g., of a pirate handing a boxer a cake); we were interested in how the prime sentence affected the syntax (DO or PO) of the picture description. The prime and target used different verbs. Experiment 2 was the same as Experiment 1 except that we swapped the order of the question answering and picture description (i.e., participants described a picture and then answered a comprehension question), as the act of answering the question might affect structural priming. Experiment 3 was preregistered to replicate the findings in the first two experiments, using the same verb between prime and target to increase experimental power (Mahowald et al., 2016); it also manipulated task order (question answering or picture description first) as a within-participant variable.

We assume that people construct a literal syntactic analysis of the actual input (e.g., a DO analysis for *The mother gave the candle the daughter*). Now consider trials on which they interpret the input nonliterally – presumably something that happens more often on implausible than plausible trials. According to the nonliteral syntactic analysis account, they also compute a nonliteral syntactic analysis associated with this interpretation (here, a PO analysis for *The mother gave the candle to the daughter*).

Thus, structural priming should be reduced following an implausible prime compared to a plausible prime (and priming might even be reversed). According to the nonliteral semantic interpretation account, they do not compute such a nonliteral syntactic analysis, and so structural priming should be equivalent following a plausible prime and an implausible prime.

We also examined whether nonliterally interpreting an implausible sentence shows greater evidence of the nonliteral syntactic analysis than literally interpreting it. According to the nonliteral syntactic analysis account, comprehenders derive the nonliteral interpretation (as well as the literal interpretation) from an associated syntactic analysis. Thus, comprehenders should engage nonliteral syntactic analysis to a greater extent if they adopt a nonliteral than a literal interpretation (as reflected in the question answering). Therefore, this account predicts a further reduction in structural priming when an implausible prime is nonliterally versus literally interpreted. But according to the nonliteral semantic interpretation account, comprehenders compute a nonliteral interpretation independently of syntactic analysis. Therefore, this account predicts no further reduction in structural priming when an implausible prime is nonliterally versus literally interpreted.

Experiment 1

We presented to participants auditory prime sentences that were either plausible or implausible and had either a DO structure or PO structure, in a 2 (plausibility) x 2 (structure) design (see Table 1), with both factors manipulated within participants and within items. Then participants answered a comprehension question about the prime sentence (which gave the indication whether the prime sentence was literally or nonliterally interpreted) and finally described a depicted dative event (see Figure 1). The prime sentence and the target picture always had different verbs.

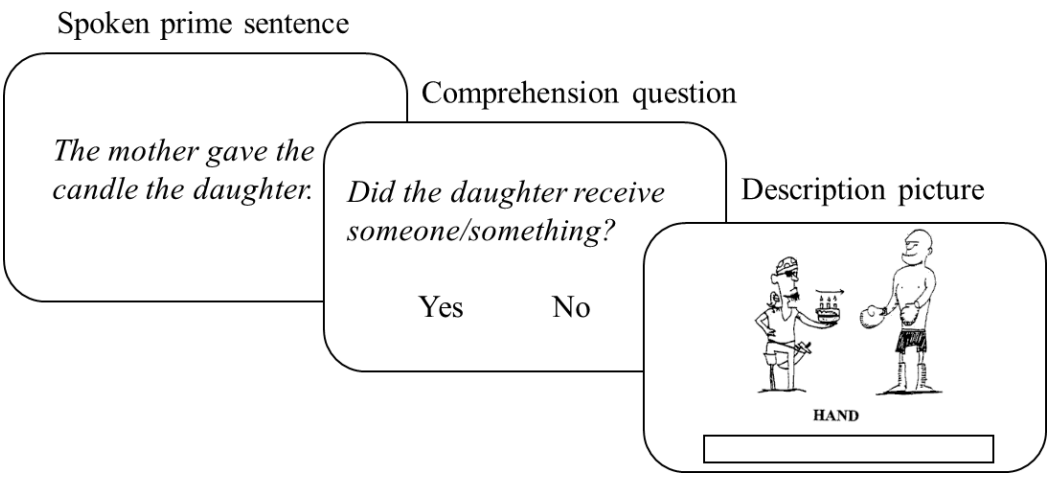
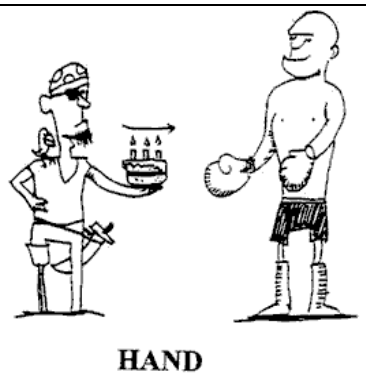


Figure 1. Trial structure in Experiment 1 (the order of the comprehension question and description picture was reversed in Experiment 2).

According to the nonliteral semantic interpretation account, people arrive at a nonliteral interpretation via semantic associations. If so, structural priming should be solely driven by the structure of the perceived sentence. Therefore, plausibility should not affect priming: Participants should be structurally primed in picture descriptions equivalently following plausible primes and implausible primes. In addition, we examined whether the way implausible primes are interpreted (literally or nonliterally) impacts structural priming. If people compute a nonliteral interpretation via nonliteral semantic interpretation, we should expect similar priming following literally and nonliterally interpreted implausible primes.

Table 1. Design and exemplar materials in Experiment 1.

Prime	Prime sentence	Question: *Did the daughter receive something/someone?*	Target picture
Plausible DO	*The mother gave the daughter the candle.*	*Yes* → literal interpretation	
		No → nonliteral interpretation	
Plausible PO	*The mother gave the candle to the daughter.*	*Yes* → literal interpretation	
		No → nonliteral interpretation	
Implausible DO	*The mother gave the candle the daughter.*	*Yes* → nonliteral interpretation	
		No → literal interpretation	
Implausible PO	*The mother gave the daughter to the candle.*	*Yes* → nonliteral interpretation	
		No → literal interpretation	

In contrast, according to the nonliteral syntactic analysis account, people entertain a nonliteral analysis of the perceived implausible sentence to arrive at a plausible nonliteral interpretation (i.e., the PO analysis for an implausible DO sentence and the DO analysis for an implausible PO sentence). If so, structural priming should be reduced following implausible compared to plausible primes. In addition, nonliterally interpreted implausible primes should lead to a further reduction in structural priming compared to literally interpreted implausible primes.

