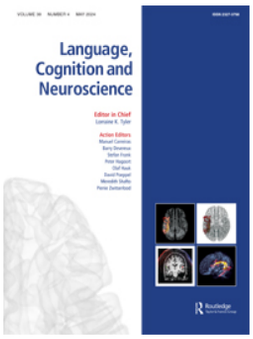

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Online reflexive resolution and interference

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ABSTRACT

A reflexive referentially depends on another NP. Long-standing inquiries in sentence processing literature revolve around whether and how forming this coreference relation during online sentence processing is susceptible to similarity-based interference. To address these questions, we conducted four experiments using L-maze tasks. The results revealed (delayed) interference in ungrammatical sentences, indicating facilitatory interference. We also found that structural information associated with a distractor and related to clause finiteness may influence memory retrieval. Interference effects were not observed in grammatical sentences across all experiments. These results suggest that online reflexive resolution may be susceptible to interference only when the reflexive mismatches its structurally accessible antecedent in features, and that structural information may influence how a distractor interferes with memory retrieval during online sentence processing.

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Dependency formation; reflexive resolution; interference; memory retrieval; sentence processing

Introduction

A reflexive, such as "himself" in (1) below, does not have independent reference and referentially depends on another expression (its *antecedent*).

(1) [$_{NP1}$ The boy who woke up [$_{NP2}$ John]] injured himself.

Reflexives agree with their antecedents in terms of number, gender, and person. In (1), there are two noun phrases (NP1 and NP2) that match the reflexive in these features. Therefore, both NPs can potentially serve as the antecedent of the reflexive. Structural relations constrain coreference (Chomsky, 1981, 1986). Roughly, a reflexive referentially depends on a locally c-commanding NP (see Reinhart, 1976). In (1), NP1 c-commands the reflexive, whereas NP2 does not. Therefore, structurally, only NP1 can serve as the reflexive's antecedent.

To establish a coreference relation during online sentence processing, the parser must assign syntactic structures that respect c-command relations and retrieve a structurally accessible antecedent at the reflexive from memory. Substantial evidence demonstrates that the parser incrementally assigns grammatical structures (e.g. see Cunnings & Fujita, 2021; Dillon et al., 2013; Frazier et al., 2015; Fujita & Cunnings, 2020, 2021a; Hall & Yoshida, 2021; Kazanina et al., 2007; Kim et al., 2020; Kush et al., 2017; Kush & Dillon, 2021; Omaki & Schulz, 2011; Phillips, 2006; Wagers & Phillips, 2009). However, the extent to which memory retrieval adheres to structural constraints remains controversial. Studies have presented conflicting results on whether a structurally inaccessible NP (a *distractor*), such as NP2 in (1), interferes with online reflexive resolution (e.g. Dillon et al., 2013; Jäger et al., 2020; Patil et al., 2016). In this study, we investigate *similarity-based retrieval interference*. Similarity-based interference is predicted to occur when a distractor shares a feature with a reflexive (Jäger et al., 2017). For example, in (1), the distractor "John" shares the gender feature (male) with the reflexive "himself". *The cue-based memory retrieval hypothesis* predicts that this feature-matching distractor NP interferes with online reflexive resolution (Lewis & Vasishth, 2005; Van Dyke & Lewis, 2003; Vasishth & Engelmann, 2021). Whether similarity-based interference influences sentence processing has been the subject of active debate, with limited and controversial evidence available in reflexive resolution. Discussions also extend to whether similarity-based interference is influenced by the position of a distractor (e.g. Parker & An, 2018). We address these issues through four lexicality maze (*L-maze*) experiments, where participants read sentences, selecting a word that continued the sentences (Forster et al., 2009; Witzel et al., 2012). We observed that online reflexive resolution is structurally

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constrained but susceptible to similarity-based interference from a distractor only in ungrammatical sentences. The experiments also suggested interference effects when a distractor was a direct object of a verb in a non-finite clause. However, no clear interference was observed when such a distractor was within a finite clause. In the following sections, before reporting the results in detail, we review previous research on similarity-based interference.

Similarity-based retrieval interference

Similarity-based interference effects during sentence processing have often been examined to test the cue-based memory retrieval hypothesis (Lewis et al., 2006; Lewis & Vasishth, 2005; Van Dyke & Lewis, 2003).[1] For reflexive resolution, this hypothesis assumes that the parser uses reflexives' features, including grammatical category, gender, number and person, as retrieval cues to identify their antecedents. As mentioned in the introduction, a reflexive referentially depends on a locally c-commanding NP. Thus, under the cue-based hypothesis, the parser must encode not only lexical features but also structural relations.[2]

The cue-based hypothesis posits that all elements that match a set of retrieval cues become retrieval candidates, and that the parser makes a direct reference to them. According to the cue-based model examined in this study (e.g. Lewis & Vasishth, 2005), elements receive base activation when they are encoded, which undergoes a time-based decay, leading to decreased accessibility over time. Each cue allocates spreading activation to potential retrieval candidates, and the one with the highest activation is retrieved. Similarity-based interference results from this activation-based direct parallel access. For example, in "(1) [$_{NP1}$ The boy who woke up [$_{NP2}$ John]] injured himself", NP1 (the structurally accessible antecedent) and NP2 (the distractor) match the reflexive in gender (*The boy … John … himself*). Thus, according to the cue-based model, the activation from the gender cue is split between NP1 and NP2, rendering it difficult for the parser to retrieve an antecedent based on this cue (*inhibitory interference*). No such interference is predicted to occur when the distractor does not match in gender, as shown below (*Mary … himself*), because, in this scenario, NP1 receives the maximum amount of spreading activation from the gender cue.

