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# MAINTAINING SYNTACTIC POSITIONS AND THEMATIC ROLES IN MEMORY

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## Abstract

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This thesis investigates syntactic and thematic factors that contribute to interference in language comprehension during the resolution of subject-verb dependencies. One self-paced reading experiment and one speeded acceptability judgment task examined the mechanisms underlying subject retrieval operations using materials that leverage syntactically alternating Double Object (DO) and Prepositional Dative (PP) structures. The self-paced reading results suggest that arguments in the PP frame inhibit retrieval during thematic binding operations, but identical arguments in the DO frame do not. The acceptability judgment results indicate that arguments in both structures can engender facilitatory interference during number agreement processing in ungrammatical sentences. This thesis proposes an account of the present results, as well as a range of previous findings, involving a single set of retrieval cues, weighted with estimates of reliability according to the grammatical function of the retrieval operation. Such an account is consistent with a cue-integration model of language comprehension (Martin 2016), which links psycholinguistic theory with neurobiological models of perception. Additionally, this work demonstrates both inhibitory and facilitatory interference effects with identical structures, providing further evidence for central predictions of the cue-based retrieval model of sentence processing (Lewis & Vasishth 2005).

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# 1

# Introduction

Various aspects of sentence processing are constrained by the cognitive architectures of memory, and much work in recent years has served to develop a comprehensive understanding of the computational processes underlying these systems. Sentence comprehension requires active and incremental parsing to establish relations between linguistic constituents, but these constituents are often separated by multiple words, phrases, or clauses. To establish relations between these non-adjacent linguistic dependents, the parser must utilize memory processes to successfully support language comprehension. Experimental investigations into the properties and limitations of these processes have leveraged linguistic contexts in which such memory mechanisms fail, providing evidence of the kinds of linguistic information relevant in the resolution of long-distance dependencies. For example, the subject of an English sentence is often displaced from its corresponding verb, and must be re-accessed to license agreement and develop a thematic structure of the unfolding sentence. Previous work has demonstrated that this process of subject retrieval is sensitive to properties of syntactic structure, whereby cues

to a clausal subject guide a direct-access search for an item to fulfil the grammatical functions of thematic binding and agreement licensing, predicting interference to arise when cue-matching items are also stored in memory (Van Dyke & Lewis 2003, Lewis & Vasishth 2005, Lewis 1996, McElree 2000, McElree, Foraker, & Dyer 2003). This picture is complicated, however, by various findings which demonstrate that syntactically mismatching direct objects do not interfere with subject retrieval, whereas syntactically prepositional phrase complements do, motivating accounts in which a gating mechanism references syntactic detail of core thematic arguments to accept or reject potential retrieval candidates, but fails to gate poorly represented oblique arguments (Van Dyke 2007, Van Dyke & McElree 2011, Parker & An 2018).

Although much progress has been made in this area of research, these works investigating interference effects across a number of linguistic contexts compare the interference profiles of items which differ in a number of syntactic and thematic dimensions. The present study aims to directly examine the granularity of syntactic and thematic cues leveraged during subject-verb dependency resolution by comparing interference effects across thematically identical items in syntactically prominent specifier positions (structurally similar to clausal subjects, which occupy specifier positions; McCloskey 1997) and syntactically mismatching complement positions. This thesis reports results from a self-paced reading experiment and a speeded acceptability judgment task investigating thematic binding and number agreement processing when the subject and verb are displaced by an intervening ditransitive structure, alternating between the Double Object, in which the thematic Goal occupies a specifier position, and the Prepositional Dative, in which the thematic Goal occupies a prepositional complement position. To

preview the main findings, the self-paced reading results in Experiment 1 superficially mirror previous findings on differences between direct object and prepositional complement distractors, with inhibitory interference arising from Prepositional Dative Goals, but not from Double Object Goals. Crucially, this pattern cannot reflect retrieval processes sensitive to the syntactic prominence of specifiers alone, nor the presence of a syntactic gating mechanism sensitive to thematic distinctions, as the thematic roles of the interfering arguments are identical across both structures. The results of the acceptability judgment task in Experiment 2 indicate that plural Goals in both structures can facilitate processing in ungrammatical sentences with singular matrix subjects and plural-marked verbs, replicating the classic agreement attraction effect in which a plural distractor licenses an illusion of grammaticality (Pearlmutter et al. 1999, Wagers et al. 2009, Dillon et al. 2013).