Methods

Participants. We recruited 96 participants from the online crowdsourcing platform Prolific (https://prolific.co/). The choice of the participant sample size (i.e., 96 participants each having 20 target trials, hence 1920 target trials before data exclusion) was based on Christianson et al. (2010), who had a similar 2 x 2 design and who tested 75 participants with 24 experimental items (hence 1800 trials before data exclusion). All participants were registered native speakers of American English, aged 18-50 and residing in USA at the time of testing; they reported no hearing impairment or reading difficulty. They were rewarded with £7. We excluded 8 participants who produced unusable responses (i.e. "other"

responses; see *Coding*) in the target trials more than 50% of the time. Thus, the data from 88 participants (mean age = 31.3, range = 20 – 50; 59 females) contributed to final data analyses.

Materials. There were 20 target items and 60 filler items. All the materials, together with experimental data and analytical scripts, are available on Open Science Framework (https://osf.io/g26u3/). Each item consisted of a spoken prime sentence, a written comprehension question, and a gray-scale line-drawing description picture. For target items, the prime sentence was a dative sentence (including plausible and implausible versions; see Table 1); for filler items, the prime sentence was a plausible non-dative sentence of various structures (e.g., *A legislator lied to the consultant about a new bill*). All the primes (spoken by a male native speaker of American English) and their associated comprehension questions were taken from Gibson et al. (2017). Comprehension questions were yes/no written questions (visually presented); in particular, they were always in the form *Did X receive something/someone?* for the dative sentences (where X stands for human event participant in the prime sentence). In the target items, the *yes* answer indicated a literal interpretation and the *no* answer indicated a nonliteral interpretation in half of the items (and the reverse in the other half); in the filler items, the correct answer was *yes* in half of the items and *no* in the other half. Description pictures were gray-scale line-drawings taken from Branigan et al. (2000). The pictures depicted an event (a ditransitive one in a target item and a transitive one in a filler item) that was unrelated to the meaning of the corresponding prime sentence. All the description pictures had a verb printed below the line-drawing indicating the action (e.g., *PASS, KICK*); the verb always differed from the main verb in the prime sentence. For description pictures depicting dative events, the agent was on the left and the recipient on the right for half of the items and the positioning was reversed for the other half (with the theme always in the middle). For description pictures depicting transitive events, the left-right positioning of the agent and the patient was also counterbalanced across items.

Procedure. The experiment was run on Qualtrics (www.qualtrics.com). After giving their consent, participants first had a practice session of two trials before continuing to the main experiment. On a trial (see Figure 1), they first heard a spoken (prime) sentence, which they could click to listen again

if needed. They then clicked → and answered a yes/no question about the spoken sentence by choosing *Yes* or *No*. Then they clicked → to view a picture and described it by typing a sentence into a textbox below the picture. Participants were told that the provided verb indicated the action in the depicted event and they should use it in their description. The experiment lasted for about 40 min on average and participants were allowed 120 min to complete the experiment.

Coding. For the comprehension questions, responses were coded as indicating either a literal or nonliteral interpretation of the sentence. For picture descriptions, a description was coded as a DO response if it was grammatical and contained a noun phrase denoting the agent, followed by the provided verb, a noun phrase denoting the recipient, and a noun phrase denoting the theme (e.g., *The cowboy handed the boxer a cake*). A response was coded as a PO response if it was grammatical and contained a noun phrase denoting the agent, followed by the provided verb, a noun phrase denoting the theme, and a prepositional phrase denoting the recipient (e.g., *The cowboy handed a cake to the boxer*). All other responses were coded as "other", including but not limited to responses where the provided verb was not used or the description was not complete/accurate (e.g., *The cowboy gave the boxer a cake* or *The cowboy had a cake to show the boxer*).

Results

We used logit mixed effects (LME) modelling on trial-level data (e.g., literal vs. nonliteral interpretation; DO vs. PO responses), adopting the maximal random effect structure justified by the data (via forward model comparison and with an alpha level of .20 instead of .05; Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017). We first report how people interpreted the prime sentences (according to the answer to the comprehension questions) and then how picture descriptions were structurally primed by the prime sentences.

Interpretation of prime sentences

Table 2 presents the results of prime sentence interpretation. We first used LME modelling to analyze how sentences were interpreted (literal vs. nonliteral interpretation; literal interpretation being the baseline level), with plausibility (plausible = -0.5, implausible = 0.5) and structure (PO = -0.5, DO = 0.5) as interacting predictors. Overall, participants had fewer nonliteral than literal interpretations (21% vs. 79%, as reflected in the significant intercept; β = -2.39, *SE* = 0.24, *z* = -9.93, $p < .001$). There was a significant main effect of plausibility (β = 2.88, *SE* = 0.46, *z* = 6.28, $p < .001$), with more nonliteral interpretations for implausible than plausible sentences (35% vs. 7%). There was a significant main effect of structure (β = 1.56, *SE* = 0.28, *z* = 5.52, $p < .001$), with DO sentences being more likely to be nonliterally interpreted than PO sentences (29% vs. 13%). The interaction of the two factors did not reach significance (β = 0.03, *SE* = 0.50, *z* = 0.70, $p = .945$). When we looked at the interpretation of implausible sentences alone, there were more nonliteral interpretations for DO than PO implausible sentences (β = 1.77, *SE* = 0.27, *z* = 6.43, $p < .001$; see Table 2).

Table 2: Interpretation of prime sentences as a function of plausibility and structure in Experiment 1.

Plausibility	Prime	Interpretation		Prop of nonliteral interpretation
		Literal	Nonliteral	
Plausible	DO	396	44	0.10
	PO	421	19	0.04
Implausible	DO	231	209	0.48
	PO	341	99	0.23

Structural priming on picture descriptions

We next analyzed how prime sentences structurally primed subsequent picture descriptions (see Table 3). Out of the 1760 picture descriptions (88 participants, each with 20 descriptions), 153 (9%) were "other" responses and were thus removed from further analyses. We conducted three LME analyses to address three questions regarding how picture descriptions were structurally primed.

First, we asked how the syntactic structure and the plausibility of the prime sentence impacted subsequent picture descriptions. To address this, we carried out an LME analysis on DO vs. PO responses (with PO as the reference level), with structure (PO = -0.5, DO = 0.5) and plausibility (plausible = -0.5, implausible = 0.5) as interacting predictors. There were in general fewer DO than PO responses (24% vs. 76%), as reflected in the intercept (β = -1.84, *SE* = 0.29, *z* = -6.33, $p < .001$). There was a significant main effect of structure (β = 0.75, *SE* = 0.15, *z* = 5.08, $p < .001$), revealing a standard structural priming effect, with more DO responses following a DO prime sentence than a PO prime sentence (28% vs. 20%). There was no significant effect of plausibility (β = -0.10, *SE* = 0.19, *z* = -0.52, $p = .601$), with comparable DO responses (24% vs. 24%) following plausible primes and implausible primes. The interaction between plausibility and structure was significant (β = -1.03, *SE* = 0.29, *z* = -3.55, $p < .001$), indicating a reduced structural priming effect following implausible primes (1% priming effect; this is the difference in DO response proportions between implausible DO and implausible PO primes) than following plausible primes (15% priming effect).