(2) [$_{NP1}$ The boy who woke up [$_{NP2}$ Mary]] injured himself.

The cue-based hypothesis also predicts a different type of similarity-based interference, called *facilitatory interference*, when no elements fully match a set of retrieval cues, as in (3a/b) below.

(3a) [$_{NP1}$ The girl who woke up [$_{NP2}$ John]] injured himself.
(3b) [$_{NP1}$ The girl who woke up [$_{NP2}$ Mary]] injured himself.

In (3a/b), no NPs fully match the retrieval cues at the reflexive; NP1, which is the structurally accessible antecedent, mismatches the reflexive in gender (*The girl … himself*), whereas NP2, the distractor, does not c-command it. It is known that gender disagreement between pronouns and their structurally accessible antecedents leads to processing difficulty (see Fujita, 2021b, 2024, 2023b; Fujita & Cunnings, 2021b; Hall & Yoshida, 2021; Kazanina et al., 2007; Kush et al., 2017; Schneider & Phillips, 2001; Sturt, 2003; Yoshida et al., 2013). This difficulty will be referred to as *ungrammaticality effects*. Therefore, we can expect longer reading times at the reflexive in (3a/b) than (1/2). The crucial difference between (3a) and (3b) lies in the gender matching between NP2 and the reflexive. In (3a), NP2 matches the reflexive in gender (*John … himself*), whereas in (3b), it mismatches (*Mary … himself*). As a result, in (3a), NP1 and NP2 match different cues (the structure-based or gender-based cues, respectively), whereas, in (3b), NP1 matches one cue (the structure-based cue), and NP2 matches none (as noted in footnote 2, only the structural and gender cues are considered here). According to the cue-based hypothesis, activation levels fluctuate due to noise. Therefore, in (3a), while NP1 and NP2 compete for retrieval, one of them is randomly retrieved, depending on which has the highest activation. However, in (3b), NP1 is always retrieved even when its activation level is relatively low due to noise. Consequently, over multiple trials, retrieval times at the reflexive become shorter on average in (3a) compared to (3b), resulting in facilitatory interference (i.e. reduced ungrammaticality effects).

Many studies have investigated the predictions of the cue-based hypothesis in terms of susceptibility to similarity-based interference across different types of dependencies. Despite the extensive investigation, several issues remain. For example, previous studies have often observed facilitatory interference, but many of them have failed to find inhibitory interference (see Cunnings & Fujita, 2023; Dillon et al., 2013; Fujita & Cunnings, 2022, 2023a, 2023b; González Alonso et al., 2021; Jäger et al., 2015, 2017, 2020; Kim et al., 2020; Lago et al., 2015; Nicenboim et al., 2018; Van Dyke, 2007; Van Dyke & McElree, 2011; Wagers et al., 2009). Nicenboim et al. (2018) argue that this so-called *grammatical*

asymmetry is due to a lack of statistical power to detect inhibitory interference. On the other hand, Wagers et al. (2009) propose that grammatical asymmetry is a consequence of sentence processing being susceptible to similarity-based interference only when top-down information conflicts with bottom-up input (i.e. grammatical asymmetry occurs because cue-based memory retrieval is not used and consequently interference does not arise when the actual input corresponds to what the parser predicts; for studies on predictive parsing, see Aoshima et al., 2004; Crocker, 1996; Fujita, 2023b; Gibson, 1998; Kimball, 1973; Kush et al., 2017; Marcus, 1980; Omaki et al., 2015; Yoshida, 2006; Yoshida et al., 2013). This proposal follows from their study on *subject-verb agreement*, as in (4a/b) below.

(4a) [$_{NP1}$ The brother of [$_{NP2}$ the boy(s)]] was very tired.
(4b) [$_{NP1}$ The brother of [$_{NP2}$ the boy(s)]] were very tired.

In (4a/b), NP1 and the verb "was/were" are grammatically related (e.g. they must agree in number). These sentences are either grammatical (4a) or ungrammatical (4b) because of number agreement or disagreement between the two elements (*The brother … was/were*). NP2 is a distractor, which either matches or mismatches the verb in number. As predicted for (1–3), according to the cue-based hypothesis, these manipulations should cause inhibitory interference in (4a) and facilitatory interference in (4b) when NP2 matches the number cue. In self-paced reading experiments, Wagers et al. found facilitatory interference but not inhibitory interference. These findings were accounted for as follows. Upon encountering "The brother", the parser predicts a verb marked with the grammatical agreement features (i.e. V-sg like *was*). When the verb appears, the parser checks number agreement with the predicted one. If they match in number, as in (4a), the parser establishes a relation between NP1 and the verb. Here, cue-based memory retrieval is not required if the parser holds the predicted representation in memory (e.g. see Gibson, 1998; Kim et al., 2020). When the verb mismatches top-down expectations, as in (4b), its features are used as retrieval cues to check NP1's features. Wagers et al. suggest that this checking process leads to misretrievals of the distractor, leading to facilitatory interference.

Hypothesis-driven parsing may play a key role in interference. However, in reflexive resolution, the parser is unlikely to predict a reflexive unless there is a strong contextual bias towards the presence of it. Thus, online reflexive resolution should often be triggered by bottom-up input, when a reflexive is recognised. In other words, upon encountering a reflexive, the parser often needs to retrieve its antecedent from memory (as there are no top-down expectations), and this memory retrieval may use the reflexive's features as retrieval cues. Therefore, online reflexive resolution can be considered susceptible to inhibitory interference. However, the evidence regarding this hypothesis is inconclusive. While some studies have observed inhibitory interference in grammatical sentences (e.g. Badecker & Straub, 2002; Jäger et al., 2015; Patil et al., 2016), others have reported no interference (e.g. Dillon et al., 2013) or even an interference pattern that opposes inhibitory interference (i.e. longer reading times in distractor-mismatch than distractor-match sentences; e.g. Cunnings & Felser, 2013; Sturt, 2003).