Together, these findings are not neatly explained by existing proposals. I propose that these results, and related findings from previous studies, can be understood if the memory processes of encoding and retrieval leverage information regarding thematic integration, or the process by which arguments saturate a given predicate. The grammatical functions of thematic binding and number agreement are executed with a single set of retrieval cues, and the cues that guide the resolution of the distinct grammatical functions are those which are most reliable in uniquely identifying the retrieval target given the available linguistic context.

The remainder of this section introduces the cue-based retrieval model in greater detail, and provides an overview of existing findings regarding the processes underlying subject-verb dependency resolution during retrieval and encoding. The fol-

lowing section presents the two experiments of the current study. The concluding section discusses the central findings and the novel thematic integration account.

## 1.1 Content-Addressable Retrieval

Language comprehension involves the active maintenance and resolution of various grammatical dependencies, often spanning long hierarchical and/or linear distances, relying on a mechanism that encodes and retrieves items from memory. The incrementality of comprehension necessitates this mechanism to incorporate incoming signal into a structured representation and maintain relevant aspects of the input for subsequent dependency resolution, which further requires integration of these stored representations in memory with successive incoming input. Take, for example, the subject-verb dependency in (1), which requires some linking between the subject and the verb to compute number agreement and fulfill the argument structure requirements of the verb, although the subject and the verb are non-adjacent (separated by a number of words, phrases, and clauses).

(1) The student who eagerly brought the teacher an apple evidently forgot their assignment.

The limited capacity of memory in processing entails some loss of the accessibility of sentence initial subject (*the student*) due to the necessary integration of the material intervening between the subject and the matrix verb (*forgot*), at which point the subject must be retrieved from memory to satisfy the syntactic and semantic requirements of that verb. Using a speed-accuracy tradeoff (SAT) procedure, McElree,

Foraker, & Dyer (2003; Exp. 1) investigate the nature of this retrieval mechanism and compare the processing of subject-verb dependencies in clefted constructions with no intervening material to the processing of non-adjacent subject-verb dependencies with either one or two intervening relative clauses. The authors observe that acceptability accuracy decreased relative to the hierarchical depth of the intervening material, while the speed of participants' responses did not significantly vary depending on the intervening material. These findings are interpreted as evidence for a content-addressable retrieval mechanism, in which cues at the retrieval site enable direct access to stored memory representations without searching through all available representations in memory (McElree, Foraker, & Dyer 2003). This mechanism contrasts with serial search mechanisms (e.g. Sternberg 1966, 1975), which posit that retrieval proceeds serially through all of the representations in memory, and predict slower retrieval speeds when more material intervenes between the subject and the verb.

Recent investigations into retrieval operations across a number of linguistic dependencies have provided support for a direct access content-addressable retrieval mechanism, situated within the cue-based retrieval model of sentence comprehension (Van Dyke & Lewis 2003, Lewis & Vasisth 2005, Wagers 2013, Parker et al. 2017, Dotlačil 2021). In this model, retrieval of a given target at the site of a probe involves a set of cues generated from the sentential context and grammatical knowledge which enable immediate and direct access to items in memory that match the content of those cues, and the likelihood of successful retrieval depends on the degree to which the target uniquely matches the cues of the particular retrieval probe. Due to capacity limitations of working memory in sentence comprehension, syntactic nodes are maintained

as feature-bundles specifying both primitive lexical and syntactic features, as well as relations to other chunks necessary for the incremental parsing of syntactic structure. Chunks have a fluctuating, numerical activation level, defined as a function of usage history and decay, whereby activations levels decline as a function of time, and rise as a function of their usage via retrieval, according to the degree of cue-match with a set of weighted retrieval cues. Activation levels, in turn, determine retrieval probability, which itself is inversely related with retrieval latency (Lewis & Vasisth 2005).

