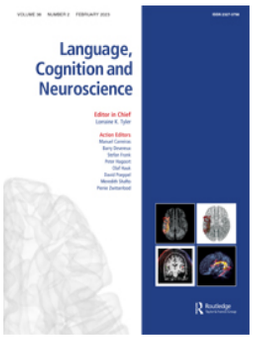
Interference in quantifier float and subject-verb agreement



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Interference in quantifier float and subject-verb agreement

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ABSTRACT

When forming a dependency between two elements of a sentence, the processor must retrieve a grammaticality licensed element from memory. Previous research has suggested that this dependency formation is susceptible to interference from structurally unlicensed elements. However, there has been debate on why dependency formation is susceptible to interference and whether interference arises in only certain dependencies or not. The present study addressed these issues in four self-paced reading experiments and four speeded judgement experiments by investigating a well-examined dependency, namely subject-verb agreement, and so-called quantifier float, which remains unexplored in existing sentence processing research. Our results largely suggested interference in ungrammatical sentences, but we did not find clear interference effects in grammatical sentences. We argue that both subject-verb agreement and quantifier float are similarly susceptible to interference when the processor initiates cue-based memory retrieval and retrieves a structurally unlicensed element due to difficulties forming grammatically licit dependencies.

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Dependency formation; interference; quantifier float; language comprehension; sentence processing

Introduction

A central goal of sentence processing research is to elucidate how the processor forms a dependency relation between two elements during online sentence processing. For example, sentence (1) below involves subject-verb dependency formation.

(1) The sister of the girls was walking back home.

This sentence contains an auxiliary, "was", with which the processor must associate the sentence subject. The auxiliary must agree with the noun phrase, "The sister", in number (e.g. *The sister was/The sisters were*). We refer to a noun phrase like "The sister" that precedes the auxiliary and controls its number feature as *a controller*. To form the subject-verb dependency in (1), the processor must construct grammatical structures, encode in memory information of each element it encounters and, when the auxiliary appears, retrieve the controller from memory. There is substantial evidence that the processor constructs grammatical structures during sentence processing (Cunnings & Fujita, 2021b; Dillon et al., 2013; Frazier et al., 2015; Fujita, 2021; in press; Fujita & Cunnings, 2020, 2021a, 2021b; Hall & Yoshida, 2021; Kazanina et al., 2007; Kush et al., 2017; Kush & Dillon, 2021; Omaki & Schulz, 2011; Sturt, 2003; Wagers & Phillips, 2009; Yoshida et al., 2014). However, research has also observed that dependency formation does not always abide by structural constraints (Hammerly et al., 2019; Pearlmutter et al., 1999; Wagers et al., 2009), such that structurally unlicensed elements (*distractors*) sometimes interfere with dependency formation. In sentence processing research, this interference effect has been often reported in ungrammatical sentences like (2a/2b) below.

(2a) *The sister of the girls were walking back home.
(2b) *The sister of the girl were walking back home.

Sentences (2a/2b) are ungrammatical because the auxiliary and its controller disagree in number. Such ungrammatical sentences are known to cause processing difficulty at "were" and be judged as unacceptable (*number mismatch effects*; Pearlmutter et al., 1999; Wagers et al., 2009). Crucially, (2a/2b) contain a distractor, which the auxiliary's number matches in (2a; "the girls were") and mismatches in (2b; "the girl were"). Studies have shown reduced number mismatch effects

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in (2a) relative to (2b), indicating interference from the distractor (e.g. Wagers et al., 2009).

Why does interference arise in (2a/2b)? One account is that when initiating memory retrieval, the processor utilises a cue-based retrieval mechanism that combines structure-based and number-based information as retrieval cues (e.g. Lewis et al., 2006; Lewis & Vasishth, 2005; Van Dyke & Lewis, 2003; but see Kush, 2013). This cue-based account predicts that interference arises when a distractor shares feature(s) to the retrieval cues. For example, in (2a/2b), the auxiliary's controller only partially matches the retrieval cues because it disagrees with the auxiliary in number. Crucially, the distractor matches the number cue in (2a) owing to its plural feature, but does not match in number in (2b). Consequently, cue-based memory retrieval accounts predict occasional misretrievals of the distractor in (2a), which results in reduced number mismatch effects relative to (2b).

A second set of models, dubbed representational accounts, considers the source of interference to be at the encoding phase rather than during memory retrieval. These accounts posit that when the distractor is encoded in memory in (2a), its plural feature affects the representation of number of the sentence subject noun phrase (Bock & Eberhard, 1993; Eberhard et al., 2005). Specifically, representational accounts assume that the distractor's plural feature either percolates up to the head noun or renders the entire noun phrase less singular. Consequently, when the processor checks number agreement at the auxiliary in (2a), reduced number mismatch effects ensue. In representational accounts, interference effects from a distractor (or an attractor) are known as *attraction*. However, in this paper, we use "interference" as a general term for the phenomenon that a distractor interferes with dependency formation. Although representational accounts have developed primarily in the literature of language production, there have been attempts to extend them to language comprehension.

Although interference has been widely examined in subject-verb agreement, in this study we examined interference in a different linguistic phenomenon, namely *quantifier float*. In quantifier float constructions, as in *The sisters of the girl all went back home*, a quantifier ("all") modifies a noun phrase ("The sisters") but is not adjacent to it. Therefore, akin to subject-verb agreement in (1/2), quantifier float requires long-distance dependency formation, but whether this dependency is susceptible to interference has not been examined. Indeed, there has been debate regarding whether interference effects vary across dependency types (e.g. Dillon et al., 2013; Kush et al., 2015; Orth et al., 2021; Pasquereau et al., in press; Wagers et al., 2009). Thus, the first aim of our study was to assess the generalisability of interference effects during sentence processing. We examined this by testing interference in quantifier float constructions. A second aim of our study was to tease apart cue-based and representational accounts of interference effects. Although examining quantifier float does not provide a unique way to tease these theories apart, it does provide a novel way of assessing these competing accounts.

A third aim was to tease apart competing cue-based retrieval models. In the literature, there has been a debate on how the processor initiates cue-based retrieval. Traditional cue-based accounts as described above assume that the processor initiates memory retrieval whenever dependency formation is required and predicts interference in grammatical and ungrammatical sentences (e.g. Lewis & Vasishth, 2005). Recently, Wagers et al. (2009) however argued that the processor initiates cue-based memory retrieval only when no element in a sentence fully matches the retrieval cues. According to this account, cue-based retrieval is an error-driven process that occurs only when a mismatch in features between an agreement controller and dependent element is detected. Our third aim was to test these competing cue-based accounts.

Our fourth and final aim was to examine the extent to which the structural position of a distractor influences interference, as it has been argued that interference effects may be dependent on where a distractor appears (Bock & Cutting, 1992; Parker & An, 2018). To this aim, we compared interference in prepositional phrases and relative clauses.

For these four aims, we conducted four self-paced reading tasks and four speeded judgement tasks that compare interference in quantifier float and subject-verb agreement across different constructions. The overall results suggest similar interference in ungrammatical but not in grammatical sentences between subject-verb agreement and quantifier float dependencies. Also, we did not find clear differences in interference between relative clauses and prepositional phrases. These findings suggest that the processor initiates cue-based memory retrieval only in ungrammatical sentences (Wagers et al., 2009). Below, we initially describe the cue-based memory retrieval and representational accounts, before discussing quantifier float.

Cue-based memory retrieval accounts

There are multiple models that implement cue-based memory retrieval in their computational architecture in the context of sentence processing (e.g. Lewis et al.,

2006; Van Dyke & Lewis, 2003; Vasishth et al., 2019). We focus on the cue-based memory retrieval model implemented by Engelmann et al. (2019) and Lewis and Vasishth (2005), which posits that when the processor encounters an element of a dependency relation such as "were" in (2a/2b), it uses features of the element as retrieval cues to retrieve the controller. When multiple elements in memory that appear in the left context match these features, interference results. The cue-based retrieval model predicts reduced number mismatch effects in (2a) because it posits that when the structurally licensed element and a distractor partially match retrieval cues as in (2a), the processor attempts to access them in parallel. When this retrieval process occurs, the distractor gets retrieved on some proportion of trials. In these trials, retrieval times become faster in (2a), relative to when the distractor does not match the number cue as in (2b). We will refer to this reduced number mismatch effect as *facilitatory interference* (Jäger et al., 2017).

In addition to facilitatory interference, the cue-based retrieval model also predicts another type of interference called *inhibitory interference* (Jäger et al., 2017) in grammatical sentences like (1), repeated here as (3b), compared to (3a).

