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Cue-Based Memory Retrieval in Garden-Path Sentences

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Abstract

This study investigates the representation of garden-path sentences and its interaction with memory retrieval. Garden-path sentences are initially misanalysed, and the initial misrepresentations tend to affect language comprehension, even after revision. Memory retrieval targets items in memory based on their representations. Our main research question investigates whether memory retrieval targets initial misrepresentations or revised representations in garden-path sentences. Using the cue-based memory retrieval model, we generated predictions for potential processing patterns stemming from this research question. The experiments used lexicality maze, self-paced reading, and offline comprehension questions. The results showed largely similar processing patterns between garden-path and non-garden-path sentences, suggesting that initial misrepresentations do not affect memory retrieval.

Keywords: Garden path; similarity-based interference; cue-based memory retrieval; sentence processing; language comprehension

Introduction

A central inquiry in sentence processing research is how locally ambiguous sentences (*garden-path sentences*), like (1) below, are processed.

(1) After the girl bathed Mary dressed quickly.

In (1), the NP "Mary" can be analysed locally in two ways: either as the direct object of "bathed" or as the subject of the matrix clause. Previous work suggests that the parser initially favours the object analysis and consequently encounters processing difficulties, known as *garden-path effects*, at the matrix verb "dressed", where "Mary" is required to serve as the clause's subject (Frazier & Rayner, 1982; Fujita, 2024; Fujita & Cunnings, 2021b; Sturt et al., 1999).

Previous research has highlighted two key observations regarding the processing of sentence (1). First, the parser revises the locally ambiguous NP as the subject (Fujita, 2024; Fujita & Cunnings, 2021b; Slattery et al., 2013). Evidence for this observation is derived from experimental designs using reflexive resolution, as follows.

(2) After the girl bathed Mary/John dressed herself quickly.

Approximately, a reflexive corefers with a locally c-commanding antecedent NP (Chomsky, 1981). This means that, in (2), "herself" corefers with the clausemate subject (*the target*) and is not referentially related to an object of "bathed". The target in (2) either matches ("Mary") or mismatches ("John") the reflexive's gender. Existing literature shows that processing difficulties occur at a pronoun when it and its antecedent mismatch in gender (Fujita, 2021, 2023; Hall & Yoshida, 2021; Kazanina et al., 2007; Sturt, 2003; Yoshida et al., 2013). This *gender mismatch effect* suggests that the locally ambiguous NP is revised as the subject after disambiguation.

The other key observation from previous research is that initial misrepresentations may linger in memory after disambiguation and affect subsequent language comprehension (Cunnings & Fujita, 2021; Fujita & Cunnings, 2020, 2021a; Jacob & Felser, 2016; Slattery et al., 2013; Sturt, 2007). Slattery et al. attribute this *lingering misinterpretation* in garden-path sentences such as (2) to the locally ambiguous NP being simultaneously represented as both the subject and the object. They argue that this coexistence hypothesis explains why gender mismatch effects occur in sentences like (2), while the object misrepresentation lingers in memory.

This study investigates the interplay between the representation of garden-path sentences and cue-based memory retrieval. Cue-based models propose that dependencies are formed using lexical and structural information as retrieval cues (Lewis & Vasishth, 2005; Vasishth & Engelmann, 2021). For example, the reflexive in (2) forms a dependency with its locally c-commanding antecedent that matches its gender. According to the cue-based models, c-command relations and gender serve as cues that guide the antecedent retrieval (see Alcocer & Phillips, 2012; Kush, 2013). Items in memory that match these retrieval cues become candidates for retrieval, with the degree of match being computed as the level of spreading activation. The greater the cue match, the higher the level of activation. Computationally, the total activation (A) of an item i is given by the equation:

(3) $A_i = B_i + \sum_j W_j S_{ij} + \varepsilon_i$

where, B_i represents the base activation and is computed as $B_i = ln(\sum_k t_k^{-d})$. Here, t_k represents the time since kth retrieval of i, and d is a decay parameter, implying that B_i refers to the historical retrievals of i. The term $\sum_j W_j S_{ij}$

implements spreading activation and computes the degree of match between cues and items. W_j denotes cue weights, which are assumed to be uniformly distributed across cues, while S_{ij} represents the strength of association between i and j. As illustrated in Figure 1, associative strengths with j decrease as more items match this cue. The last term accounts for stochastic noise, which is assumed to be a normally distributed random variable scaled by a noise parameter (x), as follows: $Normal\left(0, \sqrt{\frac{\pi^2}{3}x^2}\right)$.