Not only inhibitory interference, but also facilitatory interference has been actively debated in online reflexive resolution. This active debate is due to inconsistent findings between reflexive resolution and subject-verb agreement reported in previous studies. Specifically, some studies have observed that reflexive resolution is resistant to facilitatory interference (e.g. see Cunnings & Sturt, 2014; Dillon et al., 2013; Felser et al., 2009; Felser & Cunnings, 2012; King et al., 2012; Parker & Phillips, 2017; Sloggett, 2017; Sturt, 2003; Xiang et al., 2009). The most compelling evidence for the differential susceptibility of reflexive resolution and subject-verb agreement to facilitatory interference comes from Dillon et al. (2013), who directly compared the two dependencies and observed facilitatory interference only in subject-verb agreement. However, a recent study by Jäger et al. (2020) with a larger number of participants observed similar facilitatory interference effects for both dependencies in total viewing times, although no facilitatory interference was observed in an earlier processing measure (first-pass regression). These findings suggest that online reflexive resolution is susceptible to facilitatory interference during later processing stages.

So far, we have discussed the controversial evidence for susceptibility to similarity-based interference in online reflexive resolution. As mentioned in the introduction, there is also a lively debate about whether similarity-based interference is affected by the structural position of a distractor (Parker & An, 2018; Van Dyke & McElree, 2011). Parker and An (2018) investigated the influence of distractor position in subject-verb agreement, as follows, and argued that subject/object positions nullify interference effects.

(5a) [$_{NP1}$ The waitress who sat [$_{NP2}$ the girl(s)]] unsurprisingly were unhappy about noise.
(5b) [$_{NP1}$ The waitress who sat near [$_{NP2}$ the girl(s)]] unsurprisingly were unhappy about noise.

In (5a/b), number agreement between NP1 and "were" is violated, rendering these sentences ungrammatical. NP2 is a distractor and either matches or mismatches the verb in number. The cue-based hypothesis predicts facilitatory interference in (5a/b) when the distractor is plural. Crucially, the distractor in (5a) is a direct object of the verb "sat". In (5b), the distractor is not in a subject or object position but within an adjunct prepositional phrase. Parker and An hypothesised that a distractor in a subject/object position would be encoded distinctively during sentence processing because it plays a crucial role in sentence meaning. The parser would therefore be able to easily reject such a distractor as a retrieval candidate, resulting in the absence of facilitatory interference. In this paper, we confine subject and object positions to the specifier of a TP or the complement of a V. Parker and An conducted self-paced reading experiments and found facilitatory interference only in (5b) when the distractor was in the adjunct prepositional phrase, a finding consistent with their hypothesis. However, there are several studies showing interference effects when a distractor is in a subject/object position. (e.g. Fujita & Cunnings, 2023a, 2023b; Lago et al., 2015; Tucker et al., 2015, 2021; Wagers et al., 2009). These studies raise a question about the influence of subject/object positions on interference.

The present study

Below, we report the results of four experiments (Experiments 1–4) conducted using L-maze tasks to investigate similarity-based interference in online reflexive resolution. In Experiment 1, a distractor was embedded within an adjunct prepositional phrase (i.e. a non-subject/object position). In Experiment 2, the distractor occupied an object position, while Experiment 3 utilised sentences akin to those in Experiment 1 with the aim of replicating the results. In Experiment 4, we directly compared facilitatory interference from object and non-object positions to elucidate the influence of distractor position on memory retrieval. Throughout Experiments 1–4, we followed many previous studies (see Jäger et al., 2017) and positioned the distractor after the structurally accessible antecedent of the reflexive. Considering prior research suggesting that interference effects can be difficult to observe with small sample sizes (e.g. Jäger et al., 2020), each experiment involved a relatively large number of participants (Experiment 1 = 144, Experiment 2 = 224, Experiment 3 = 144, Experiment 4 = 140; the rationale for the larger participant count in Experiment 2 will be discussed later in this paper).

Experiment 1

Experiment 1 tested sentences, as in (6a–d) below, to investigate similarity-based interference during online reflexive resolution.

(6a) *Grammatical, Distractor match*Which lady near Jenny needed to prepare herself for the meeting?
(6b) *Grammatical, Distractor mismatch*Which lady near Henry needed to prepare herself for the meeting?
(6c) *Ungrammatical, Distractor match*Which man near Jenny needed to prepare herself for the meeting?
(6d) *Ungrammatical, Distractor mismatch*Which man near Henry needed to prepare herself for the meeting?

(6a/b) are grammatical, while (6c/d) are ungrammatical due to gender disagreement between the reflexive ("herself") and its structurally accessible antecedent ("Which lady/man … "). A distractor ("Jenny/Henry") is inside an adjunct prepositional phrase, not in a subject/object position. This distractor either matches or mismatches the reflexive in gender.

If online reflexive resolution obeys structural constraints, ungrammatical sentences (6c/d) should cause longer reading times at the reflexive than grammatical sentences (6a/b) due to ungrammaticality effects (e.g. Sturt, 2003). The cue-based hypothesis predicts longer reading times at the reflexive in (6a) than in (6b) due to inhibitory interference and shorter reading times in (6c) than in (6d) because of facilitatory interference (Vasishth & Engelmann, 2021).