Table 3: Responses as a function of plausibility and structure in Experiment 1.

Plausibility	Interpretation	Structure	Response			Prop DO	Priming
			DO	PO	Other		
Plausible	Literal	DO	122	247	27	0.33	0.16
		PO	65	326	30	0.17	
	Nonliteral	DO	6	29	9	0.17	0.03
		PO	2	12	5	0.14	
Implausible	Literal	DO	56	155	20	0.27	0.03
		PO	72	238	31	0.23	
	Nonliteral	DO	41	146	22	0.22	-0.01
		PO	21	69	9	0.23	

Second, we investigated whether the interpretation (literal vs. nonliteral) of an implausible prime sentence led to different structural priming effects (note that we did not consider plausible primes, as

nonliteral interpretations of plausible prime sentences were rare). The LME analysis included structure (PO = -0.5, DO = 0.5) and interpretation (centered and z-transformed due to imbalance in number between literal and nonliteral interpretation trials) as interacting factors. Structure did not produce a significant effect (β = 0.20, *SE* = 0.27, *z* = 0.73, *p* = .465), with comparable DO responses (24% vs. 23%) following DO and PO implausible primes. Interpretation also did not produce a significant effect (β = -0.07, *SE* = 0.19, *z* = -0.36, *p* = .722), with comparable DO responses (25% vs. 22%) following literally- and nonliterally-interpreted implausible primes. Critically, there was a significant interaction between structure and plausibility (β = -0.70, *SE* = 0.33, *z* = -2.11, *p* = .035), indicating less structural priming when implausible primes were interpreted nonliterally than literally (see Table 3).

Finally, we asked whether participants considered a nonliteral syntactic analysis even when they literally interpreted an implausible sentence. To address this, we did a further comparison between literally interpreted plausible primes and literally interpreted implausible primes. There was a significant main effect of structure (31% and 20% DO responses following DO and PO primes respectively; β = 0.85, *SE* = 0.17, *z* = 4.95, *p* < .001) but no significant main effect of plausibility (25% and 25% DO responses following plausible and implausible primes; β = -0.15, *SE* = 0.23, *z* = -0.66, *p* = .508); critically, there was a significant interaction between structure and plausibility (β = -0.86, *SE* = 0.34, *z* = -2.56, *p* = .011), indicating a reduced priming effect following literally interpreted implausible primes in comparison to literally interpreted plausible primes (see Table 3).

Discussion

We found that participants were more likely to nonliterally interpret implausible than plausible sentences, and to nonliterally interpret implausible DO sentences than implausible PO sentences (in accord with Gibson et al., 2013). More importantly, structural priming was reduced following implausible primes compared to following plausible primes. These results are thus not consistent with the nonliteral semantic interpretation account, which predicts equivalent priming following implausible and plausible prime sentences. Instead, our results are consistent with the nonliteral syntactic analysis account, which

predicts reduced structural priming following implausible primes than plausible primes. In addition, the reduction in priming following literally interpreted implausible primes (as compared to literally interpreted plausible primes) suggests that participants even considered the nonliteral syntactic analysis of an implausible prime even when they eventually literally interpreted it. Finally, the finding that priming was reduced to a greater extent following nonliterally implausible prime sentences than following literally interpreted implausible prime sentences suggests that participants were more likely to adopt the nonliteral analysis of an implausible sentence when they interpreted the sentence nonliterally than when they interpreted it literally.

However, note that participants explicitly interpreted a prime sentence before they described a picture. Thus, the effects of plausibility and interpretation (literal vs. nonliteral) on structural priming may have not solely reflected online processing of the prime sentence but also may have been shaped by the explicit decision on the (implausible) prime sentence. To address this issue, in Experiment 2, we swapped the task order of question answering and picture description: After comprehending a prime sentence, participants described a picture first and then answered a question about the prime sentence.

Experiment 2

Methods

The experiment was the same as Experiment 1, except that participants described the picture first and then answered a comprehension question. We removed 13 participants for producing "other" responses for more than 50% of the time, leaving 83 participants (mean age = 29.4, range = 18 – 48; 43 females) for further data analysis.

Results

Interpretation of prime sentences

Table 4 presents the proportions of nonliteral interpretations. LME analysis showed that there were in general fewer nonliteral interpretations than literal interpretations (23% vs. 77%, as reflected in

the significant intercept; β = -1.96, *SE* = 0.20, *z* = -10.04, *p* < .001). Nonliteral interpretations occurred more often for implausible than plausible sentences (37% vs. 10%; β = 2.38, *SE* = 0.44, *z* = 5.43, *p* < .001), and for the DO than PO structure (30% vs. 17%; β = 1.40, *SE* = 0.30, *z* = 4.65, *p* < .001). The interaction did not reach significance (β = -0.55, *SE* = 0.58, *z* = -0.93, *p* = .350). For implausible primes, there was a significant effect of structure (β = 1.05, *SE* = 0.21, *z* = 5.10, *p* < .001), with more nonliteral interpretations for implausible DO than implausible PO sentences (see Table 4), as we observed in Experiment 1.

Table 4: Interpretation of prime sentences as a function of plausibility and structure in Experiment 2.

Plausibility	Prime	Interpretation		Prop of nonliteral interpretations
		Literal	Nonliteral	
Plausible	DO	357	58	0.14
	PO	387	28	0.07
Implausible	DO	224	191	0.46
	PO	303	112	0.27

Table 5: DO, PO and Other responses as a function of plausibility, interpretation, and structure in Experiment 2.

Plausibility	Interpretation	Structure	Response			Prop DO	Priming
			DO	PO	Other		
Plausible	Literal	DO	119	206	32	0.37	0.12
		PO	91	273	23	0.25	
	Nonliteral	DO	15	39	4	0.28	0.11
		PO	4	19	5	0.17	
Implausible	Literal	DO	79	130	15	0.38	0.10
		PO	79	199	25	0.28	
	Nonliteral	DO	44	133	14	0.25	0.05
		PO	20	79	13	0.20	

Structural priming of picture descriptions

Out of all the 1660 picture descriptions, 131 (8%) were "other" responses and were thus removed from further analyses. As in Experiment 1, we conducted three LME analyses.