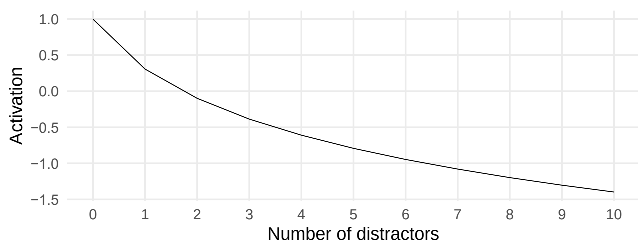

Figure 1. Associative strength with cue *j*. Activation decreases as more items match *j*.

Retrieval times (RT) are calculated based on item activation, as follows: $RT = Fe^{-A_i}$, where F is a constant. The negative exponential function of A_i implies that lower activations lead to longer retrieval times. In reflexive resolution, the second term in (3) determines the activation levels of items in memory depending on the degree to which their features match retrieval cues. For example, consider the following grammatical sentences.

(4a) After we left(,) Jenny cooked with the girl and embarrassed herself by burning the meat.

(4b) After we left(,) Jenny cooked with the boy and embarrassed herself by burning the meat.

In (4a), where “the girl”, a structurally inaccessible item for the reflexive, matches its gender, the activation from the gender cue is split between this *distractor* and the target. No such effects occur in (4b), where the distractor mismatches the gender cue. Consequently, the cue-based models predict longer retrieval times at the reflexive in (4a) than in (4b). This effect is known as *inhibitory interference* (Dillon et al., 2013). In addition, the cue-based models predict shorter retrieval times at the reflexive in (4c) than in (4d) over multiple trials.

*(4c) After we left(,) Henry cooked with the girl and embarrassed herself by burning the meat.

*(4d) After we left(,) Henry cooked with the boy and embarrassed herself by burning the meat.

These sentences are ungrammatical because the target mismatches the reflexive’s gender. In (4c), the distractor matches the gender cue. Consequently, the activation levels between the target and the distractor become similar. Activation fluctuates stochastically from trial to trial due to noise (i.e., the third term in (3)), resulting in a non-deterministic variation in activation. In other words, in (4c), either the target or the distractor is retrieved randomly with a probability of about 0.5. Crucially, when one of them is retrieved, its activation level is relatively high, as a retrieved item always has the highest activation. In contrast, in (4d), where the distractor mismatches the gender cue, the target is consistently retrieved, even when its activation level is relatively low due to noise. As a result, over multiple trials, retrieval times in (4c) become shorter on average than in (4d). This effect is referred to as *facilitatory interference*. These interference patterns are depicted in the left graph of Figure 2.

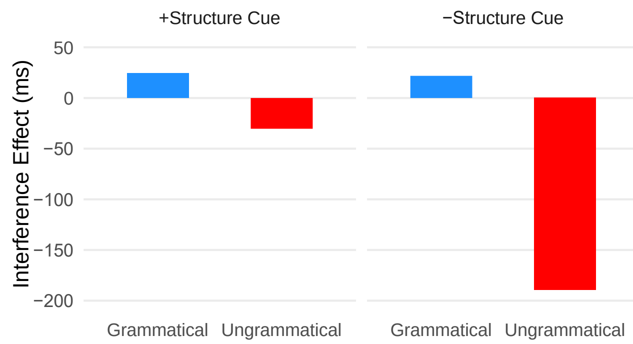

Figure 2. Interference patterns. The left graph illustrates a case where the target matches the structure-based cue, while the right graph depicts a situation where it does not. Positive values on the y-axis indicate inhibitory interference, while negative values denote facilitatory interference.

Interference is influenced by the target’s representation. To illustrate, consider a scenario in (4a–d) where the comma after “left” is absent, and the target is misanalysed as the object even after disambiguation. Upon encountering the reflexive, the parser searches for its antecedent. However, no item matches the structure-based cue because the object NP does not c-command the reflexive. The cue-based models predict that this circumstance leads to increased facilitatory interference, as depicted in the right graph of Figure 2. Facilitatory interference increases primarily because all items in (4d) now mismatch the structure-based and gender cues and thus have very low activation levels. This leads to no items being retrieved (when only the two cues are considered), resulting in increased retrieval times. In contrast, when the distractor matches the gender cue, as in (4c), retrieval times become significantly shorter. The size of inhibitory interference remains largely unchanged, as it emanates from the gender cue, which is irrelevant to the structural representation of the target. Obviously, this scenario represents an extreme case in which the target is *always* encoded as the object after disambiguation, which deviates from previous findings (Slattery et al., 2013). However, if the parser probabilistically revises the locally ambiguous NP as the subject, the extent of facilitatory interference is expected to increase over multiple trials, falling somewhere between the left and right graphs in Figure 2.