Participants

Experiment 1 had 144 participants who were recruited via Prolific (https://www.prolific.co). All participants were between 18 and 40 years old, British citizens, grew up in the UK and spoke English as their native language.

Materials

Experiment 1 included 24 sets of experimental sentences, as illustrated in (6a–d), and 72 filler sentences consisting of various syntactic structures. None of these fillers had a reflexive.

Procedure

We measured reading times for each word with a L-maze task (Forster et al., 2009; Witzel et al., 2012) in IbexFarm (https://github.com/addrummond/ibex). In this task, participants read each sentence, presented as a sequence of paired words, by selecting a word that

continued the sentence. When participants made an incorrect choice, a warning message appeared, and the trial was terminated. The first four sentences were practice trials, and the experiment lasted approximately 25 min. The maze task was created using code available online (Boyce et al., 2020; Fujita, 2021a).

Data analysis

We analysed log-transformed reading times of correctly selected words at the reflexive ("herself") and post-reflexive ("for") regions as the dependent variable in R (R Core Team, 2022). Before data analysis, reading times shorter than 200 milliseconds or longer than 5000 milliseconds were excluded, as these data points (less than 0.01% of the data) likely index lapses in attention. For data analysis, linear mixed models were fit using the lme4 package (Bates et al., 2015). Fixed effects were sum-coded (.5/–.5) main effects of grammaticality (grammatical or ungrammatical) and distractor (gender match or gender mismatch), and their interaction. The models also included random intercepts for participants and materials and all relevant slopes for participants and materials. When this maximal model (Barr et al., 2013) failed to converge, we initially removed the random effect correlations and then iteratively removed the random effect with the smallest variance until the model converged. We estimated *p* values from the *t* distribution (Baayen, 2008) and interpreted *p* values smaller than .05 as significant. When a significant interaction appeared, it was examined with an additional model containing nested contrasts.

Results

Inferential statistics are summarised in Table 1, and reading times at the (post-)reflexive regions are illustrated in Figure 1.

Reflexive region

There was a significant main effect of grammaticality, with longer reading times in the ungrammatical than grammatical conditions, suggesting ungrammaticality effects. Although numerically, there appeared to be some distractor effect, the main effect of distractor was not statistically significant. There was also no significant interaction between grammaticality and distractor.

Post-reflexive region

There was a significant main effect of grammaticality, suggesting ungrammaticality effects. Analysis also showed a significant main effect of distractor and a significant grammaticality by distractor interaction. As a follow-up analysis, we examined distractor effects within each level of grammaticality. This analysis showed a significant distractor effect in the ungrammatical conditions, suggesting reduced ungrammaticality

Table 1. Inferential statistics for Experiment 1.

	Reflexive region				Post-reflexive region			
	Estimate	SE	*t*	*p*	Estimate	SE	*t*	*p*
Intercept	6.642	0.02	428.08	<.001	6.574	0.02	381.87	<.001
Grammaticality	**–0.077**	**0.01**	**–7.14**	**<.001**	**–0.042**	**0.01**	**–4.66**	**<.001**
Distractor	–0.018	0.01	–1.77	.077	**–0.025**	**0.01**	**–2.59**	**.010**
Grammaticality x Distractor	–0.004	0.02	–0.21	.837	**0.041**	**0.02**	**2.20**	**.028**
Distractor: Grammatical conditions	–	–	–	–	–0.005	0.01	–0.35	.728
Distractor: Ungrammatical conditions	–	–	–	–	**–0.045**	**0.01**	**–3.19**	**.001**

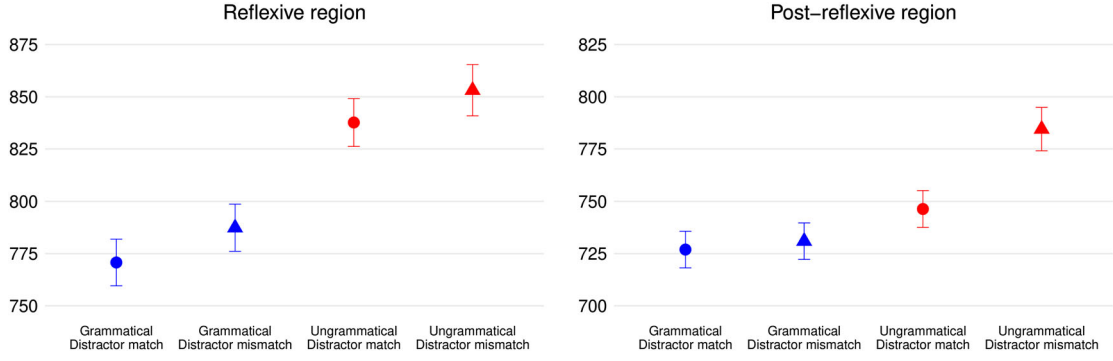

Figure 1. Reading times in milliseconds at the (post-)reflexive regions in Experiment 1. Error bars are standard errors.

effects when the distractor matched the reflexive in gender. There was, however, no distractor effect in the grammatical conditions.

Discussion

The results showed ungrammaticality effects at the (post-)reflexive regions, suggesting that the parser searches for the structurally accessible antecedent of a reflexive immediately after encountering it. At the reflexive, there was some numerical trend towards a main effect of distractor, but this effect was not statistically significant. The post-reflexive region showed a significant grammaticality by distractor interaction due to reduced ungrammaticality effects when the distractor matched the reflexive in gender. This interference pattern is consistent with facilitatory interference, as predicted by the cue-based hypothesis. However, there were no interference effects in grammatical sentences, suggesting the grammatical asymmetry (Wagers et al., 2009). These observations suggest that online reflexive resolution is susceptible to facilitatory interference and may be insusceptible to inhibitory interference, a finding compatible with Jäger et al. (2020).