(3a) The sister of the girl was walking back home.
(3b) The sister of the girls was walking back home.

Unlike in ungrammatical sentences like (2a/2b), in (3a/3b), the controller fully matches the retrieval cues at the auxiliary. Crucially, the distractor in (3a) is singular and thus matches the auxiliary in number. According to the cue-based retrieval model, this partial match elicits competition between the controller and the distractor, causing interference with memory retrieval at "was". This is known as *inhibitory interference* and predicts longer reading times in (3a) than (3b) (Nicenboim et al., 2018).

Many studies have tested the cue-based retrieval model, but their findings are not consistent. While there is substantial evidence that subject-verb dependency formation is susceptible to facilitatory interference, evidence of inhibitory interference is inconclusive (Cunnings & Fujita, 2021a; Cunnings & Sturt, 2018; Dillon et al., 2013; González Alonso et al., 2021; Jäger et al., 2020; Kim et al., 2020; Lago et al., 2015; Nicenboim et al., 2018; Orth et al., 2021; Patil et al., 2016; Tanner et al., 2014; Van Dyke, 2007; Wagers et al., 2009). Wagers et al. (2009) argued that dependency formation is susceptible to only facilitatory interference because the processor engages in cue-based memory retrieval and retrieves a distractor only when there is no grammatical controller, as in (2a/2b). According to Wagers et al., upon encountering the sentence subject noun phrase (e.g. *The sister*), the processor stores it in memory, maintains it and predicts a matrix verb marked with the appropriate agreement features (e.g. $[_{TP}$ $[_{NP}$ The sister] $[_{VP}$ verb-SG]]; see Abney & Johnson, 1991; Crocker, 1996; Fujita, in press; Yoshida et al., 2013 for discussion on predictive structure building). Predicting the matrix verb is possible because the predicate is necessary for the sentence to be grammatical (Crocker, 1996; Fujita, in press; Gibson, 1991; Weinberg, 1999). When the matrix verb appears (e.g. *walks*), the processor checks its features against the predicted ones, and if they match, the processor forms a dependency between the verb and the noun phrase in memory. Thus, inhibitory interference is not expected in grammatical sentences because the processor does not need to initiate cue-based memory retrieval. When a feature-mismatching verb appears (e.g. *walk*), the processor attempts to retrieve its controller from memory using the verb's features as retrieval cues. It is at this checking stage that Wagers et al. predict that the processor may misretrieve a distractor matching the verb in number, and thereby causing facilitatory interference.

Alternatively, Nicenboim et al. (2018) suggested that many previous studies failed to observe inhibitory interference because they did not have enough statistical power. However, there is also evidence that facilitatory interference does not always arise (Dillon et al., 2013; Kush et al., 2015; Orth et al., 2021; Parker & An, 2018), although the absence of facilitatory interference may be also due to the lack of statistical power (Jäger et al., 2020). For example, Parker and An (2018) investigated whether the distractor's argument status influences interference effects as below.

(4a) *The lady who sat the girl(s) were looking tired.
(4b) *The lady who sat near the girl(s) were looking tired.

These sentences are ungrammatical due to the number mismatch between the auxiliary and its controller. (4a/4b) manipulate whether the distractor is a core argument of the embedded verb, as in (4a), or an oblique argument, which appears inside a prepositional phrase (4b). In a self-paced reading experiment, Parker and An (2018) observed facilitatory interference in (4b) but not in (4a), suggesting the potential role that the distractor's argument status plays in interference effects. Specifically, they argued that interference effects disappear when the distractor is a core argument because core arguments are encoded more distinctly in memory than oblique arguments and thus can be easily rejected as retrieval candidates.

In summary, the inconclusive evidence of inhibitory interference and possible selective facilitatory interference challenge the traditional cue-based retrieval model (Lewis & Vasishth, 2005). The absence of interference in grammatical sentences may be because cue-based memory retrieval is an error-driven process (Wagers et al., 2009) or because inhibitory interference requires high statistical power (Nicenboim et al., 2018).

Representational accounts

As described in the Introduction, representational accounts also predict interference, typically referred to as attraction within this literature, from a distractor. Within representational accounts, two models have been influential. One is *the percolation model* (Bock & Eberhard, 1993; Franck et al., 2002). This model postulates that, for a complex noun phrase like *The sister of the girls*, the number feature of the embedded noun phrase percolates up to the head noun. Because the two noun phrases have different number features, this percolation disrupts the computation of the subject-verb agreement relation, leading to interference effects. The other proposed model is *the marking and morphing model* (Eberhard et al., 2005). This model assumes that the representation of number of a noun phrase is not categorially but continuously singular or plural on a scale from −1 to 1. For the complex noun phrase above, the model calculates the gradient value of the entire noun phrase based on the number values of individual elements within the phrase. Number values of each element are subject to its notional number and number morpheme. This conception means that the embedded noun phrase "the girls" increases the plurality of the entire noun phrase due to its plural suffix *-s*. Consequently, the marking and morphing model predicts interference effects.

Although the percolation and marking and morphing models have developed primarily within the literature of language production, there have been attempts to explain dependency formation in language comprehension based on them (Hammerly et al., 2019; Patson & Husband, 2016; Pearlmutter et al., 1999). Adapting these models to comprehension, representational accounts make similar predictions to the cue-based retrieval model in ungrammatical sentences, such that partially matching distractors should lead to reduced processing times in (2a) compared to (2b). However, different predictions are made for grammatical sentences. If, as predicted by representational accounts, the distractor's number feature affects the representation of number of the head noun, in grammatical sentences like (3a/b), the plural distractor in (3b) should cause processing difficulty at "was" relative to (3a). This interference pattern differs from what the traditional cue-based retrieval model predicts: this model predicts the opposite pattern, with processing difficulty in (3a) relative to (3b) due to inhibitory interference.

Additionally, representational accounts posit several constraints on interference effects, which the cue-based retrieval model does not consider, based on findings of language production research. One is structural depth: a more deeply embedded distractor leads to reduced interference effects (Bock & Cutting, 1992; Franck et al., 2002; Nicol, 1995). As an example, Bock and Cutting (1992) observed larger interference effects when the distractor was embedded in a prepositional phrase (e.g. *The brother of the girls …*) than in a relative clause (e.g. *The boy who saw the girls …*). Also, representational models predict reduced interference effects when the distractor is singular compared to when it is plural and has a suffix *-s* (*the mismatch asymmetry*; Eberhard, 1997). This prediction is typically described in terms of singular being an unmarked and underspecified feature. However, while many studies have reported larger interference effects for plural rather than singular distractors (e.g. Bock & Cutting, 1992), several studies have reported interference effects from a singular distractor, and such a finding is not uncommon for production studies (Franck et al., 2002, 2006; Häussler, 2009; Staub, 2009; Vigliocco et al., 1995).

As discussed in the previous section, many sentence processing studies have observed facilitatory interference in ungrammatical sentences like (2a/2b), and these findings are consistent with the predictions of representational accounts. Inhibitory interference observed in grammatical sentences in some studies (Nicenboim et al., 2018; Patil et al., 2016) is incompatible with representational accounts, although, as mentioned earlier, this type of interference has not frequently been reported. There is some evidence that interference effects predicted by representational accounts arise in the comprehension of grammatical sentences from some studies (Hammerly et al., 2019; Hammerly & Dillon, 2017; Patson & Husband, 2016; Pearlmutter et al., 1999). However, a *grammatical asymmetry* has been reported in the majority of sentence processing studies (e.g. Jäger et al., 2020; Wagers et al., 2009), with interference effects observed in ungrammatical but not in grammatical sentences. This asymmetry is not compatible with representational accounts. Additionally, some effects reported in grammatical sentences, argued to be compatible with representational accounts, may be confounded with spillover processing related to noun plurality (Wagers et al., 2009). For example, in sentences like *The key to the cabinet(s) was rusty*, Pearlmutter et al. (1999) reported longer reading

times at "was" in the plural distractor ("the cabinets") than singular distractor ("the cabinet") conditions. This pattern is consistent with representational accounts. However, Wagers et al. argued that it may be due to processing costs incurred by the processing of the plural distractor rather than interference effects and demonstrated that this effect disappears if additional material intervenes between the distractor and verb.