It is also conceivable that the locally ambiguous NP serves as both the subject and the object after disambiguation (Slattery et al., 2013). In this scenario, the object misrepresentation matches retrieval cues such as gender in (4a). Therefore, we can expect reduced activations from these cues to the target, as illustrated in Figure 1. This should result in increased inhibitory interference. The present study addresses these research questions by conducting a comparative analysis of the size of interference between garden-path sentences, such as (4a–d) without the comma, and unambiguous sentences, such as (4a–d) with the comma.

Experiment 1

In Experiment 1, participants were assigned to one of two groups. One group read ambiguous sentences, while the other group read unambiguous sentences. We employed a 2×2 factorial design, manipulating the gender of the target (match/mismatch) and distractor (match/mismatch). Thus, one group read sentences like (4a–d) without the comma, and the other group read those like (4a–d) with the comma.

Participants

A total of 480 native English speakers participated via the Prolific platform. All participants held university degrees, were British citizens, and had primarily lived in the UK before turning 18. Half of the participants were assigned to the "ambiguous" group (N = 240), and half to the "unambiguous" group (N = 240).

Items, Procedure, and Analysis

We created 24 item sets for the ambiguous conditions and 24 unambiguous item sets for unambiguous conditions, as in (4a–d), and 72 fillers. Participants' reading times were measured using lexicality maze (*L-maze*) tasks (Forster et al., 2009). In this task, sentences were presented word by word, accompanied by a pseudoword. Participants needed to choose correct words to read the sentences, and if a pseudoword was chosen, the trial was immediately terminated.

Log-transformed reading times at the reflexive and subsequent (spillover) regions were analysed using linear mixed effects models (Bates et al., 2015) in R (R Core Team, 2022). Models included random intercepts and all pertinent slopes for participants and items. The fixed effects included sum-coded (.5/–.5) within-participant factors of Grammaticality (grammatical or ungrammatical) and Distractor (match or mismatch), and their interaction. Additionally, a sum-coded fixed effect of Ambiguity (ambiguous or unambiguous) was included as a between-participant factor.

Results

Log-transformed reading times are illustrated in Figure 3.

Reflexive region: There was a significant main effect of Grammaticality (95% CI [73, 91] ms, t = 18.46), suggesting gender mismatch effects. The Grammaticality by Distractor interaction was also statistically significant (t = 2.73). A follow-up analysis indicated shorter reading times in the distractor match than in the distractor mismatch conditions for ungrammatical sentences (95% CI [–12, –38] ms, t = –3.85). This pattern is consistent with facilitatory interference. For grammatical sentences, no significant difference was observed (–6ms 95% CI [–16ms, 4ms], t = –1.22). Although there was a numerical trend, the three-way interaction was not statistically significant (t = 1.89).

Spillover region: There was a significant main effect of Grammaticality (95% CI [29, 43] ms, t = 10.07), indicating gender mismatch effects. The main effect of Distractor was significant (95% CI [–1ms, –18ms], t = –2.14), suggesting shorter reading times in the distractor match than distractor mismatch conditions. Although there was a numerical trend, the Grammaticality by Distractor interaction was not statistically significant (t = 1.59). Likewise, the three-way interaction was not statistically significant (t = 0.41).