In Experiment 2, we investigated whether a distractor in an object position causes similarity-based interference. Recall that Parker and An (2018) examined subject-verb agreement and found facilitatory interference only with a distractor in a non-subject\object position, and our Experiment 1 had a distractor in a similar position. Experiment 2 had a larger sample size than Experiment 1 because there was a numerical trend towards a main effect of distractor at the reflexive, and we aimed to investigate if the absence of a significant main effect of distractor was due to a lack of statistical power.

Experiment 2

In Experiment 2, we investigated similarity-based interference with a distractor as a direct object of a verb as follows.

(7a) *Grammatical, Distractor match*The girl who woke up Jenny dressed herself quickly after breakfast.

(7b) *Grammatical, Distractor mismatch*The girl who woke up Henry dressed herself quickly after breakfast.

(7c) *Ungrammatical, Distractor match*The boy who woke up Jenny dressed herself quickly after breakfast.

(7d) *Ungrammatical, Distractor mismatch*The boy who woke up Henry dressed herself quickly after breakfast.

(7a–d) contain a reflexive, whose structurally accessible antecedent is the matrix subject NP ("The girl/boy … "). There is also a distractor ("Jenny/Henry") in an object position. These NPs either match or mismatch the reflexive in gender.

Ungrammaticality effects were expected at the reflexive, with longer reading times in (7c/d) than in (7a/b). The cue-based hypothesis makes the same predictions as those for Experiment 1, i.e. inhibitory interference in (7a) and facilitatory interference in (7c). However, if a distractor in an object position resists similarity-based interference, these interference effects should be absent (Parker & An, 2018).

Participants

Experiment 2 included 224 participants recruited via Prolific from the same participant pool as in Experiment 1. None of these participants took part in Experiment 1.

Materials

Materials consisted of 24 sets of experimental sentences, as in (7a–d), and 72 fillers sentences.

Procedure and data analysis

The procedure and data analysis were identical to those of Experiment 1.

Results

Table 2 shows inferential statistics, and Figure 2 illustrates reading times at the (post-)reflexive regions.

Table 2. Inferential statistics for Experiment 2.

	Estimate	SE	*t*	*p*	Estimate	SE	*t*	*p*
Intercept	6.628	0.01	463.29	<.001	6.613	0.02	327.18	<.001
Grammaticality	**−0.079**	**0.01**	**−8.65**	**<.001**	**−0.051**	**0.01**	**−7.25**	**<.001**
Distractor	−0.013	0.01	−1.55	.120	−0.006	0.01	−0.88	.376
Grammaticality x Distractor	0.017	0.01	1.12	.264	0.016	0.01	1.17	.244

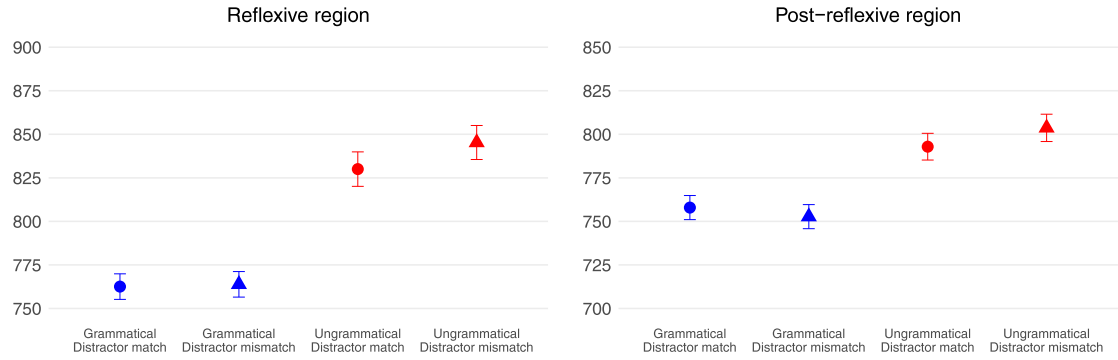

Figure 2. Reading times in milliseconds at the (post-)reflexive regions in Experiment 2. Error bars are standard errors.

Reflexive region

There was a significant main effect of grammaticality, suggesting ungrammaticality effects. The other effects were not statistically significant.

Post-reflexive region

Similar to the reflexive region, the post-reflexive region revealed a significant main effect of grammaticality, showing ungrammaticality effects. The other effects were not statistically significant.

Discussion

Consistent with Experiment 1, Experiment 2 observed ungrammaticality effects at the (post-)reflexive regions, suggesting the online application of structural constraints in reflexive resolution. Crucially, there were no significant interference effects. These observations are consistent with the hypothesis that a distractor serving as a direct object of a verb resists similarity-based interference in online reflexive resolution.

In Experiment 3, we further aimed to replicate the results of Experiment 1 by testing similar sentences. Recall that Experiment 1 demonstrated clear facilitatory interference only at the post-reflexive region, while the reflexive region exhibited ungrammaticality effects, with a subtle numerical trend towards a main effect of distractor. A minor distinction between Experiments 1 and 3 is that the reflexive is closer to the distractor in Experiment 3, which may show clear interference effects at the reflexive, given the time-based decay predicted by the cue-based hypothesis, as mentioned in the introduction.

Experiment 3

Experiment 3 tested sentences, as below, to further investigate similarity-based interference.