Although many studies have reported a grammatical asymmetry incompatible with representational accounts, Hammerly et al. (2019) recently argued that comprehension data from many forced-choice judgement tasks are actually compatible with representational accounts if one accounts for response bias. In these tasks, participants are presented sentences word by word and judge their grammaticality or acceptability. Hammerly et al. pointed out that studies that utilised a judgement task and observed interference effects in ungrammatical but not grammatical sentences (e.g. Schlueter et al., 2018; Wagers et al., 2009) often showed lower overall judgement accuracy in ungrammatical sentences. Hammerly et al. claimed that once this response bias is accounted for, judgement data become consistent with representational accounts.

In summary, dependency formation is susceptible to interference from a distractor, but different accounts exist to explain this finding. The traditional cue-based retrieval model relies on a feature-based approach and predicts inhibitory interference in grammatical sentences and facilitatory interference in ungrammatical sentences, while Wagers et al. (2009) consider that prediction plays a role in agreement computation and assume facilitatory interference only in ungrammatical sentences. Representational accounts predict similar interference effects in grammatical and ungrammatical sentences. Additionally, these accounts predict that structural depth and number markedness influence the degree of interference effects. The present study tested these predictions using subject-verb agreement and the quantifier float construction discussed below.

Quantifier float

In standard English, a universal quantifier such as *all* and *both* can quantify a noun phrase (e.g. *all the boys*). One property of these quantifiers is that they can float off their associate noun phrase as illustrated in (5a/5b) below (*quantifier float*; Al Khalaf, 2019; Bošković, 2004; Kayne, 1975; McCloskey, 2000; Sportiche, 1988; Zyman, 2018).

(5a) All the sisters of the girls went back home.
(5b) The sisters of the girls all went back home.

In (5a/5b), the quantifier "all" quantifies the noun phrase "the sisters". In (5a), "all" is adjacent to its associate. However, in (5b), "all" floats off its associate and appears near the matrix verb because of quantifier float. Quantifier float has been the subject of extensive investigation in linguistics. Broadly, there are two accounts of the derivation of quantifier float sentences. One is *the stranding account* (Koopman & Sportiche, 1991; McCloskey, 2000; Sportiche, 1988; Zyman, 2018). This account posits that a floating quantifier and its associate form a constituent but drift apart at some point of derivation when only the associate moves leftwards. Under this account, the quantifier float sentence (5b) has a structure where only "The sisters" moves to the higher position from the VP specifier position and strands "all" there. The other is *the adverbial account* (Baltin, 1995; Benmamoun, 1999; Torrego, 1996). This account postulates that a floating quantifier and its associate are not a constituent and that a floating quantifier is an adverbial adjunct. For example, in (5b), we can consider that "all" is an adjunct to the matrix verb phrase. In either account, a floating quantifier and its associate must match in number as exemplified by the ungrammaticality of the following sentence, **The sister of the girls all went back home*. Additionally, a floating quantifier in English must be *c-commanded* (Reinhart, 1976) by its associate. In this paper, we assume that x c-commands y if and only if neither x nor y dominates the other and the first branching node that dominates x also dominates y (Reinhart, 1976). In (5b), "the girls" matches the quantifier in number but does not c-command it because the first branching node dominating this noun phrase does not dominate the quantifier. Thus, the c-command constraint prohibits dependency formation between them, which provides a test case of interference as in subject-verb agreement. Examining quantifier float allows us to explore the extent to which different linguistic dependencies are susceptible to interference. In examining interference in quantifier float constructions, we also test different cue-based and representational accounts of interference effects.

Below, we report eight experiments. Experiments 1 and 3 investigated the processing of floating quantifiers, and Experiments 2 and 4 examined sentences involving subject-verb agreement. These experiments aimed to compare the two different dependencies indirectly and explore whether consistent interference patterns emerge between them. Also, we tested the relative clause construction in Experiments 1 and 2 and the prepositional phrase construction in Experiments 3 and 4 to examine the potential influence of the distractor's argument status and structural depth on interference. These

experiments employed a self-paced reading task. Experiments 5–8 further investigated interference using sentences similar to those tested in Experiments 1–4 in a speeded judgement task. These experiments aimed to conceptually replicate the results of Experiments 1–4 and explore whether speeded judgement tasks show results compatible with representational accounts (Hammerly et al., 2019). The research designs, sampling methods and data analysis plans for each experiment were pre-registered on the Open Science Framework website (https://osf.io/pykua/) before we started data collection.

Experiment 1

Experiment 1 investigated whether the processing of floating quantifiers is susceptible to interference using experimental sentences like (6a–6b).

(6a) *Grammatical, Plural distractor*
The boys who the girls saw quite recently, all walked back home from school.

(6b) *Grammatical, Singular distractor*
The boys who the girl saw quite recently, all walked back home from school.
(6c) *Ungrammatical, Plural distractor*
The boy who the girls saw quite recently, all walked back home from school.
(6d) *Ungrammatical, Singular distractor*
The boy who the girl saw quite recently, all walked back home from school.

Regions: | The boy(s) | who the girl(s) saw | quite recently, | all walked | back home | from school. |

(6a–6d) contain a floating quantifier "all" in the matrix clause, which modifies the noun phrase "The boy(s)". (6a/6b) are grammatical whereas (6c/6d) are ungrammatical due to the number match and mismatch respectively between the floating quantifier and its associate noun phrase. (6a–6d) also contain a distractor, "the girl (s)", which matches the quantifier in number in (6a/6c) but mismatches in (6b/6d).

We predicted longer reading times at the quantifier in (6c/6d) than (6a/6b) due to number mismatch effects. If the processing of floating quantifiers is susceptible to inhibitory and facilitatory interference (Lewis & Vasishth, 2005), reading times should be longer in (6a) than (6b) and shorter in (6c) than (6d). If cue-based memory retrieval is an error-driven process and arises only in ungrammatical sentences (Wagers et al., 2009), only facilitatory interference should arise. If interference effects predicted by representational accounts arise (Bock & Eberhard, 1993; Eberhard et al., 2005), reading times should be shorter in (6a/c) than in (6b/d). Note that, in many previous studies, the controller in grammatical conditions is often singular, whereas it is plural in our study due to the plural property of quantifiers. As discussed in the Introduction, representational accounts posit the mismatch asymmetry, with reduced interference effects when a distractor does not have a plural suffix as in (6b). Thus, the mismatch asymmetry may appear, with reduced interference in (6a/6b) relative to (6c/6d). Either way, observing longer reading times in (6b) than (6a) would be more compatible with representational accounts than cue-based retrieval models.

Participants

Participants (mean age 21; range 18–60) were recruited from the University of Reading community. In the preregistration, we specified that we would continue participant recruitment until we had 80 native English speakers who correctly answered more than 75% of the comprehension questions to experimental sentences, as an index that they paid attention. During data collection, we incrementally checked participants' comprehension accuracy rates only (but did not analyse any other data) until we reached this number. Following this criterion, an additional 18 native English speakers were recruited but excluded from the analysis. All participants completed the experiment online. The number of participants and materials are based on previous research and the timeframe of the project.

Materials

The materials were 24 sets of experimental sentences as in (6a–6d) and 72 filler sentences. The filler sentences consisted of various syntactic structures. A yes/no comprehension question, which did not probe the interpretation of the critical dependency, followed all experimental sentences and two-thirds of the filler sentences.

Procedure

We measured participants' reading times using a non-cumulative phrase-by phrase self-paced reading task in IbexFarm. Experimental sentences were presented to participants in phrases as illustrated below (6a–6d). Each trial began with a sequence of dashes that masked a whole sentence. Participants then pressed the space bar to read each phrase. After participants read the last phrase, the sentence disappeared, and participants either started reading the next trial or answered a comprehension question. The experiment began with four practice trials and lasted approximately 20 min.

Pre-registered data analysis

We analysed reading times at the critical and spillover regions as the dependent variable in R (R Core Team, 2020). The critical region consisted of the floating quantifier and the matrix verb ("all went"). The spillover region was the following region ("back home"). Before data analysis, we removed reading times shorter than 100 milliseconds and longer than 10 s, as these likely index lapses in attention.[1] Reading times were also log-transformed to remove skew. We fit linear mixed models to reading times using the lme4 package (Bates et al., 2015). We conducted one analysis containing the data from both the critical and spillover regions, and thus the fixed effects included sum-coded (–.5/.5) main effects of region (critical region/spillover region), grammaticality (grammatical/ungrammatical), distractor (plural/singular) and their interactions. The models also contained random intercepts for participants and materials, and by-participant and by-material random slopes for all fixed effects. As we included region as a fixed effect, we included a by-trial random intercept, the unique participant and material pairing that constituted each trial, to account for the two non-independent data points from each trial. When this maximal random-effects model did not converge, we initially removed random effect correlations (Barr et al., 2013). If this model still did not converge, we removed the random slope accounting for the least variance iteratively until the model converged. We estimated *p* values from the *t* distribution (Baayen, 2008) and interpreted *p* values smaller than .05 as significant.