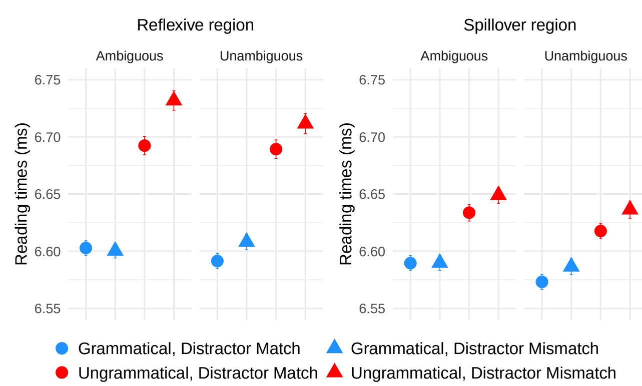

Figure 3. *Reading times in Experiment 1.*

Discussion: The gender mismatch effects indicate that the locally ambiguous NP is revised as the subject after disambiguation. At the reflexive, facilitatory interference was observed. This finding is consistent with the cue-based models. However, we did not observe inhibitory interference. At the spillover region, reading times were shorter in the distractor match conditions than in the distractor mismatch conditions, irrespective of Grammaticality. Although this effect appears to be largely driven by ungrammatical sentences or unambiguous sentences, there was no clear evidence for the relevant interaction effects. Importantly, the results did not suggest clear differences in interference between ambiguous and unambiguous sentences. This finding, together with the gender mismatch effects, suggests that the locally ambiguous NP is consistently encoded as the subject after disambiguation, and that memory retrieval targets the revised representation. In summary, Experiment 1 suggested similar patterns of interference between ambiguous and unambiguous sentences, which were numerically clear in the ungrammatical conditions, but less so in the grammatical conditions. Below, we report Experiment 2, which focused on interference effects in grammatical sentences, in part to clarify the less clear findings. In addition, Experiment 2 used a self-paced reading (SPR) task, together with comprehension questions probing the ambiguity and the reflexive's antecedent. The aim was to replicate the results of Experiment 1 using a more established and widely used method in psycholinguistics and to investigate the representation of ambiguous sentences and interference at the offline level.

Experiment 2

Experiment 2 included only grammatical sentences, which were either ambiguous or unambiguous and had either a gender matching or gender mismatching distractor, like (4a/b). Offline comprehension questions were presented in a yes/no format, such as "Did Jenny embarrass herself?" for (4a/b). These questions test whether the subject interpretation is successfully derived from the revised structural representation. If the locally ambiguous NP is revised as the subject, and an interpretation is derived from it, similar comprehension accuracy should be observed between ambiguous and unambiguous sentences. These questions also test inhibitory interference at the offline level. Specifically, if the gender-matching distractor interferes with offline comprehension, we can expect longer response times in (4a) than (4b).

Participants

For Experiment 2, we recruited 428 participants who had not taken part in Experiment 1. Average comprehension accuracy of fillers was 87% (all above 70%).

Items, Procedure and Analysis

The experimental sentences were the same as the grammatical sentences used in Experiment 1. Each sentence was accompanied by a comprehension question probing the ambiguity and the reflexive's antecedent.

The sentences were presented in a non-cumulative word-by-word SPR task. In this task, a sequence of dashes masking the entire sentence appeared before each sentence presentation. Participants read each word by pressing the space bar. At the completion of each sentence, the sentence disappeared, and a comprehension question appeared.

Linear mixed effects models were fitted for reading times and response times to comprehension questions. For comprehension accuracy, logistic regression was fitted using generalised linear mixed effects models. These models were fitted in a similar way to Experiment 1.

Results for Reading Times

Log-transformed reading times at the four regions are illustrated in Figure 4.

(Post-)Disambiguating region: There was a significant main effect of Ambiguity at the disambiguating (95% CI [23, 42] ms, t = 6.98) and post-disambiguating (95% CI [17, 31] ms, t = 7.12) regions, suggesting garden-path effects.

(Post-)Reflexive region: The main effect of distractor was not statistically significant at the reflexive (95% CI [–2, 5] ms, t = 0.91) and post-reflexive (95% CI [–5, 2] ms, t = –0.84) regions. The models also showed no interaction effect at the reflexive (95% CI [–6, 8] ms, t = 0.37) and post-reflexive (95% CI [–4, 9] ms, t = 0.79) regions.

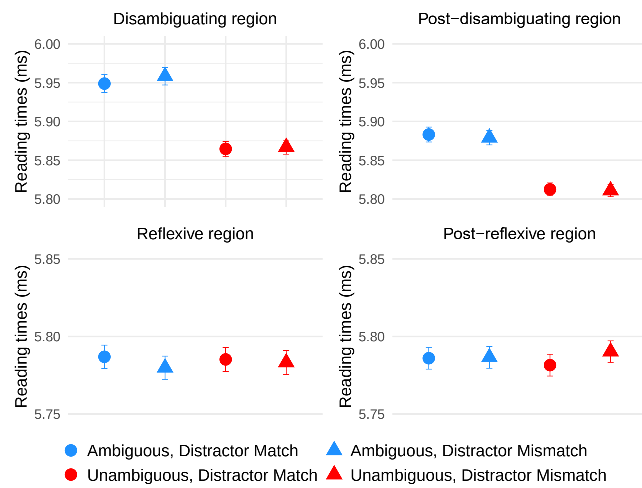

Figure 4. *Reading times in Experiment 2.*

Results for Comprehension Questions

Figure 5 illustrates response times and comprehension accuracy.