Inhibitory interference or cue-overload can arise when multiple items match the cues of the retrieval probe, such that the target is not sufficiently distinct for the purposes of selective retrieval, thus increasing the likelihood of erroneous retrieval, which is associated with greater processing costs (Watkins & Watkins 1975, Nairne 2002, Lewis 1996, Van Dyke & Lewis 2003, i.a.). Spreading activation due to the fan effect, in which activation levels distributed by the retrieval cues are shared between all items with matching cues, reduces the activation of the target, slowing reading times at the retrieval site. Similarity-based interference effects in comprehension have served to identify the cues leveraged to resolve various dependencies, following the assumption that such interference is caused by multiple chunks in memory bearing features matching the set of cues used in retrieval (Lewis 1996, Van Dyke & Lewis 2003, Lewis & Vasisth 2005). In addition to SAT findings (McElree, Foraker, & Dyer 2003, Van Dyke & McElree 2011), evidence for inhibitory retrieval interference in subject-verb dependencies has also been demonstrated in self-paced reading and eye-tracking while reading tasks (Van Dyke & Lewis 2003, Van Dyke 2007, Van Dyke & McElree 2011, Arnett & Wagers 2017). For example, Van Dyke & Lewis (2003) compare reading times at the embedded

verb, the site at which the embedded subject must be retrieved and integrated, across sentences like (2a-b), which differ in terms of the structure of the embedded clause separating the subject from the verb.

(2) a. The principal remembered that *the teacher* who guessed that *the boys* were cheating would come to his office.

b. The principal remembered that *the teacher* who was designing the new curriculum would come to his office.

The embedded subject (*the teacher*) must be integrated with the embedded verb (*would come*). Both sentences in (2) contain a relative clause modifying the embedded subject, but the relative clause in (2a) contains a complement clause with an overt subject (*the boys*), whereas (2b) does not introduce another clausal subject. Using a self-paced reading task, the authors report significantly longer reading times at the embedded verb in (2a) compared with (2b). These findings are interpreted as evidence of interference within a cue-based retrieval mechanism, whereby the retrieval site (the embedded verb) provides a set of cues to retrieve the embedded subject, having been displaced from the focus of attention, and greater processing cost arises precisely in contexts in which another subject intervenes between the embedded subject and the embedded verb, whereas retrieval is comparatively easy for the parser when no items overlapping in cues to the embedded subject intervene. Van Dyke & Lewis (2003) posit that the cue provided by the verb is something like [+SUBJECT], representing a set of morphosyntactic features that identify accessible grammatical subjects, and thus the cue-overlap between *the teacher* and *the boys* in (2a) drives retrieval interference.

Alongside consistent findings of inhibitory interference in subject-verb dependencies (Van Dyke & Lewis 2003, Van Dyke 2007, Van Dyke & McElree 2011), the cue-based retrieval model also predicts facilitatory interference effects when the retrieval target does not fully match the set of retrieval cues, and a partially matching distractor is erroneously retrieved (Wagers et al. 2009, Dillon et al. 2013, Lago et al. 2015, Jäger et al. 2020, Yadav et al. 2023). During retrieval, partial matches become candidates for retrieval, and as neither chunk fully matches the set of retrieval cues, a race ensues and the chunk with the highest activation is retrieved. Effects of facilitatory interference are neatly illustrated in agreement attraction phenomena, as investigated by Dillon et al. (2013), who compared the processing of number agreement in ungrammatical sentences with singular and plural direct object distractors as in (3).

(3) a. *The new executive who oversaw the middle manager apparently were dishonest about the company's profits.

b. *The new executive who oversaw the middle managers apparently were dishonest about the company's profits.

In an eye-tracking-while-reading task, Dillon and colleagues observe longer total reading times and greater probability of regression at the VP region in ungrammatical sentences like (3) in comparison to their grammatical counterparts with singular agreement. In such grammatical sentences, no significant differences are observed between conditions with singular or plural distractors. Within the ungrammatical conditions, however, the VP region in sentences with plural interveners (3b) elicited shorter reading times with fewer regressions than those with singular interveners (3a), replicating previous findings

observing similar facilitatory interference effects (Pearlmutter et al. 1999, Wagers et al. 2009). This facilitatory profile in ungrammatical sentences is neatly understood within the cue-based retrieval model, as in ungrammatical sentences like (3b), neither the syntactically licit agreement controller nor the syntactically mismatching distractor fully match the retrieval cues of the plural verb, which probes for a chunk bearing [+PLURAL] and [+SUBJECT] features. Thus, the target and distractor chunks compete for retrieval, and in a proportion of trials, the plural distractor is erroneously retrieved, licensing an illusion of grammaticality and speeding up reading times at the retrieval site in ungrammatical sentences.