Results

The mean accuracy rates for comprehension questions of experimental sentences were 89% (range 75–100%). Table 1 reports inferential statistics and Figure 1 illustrates reading times at the last four regions.

Critical and spillover regions

Although there was a numerical trend for longer reading times in ungrammatical sentences, the main effect of grammaticality was not statistically significant at the critical and spillover regions. Also, there was no significant evidence of either the main effect of distractor or the grammaticality by distractor interaction.

Discussion

Reading times were numerically longer at the critical/spillover regions in the ungrammatical than grammatical conditions, but this effect was not statistically significant. Also, the results did not show any interference. This finding potentially suggests that the processing of floating quantifiers is insensitive to interference. The absence of interference may be because, unlike subject-verb agreement, a floating quantifier and its associate may form a constituent as claimed by the stranding account (e.g. Koopman & Sportiche, 1991) and thus may be strongly tied. However, we are cautious in drawing strong conclusions about this here, as there are two other possible accounts of why Experiment 1 did not show clear interference effects. One could be that sentence processing is susceptible to interference effects, but they were absent because Experiment 1 used the relative clause construction, and the controller and the distractor were structurally too distant (Bock & Cutting, 1992). The other is that the distractor was always a core argument, which nullified interference effects (Parker & An, 2018). Recall that Parker and Ann found facilitatory interference only when the distractor was an oblique argument but not when it was a core argument as in Experiment 1 of the present study. Experiment 2 explored these possibilities in subject-verb agreement, a dependency known to elicit facilitatory interference relatively robustly (e.g. Wagers et al., 2009), using items similar to Experiment 1, with a distractor as a core argument in a relative clause. If Experiment 2 does not show clear interference, as would be predicted by Parker and An (2018). it will provide convincing evidence that the structural depth and/or the distractor's argument status prevented interference in Experiment 1.

Table 1. A summary of statistical analyses for reading times in Experiment 1 and 2.

	Experiment 1			Experiment 2		
	Estimate (SE)	*t*	*p*	Estimate (SE)	*t*	*p*
Intercept	6.376 (0.03)	184.37	<.001	6.401 (0.03)	203.59	<.001
Region	−0.116 (0.02)	−7.00	<.001	−0.136 (0.01)	−12.83	<.001
Grammaticality	0.029 (0.02)	1.86	.063	0.059 (0.01)	4.34	<.001
Distractor	−0.005 (0.01)	−0.33	.739	0.036 (0.01)	2.64	.008
Region: grammaticality	0.015 (0.02)	0.74	.459	−0.018 (0.02)	−0.84	.400
Region: distractor	−0.017 (0.02)	−0.85	.393	−0.013 (0.02)	−0.60	.547
Grammaticality: distractor	0.004 (0.02)	0.16	.870	0.044 (0.03)	1.62	.105
Region: grammaticality: distractor	0.003 (0.04)	0.07	.945	0.017 (0.04)	0.40	.692

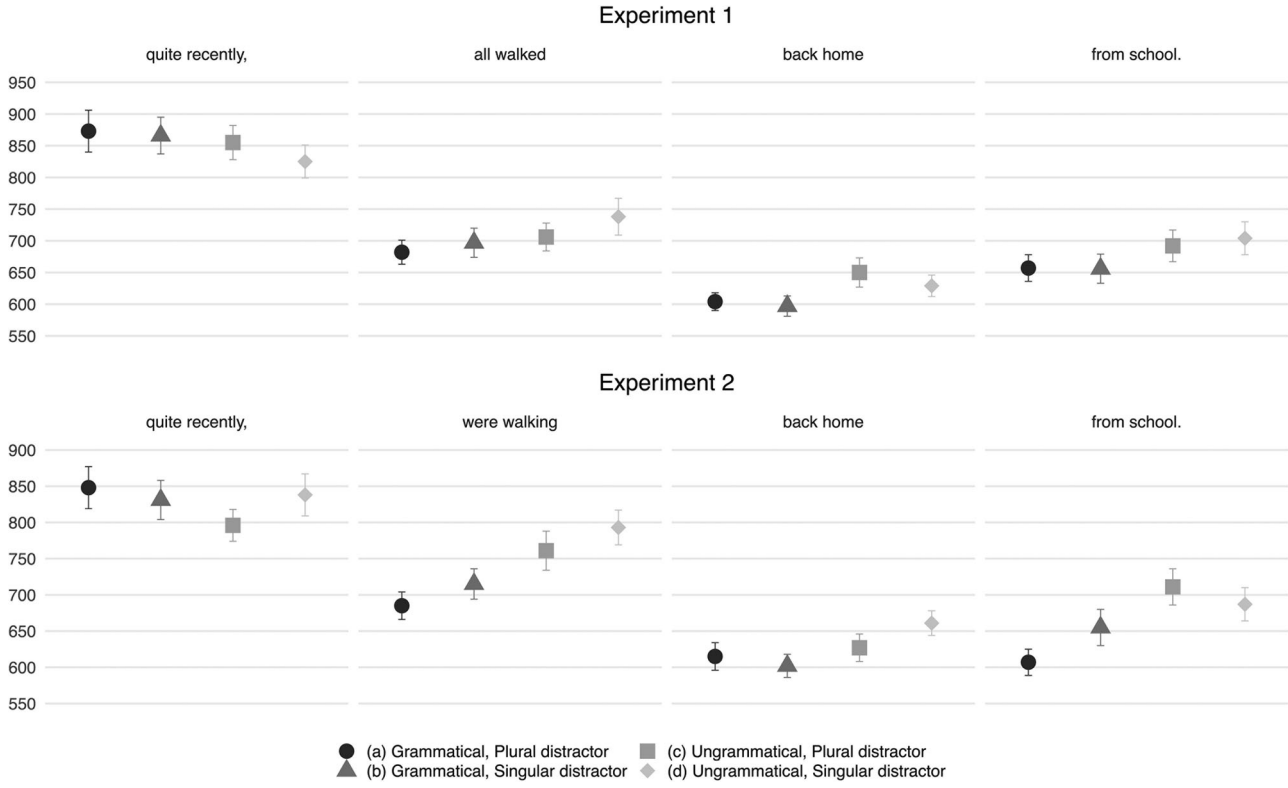

Figure 1. Mean raw reading times in milliseconds at the last four regions in Experiments 1 and 2. Error bars indicate standard errors. The preceding regions are | The boy(s) | who the girl(s) saw |.

Experiment 2

Experiment 2 investigated whether the relative clause construction or the distractor as a core argument prevent interference in subject-verb agreement using experimental sentences such as (7a–7d).

(7a) *Grammatical sentence, Plural distractor*
The boys who the girls saw quite recently, were going back home from school.

(7b) *Grammatical sentence, Singular distractor*
The boys who the girl saw quite recently, were going back home from school.
(7c) *Ungrammatical sentence, Plural distractor*
The boy who the girls saw quite recently, were going back home from school.
(7d) *Ungrammatical sentence, Singular distractor*
The boy who the girl saw quite recently, were going back home from school.

Regions: | The boy(s) | who the girl(s) saw | quite recently, | were going | back home | from school. |

(7a–7d) are akin to (6a–6d) except that (7a–7d) have a plural auxiliary, and the matrix verb is in progressive form ("were going"). The cue-based memory retrieval and representational accounts should make the same predictions for Experiment 2 as in Experiment 1. However, if either the structural distance between the controller and the distractor (Bock & Cutting, 1992) or the distractor's core argument status (Parker & An, 2018) render dependency formation insusceptible to interference, findings similar to those reported in Experiment 1 are expected.

Participants

Eighty native English speakers from the University of Reading community (mean age 21; range 18–50), none of whom took part in Experiment 1, completed Experiment 2 online and were included in our analysis. An additional 10 participants took part, but we did not include them in data analysis due to their low comprehension accuracy.

Materials

The materials were 24 sets of experimental sentences as in (7a–7d) and 72 filler sentences. As in Experiment 1, a yes/no comprehension question followed all experimental sentences and two-thirds of the filler sentences.

Procedure and data analysis

The procedure and data analysis are the same as in Experiment 1.

Results

The mean accuracy rates for experimental sentences were 88% (range 75%–100%). Inferential statistics are reported in Table 1. Reading times at the last four regions are illustrated in Figure 1.