Response times: There was a significant main effect of Distractor (95% CI [44, 83] ms, t = 6.53), with longer response times in the distractor match conditions than in the distractor mismatch conditions. The main effect of Ambiguity was not statistically significant (95% CI [–32, 4] ms, t = –1.55). Also, the interaction effect was not statistically significant (95% CI [–17, 56] ms, t = 1.07).

Comprehension accuracy: No effects were statistically significant (for all, z < 0. 78).

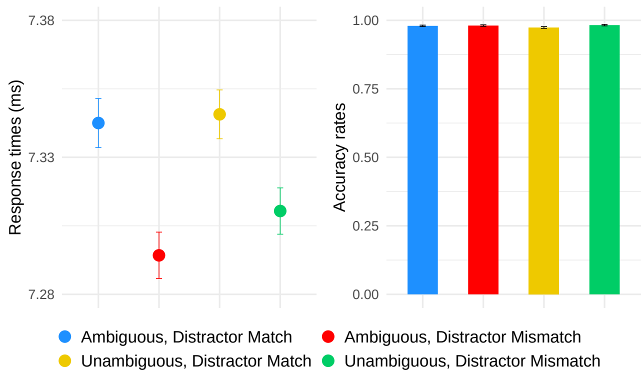

Figure 5. Response times and accuracy rates in Experiment 2.

Discussion: In Experiment 2, garden-path effects were observed at the (post-)disambiguating regions, suggesting that our ambiguous sentences are initially misanalysed. Crucially, there was no significant effect of Distractor at the (post-)reflexive region. This finding is inconsistent with Experiments 1, which used L-maze and suggested reduced reading times in the distractor match conditions at the post-reflexive region in grammatical sentences. Regarding offline measures, longer response times were observed in the distractor match conditions than in the distractor mismatch conditions. This observation is consistent with inhibitory interference, as predicted by the cue-based models. This interference pattern was similar between ambiguous and unambiguous sentences, suggesting that lingering misrepresentations do not affect memory retrieval. Also, similar accuracy rates between ambiguous and unambiguous sentences suggest that the subject interpretation is successfully derived from the revised representation after disambiguation.

General Discussion

The present study investigated the representation of locally ambiguous sentences and its relations with memory retrieval using L-maze, SPR, and comprehension questions. Below is a summary of the results.

Regarding the representation of garden-path sentences,

(A) Garden-path effects were observed at the disambiguating region (Experiment 2).
(B) Gender mismatch effects were observed at the reflexive region (Experiment 1).
(C) Similar comprehension accuracy rates were observed between the ambiguous and unambiguous conditions (Experiment 2).

Regarding cue-based memory retrieval,

(D) Similar facilitatory interference was observed between the ambiguous and unambiguous conditions (Experiment 1).
(E) There was delayed interference from a gender-mismatching distractor in grammatical sentences in L-maze (Experiments 1).
(F) This interference effect was not observed in SPR (Experiment 2).
(G) Inhibitory interference was observed at the offline level, in response times to comprehension questions (Experiment 2).

Garden Path and Cue-Based Memory Retrieval

The present study suggests broadly similar interference effects between ambiguous and unambiguous sentences. This finding, together with gender mismatch effects and comprehension accuracy, indicates that similar representations are derived for ambiguous and unambiguous sentences after disambiguation. Indeed, the size of the facilitatory interference observed in Experiment 1 aligns with what the cue-based models predict when the temporarily ambiguous NP always locally c-commands the reflexive (see Figure 2). However, the question arises as to how our findings can be reconciled with previous studies that have reported lingering object misrepresentation (Fujita & Cunnings, 2021b; Jacob & Felser, 2016; Slattery et al., 2013). One possible answer is that, after disambiguation, the locally ambiguous NP is analysed as both the subject and the object, as proposed by Slattery et al. (2013). In such a structural representation, the temporarily ambiguous NP locally c-commands the reflexive, while simultaneously serving as the source of the lingering object misinterpretation. A potential problem with this proposal, however, is the lack of an explanation for why the object representation does not affect memory retrieval. As noted in the Introduction, although the object NP does not c-command the reflexive, it is, for example, encoded as a singular, feminine NP in (4a). If these features are used as retrieval cues (Jäger et al., 2020; Wagers et al., 2009), they should cause retrieval difficulties under the cue-based models. However, our response time data, which showed clear inhibitory interference, did not show longer response times in ambiguous sentences than in unambiguous sentences.