## 1.2 Syntactic representations in retrieval

As discussed above, the relevant syntactic feature assumed to be guiding subject retrieval is simply [+SUBJECT], following evidence of retrieval interference due to intervening subjects (Van Dyke & Lewis 2003, Van Dyke 2007, Van Dyke & McElree 2011). Contemporary notions of phrase structure in the dominant Minimalist Program syntactic framework (Chomsky 1995, McCloskey 1997, Chomsky 2000, i.a.), however, do not simply define a subject as a primitive grammatical object (c.f. Bresnan 1982, Pollard & Sag 1994, i.a.). Rather, grammatical subjects are defined according to structural dimensions, as the specifier of a finite clause bearing nominative case, and thematic dimensions, as a verb's external argument or most prominent argument which is the last to saturate a predicate (Dowty 1982, Gazdar et al. 1985). These syntactic notions of subjecthood motivated the experimental work of Arnett & Wagers (2017), who in-

vestigate the precise ways in which retrieval cues of a verb characterize and retrieve a subject. Experiment 1 compared interference profiles in sentences like (4), in which a nominalization intervened between the subject-verb dependency in either an embedded subject (4a) or direct object position (4b). The possessor of the nominalization is thematically similar to the matrix subject as an external argument, but is not syntactically similar as a genitive argument within a nominal clause. If subject retrieval operates according to thematic cues to the external argument, interference is expected to arise due to the possessor in the nominalization across both syntactic contexts. The results of Experiment 1, however, demonstrated that subject retrieval of the verb distinguishes between thematic subjects of nominalizations and grammatical subjects of clauses, in that interference effects only arose when the nominalization occurred in subject position (4a), indicating that retrieval is sensitive to structural dimensions of subjecthood, involving abstract case and structural position.

(4) a. The hostess who thought that the chef's careful preparation of the blowfish delayed the guest was yelling in the kitchen.

b. The hostess who thought that the guest delayed the chef's careful preparation of the blowfish was yelling in the kitchen.

The subsequent experiments directly investigated the role of case and structure during subject retrieval by comparing the processing of S-Complement, ECM, and Object Control constructions, illustrated in (5a-c), respectively.

(5) The explorer who ...

a. believed that the monster$_{[\text{NOM}]}$ was prowling the ruins ... was insane.

b. believed the monster$_{[\text{ACC}]}$ to be prowling the ruins ... was insane.

c. persuaded the monster$_{[\text{ACC}]}$ to prowl the ruins ... was insane.

In the S-Complement constructions (5a), the underlined DP bears nominative case and is the specifier of a finite TP. In ECM constructions (5b), the underlined DP is the specifier of a non-finite TP, and bears accusative case. Finally, in Object Control constructions (5c), the underlined DP is not the specifier of a finite TP, but controls a null pronominal element in the specifier of the embedded non-finite clause. This DP surfaces as the object to the verb *persuade*, and bears accusative case. If retrieval cues target structural position alone, the underlined DP in S-Comp. and ECM constructions are predicted to elicit greater interference effects than the underlined DP in Object Control constructions. If retrieval cues target case alone, only the underlined DP in S-Comp constructions will engender retrieval interference. If retrieval cues target both structural position and case, S-Comp constructions will elicit the greatest interference effects due to the full cue-match between the matrix subject (*the explorer*) and the underlined DP, with ECM constructions eliciting smaller interference effects due to the partial match, and no interference effects in Object Control constructions due to the complete mismatch.

The results of an eye-tracking while reading study show slower go-past reading times and a greater probability of regressions at the critical and spillover regions following the matrix verb in S-Comp conditions compared with ECM conditions, sug-

gesting that ECM constructions did not elicit retrieval interference to the same extent as S-Comp conditions. In the same regions, processing difficulties were attenuated for Object Control sentences, suggesting an absence of inhibitory interference effects. These findings are understood to reflect the retrieval cues for subject attachment as targeting the nominative specifier of a finite clause, which accounts for the distinction between S-Comp and ECM constructions, and the lack of interference in Object Control constructions. Crucially, the findings of Arnett & Wagers (2017) demonstrate that subject retrieval is guided by syntactic cues to subjecthood, involving both case and structural position. These findings suggest further that incremental encoding of constituents makes reference to their structural status, and that the processing mechanism maintains information such as whether a constituent is in a specifier or complement position, as this is a necessary dimension to identify the grammatical subject in resolving the subject-verb dependency.