Critical and spillover regions

There was a significant main effect of grammaticality, which shows longer reading times at the critical and spillover regions in the ungrammatical than grammatical conditions. There was also a significant main effect of distractor due to longer reading times in the plural distractor than singular distractor conditions. The grammaticality by distractor interaction was not significant.

Exploratory analysis

The pre-registered analysis revealed a significant main effect of distractor, but the grammaticality by distractor interaction was not statistically significant. However, the interference effects seem to mainly come from the ungrammatical conditions. To explore the source of the interference effects, we conducted an exploratory (non-pre-registered) analysis of simple effects of distractor for the grammatical and ungrammatical conditions separately. Across the critical and spillover regions, this analysis showed clear interference effects in the ungrammatical conditions (Estimate = 0.058, SE = 0.02, $t = 3.01$, $p = .003$) but not in the grammatical conditions (Estimate = 0.014, SE = 0.02, $t = 0.72$, $p = .474$).

Discussion

The results provided clear evidence of number mismatch effects. This effect indicates that, upon encountering the auxiliary, participants attempted to retrieve its controller. The pre-registered analysis also showed interference effects; reading times were longer when the distractor mismatched the auxiliary's number than when it matched in both grammatical and ungrammatical conditions. This interference pattern is consistent with representational accounts, if these accounts predict clear interference effects from a singular distractor. However, as suggested by the exploratory analysis, the main source of interference effects was ungrammatical sentences, and there were no clear interference effects in grammatical sentences, which could also be compatible with some cue-based models. We do not mean to draw a strong conclusion from this exploratory analysis, given that the grammaticality by distractor interaction was not statistically significant.

Experiments 2 suggested that the relative clause construction and the distractor's core argument status do not nullify interference effects. However, they may still have weakened interference effects in Experiment 1, which may have rendered interference difficult to observe. Therefore, we further investigated the processing of floating quantifiers in Experiment 3 using the prepositional phrase construction. In this construction, the controller and the distractor are structurally closer compared to relative clauses. Also, the distractor in the prepositional phrase construction appears as an oblique argument. Thus, based on previous research (Parker & An, 2018), we expected interference if the processing of floating quantifiers is susceptible to it.

Experiment 3

Experiment 3 examined whether the processing of floating quantifiers is susceptible to interference using experimental sentences like (8a–8d).

(8a) *Grammatical sentence, Plural distractor*
The sisters of the girls recently all walked back home from school.
(8b) *Grammatical sentence, Singular distractor*
The sisters of the girl recently all walked back home from school.
(8c) *Ungrammatical sentence, Plural distractor*
The sister of the girls recently all walked back home from school.
(8d) *Ungrammatical sentence, Singular distractor*
The sister of the girl recently all walked back home from school.

Regions: | The sister(s) | of the girl(s) | recently | all went | back home | from school. |

(8a–8d) manipulate whether the structurally licensed element and the distractor match the floating quantifier in number as in Experiment 1. One crucial difference from Experiment 1 is that, in (8a–8d), the distractor is an oblique argument rather than a core argument. We predicted longer reading times at the floating quantifier in (8c/8d) than (8a/8b) due to number mismatch effects. If dependency formation involving a floating quantifier is unsusceptible to interference as suggested by Experiment 1, interference effects should be absent. However, if the distractor's core argument status rendered it difficult to detect interference in Experiment 1, we should observe interference effects in (8a–8d) in Experiment 3, as the distractor is now an oblique argument.

Participants

Eighty native English speakers completed Experiment 3 and were included in the analysis. An additional two participants were removed due to their low comprehension accuracy (mean age of the remaining participants 23; range 18–40). We recruited the participants via Prolific

Table 2. A summary of statistical analyses for reading times in Experiment 3 and 4.

	Experiment 3			Experiment 4		
	Estimate (SE)	*t*	*p*	Estimate (SE)	*t*	*p*
Intercept	6.185 (0.03)	198.43	<.001	6.275 (0.04)	177.95	<.001
Region	0.024 (0.02)	1.20	.232	−0.015 (0.03)	−0.59	.552
Grammaticality	0.029 (0.01)	2.37	.018	0.04 (0.01)	3.33	<.001
Distractor	0.016 (0.01)	1.44	.149	0.025 (0.01)	2.16	.031
Region: grammaticality	0.041 (0.02)	1.98	.047	−0.037 (0.02)	−1.69	.091
Region: distractor	0.037 (0.02)	2.05	.040	0.001 (0.02)	0.07	.945
Grammaticality: distractor	0.011 (0.03)	0.33	.745	0.033 (0.02)	1.40	.161
Region: grammaticality: distractor	0.103 (0.03)	3.09	.002	0.031 (0.04)	0.77	.442

(https://prolific.co/). The participants were university students, had UK nationality, lived in the UK, and spoke English as their native language.

Materials

The materials were 24 sets of experimental sentences as in (8a–8d) and 72 filler sentences. As in Experiments 1 and 2, a yes/no comprehension question followed all experimental sentences and two-thirds of the filler sentences.

Procedure and data analysis

The procedure and data analysis are identical to those for Experiments 1 and 2.

Results

The mean accuracy rates for experimental materials were 94% (range 79%–100%). Table 2 details the inferential statistics. Figure 2 illustrates reading times at the last four regions.

Critical and spillover regions

There was a significant main effect of grammaticality at the critical and spillover regions, which shows number mismatch effects. There was also a significant grammaticality by region interaction because number mismatch effects were significant only at the spillover region (critical region: Estimate = 0.008, SE = 0.02, $t = 0.51$, $p = .607$; spillover region: Estimate = 0.049, SE = 0.02, $t = 3.13$, $p = .002$). Crucially, there was a significant region by distractor interaction and a significant three-way interaction. A follow-up analysis examined simple effects of distractor for each level of grammaticality and region. In the ungrammatical conditions, this analysis provided significant evidence of reduced number mismatch effects when the distractor matched the quantifier in number compared to when it mismatched at the spillover region (critical region: Estimate = 0.023, SE = 0.02, $t = 1.00$, $p = .317$; spillover region: Estimate = –0.066, SE = 0.03, $t = -2.49$, $p = .013$). By contrast, we did not find significant evidence of interference effects at the critical or spillover regions in the grammatical conditions (critical region: Estimate = –0.018, SE = 0.02, $t = -0.89$, $p = .374$; spillover region: Estimate = –0.004, SE = 0.02, $t = -0.18$, $p = .854$).

Discussion

The results provided clear evidence of number mismatch effects. This effect indicates that when encountering the floating quantifier, the participants retrieved its structurally licensed associate noun phrase. Crucially, there was significant evidence of the grammaticality by distractor interaction, which also interacted with region, because of reduced number mismatch effects in the ungrammatical conditions. This interference effect was largely restricted to the spillover region and is consistent with Wager et al.'s cue-based memory retrieval account. However, we did not find significant evidence of interference in the grammatical conditions.

In summary, Experiment 1 did not observe interference effects, but Experiments 2 and 3 suggested interference effects in ungrammatical sentences. Experiments 5–8 partially aimed to replicate these findings in speeded judgement tasks, but before that, we report Experiment 4. We conducted Experiment 4 to indirectly compare interference patterns observed in Experiment 3 with those in subject-verb agreement using an otherwise similar construction.

Experiment 4

Experiment 4 tested experimental sentences involving subject-verb agreement like (9a–9d).

(9a) *Grammatical sentence, Plural distractor*
The sisters of the girls recently were going back home from school.
(9b) *Grammatical sentence, Singular distractor*
The sisters of the girl recently were going back home from school.
(9c) *Ungrammatical sentence, Plural distractor*
The sister of the girls recently were going back home from school.
(9d) *Ungrammatical sentence, Singular distractor*
The sister of the girl recently were going back home from school.