Another plausible explanation is the persistence of semantic representations (Sturt, 2003). Specifically, after disambiguation, the locally ambiguous NP that is analysed as the object is erased from the structural representation. However, the misinterpretation derived from the object structure persists in memory. Given that cue-based memory retrieval targets structural representations, this hypothesis can explain why similar interference effects were observed between ambiguous and unambiguous sentences in our study.

On the Cue-Based Memory Retrieval Model

Our study showed facilitatory interference during real-time sentence processing, consistent with many previous studies

(Fujita, 2021; Fujita & Cunnings, 2022, 2023, 2024; González Alonso et al., 2021; Jäger et al., 2017, 2020; Kim et al., 2019, 2020; Orth et al., 2021; Wagers et al., 2009) and the cue-based models (Vasishth & Engelmann, 2021). For grammatical sentences, however, we observed three different patterns of processing. The L-maze experiment suggested shorter reading times in the distractor match conditions than in the distractor mismatch conditions (E), a result inconsistent with inhibitory interference. In the SPR experiment, no interference effects were observed during real-time sentence processing (F), while clear inhibitory interference was observed in question response times (G). These inconsistent findings may suggest task-dependent effects. One possible explanation is that, in L-maze, participants engage in lexical judgment while comprehending sentences, making it potentially more cognitively demanding than SPR in terms of memory retention. Consequently, participants in L-maze may have encountered some difficulty forming a long-distance dependency at the reflexive and been more susceptible to local information, leading to (occasional) retrievals of the distractor as the antecedent of the reflexive. One way to model this within the cue-based framework is to assume that, in L-maze, the distractor maintains (relatively) high activation at the reflexive due to its linear proximity to it. Also, in our sentences, the target is linearly far from the reflexive (cf. Fujita & Yoshida, 2024), and thus may have a reduced activation due to decay. Suppose that these cause the distractor to attain higher activation than the target at the reflexive. In such a scenario, a gender matching distractor is retrieved faster than a gender-mismatching distractor, resulting in the observed interference pattern (see also Engelmann et al., 2019). The model incorporating these assumptions provides a better fit to our L-maze data, as illustrated in Figure 5 below, compared to the traditional model shown in the left graph of Figure 2.

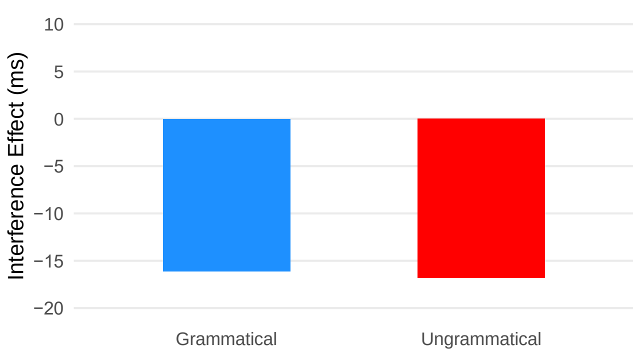

Figure 6. Predicted interference patterns when the distractor receives a higher activation than the target.

One challenge with this modelling approach, however, is that when the distractor is more likely to be retrieved than the target, it becomes difficult (at least conceptually) to account for large gender mismatch effects, as observed in Experiment 1.

The differences between the online SPR data (F) and the offline data (G) may be attributed to the accessibility of structural information at the online and offline levels. In real-time processing, structural information should be readily available because structures are constructed incrementally, and structural information is retained for language comprehension. Thus, the parser should be able to easily retrieve a structurally accessible antecedent, thereby resulting in no inhibitory interference (Dillon et al., 2013; Jäger et al., 2020; Mertzen et al., 2024; Wagers et al., 2009). In contrast, when responding to an antecedent probe question, robust structural representations may not be maintained in memory because language comprehension is complete and structural information may decay rapidly (Sachs, 1967). Consequently, when a reflexive appears in a question, readers may be less certain about its antecedent, leading to longer response times.

Further research is needed to clarify the influence of task-related factors on memory retrieval during real-time sentence processing, and to investigate potential divergences in interference effects between online and offline language comprehension processes.

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