First, to compare whether structural priming differs between plausible and implausible primes, we ran an LME model on DO vs. PO responses (with PO as the reference level), using structure (PO = -.05, DO = 0.5) and plausibility (plausible = -0.5, implausible = 0.5) as interacting predictors. There were in general fewer DO than PO responses (29% vs. 71%), as reflected in the intercept (β = -1.44, *SE* = 0.32, *z* = -4.51, $p < .001$). There was a significant main effect of structure (β = 0.66, *SE* = 0.22, *z* = 3.04, *p* = .002), with more DO responses following DO prime sentences than PO prime sentences (34% vs. 25%). Plausibility did not produce a significant main effect (β = -0.06, *SE* = 0.14, *z* = -0.47, *p* = .639), with comparable DO responses following implausible and plausible primes (29% vs. 30%). There was a marginally significant interaction between structure and plausibility (β = -0.54, *SE* = 0.28, *z* = -1.93, *p* = .054), with a trend toward reduced structural priming following implausible prime sentences compared to following plausible prime sentences (see Table 5).

Next, we compared structural priming following implausible sentences that were either later literally or nonliterally interpreted (after picture description), using structure (PO = -.05, DO = 0.5) and interpretation (transformed into z-scores) as interacting predictors. There was a significant effect of structure (β = 0.43, *SE* = 0.20, *z* = 2.11, *p* = .035), with more DO responses following DO implausible prime sentences than PO implausible prime sentences (32% vs. 26%); there was also a significant effect of interpretation (β = -0.26, *SE* = 0.12, *z* = -2.19, *p* = .029), with more DO responses if implausible prime sentences were literally than nonliterally interpreted (32% vs. 23%). Interestingly, there was no significant interaction between structure and interpretation (β = -0.02, *SE* = 0.22, *z* = -0.09, *p* = .927), which suggests that the priming effect of an implausible prime was not modulated by how the implausible prime was interpreted.

Finally, we tested whether structural priming differed between plausible and implausible primes that were later literally interpreted. There was a significant main effect of structure (37% and 26% DO

responses following DO and PO primes respectively; β = 0.68, *SE* = 0.24, *z* = 2.80, *p* = .005) but no significant main effect of plausibility (30% and 32% DO responses following plausible and implausible primes respectively; β = 0.08, *SE* = 0.16, *z* = 0.50, *p* = .620); there was no significant interaction between structure and plausibility (β = -0.39, *SE* = 0.32, *z* = -1.23, *p* = .219), suggesting comparable structural priming following literally interpreted plausible primes and literally interpreted implausible primes.

Between-experiment comparison of structural priming

We compared structural priming between Experiment 1 (where participants answered the comprehension question first and then described a picture) and Experiment 2 (where participants described a picture first and then answered the comprehension question). We first examined priming following plausible and implausible sentences, using structure, plausibility, and Experiment as interacting factors. There was a significant main effect of structure (i.e., revealing structural priming; β = 0.58, *SE* = 0.12, *z* = 4.79, *p* < .001) and a significant interaction between structure and plausibility (β = -0.80, *SE* = 0.21, *z* = -3.90, *p* < .001; with reduced priming following implausible primes than plausible primes). Experiment only produced a marginally significant effect (β = 0.47, *SE* = 0.24, *z* = 1.94, *p* = .052), with a trend toward fewer DO responses in Experiment 2 than in Experiment 1. No other effects reached significance; critically, the lack of a significant three-way interaction suggests that the reduction in priming following implausible primes was comparable between the two experiments.

We next examined priming from the implausible sentences and how it might be modulated by interpretation, using structure, interpretation, and Experiment, as interacting factors. We observed again a significant effect of structure (β = 0.36, *SE* = 0.15, *z* = 2.41, *p* = .016) and a marginally significant effect of interpretation (β = 0.47, *SE* = 0.24, *z* = 1.94, *p* = .052; with a trend toward fewer DO responses when implausible primes were nonliterally than literally interpreted). The interaction between structure and interpretation was marginally significant (β = -0.52, *SE* = 0.27, *z* = -1.90, *p* = .058), again with a trend toward reduced structural priming when implausible primes were nonliterally interpreted compared to when they were literally interpreted. No other effects were significant; critically, there was no significant

three-way interaction, suggesting that the reduction in priming following nonliterally interpreted implausible primes (compared to literally interpreted ones) was comparable between the two experiments.

Finally, we examined whether priming differed between literally interpreted plausible primes and literally interpreted implausible primes, using structure, plausibility and Experiment as interacting factors. We found a significant main effect of structure (β = 0.73, *SE* = 0.12, *z* = 6.31, *p* < .001) and of Experiment (β = 0.55, *SE* = 0.23, *z* = 2.34, *p* = .019; with fewer DO responses in Experiment 2 than in Experiment 1), and a significant interaction between structure and plausibility (β = -0.62, *SE* = 0.23, *z* = -2.70, *p* = .007; suggesting a reduction in priming following literally interpreted implausible primes compared to literally interpreted plausible primes). No other effects were significant; critically, the lack of a significant three-way interaction suggests that the reduction in priming following literally interpreted implausible primes was comparable between the two experiments.

Discussion

The results from sentence interpretation in Experiment 2 again echo those in Gibson et al. (2013), with people being more likely to nonliterally interpret DO sentences than PO sentences, even though the interpretation was made after an intervening picture-description task. More importantly, structural priming was reduced following implausible prime sentences than plausible prime sentences, as in Experiment 1. The results again suggest that people activate the nonliteral syntactic analysis in comprehending implausible sentences and this occurs even when they have not already made an explicit interpretation of implausible sentences. But while we observed a reduction in priming following nonliterally interpreted implausible primes compared to literally interpreted ones, and following literally interpreted implausible primes compared to literally-interpreted plausible primes, these reductions were not statistically significant in Experiment 2 (though between-experiment comparisons did not show that these reductions differed between the two experiments).

We used different verbs between the prime and the target and we note that structural priming effects with different verbs are relatively weak (e.g., Mahowald et al., 2016). Thus, it is possible that the

discrepancies in some effects between the two experiments might be due to a lack of experimental power. In Experiment 3, which we preregistered, we made two changes to increase experimental power: We used the same verbs between the prime and the target (e.g., Pickering & Branigan, 1998) and we also increased the number of target items. In addition, participants did both question-first and picture-first orders (counterbalanced between participants).

Experiment 3

We preregistered the experiment on Open Science Framework (https://osf.io/5bpu9) before data collection. Apart from plausibility and structure, we also manipulated the task order of question answering and picture description, with half of the participants answering the question first and the other half describing the picture first, in a blocked design.