Regions: | The sister(s) | of the girl(s) | recently | were going | back home | from school. |

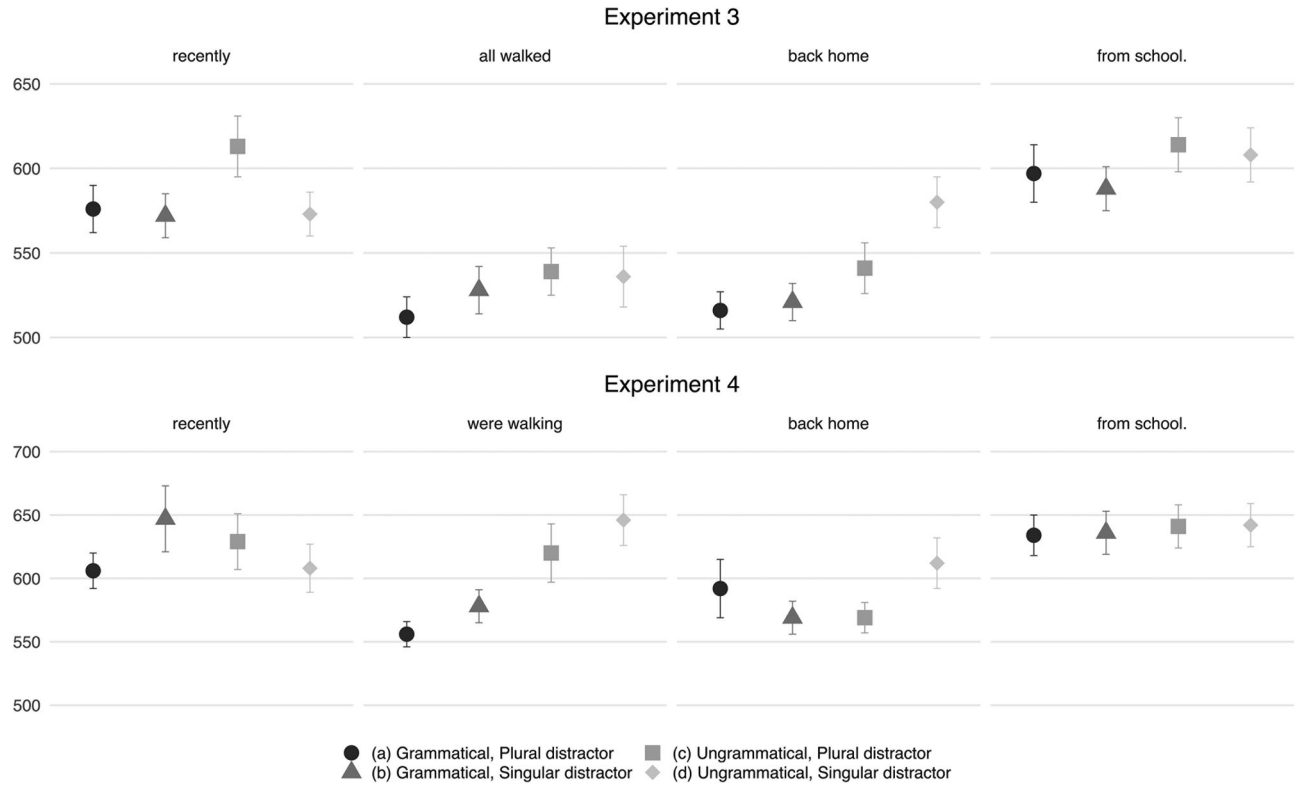

Figure 2. Mean raw reading times in milliseconds at the last four regions in Experiments 3 and 4. Error bars indicate standard errors. The preceding regions are | The sister(s) | of the girl(s) |.

We created experimental sentences for Experiment 4 based on those in Experiment 3 by replacing the floating quantifier with a plural auxiliary, "were", and changing the matrix verb to the progressive form. We predicted increased reading times at "were going" in the ungrammatical conditions due to number mismatch effects. We also expected interference patterns similar to those observed in Experiment 3.

Participants

Eighty native English speakers (mean age 24; range 18–40), who were recruited via Prolific and did not take part in Experiment 3, participated in Experiment 4. 10 additional participants completed the experiment, but their data were not included in analysis due to their low comprehension accuracy.

Materials

The materials were 24 sets of experimental sentences like (9a–9d) and 72 filler sentences, and as in the other experiments, a yes/no comprehension question followed all experimental sentences and two-thirds of the filler sentences.

Procedure and data analysis

The procedure and data analysis are identical to those described in Experiment 1.

Results

The mean accuracy rates for experimental materials were 95% (range 79%–100%). Inferential statistics are reported in Table 2. Figure 2 illustrates reading times at the last four regions.

Critical and spillover regions

The models showed a significant main effect of grammaticality at the critical and spillover regions, which indicates number mismatch effects. There was also a significant main effect of distractor, with shorter reading times in the plural distractor than singular distractor conditions. The grammaticality by distractor interaction was not significant.

Exploratory analysis

Experiment 4 observed a significant main effect of distractor but no significant grammaticality by distractor

interaction. However, as in Experiment 2, the distractor effect seems to mainly come from the ungrammatical conditions. Therefore, we conducted an exploratory analysis by investigating simple effects of distractor for each level of grammaticality. Across regions, in the ungrammatical conditions, the results showed clear reduced number mismatch effects when the distractor matched the auxiliary in number compared to when it mismatched (Estimate = 0.042, SE = 0.02, $t = 2.53$, $p = .011$). However, there was no significant evidence of interference in the grammatical conditions (Estimate = 0.009, SE = 0.02, $t = 0.52$, $p = .603$).

Discussion

The results showed number mismatch effects. This effect demonstrates that when participants encountered the auxiliary, they retrieved its controller. Also, reading times were significantly longer in the plural distractor than singular distractor conditions. This interference effect is consistent with representational accounts if these accounts predict robust interference effects from a singular distractor. However, the exploratory analysis suggested interference effects only in ungrammatical sentences, reduced number mismatch effects in the plural distractor conditions, and there was no clear evidence of interference in grammatical sentences. As with Experiment 2, we do not mean to draw a strong conclusion from this exploratory analysis given the absence of the significant grammaticality by distractor interaction in the pre-registered analysis. However, this exploratory analysis is consistent with Experiments 2 and 3.

In summary, Experiment 4 suggests interference effects during dependency formation, which are largely compatible with Experiments 2 and 3. However, these experiments are partially inconsistent with Experiment 1 because Experiment 1 did not show interference effects in both grammatical and ungrammatical conditions. Experiments 5–8 aimed to conceptually replicate these findings using speeded acceptability judgment tasks. We used judgement tasks because these tasks have been widely adopted in sentence processing studies (Fujita & Cunnings, 2022; González Alonso et al., 2021; Schlueter et al., 2018; Wagers et al., 2009), and interference effects have been robustly observed in these studies. Therefore, judgment tasks can be useful in testing the possible differences in the degree of susceptibility to interference between quantifier float and subject-verb agreement and between the relative clause and prepositional phrase constructions. Also, as discussed in the Introduction, Hammerly et al. (2019) recently argued that data from speeded judgement tasks are more compatible with the representational accounts once response bias is accounted for. Thus, these tasks can be a useful method to test representational accounts.

Experiments 5–8

Experiments 5–8 investigated interference in language comprehension by testing experimental sentences like (10–13), which are similar to those examined in Experiments 1–4, in speeded acceptability judgement tasks.

(10) *Quantifier float, Relative clause (Ex5)*
The boy(s) who the girl(s) saw recently all walked home.
(11) *Subject-verb agreement, Relative clause (Ex6)*
The boy(s) who the girl(s) saw recently were walking home.
(12) *Quantifier float, Prepositional phrase (Ex7)*
The sister(s) of the girl(s) all walked home.
(13) *Subject-verb agreement, Prepositional phrase (Ex8)*
The sister(s) of the girl(s) were walking home.

(10–13) are similar to (6–9), but we shortened their length by removing some words from the spillover region to minimise the time between participants reading the critical region and making the speeded judgement. If the comprehension of these sentences is susceptible to facilitatory interference, as predicted by the cue-based retrieval accounts, the ungrammatical conditions should show lower accuracy rates when the distractor is plural than singular. Representational accounts similarly predict lower accuracy rates in the ungrammatical conditions when the distractor is plural. Additionally, there may be interference effects in the grammatical conditions with lower accuracy rates in the singular distractor conditions, depending on the degree to which language comprehension is subject to the mismatch asymmetry. This pattern in the grammatical conditions would not be consistent with the cue-based retrieval accounts.

Participants

We continued participant recruitment until we had 80 native English speakers who scored over 80% accuracy rates on comprehension questions to experimental sentences for each experiment (320 participants in total; mean age 18 for Ex5, 21 for Ex6, 22 for Ex7, 22 for Ex8; range 18–49). In total, there were five participants who did not meet this criterion. We excluded their data before data analysis. The participants in Ex5 and Ex6 were from the University of Reading community, and those in Ex7 and Ex8 were from Prolific. None of these participants took part in Experiments 1–4, and all of them completed the task online.

Table 3. Mean accuracy rates and standard errors (SE) in Ex5, Ex6, Ex7 and Ex8.