(8a) *Grammatical, Distractor match*Which lady near Jenny prepared herself for the meeting?
(8b) *Grammatical, Distractor mismatch*Which lady near Henry prepared herself for the meeting?
(8c) *Ungrammatical, Distractor match*Which man near Jenny prepared herself for the meeting?
(8d) *Ungrammatical, Distractor mismatch*Which man near Henry prepared herself for the meeting?

These sentences closely resemble those used in Experiment 1, differing solely in the proximity of the reflexive to the distractor. We expected ungrammaticality effects and similarity-based interference similar to those observed in Experiment 1. However, if the numerical trend towards distractor effects observed at the reflexive in Experiment 1 indicates interference effects, reading times at the reflexive are expected to be longer in the distractor-match conditions than in the distractor-mismatch conditions, regardless of grammaticality. We also predicted that clear interference effects might be observed in Experiment 3 given the closer proximity of the reflexive to the distractor.

Participants

We recruited 144 participants from the same participant pool as in Experiments 1/2 via Prolific. These participants had not taken part in Experiments 1/2.

Materials

Experiment 3 contained 24 sets of experimental sentences, as in (8a–d), and 72 fillers.

Procedure and data analysis

The procedure and data analysis were the same as in Experiments 1/2.

Results

Table 3 shows inferential statistics, and Figure 3 illustrates reading times at the (post-)reflexive regions.

Reflexive region

There was a significant main effect of grammaticality, suggesting ungrammaticality effects. There were also a significant main effect of distractor and a significant grammaticality by distractor interaction. A follow-up analysis examining distractor effects within each level of grammaticality showed reduced ungrammaticality effects when the distractor matched the reflexive in gender. For the grammatical conditions, distractor effects were not statistically significant.

Post-reflexive region

There was a significant main effect of grammaticality, suggesting ungrammaticality effects. The main effect of distractor and the grammaticality by gender interaction were not statistically significant.

Discussion

Experiment 3 showed statistically similar results to Experiment 1. Specifically, ungrammaticality effects were observed at the (post-)reflexive regions, suggesting that the parser adheres to structural constraints during online reflexive resolution. Also, there was no significant inhibitory interference. A slight distinction from Experiment 1 is the presence of facilitatory interference at the reflexive region in Experiment 3, whereas in Experiment 1, clear facilitatory interference was confined to the post-reflexive region. Below, we present the final experiment, aiming to directly examine the influence of object and non-object positions on facilitatory interference.

Experiment 4

Experiment 4 examined sentences as below to further investigate whether distractor position influences facilitatory interference.

(9a) *Preposition, Distractor match*The lady near John dressed himself for the party.
(9b) *Preposition, Distractor mismatch*The lady near Mary dressed himself for the party.
(9c) *Direct object, Distractor match*The lady phoning John dressed himself for the party.
(9d) *Direct object, Distractor mismatch*The lady phoning Mary dressed himself for the party.

These sentences are similar to ungrammatical sentences used in Experiments 1–3, where the reflexive mismatches its structurally accessible antecedent in gender, and the distractor either matches or mismatches the reflexive's gender. Crucially, in (9a/b), the distractor is embedded within a prepositional phrase, while in (9c/d), it is in a direct object position of a verb. If

Table 3. Inferential statistics for Experiment 3.

	Estimate	SE	*t*	*p*	Estimate	SE	*t*	*p*
Intercept	6619	0.01	462.62	<.001	6.542	0.02	361.64	.001
Grammaticality	**−0.072**	**0.02**	**−4.43**	**<.001**	**−0.039**	**0.01**	**−3.91**	**<.001**
Distractor	**−0.036**	**0.01**	**−2.56**	**.011**	−0.011	0.01	−1.26	.210
Grammaticality x Distractor	**0.074**	**0.02**	**4.02**	**<.001**	0.035	0.02	1.95	.051
Distractor: Grammatical conditions	0.001	0.01	0.11	.912	–	–	–	–
Distractor: Ungrammatical conditions	**−0.072**	**0.02**	**−3.64**	**<.001**	–	–	–	–

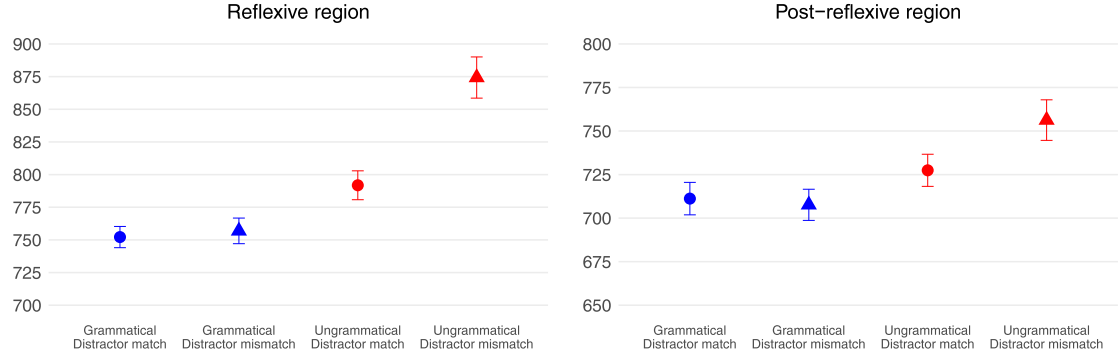

Figure 3. Reading times in milliseconds at the (post-)reflexive regions in Experiment 3. Error bars are standard errors.

memory retrieval is influenced by distractor position, as suggested by Parker and An (2018) and Experiment 2 of our study, facilitatory interference should be present only in (9a) and absent in (9c).

Participants

In Experiment 4, 140 participants were recruited from the same participant pool as in Experiments 1–3 via Prolific. These participants had not taken part in Experiments 1–3.