Methods

Participants. We planned a sample size of 96 participants, replacing participants who were to be excluded because they produced >50% other responses (the same exclusion criterion as in Experiments 1 and 2). Participants were recruited in the same way and from the same population as in Experiments 1 and 2.

Materials. We constructed 40 target items and 60 filler items (in addition to 2 practice items). These sentences were similar to those in Experiments 1 and 2, except that the description picture had the same verb as the one used in the prime sentence (e.g., prime: *The painter gave the clothes to the saint*; target: a picture depicting a pirate giving a cake to a clown, with the verb *GIVE* printed beneath the picture). Materials were preregistered (https://osf.io/5bpu9).

Procedure. The trial structure in the question-first block was the same as that in Experiment 1 and the trial structure of the picture-first block was the same as that in Experiment 2.

Results of preregistered analyses

Interpretation of prime sentences

One participant failed to provide an answer to the comprehension question in 11 of the target trials and these 11 trials were excluded from analyses of interpretation and priming. Table 6 presents participants' responses, and Table 7 reports LME analyses. There were fewer nonliteral than literal interpretations (24% vs. 76%), as indicated by the significant intercept. There was an effect of plausibility, with more nonliteral interpretations for implausible than plausible primes (33% vs. 15%). There was a marginal effect of structure, with a tendency toward more nonliteral interpretations for DO than PO prime sentences (28% vs. 20%). When we did a separate analysis on implausible primes, the only significant effect was that of structure, with more nonliteral interpretations for implausible DO primes than implausible PO primes (β = 1.08, *SE* = 0.37, *z* = 2.90, *p* = .004).

Table 6: Interpretation of prime sentences as a function of task order, plausibility, and structure in Experiment 3.

Order	Plausibility	Structure	Interpretation		Prop of nonliteral
			Literal	Nonliteral	
Question-first	Plausible	DO	379	51	0.12
		PO	359	71	0.17
	Implausible	DO	231	199	0.46
		PO	309	121	0.28
Picture-first	Plausible	DO	457	93	0.17
		PO	460	85	0.16
	Implausible	DO	342	208	0.38
		PO	423	121	0.22

Table 7: LME results of interpretation of prime sentences in Experiment 3.

Effect	β	*SE*	*z*	*p*
(Intercept)	-2.32	0.23	-10.29	< 0.001
Order	0.19	0.43	0.44	0.658
Structure	0.56	0.31	1.82	0.069
Plausibility	1.97	0.33	5.91	< 0.001
Order:Structure	-0.51	0.64	-0.80	0.427
Order:Plausibility	0.48	0.65	0.74	0.460
Structure:Plausibility	1.01	0.73	1.38	0.166
Order:Structure:Plausibility	1.69	1.47	1.15	0.250

Structural priming of picture descriptions

Out of the 3920 picture descriptions, 244 (6%) were "other" responses and were thus removed from further analyses. Following the preregistered analytical plan, we conducted an LME model on DO vs. PO responses (with PO as the reference level; see Table 8 for a summary of results), using task order (question-first = 0.5, picture-first = -0.5), structure (PO = -.05, DO = 0.5) and plausibility (plausible = -0.5, implausible = 0.5) as interacting predictors (see Table 9 for the statistics). There were fewer DO than PO responses (25% vs. 75%), as indicated by the significant intercept. There was a significant main effect of structure, with more DO responses following DO prime sentences than PO prime sentences (34% vs. 17%). There was a significant interaction between structure and plausibility, with reduced structural priming following implausible prime sentences than plausible prime sentences (22% vs. 12% in priming effect; see also Table 8). There was no significant three-way interaction involving task order, suggesting that the reduction in priming effect due to implausibility was similar between the question-first and the picture-first blocks.

Table 8: Responses as a function of task order, plausibility, interpretation, and structure in Experiment 3.

Order	Plausibility	Interpretation	Structure	Response			Prop of DO	Priming
				DO	PO	Other		
Question-first	Plausible	Literal	DO	126	221	32	0.36	0.18
			PO	60	276	23	0.18	
		Nonliteral	DO	19	30	2	0.39	0.33
			PO	4	61	6	0.06	
	Implausible	Literal	DO	79	143	9	0.36	0.20
			PO	44	242	23	0.15	
		Nonliteral	DO	35	136	28	0.20	-0.08
			PO	31	79	11	0.28	
Picture-first	Plausible	Literal	DO	180	264	13	0.41	0.28
			PO	53	383	24	0.12	
		Nonliteral	DO	23	68	2	0.25	-0.05
			PO	24	54	7	0.31	
	Implausible	Literal	DO	112	219	11	0.34	0.19
			PO	58	346	19	0.14	
		Nonliteral	DO	50	142	16	0.26	0.01
			PO	29	85	7	0.25	

Table 9: LME results of structural priming in Experiment 3.

Effect	β	*SE*	*z*	*p*
(Intercept)	-1.87	0.24	-7.76	< 0.001
Order	0.04	0.37	0.10	0.917
Structure	1.50	0.19	7.89	< 0.001
Plausibility	-0.14	0.10	-1.38	0.166
Order:Structure	-0.43	0.38	-1.15	0.250
Order:Plausibility	0.31	0.26	1.22	0.224
Structure:Plausibility	-0.81	0.20	-4.09	< 0.001
Order:Structure:Plausibility	-0.57	0.56	-1.02	0.309

We next examined whether structural priming was modulated by the way an implausible prime was (literally or nonliterally) interpreted, using task order, structure, and interpretation (centered and transformed into z-scores) as interacting predictors (see Table 10 for the statistics). There was a main effect of structure, with more DO responses following implausible DO primes than PO primes (30% vs. 18%). Crucially, there was an interaction of structure and interpretation, with less priming when an implausible prime was nonliterally than literally interpreted (0% vs. 20% priming effect, collapsed over task order; see Table 8). The lack of a significant three-way interaction suggests that the reduction in priming due to nonliteral interpretation was similar between the two task orders.

Table 10: LME results for comparison in priming between literally and nonliterally interpreted implausible primes in Experiment 3.