	Ex5		Ex6		Ex7		Ex8	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Grammatical, plural distractor	0.78	0.02	0.83	0.02	0.72	0.02	0.61	0.02
Grammatical, singular distractor	0.75	0.02	0.84	0.02	0.67	0.02	0.56	0.02
Ungrammatical, plural distractor	0.52	0.02	0.54	0.02	0.59	0.02	0.71	0.02
Ungrammatical, singular distractor	0.77	0.02	0.82	0.02	0.84	0.02	0.89	0.01

Materials

We created 24 sets of experimental sentences and 60 filler sentences for each speeded acceptability judgment task. Half of the filler sentences were grammatical, and the other half ungrammatical. A comprehension question followed eight experimental sentences and 20 filler sentences to check that participants paid attention.

Procedure

We administered the speeded acceptability judgement tasks using IbexFarm. At the start of each trial, participants saw a cross at the centre of the screen. When participants pressed the space bar, the cross disappeared, and a sentence was presented word by word. The pacing was 500 milliseconds per word. After the last word, a question mark appeared, and participants judged whether the sentence was acceptable within 1500 milliseconds. Participants received feedback ("Too slow!") only when they missed the timeout, but did not receive feedback about the accuracy of their responses. They sometimes answered a comprehension question after making a judgement. The experiment lasted approximately 15 min.

Data analysis

We analysed judgement accuracy (0 = incorrect, 1 = correct) as the dependent variable in R by fitting mixed logistic regression models. We conducted data analysis for each experiment separately. The fixed and random effects were identical to those included in Experiments 1–4, except that the models did not contain a region variable and a by-trial random intercept.

Results

The mean comprehension accuracy rates for experimental sentences were 94% for Ex5 and Ex8 and 95% for Ex6 and Ex7 (all above 80%). Tables 3 and 4 report mean accuracy rates and inferential statistics, respectively.

Experiment 5

The model showed a significant main effect of grammaticality indicating higher accuracy in the grammatical than ungrammatical conditions. There was also a significant main effect of distractor with higher accuracy in the plural distractor than singular distractor conditions. Crucially, there was a significant grammaticality by distractor interaction. A follow-up analysis examined simple effects of distractor. This analysis showed significantly lower accuracy in the plural distractor than singular distractor conditions for the ungrammatical conditions (Estimate = –1.507, SE = 0.19, z = –7.87, p < .001). By contrast, distractor effects in the grammatical conditions were not significant (Estimate = 0.261, SE = 0.18, z = 1.44, p = .151).

Experiment 6

The significant main effect of grammaticality indicates higher accuracy in the grammatical than ungrammatical conditions. Also, the main effect of distractor was significant because accuracy was higher in the plural distractor than singular distractor conditions. As in Experiment 5, the grammaticality by distractor interaction was significant. A follow-up analysis showed significant distractor effects in the ungrammatical conditions with lower accuracy in the plural distractor condition (Estimate = –2.279, SE = 0.30, z = –7.54, p < .001), but no significant differences between the two grammatical conditions (Estimate = –0.071, SE = 0.22, z = –0.33, p = .744).

Table 4. A summary of statistical analyses for judgement rates in Ex5, Ex6, Ex7 and Ex8 (Est = Estimate).

	Ex5			Ex6			Ex7			Ex8		
	Est (SE)	z	p	Est (SE)	z	p	Est (SE)	z	p	Est (SE)	z	p
Intercept	1.188 (0.12)	10.31	<.001	1.889 (0.15)	12.29	<.001	1.303 (0.12)	10.92	<.001	1.330 (0.12)	11.08	<.001
Grammaticality	–0.681 (0.31)	–2.17	.030	–1.107 (0.48)	–2.31	.021	0.327 (0.48)	0.68	.495	1.699 (0.51)	3.32	<.001
Distractor	0.617 (0.13)	4.65	<.001	1.157 (0.18)	6.35	<.001	0.764 (0.13)	5.73	<.001	0.719 (0.14)	5.03	<.001
Grammaticality: distractor	1.767 (0.27)	6.53	<.001	2.148 (0.37)	5.83	<.001	2.143 (0.29)	7.30	<.001	1.997 (0.34)	5.86	<.001

Experiment 7

There was a significant main effect of distractor indicating higher accuracy when the distractor was plural than singular. The model also showed a significant grammaticality by distractor interaction because of lower accuracy in the plural distractor conditions for the ungrammatical conditions (Estimate = –1.837, SE = 0.22, z = –8.35, p < .001). By contrast, the grammatical conditions did not show significant distractor effects (Estimate = 0.306, SE = 0.18, z = 1.72, p = .085).

Experiment 8

There was a significant main effect of grammaticality, but unlike Experiments 5 and 6, this effect indicates higher accuracy in the ungrammatical conditions. As in the other judgement experiments, there was also a significant main effect of distractor because of higher accuracy in the plural distractor than singular distractor conditions. The grammaticality by distractor was significant. A follow-up analysis indicated lower accuracy in the plural distractor conditions for the ungrammatical conditions (Estimate = –1.720, SE = 0.24, z = –7.22, p < .001). However, there were no significant distractor effects for the grammatical conditions (Estimate = 0.274, SE = 0.19, z = 1.47, p = .142).

Discussion

All experiments showed significant distractor effects in the ungrammatical conditions, indicating interference effects. However, there was no significant evidence of interference in the grammatical conditions. Below, we discuss the implications of the results of all experiments reported in this study.

General discussion

The present study investigated the processing of sentences involving quantifier float or subject-verb agreement in eight experiments. Recall that we had four aims. First, we aimed to test whether quantifier float is susceptible to interference, to assess the generalisability of interference effects. Second, we aimed to tease apart cue-based and representational accounts of interference. Third, we aimed to test if cue-based retrieval is initiated in both grammatical and ungrammatical sentences or only in ungrammatical sentences and fourth, we aimed to assess whether a distractor's position influences interference.

Our experiments revealed several crucial findings. One is that quantifier float causes number mismatch effects when the floating quantifier mismatches its associate in number during sentence processing. Another is that reduced number mismatch effects arise when the distractor matches the floating quantifier in number. However, we did not find clear interference effects in grammatical sentences. We also observed largely similar interference patterns between quantifier float and subject-verb agreement, and across distractors in both core and oblique argument positions. We discuss the implications of these findings for our four aims in turn.

Subject-verb and quantifier float dependency formation

Although results were suggestive in Experiment 1, participants in Experiments 1 and 3 showed number mismatch effects when they encountered a floating quantifier mismatching its associate in number. This finding indicates that dependency formation between a floating quantifier and its associate conforms to the c-command constraint during sentence processing, and consequently, the processor encounters processing difficulty when their number features mismatch. Regarding our first aim, Experiment 3 found reduced number mismatch effects when the distractor matched the floating quantifier in number compared to when it mismatched. Although Experiment 1 did not observe this interference effect, Experiment 5, which tested sentences and constructions comparable to those used in Experiment 1, provided evidence of it. Given Experiments 3, 5 and 7, we assume that the processing of floating quantifiers is susceptible to interference in ungrammatical sentences.

Interference effects in the ungrammatical conditions are consistent with many sentence processing studies on interference (Cunnings & Sturt, 2018; Jäger et al., 2020; Wagers et al., 2009), and our study provided the first evidence that the processing of the quantifier float construction is susceptible to interference from a distractor when the quantifier and its associate disagree in number. We also observed interference in subject-verb agreement, especially in speeded judgement Experiments 6 and 8. Given that quantifier float and subject-verb agreement largely showed similar interference effects in ungrammatical sentences, we assume that the same mechanism underlies how these dependencies are subject to interference. These findings can be readily explained by the cue-based retrieval and representational accounts, which predict interference effects due to a partially matching distractor.

By contrast, across Experiments 1–8, we did not find clear interference effects when sentences were

grammatical. That is, there was no significant evidence of interference in the grammatical conditions of Experiments 1 and 3. Experiments 2 and 4 found a significant main effect of distractor, but this effect was largely due to reduced number mismatch effects that arose in the ungrammatical conditions when the distractor matched the number cue. Experiments 5–8 showed significant interference effects only in the ungrammatical conditions but not in the grammatical conditions. The absence of interference in grammatical sentences is consistent with many sentences processing studies on interference (e.g. Wagers et al., 2009). This finding provides implications for both representational and cue-based retrieval accounts, which we discuss below.