Materials

The materials were 24 sets of experimental sentences, as in (9a–d), and 72 fillers.

Procedure and data analysis

The procedure and data analysis were the same as in Experiments 1–3, except that the models contained a fixed effect of position (preposition or direct object) instead of grammaticality.

Results

Inferential statistics are summarised in Table 4, and reading times at the (post-)reflexive regions are visualised in Figure 4.

Reflexive region

There was a significant main effect of distractor, suggesting shorter reading times in the distractor-match conditions than in the distractor-mismatch conditions. This effect indicates facilitatory interference. The position by distractor interaction was not statistically significant.

Post-reflexive region

No effects were statistically significant.

Discussion

Experiment 4 revealed facilitatory interference, irrespective of distractor position. This finding is compatible with Experiments 1 and 3, but incompatible with Experiment 2, which had a distractor in an object position and showed no clear facilitatory interference. Below, we discuss the implications of the findings from Experiments 1–4.

General discussion

The present study aimed to investigate similarity-based interference in online reflexive resolution, while also considering the potential influence of distractor position.

Across Experiments 1–3, we constantly observed ungrammaticality effects at the reflexive. These findings are consistent with numerous previous studies (e.g. Sturt, 2003), indicating that online reflexive resolution is a structure dependent process. Regarding

Table 4. Inferential statistics for Experiment 4.

	Reflexive region				Post-reflexive region			
	Estimate	SE	*t*	*p*	Estimate	SE	*t*	*p*
Intercept	6.738	0.03	268.24	<.001	6.612	0.02	340.22	<.001
Position	−0.004	0.01	−0.35	.729	0.016	0.01	1.75	.081
Distractor	**−0.066**	**0.02**	**−2.70**	**.007**	−0.012	0.01	−1.23	.218
Position x Distractor	0.004	0.02	0.21	.836	0.004	0.02	0.20	.840

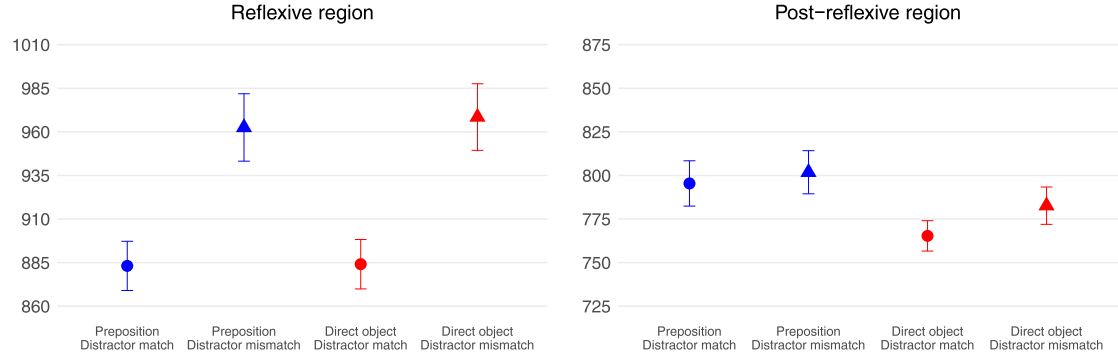

Figure 4. Reading times in milliseconds at the (post-)reflexive regions in Experiment 4. Error bars are standard errors.

similarity-based interference, Experiments 1 and 3 revealed (delayed) facilitatory interference, while facilitatory interference was absent in Experiment 2, where a distractor served as a direct object of a verb within a finite clause. However, Experiment 4 exhibited clear facilitatory interference, irrespective of the distractor's position. Notably, no significant similarity-based interference was observed in grammatical sentences within the present study.

The findings of facilitatory interference contradict the hypothesis that online reflexive resolution resists similarity-based interference but align with a recent study by Jäger et al. (2020), who observed facilitatory interference in a late eye-movement measure. Jäger et al. showed that the estimated statistical power for facilitatory interference was at most around 25% with 40 participants. Jäger et al. recruited 181 participants and observed facilitatory interference. Given that Experiments 1, 3, and 4 of the present study had a comparable number of participants to Jäger et al., it is sensible to claim that online reflexive resolution is susceptible to facilitatory interference, at least under certain circumstances. This claim is compatible with the cue-based hypothesis (Lewis & Vasishth, 2005).

As noted above, our study yielded several other findings about facilitatory interference. Firstly, Experiment 2 showed no significant facilitatory interference when a distractor was in an object position. This finding is compatible with Parker and An (2018), who observed facilitatory interference in subject-verb agreement when a distractor was within an adjunct prepositional phrase but not when it was a direct object of a verb. As discussed in the introduction, Parker and An argue that a distractor in a subject/object position plays a crucial role in sentence interpretations and thus is encoded distinctively; as a result, such a distractor is easily rejected as a retrieval candidate. This hypothesis might account for the results of Experiment 2. However, as noted in the introduction, some studies have observed facilitatory interference even when a distractor occupied a subject/object position, suggesting that the influence of subject/object positions on similarity-based interference is not a decisive phenomenon (e.g. Fujita & Cunnings, 2023; Lago et al., 2015; Wagers et al., 2009). Crucially, Experiment 4, which directly compared interference effects from object and non-object positions, observed clear facilitatory interference, irrespective of distractor position. This experiment similarly indicates that distinctions between object and non-object positions alone do not influence similarity-based interference.