Another set of related agreement attraction findings similarly demonstrate further syntactic granularity in subject retrieval operations. Franck et al. (2006) and Franck et al. (2010) aimed to bridge the gap between the theoretical notion of the Chomsky's (1995, 2000) Agree mechanism and the on-line production phenomenon of agreement attraction through experimental work investigating the structural conditions under which attraction arises. One important takeaway from these authors' works is the observation that moved objects trigger interference, whereas objects in base-generated positions do not. Experiment 1 of Franck et al. (2010), for example, compares relative clauses and complement clauses in French, which exhibit a similar surface word order yet differ in the status of the object: in relative clauses (6a), the moved object is assumed

to move through an intermediate specifier position (SpecAgrO), which hierarchically intervenes between the AGREE relation of the subject and the verb, whereas the object in the complement clause (6b) is assumed to be base-generated in the object position.

(6) a. Jean parle aux patientes que le médicament guerit
John speaks to patients.DEF that the medicine cures
'John speaks to the patients that the medicine cures.'

b. Jean dit aux patientes que le médicament guerit
John says to patients.DEF that the medicine cures
'John says to the patients that the medicine cures.'

Using a sentence-completion task manipulating the number of the object (single, plural), the authors report greater error rates in relative clause completions than in complement clause completions. Franck and colleagues argue that this inhibitory interference is driven by the trace, or null copy, of the object in an intervening specifier position due to movement. Experiment 5 solidifies this finding, observing interference effects in relative clauses and complement clauses with an extracted object, whose derivations similarly involve the object raising through an intermediate specifier position, thus leaving behind a trace structurally intervening with the AGREE relation of the subject-verb dependency. These findings are naturally understood under the cue-based retrieval account of agreement attraction (Badecker & Lewis 2007, Wagers, et al. 2009, Dotlačil 2021), whereby the intermediate specifier positions are sufficiently subject-like to engender interference effects.

Dillon et al. 2017 also provide consistent evidence of facilitatory interference in acceptability ratings of ungrammatical wh-questions like (7), in which the direct object is raised to SpecCP.

(7) a. *Which tree are the gardener planting?

b. *Which trees are the gardener planting?

Results from several acceptability judgment studies indicate reliable effects of facilitatory interference in sentences like (7b) compared to (7a), such that constructions with a plural object are rated to be more acceptable than those with a singular object. These authors interpret these findings in relation to the account of syntactic interference of Franck et al. (2006, 2010), such that the specifier-head relation between the displaced object and the auxiliary causes interference during retrieval of the appropriate agreement controller. Thus, the structural prominence of the object as a specifier in such configurations creates a degree of similarity with the matrix subject, licensing the illusion of grammaticality in these ungrammatical sentences.

## 1.3 Syntactic representations in encoding

Syntactic cues are known to play a central role in the resolution of a number of dependencies, and the findings discussed above implicate the sensitivity of retrieval operations to fine-grained syntactic distinctions. Recent studies also indicate that the incremental encoding of chunks in memory similarly operates according to detailed syntactic representations, whereby certain cue-mismatching distractors are demonstrated to interfere with subject retrieval operations. These findings suggest that interference effects do not solely reflect erroneous retrieval processes, but may also evidence an error prone encoding mechanism which modulates the set of retrieval candidates on the basis of syntactic features encoded during incremental parsing. For example, Van Dyke &

McElree (2011) compare sentences like (8), which manipulate the syntactic context of the distractor and the semantic match of the distractor (underlined) with the matrix predicate.

(8) a. The attorney who the judge realized had declared that the witness was inappropriate compromised.

b. The attorney who the judge realized had declared that the motion was inappropriate compromised.

c. The attorney who the judge realized had rejected the witness in the case compromised.

d. The attorney who the judge realized had rejected the motion in the case compromised.

The authors report lower SAT asymptotic accuracy, longer reading times, and a greater probability of regression in comparison of sentences like (8a) and (8b), indicating that a semantically matching distractor in subject position elicits inhibitory interference effects to a greater extent than a semantically mismatching distractor in the same position. This pattern is expected, given the cue-overlap between the matrix and embedded subjects. However, no such differences were observed between sentences like (8c) and (8d) in which the distractor occurs in a direct object position, thus attenuating semantic similarity-based interference effects for distractors syntactically mismatching with the retrieval target. These findings provide evidence for the differential weighting of syntactic and semantic cues during retrieval, yet contrast with the findings of Van Dyke (2007), who observes inhibitory interference due to semantic match when the distractor

occurs as the argument of a prepositional phrase.