Effect	β	*SE*	*z*	*p*
(Intercept)	-2.01	0.27	-7.52	< 0.001
Order	0.13	0.44	0.30	0.764
Structure	1.13	0.26	4.38	< 0.001
Interpretation	0.09	0.10	0.85	0.395
Order:Structure	-0.66	0.64	-1.03	0.302
Order:Interpretation	0.003	0.19	-0.02	0.986
Structure:Interpretation	-0.49	0.23	-2.13	0.033
Order:Structure:Interpretation	0.40	0.48	0.83	0.405

Results of non-preregistered analyses

Though not part of the analytical plan we preregistered, we also followed what we did in Experiments 1 and 2 by carrying out a comparison between literally interpreted plausible primes and literally interpreted implausible primes (see Table 11 for the statistics). There was structural priming, as indicated by the significant main effect of structure. Importantly, this structural priming effect was modulated by plausibility, with reduced priming following literally interpreted implausible primes than following literally interpreted plausible primes (20% vs. 24% priming effect, collapsed over task order;

see Table 8). This interaction was not further qualified by task order, suggesting that the reduction in priming for literally interpreted implausible primes was similar across the two task orders. The significant interaction between structure and task order reveals stronger priming when participants described the picture first than when they answered the question first.

Table 11: LME results for comparison in priming between literally-interpreted implausible and plausible primes in Experiment 3.

Effect	β	*SE*	*z*	*p*
(Intercept)	-1.86	0.24	-7.88	< 0.001
Order	0.15	0.37	0.41	0.679
Structure	1.68	0.24	7.07	< 0.001
Plausibility	-0.23	0.12	-1.90	0.057
Order:Structure	-0.97	0.46	-2.09	0.037
Order:Plausibility	0.26	0.32	0.84	0.403
Structure:Plausibility	-0.53	0.25	-2.15	0.032
Order:Structure:Plausibility	-0.09	0.66	-0.14	0.886

Discussion

Compared to Experiments 1 and 2, this preregistered experiment increased experimental power by having the same verb between the prime and the picture description and by having more target items. First, we observed an interaction between structure and plausibility, with reduced structural priming following implausible primes than plausible primes. This interaction was not further qualified by task order, suggesting that the interaction between structure and plausibility was comparable regardless of whether participants answered the question first or described the picture first (thus replicating what we observed in Experiments 1 and 2 and in the between-experiment comparisons). Second, structural priming was reduced following nonliterally interpreted implausible primes than literally interpreted implausible primes and the reduction was comparable for the two task orders (again replicating the corresponding comparison between Experiments 1 and 2); this result replicates the finding in Experiment 1 and suggests

that the lack of such an effect in Experiment 2 was likely due to insufficient experimental power. Third, a non-preregistered analysis also showed reduced structural priming following literally interpreted implausible primes than literally interpreted plausible primes and the reduction was comparable for the two task orders (thus replicating the comparison between Experiments 1 and 2); again, this result replicates that in Experiment 1 and suggests that the non-significance of the effect in Experiment 2 was probably due to insufficient experimental power. In summary, Experiment 3 suggests that implausibility and nonliteral interpretation both led to a reduction in structural priming, regardless of whether participants answered a question first or described a picture first.

General discussion

In three experiments, we found a reduced tendency for people to reuse a syntactic structure of a prime sentence (i.e., a reduction in structural priming) when the prime sentence was implausible than when it was plausible. This finding is inconsistent with the nonliteral semantic interpretation account, according to which people arrive at a nonliteral interpretation via semantic processing; instead, it supports the nonliteral syntactic analysis account, according to which people arrive at a nonliteral interpretation by revising the syntactic structure of the implausible sentence. In further support of the nonliteral syntactic analysis account, the experiments showed that structural priming was additionally reduced following a nonliterally interpreted implausible prime than following a literally interpreted implausible prime, thereby suggesting that people are more likely to adopt the nonliteral syntactic analysis when they arrive at a nonliteral interpretation than when they arrive at a literal interpretation of an implausible sentence. In addition, the experiments revealed a reduction in priming following literally interpreted implausible primes than following literally interpreted plausible primes, suggesting that people still consider a nonliteral syntactic analysis of an implausible sentence even if they eventually literally interpret the sentence, again in accord with the nonliteral syntactic analysis account.

Before we consider the theoretical implications of our findings, we note that we found the same pattern of priming whether picture description occurred before or after question answering, suggesting

that our conclusions do not depend on task order. In fact, the magnitude of priming was broadly similar across task order, though Experiment 3 did find a slight reduction in (same-verb) priming when question-answering occurred first – that is, when there was intervening material between prime and target (in accord with Branigan et al., 1999, and Hartsuiker et al., 2008).

We further note that in a recent (unpublished) study, Slevc and Buxó-Lugo (2020) showed reduced structural priming following implausible datives than following plausible datives (as in our study), though their participants made nonliteral interpretations at an unusually high rate (about 20% for plausible sentences and strikingly 50% for implausible sentences). Their results (like ours) are thus consistent with the nonliteral syntactic analysis account (but inconsistent with the nonliteral semantic interpretation account). We now discuss three mechanisms for the construction of the nonliteral syntactic analysis.

Semantic feedback affecting syntactic analysis

Karimi and Ferreira (2016) provided a development of Ferreira's (2003) proposals, in which they argued that the heuristic route can reach a semantic interpretation more quickly than the algorithmic route can. They proposed that it then provides semantic feedback that can coerce the algorithmic route to output a nonliteral syntactic analysis. Thus, this approach appears compatible with the nonliteral syntactic analysis account. In accord with Karimi and Ferreira, Christianson et al. (2010) used semantic feedback to explain their finding of reversed structural priming following implausible transitives. For instance, in comprehending *The angler was caught by the fish*, participants used heuristic processing to quickly compute the meaning "angler catching fish", which then led them to compute the active syntactic analysis for *The angler caught the fish*, resulting in the priming of actives in subsequent picture description. Thus, while Christianson et al.'s feedback-based explanation first involves nonliteral semantic interpretation, it can then lead to nonliteral syntactic analysis.

For reversed structural priming following an implausible passive prime such as *The angler was caught by the fish*, the heuristic-based nonliteral interpretation of "angler catching fish" would need to

activate an associated active analysis (presumably for *The angler caught the fish*) to a greater extent than the literal passive analysis (and not activate an associated passive analysis for *The fish was caught by the angler*). However, there is evidence that such heuristics do not have such a strong effect: Gibson et al. (2013) showed that implausible actives/passives were rarely nonliterally interpreted (less than 5% in their Experiment 1). Moreover, if heuristic-based nonliteral interpretation can cause comprehenders to syntactically reanalyze, we should expect a correlation between syntactic revision (and hence structural priming) and subsequent interpretation (i.e., a literal interpretation of fish as agent or a nonliteral interpretation of angler as the agent) such that a more activated nonliteral interpretation would lead to both a more activated nonliteral syntactic analysis and more likelihood of nonliteral interpretation (e.g., angler as the agent). But Christianson et al. (2010) did not find such an effect – the extent of structural priming was similar regardless whether comprehenders gave literal or nonliteral interpretation decision in the thematic role task. This lack of a correlation of course contrasts with what we have found for dative sentences in the current study.