The facilitatory interference observed in Experiment 4 and its absence in Experiment 2 may be attributed to the distractor not only serving as a direct object of a verb but also being embedded within a finite clause in Experiment 2, in contrast to Experiment 4. Existing literature, particularly in language production studies, suggests that interference effects are reduced when a distractor is located in a finite clause (e.g. Bock & Cutting, 1992). Indeed, when facilitatory interference was not observed in Parker and An (2018), a distractor was both a direct object of a verb and within a finite clause. Some previous studies, including those by Cunnings and Sturt (2014), Dillon et al. (2013) and Jäger et al. (2020) (in an early eye-movement measure), have also reported no facilitatory interference in online reflexive resolution under such conditions. Hence, it is conceivable that the combination of clause finiteness and distractor position plays a role in influencing facilitatory interference, either reducing or nullifying its effect. Since Experiment 4 demonstrated clear facilitatory interference with a distractor serving as a direct object of a verb within a non-finite clause, we propose that a distractor in an object position does not necessarily nullify facilitatory interference in online reflexive resolution. Further investigation into the interplay of clause finiteness and distractor position in online memory retrieval presents a promising avenue for future research.

Another important finding about facilitatory interference is the temporal aspect of its effects. In Experiment 1, ungrammaticality effects surfaced at the reflexive region, whereas facilitatory interference manifested only at the post-reflexive region. In contrast, Experiments 3 and 4 exhibited both effects at the reflexive region. How can we account for these discrepancies in the timing of interference effects? One possible account is that interference effects typically exhibit delays (Fujita & Cunnings, 2023b; Lago et al., 2015; Parker & Phillips, 2017; Sturt, 2003), at least in online reflexive resolution (Jäger et al., 2020). However, maze tasks do not consistently capture these delayed effects, given that the effects observed in maze tasks often appear localised (Forster et al., 2009). Alternatively, the delayed interference effects observed in Experiment 1 may be attributed to the focus of attention on the distractor in memory. Suppose that facilitatory interference emerges after the parser attempts to establish coreference between the reflexive and its structurally accessible antecedent, during the search for another NP to interpret the reflexive (to be discussed in more detail later). When a distractor has been recently encountered (Experiments 3/4), the parser can quickly retrieve its information from memory. However, when it has not (Experiment 1), it may take the parser some time to locate it. This temporal lag might explain why we observed clear facilitatory interference only at the post-reflexive region in Experiment 1.

In contrast with facilitatory interference, we did not observe inhibitory interference across Experiments 1–3. That is, in the grammatical conditions, similar reading times were observed irrespective of whether a distractor matched or mismatched the reflexive in gender. This finding is inconsistent with the cue-based hypothesis but consistent with studies showing the grammatical asymmetry (e.g. Wagers et al., 2009).

Descriptively, the findings described above are most consistent with one of the proposals made by Wagers et al. (2009) that the cue-based memory retrieval is initiated only when no elements fully match retrieval cues. However, the reasoning behind this proposal is not compatible with online reflexive resolution. Recall that Wagers et al. propose, based on subject-verb agreement, that sentence processing may be insusceptible to inhibitory interference but susceptible to facilitatory interference because the parser predicts a verb after encountering the sentence subject NP. If this top-down expectation matches in number the verb that the parser actually encounters, no cue-based retrieval is required, resulting in the absence of inhibitory interference in subject-verb agreement. However, as mentioned in the introduction, the parser is unlikely to predict a reflexive, and some bottom-up memory retrieval is required during online reflexive resolution. Therefore, we cannot use the proposal made by Wagers et al. to interpret our results.

One possible account of our findings is that the parser gives weight to structural information during online reflexive resolution and retrieves a distractor only as a last resort for interpretive reasons (see also Dillon, 2014; Parker & Phillips, 2017). Specifically, upon encountering a reflexive, the parser initially searches for its antecedent based on structural relations. If no grammatical antecedent is identified, for example, due to the violation of gender agreement, the parser (sometimes) shifts its focus to locating a different NP that could be used to interpret the reflexive. This hypothesis could be applicable to the grammatical asymmetry observed in number agreement (Wagers et al., 2009) and accords well with some previous studies (e.g. Jäger et al., 2020; Sturt, 2003) and Experiment 1 in terms of a delay in interference. If the parser initially searches for a structurally licensed element, and a distractor plays a role later, we can explain why studies sometimes show delayed interference effects.

Conclusion

In the present study, we investigated similarity-based interference in online reflexive resolution. Our results showed that, upon encountering a reflexive, the parser attempts to form a coreference relation with its structurally accessible antecedent. Our study showed that online reflexive resolution is susceptible to (delayed) facilitatory interference even when a distractor was a direct object of a verb in a non-finite clause. However, we observed that distractor position and clause finiteness may combine to influence memory retrieval. Also, we did not find significant inhibitory interference. We interpreted our findings as indicating that the parser initially attempts to establish coreference relations based on structural constraints, and when there is no grammatical antecedent, it searches for another NP to interpret the reflexive, leading to interference effects.

Notes

1. There are different cue-based hypotheses (e.g., see Vasishth et al., 2019). This study focuses on the activation-based cue-based hypothesis (Lewis & Vasishth, 2005; Vasishth & Engelmann, 2021).
2. Encoding relational information as a feature may pose computational challenges (Kush, 2013). For the purpose of discussing the cue-based hypothesis, we will set aside these challenges and assume the existence of a computationally feasible encoding process that establishes connections between reflexives and their antecedents or encodes c-command relations (Alcocer & Phillips, 2012). Also, for expository purposes, we will focus only on the structure-based cue and the gender-based cue.

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Consent to participate

Informed consent was obtained from all participants in the study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Ethical approval

This study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki.

Data availability

Data, materials and analysis code used in the study are available at https://osf.io/ehf43/.

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