Implications for representational and cue-based memory retrieval accounts

Regarding our second aim to tease apart cue-based and representational models of interference, recall that representational accounts predict interference effects when a distractor mismatches the controller in number (e.g. *The sister of the girls*), with the main sources of interference effects predicted to be the distractor's conceptual number and morphologically realised plural suffix (e.g. Eberhard et al., 2005). The absence of interference effects in grammatical sentences could be compatible with representational accounts if these accounts assume that interference effects rely primarily on the number morphology. That is, in our grammatical sentences, the source of interference effects was always a singular distractor due to the use of quantifiers (e.g. *The sisters of the girl(s) all*). Indeed, as stated in the introduction, the marking and morphing model (Eberhard et al., 2005) considers the mismatch asymmetry and predicts only slight interference effects when a distractor is singular. However, as noted in the introduction, it is not uncommon for production studies to observe interference effects from a morphologically unrealised singular distractor, suggesting that conceptual number plays a role in interference effects during production (Franck et al., 2002, 2006; Vigliocco et al., 1995).

It is also worth discussing the possibility that the absence of interference effects in grammatical sentences is due to response bias. As discussed in the introduction, Hammerly et al. (2019) recently argued that response bias explains why speeded judgement tasks often fail to observe interference effects in grammatical sentences: in these tasks, participants often respond overall less accurately to ungrammatical than grammatical sentences. Hammerly et al. reported that once this bias is removed, grammatical sentences show interference effects consistent with representational accounts. Consistent with Hammerly et al.'s claim, Experiments 5 and 6 showed response bias. However, Experiments 7 and 8 observed similar accuracy rates between the grammatical and ungrammatical conditions, or higher accuracy rates in the ungrammatical conditions. Given these findings, we consider that response bias cannot fully explain why the distractor did not significantly affect the ratings of the grammatical conditions in our speeded judgement tasks.

Regarding our third aim, whether cue-based retrieval occurs in grammatical and ungrammatical sentences, the absence of interference effects in grammatical sentences is challenging for the traditional cue-based retrieval account. As delineated in the Introduction, this account predicts inhibitory interference when the controller and distractor match retrieval cues in grammatical sentences (e.g. Lewis & Vasishth, 2005). We did not observe such effects in any of our experiments, however. By contrast, our observations are consistent with Wagers et al.'s (2009) account that the processor retrieves a distractor only when there is no grammatically licensed element for dependency formation (Wagers et al., 2009). As discussed in the Introduction, Wagers et al.'s account relies on the hypothesis that upon encountering the sentence subject noun phrase, the processor predicts a feature-matching verb. Our results of subject-verb agreement are largely compatible with this account. Regarding quantifier float, although the processor is unlikely to predict a floating quantifier, the quantifier matches the processor's prediction in terms of number agreement in grammatical sentences. Concretely, we contend that upon encountering the plural sentence subject noun phrase (e.g. *The girls*), the processor predicts a feature-matching verb (e.g. *walk*). At this point, the processor stores and retains the sentence subject noun phrase in memory (Gibson, 1998; Kim et al., 2020). In the quantifier float construction, when a quantifier appears, although it is not predicted by the processor, it has a plural feature and is consistent with the processor's prediction in terms of number. We argue that, given that the sentences subject noun phrase is retained in memory, the processor does not need to initiate cue-based memory retrieval to form a quantifier float dependency in grammatical sentences. Consequently, inhibitory interference does not arise. Our findings on quantifier float support the view that prediction and maintenance play a crucial role in dependency formation (Kim et al., 2020; Wagers et al., 2009).

Another possible account of the absence of inhibitory interference is that misrepresentation of the distractor's number feature masked inhibitory interference (Yadav et al., 2021). Yadav et al. (2021) recently combined representational accounts with the cue-based memory

retrieval model. They argued that when the processor processes a complex noun phrase such as *The sister of the girls*, the distractor's number features may lead to a misrepresentation of the number features of the head noun, as predicted by representational accounts. Cue-based retrieval is still predicted to occur when the processor encounters the matrix verb. Dependency formation is thus predicted to be influenced by both feature (mis)representation and retrieval interference. In ungrammatical conditions, these effects go in the same direction, and thus lead to clear facilitatory interference. In grammatical sentences, Yadav et al.'s model predicts two different sources of difficulty, inhibitory interference and number (mis)representation. These two competing sources of difficulty are argued to effectively cancel each other out, leading to no significant interference effects in grammatical sentences. However, it is not clear if Yadav et al.'s account can explain our findings. The reason is that because Yadav et al.'s account is partially based on representational accounts, it must predict structural depth effects (i.e. reduced interference effects when the controller and the distractor are structurally more distant), which our study did not observe. Also, as discussed earlier, representational accounts assume reduced interference effects from a morphologically unrealised singular distractor. However, to explain the absence of inhibitory interference in our study, Yadav et al.'s account must assume robust number misrepresentation effects from a singular distractor that mask inhibitory interference. Given these issues, Yadav et al.'s account may have difficulty explaining the lack of inhibitory interference observed in our study.

It is also conceivable that our study did not find inhibitory interference because it did not have enough statistical power to detect inhibitory interference (Nicenboim et al., 2018). Further research is required to replicate our study with a larger sample to elucidate whether inhibitory interference arises during dependency formation.

Structural depth effects and distractor's argument status

Our fourth aim was to examine if a distractor's structural position influences interference. We discussed earlier that the absence of interference in Experiment 1 may be due to the distractor's argument status (Parker & An, 2018; Van Dyke & McElree, 2011). According to Parker and An (2018), a distractor that is a core argument prevents interference because it plays a significant role in determining the meaning of the sentence (as it is an argument of a verb) and thus is distinctive in memory and easy to reject as a structurally illicit licenser. However, contrary to this claim, Experiment 2, which tested subject-verb agreement with a distractor as a core argument, showed interference caused largely by the ungrammatical conditions. Also, Experiments 5 and 6, where a distractor was a core argument, showed clear interference effects in the ungrammatical conditions in speeded judgement tasks. These experiments suggest that a distractor's argument status at least does not nullify interference effects.

Also, our study did not provide clear evidence that structural depth influences interference effects. This finding may be challenging for representational accounts, which postulate reduced interference effects when the controller and the distractor are structurally more distant (e.g. Bock & Cutting, 1992). Experiment 1, which examined relative clauses in the quantifier float construction, showed no clear interference effects, which could be compatible with this postulation. However, Experiment 2, which similarly tested relative clauses but in subject-verb agreement, showed interference effects largely attributable to ungrammatical sentences. Furthermore, our speeded judgement tasks (Experiments 5–8) observed numerically similar size of interference effects in ungrammatical sentences across relative clause and prepositional phrase constructions. Thus, to account for our findings, representational accounts may need to abandon the notion of structural depth. However, this does not seem to be a sensible conception, given that structural depth effects are observed in several production studies (e.g. Bock & Cutting, 1992; Franck et al., 2002).

Alternatively, the finding that structural depth exerted no clear influence on interference effects is compatible with cue-based retrieval accounts. Because these accounts adopt a feature-based approach, which utilises a direct access mechanism that activates all elements matching retrieval cues in parallel, cue-based memory retrieval is predicted to proceed independently of structural distance between the controller and the distractor. However, given that our study did not show inhibitory interference in grammatical sentences, which is inconsistent with the traditional cue-based memory retrieval account (e.g. Lewis & Vasishth, 2005), we argue that our results are most compatible with Wagers et al.'s (2009) account that the processor initiates cue-based memory retrieval only when it has difficulty forming grammatically licit dependencies.

Conclusion

We conducted eight experiments that investigated the processing of sentences involving quantifier float and

subject-verb agreement to test the nature of interference during dependency formation. The results indicated that when the processor encounters an element of a dependency relation, it retrieves the structurally licensed element. Also, our results largely indicated that quantifier float and subject-verb agreement are susceptible to interference in ungrammatical sentences when a distractor matches the number cue compared to when it mismatches. However, we did not observe clear interference effects in grammatical sentences. Additionally, and contrary to some previous findings, we found significant interference effects irrespective of the structural distance between the controller and the distractor and the distractor's argument status. These findings cast doubt on claims that distractors in certain positions resist interference.

In summary, our results indicate interference across linguistic phenomena, both subject-verb agreement and quantifier float, and in different structures, suggesting interference is a general property of comprehension. We conclude that our findings are most consistent with the claim that the processor initiates cue-based memory retrieval and sometimes retrieves a distractor only when it has difficulty forming structurally legitimate dependencies.

Note

1. We mistakenly did not specify this removal procedure in our pre-registration for Experiment 1 but did so for the other self-paced reading experiments.

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