Noisy-channel editing

As discussed in the introduction, Gibson et al. (2013) treated language comprehension as a noisy channel, with comprehenders aiming to revise an implausible sentence into its intended form. Thus, the more likely it is that comprehenders believe an implausible sentence to have been corrupted from a plausible sentence, the more likely it is that they revise the implausible sentence back to its intended form. Such an editing account can explain why implausible DO sentences are more often interpreted nonliterally than implausible PO sentences. In particular, Gibson et al. argued that linguistic omission is a more likely form of corruption during misproduction or misperception than linguistic insertion, according to the Bayesian size principle (e.g., Tenenbaum, 1999; Xu & Tenenbaum, 2007). For example, an implausible DO can be corrupted from a plausible PO by omitting *to* and an implausible PO can be corrupted from a plausible DO by inserting *to*. Assuming that omission and insertion occur equally often, Gibson et al. reasoned that if the intended utterance is a plausible PO and a word is omitted to result in an

implausible DO, then the probability that the omitted word is *to* is relatively high, as *to* only has to be randomly selected from the intended sentence. But if the intended utterance is a plausible DO and a word is inserted to result in an implausible PO, then the probability that the inserted word is *to* is (very) low, as the inserted word could be any word in a relevant subset of the producer's lexicon (see p.8053). Therefore, comprehenders are more likely to assume that an implausible DO is corrupted from a plausible PO (by omission of *to*) than to assume that an implausible PO is corrupted from a plausible DO (by insertion of *to*); as a result, they are more likely to have nonliteral interpretations for implausible DO sentences than for implausible PO sentences (as shown in the current study and also in Gibson et al., 2013).

In addition, comprehenders are more likely to revise an implausible sentence when the corruption in question involves fewer "edits". In support of this, Gibson et al. showed that implausible datives (and other structures), which arguably involve one corruptive edit (e.g., an implausible DO from a plausible PO using a deletion edit), resulted in more nonliteral interpretations than implausible actives and passives, which arguably involve two corruptive edits (e.g., the intended plausible passive *The fish was caught by the angler* can be corrupted into the perceived implausible active *The fish caught the angler* by deleting *was* and also deleting *by*) (see also Gibson et al., 2016).

By assuming that implausible sentences are likely corrupted speech and thus comprehenders will sometimes revise these sentences back to their plausible intended form, Gibson et al. (2013) straightforwardly offer an explanation why our participants would construct a nonliteral syntactic analysis in comprehending implausible sentences. However, it is less clear why an implausible sentence has to be corrupted from, and therefore to be revised back into, a different syntactic structure rather than into the same syntactic structure with reordered words (see Poppels & Levy, 2016, for evidence of word swapping for nonliteral interpretation). For example, in the case of datives, why does an implausible DO (e.g., *The mother gave the candle the daughter*) have to be corrupted from a plausible PO (here, *The mother gave the candle to the daughter*) rather than from DO with swapped nouns (e.g., *The mother gave the daughter the candle*)? It is true that comprehenders are more likely to misperceive a preposition by

omission/insertion than to misperceive the order of two noun phrases. Thus, comprehenders might assume that an implausible DO/PO could have resulted from a plausible PO/DO. But implausible sentences can also be the result of word swapping during production, which is a common type of speech error (e.g., *I left the briefcase in my cigar*; Garrett, 1976). Indeed, there is evidence that comprehenders assume implausible sentences can be the result of word swapping (e.g., Ryskin et al., 2018). Thus, comprehenders might assume that an implausible DO/PO could be the result of a swapping of the two postverbal noun phrases in an otherwise plausible DO/PO sentence (see Poppels & Levy, 2016). In a similar way, an implausible PO (e.g., *The mother gave the daughter to the candle*) could be corrupted from a plausible PO (here, *The mother gave the candle to the daughter*). Our priming results demonstrated that syntactic revision does occur, in accord with the nonliteral syntactic analysis account; more specifically, they showed that at least some of that revision involves change in syntactic structure (between DO and PO) rather than word swapping.

Plausibility-driven syntactic prediction

We now propose an account, couched in syntactic prediction and local-plausibility analysis, to explain how people arrive at a nonliteral interpretation of an implausible sentence; then we use it to explain the priming data, the preference for structural revision and the finding of different rates nonliteral interpretation among different structures. There is now good evidence that comprehenders at least sometimes predict upcoming speech or text at different linguistic levels (Huettig, 2015; Kuperberg & Jaeger, 2016; Pickering & Gambi, 2018), including semantics (Altmann & Kamide, 1999), syntax (Staub & Clifton, 2006), lexical properties of upcoming words (Kwon, Sturt, & Liu, 2017), and on some occasions their forms (e.g., Ito et al., 2018). Importantly, comprehenders may predict (or "project") a syntactic analysis early on in the sentence (e.g., Arai et al., 2007; Gibson & Hickok, 1993; Staub & Clifton, 2006; see Crocker, 1999; Ferreira & Qiu, 2021).

There is also evidence that abandoned "garden-path" analyses can linger (Cai et al., 2012; Christianson et al., 2001; Van Gompel et al., 2006), and that comprehenders sometimes construct a

globally ungrammatical analysis that is locally grammatical (e.g., Tabor, Galantucci, & Richardson, 2004). Importantly, if an initially-constructed syntactic analysis is plausible, it can linger even in face of syntactically inconsistent incoming information. Thus, we propose that a plausible predicted analysis that becomes ungrammatical in the face of incoming words can be maintained together with a grammatical (i.e., globally correct) analysis.

First consider the implausible DO sentence *The mother gave the candle the daughter*. After *gave*, comprehenders consider both the PO and the DO analyses (see MacDonald et al., 1994). On the PO analysis, the upcoming noun phrase serves as the theme; on the DO analysis, it serves as the recipient. They then encounter *the candle*, and draw on the fact that it is more plausible as the theme than as the recipient. We assume that this leads them to select the PO analysis – that is, to assign it a much higher level of activation than the DO analysis, or to abandon the DO analysis entirely. Thus, we assume that, after *the candle*, comprehenders predict an upcoming prepositional phrase. When this sentence continues with *the daughter*, they construct (or reactivate) the grammatical-but-implausible DO analysis. But they also maintain the initially plausible PO analysis, and in particular the predicted prepositional phrase. They need to integrate *the daughter* into this analysis, so that they produce the plausible interpretation. To do this, they assume that they encountered the preposition *to* as well as the noun phrase *the daughter* (i.e., *The mother gave the candle to the daughter*). Therefore, comprehenders read the implausible interpretation off the DO analysis and also the plausible interpretation off the (nonliteral) PO analysis. Then they choose one or other interpretation (as indicated by the question answering), and are more likely to choose whichever analysis is more strongly activated.

This is not the case for a plausible DO sentence such as *The mother gave the daughter the candle*. In this example, the comprehender focuses on the DO analysis after *the daughter*, and this analysis continues to be activated following *the candle*. Importantly, the PO analysis is implausible at *the daughter*, and so it does not linger – it is therefore not considered at *the candle*. Therefore, comprehenders read the (plausible) interpretation off the DO analysis (as indicated by the question answering).

Now consider the implausible PO sentence *The mother gave the daughter to the candle*. After *gave*, comprehenders consider both the PO and the DO analyses. They then encounter *the daughter*, and draw on the fact that it is more plausible as the recipient than as the theme. We assume that this leads them to select the DO analysis – that is, to assign it a much higher level of activation than the PO analysis, or to abandon the PO analysis entirely. Thus, we assume that, after *the daughter*, comprehenders predict an upcoming noun phrase. When this sentence continues with *to the candle*, they construct (or reactivate) the grammatical-but-implausible PO analysis. But they also maintain the initially plausible DO analysis, and in particular the predicted noun phrase. They need to integrate *to the candle* into this analysis, so that they produce the plausible interpretation. To do this, they assume that they did not encounter the preposition *to*, and merely encountered the noun phrase *the candle* (i.e., *The mother gave the daughter the candle*). Therefore, comprehenders read the implausible interpretation off the PO analysis and also the plausible interpretation off the (nonliteral) DO analysis. Then they choose one or other interpretation, and are more likely to choose whichever analysis is more strongly activated.

This is not the case for a plausible PO sentence such as *The mother gave the candle to the daughter*. In this example, the comprehender focuses on the PO analysis after *the candle*, and this analysis continues to be activated following *to the daughter*. Importantly, the DO analysis is implausible at *the candle*, and so it does not linger – it is therefore not considered at *to the daughter*. Therefore, comprehenders read the (plausible) interpretation off the PO analysis.

How the prediction account can explain our findings

In the syntactic prediction account of our results, priming is a consequence of the level of activation of an analysis. For the plausible DO sentence *The mother gave the daughter the candle*, comprehenders quickly (i.e., at the point of *the daughter*) settled on the DO analysis and the sentence therefore primed the production of DO picture descriptions. For the plausible PO sentence *The mother gave the candle to the daughter*, comprehenders quickly (i.e., at the point of *the candle*) settled on the PO analysis and the sentence therefore primed the production of PO picture descriptions. For the implausible

sentences *The mother gave the candle the daughter* and *The mother gave the daughter to the candle*, comprehenders maintained both the literal and nonliteral analyses, and both sentences therefore primed both DO and PO picture descriptions. Thus, participants tended to produce fewer DO descriptions (i.e., were primed to a lesser extent) following the implausible DO prime than following the plausible DO prime. Similarly, they tended to produce fewer PO descriptions (i.e., were primed to a lesser extent) following the implausible PO prime than following the plausible PO prime.

Of course, the relative level of activation of the two analyses of an implausible sentence varies from one trial to the next. We assume that the level of activation affects how people answer the comprehension questions – a higher level of activation is associated with a greater likelihood of selecting the answer compatible with that analysis. On this basis, we can explain the finding of less priming when an implausible sentence was nonliterally interpreted than when it was literally interpreted. Again, consider the implausible DO sentence *The mother gave the candle the daughter*. When comprehenders activate the literal DO analysis to a higher level than the nonliteral PO analysis, they interpret the sentence literally and tend to produce a DO picture description; when they activate the nonliteral PO analysis to a higher level than the literal DO analysis, they interpret the sentence nonliterally and tend to produce a PO picture description. In this way, we can explain the (further) reduction in structural priming when an implausible prime was nonliterally than literally interpreted.

To explain the finding that nonliteral interpretations are more likely for implausible DO sentences than implausible PO sentences, we appeal to the same Bayesian size principle as in Gibson et al. (2013). For the implausible DO sentence *The mother gave the candle the daughter*, comprehenders predict the PO analysis at *the candle*, specifically predicting *to* followed by a noun phrase. When they hear *the daughter*, they can fit it into the predicted PO analysis by assuming that they actually heard *to the daughter* – that is, *to* was missed. Such an omission is relatively likely. But for the implausible PO sentence *The mother gave the daughter to the candle*, comprehenders predict the DO analysis at *the daughter*, specifically predicting (just) a noun phrase. When they hear *to the candle*, they can fit it into the predicted DO

analysis by assuming that they actually heard *the candle* – that is, *to* was illusively inserted. Such an insertion is relatively unlikely.

Our prediction account also explain why comprehenders rarely arrive at a nonliteral interpretation for implausible transitives (at least less frequently than implausible datives; Gibson et al., 2013; Poppels & Levy, 2016). After hearing *The fish caught*, comprehenders pursue only the active analysis, because there is no possible passive analysis; after *The angler was caught*, they pursue only the passive analysis, because there is no possible active analysis. Thus, it follows that the nonliteral analysis is rarely activated for implausible transitives.

As we discussed above, the prediction account and the noisy-channel account make many similar claims about people process implausible sentences. However, the prediction account claims that the DO analysis is more strongly activated at *the lady* in *The mother gave the lady to the book* than at *the baby* in the similarly implausible *The mother gave the baby to the book*, assuming that a lady is a more likely recipient and less likely theme than a baby is. Thus, there should be reduced greater reduction in structural priming following the former than the latter sentence. In other words, the strength of the prediction of the nonliteral analysis depends on the plausibility of the post-verb noun phrase as a theme or recipient. The prediction account claims that the activation of alternative analyses is affected by their plausibility before the final argument is encountered, whereas the noisy channel account claims that such activation depends only on their plausibility at the end of the sentence.

Conclusion

In three experiments, we showed that, compared to plausible primes, implausible primes led to reduced structural priming. In addition, there was further reduction in structural priming when an implausible prime was nonliterally interpreted than when it was literally interpreted. We conclude that people compute a nonliteral syntactic analysis that supports a nonliteral but plausible interpretation, and argue that the nonliteral syntactic analysis is achieved via syntactic prediction.

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