Van Dyke & McElree (2011) interpret their findings and that of Van Dyke (2007) as reflecting a syntactic gating mechanism, in which core arguments, or those which are central to the semantic and thematic interpretation of the predicate, are distinctly encoded with syntactic features, and thus provide ample mismatching cues to reject from the set of retrieval candidates. Although subjects are core arguments, their syntactic features do not mismatch with the retrieval cues, and thus remain as viable retrieval candidates. While this mechanism accounts for the absence of interference in direct object conditions like (8c-d), a further assumption must be made to account for the presence of interference from prepositional phrase distractors, such that oblique arguments, or those which are not integral to the semantic and thematic interpretation of the predicate, are encoded without fine-grained syntactic detail, and do not provide sufficient cues for rejection from the set of potential retrieval candidates. Arguments in adjunct prepositional phrases, therefore, are expected to interfere when intervening between long-distance dependencies, as they are not ruled out as inaccessible distractors, and remain within the set of potential retrieval candidates.

Directly testing this hypothesis, Parker & An (2018) compare intrusion profiles across sentences like (9), using self-paced reading tasks to probe for facilitatory effects in ungrammatical sentences with a plural distractor.

(9) a. The dog that dug the hole(s) unfortunately {was/were} covered in mud.

b. The dog that dug in the hole(s) unfortunately {was/were} covered in mud.

c. The toy that had been hidden by the kid(s) quickly {was/were} found by the babysitter.

Comparison of sentences like (9a-b) served to evaluate the role of distractors in direct object versus prepositional object positions interfering with subject-verb agreement operations, following the claim of Van Dyke & McElree (2011) regarding the distinct representations of core thematic arguments and oblique thematic arguments. Parker & An (2018) report significant facilitatory intrusion effects in ungrammatical sentences with prepositional object distractors, whereby the plural verb is read faster following a plural distractor as compared to a singular distractor, and find no intrusion effects in ungrammatical sentences with direct object distractors. The authors interpret these findings as direct evidence in favor of the Van Dyke & McElree (2011) proposal, such that core arguments are encoded with distinct syntactic representations which enable the gating mechanism to reject direct objects as potential retrieval candidates, whereas oblique arguments are not encoded with sufficient detail and do not provide the syntactic cues necessary for rejection from the candidate set, thus giving rise to potential interference during retrieval. Parker & An (2018) observe further that sentences like (9b), which involve passivized relative clauses with the oblique agent as the intervening distractor, do not elicit intrusion effects, whereby the plural distractor does not facilitate processing at the ungrammatical verb. In tandem with the findings from direct objects and prepositional objects, these findings indicate that interference is not modulated by

the position of a distractor within a prepositional phrase, but rather, that interference is modulated by the thematic-semantic properties of the argument, such that core arguments resist intrusion effects regardless of their syntactic contexts (cf. Dillon et al. 2013, Wagers et al. 2009, i.a.).

More broadly, Parker & An (2018) argue that the memory mechanisms involved in dependency resolution, including both the encoding of arguments and their later retrieval, are closely aligned with and sensitive to grammaticalized argument hierarchies and fine-grained syntactic distinctions. Yadav et al. (2023) similarly argue, on the basis of a Bayesian meta-analysis of previous studies on number-agreement findings, that models of such facilitatory effects in ungrammatical sentences paired with the relative absence of facilitatory or inhibitory effects in grammatical sentences must incorporate (error-prone) mechanisms for encoding and representing chunks with relevant syntactic features, as well as the retrieval mechanisms assumed in cue-based retrieval models.

# 2

# Present Study

Previous studies have provided a variety of evidence indicating sensitivity to fine-grained syntactic detail in both encoding and retrieval mechanisms necessary for resolving long-distance dependencies. Effects of both inhibitory and facilitatory interference in subject-verb dependencies indicate that subject retrieval operates primarily via syntactic cues to subject-hood, distinguishing between retrieval candidates in subject and object positions (e.g. Van Dyke & McElree 2011, Dillon et al. 2013), and further, between nominative and accusative marked clausal specifiers (Arnett & Wagers 2017). Related studies have demonstrated that syntactically prominent elements occupying specifier positions may interfere when computing subject-verb agreement, leveraging structures in which the specifier stands in a particular hierarchical (Spec-Head) relationship with the verb (Dillon et al. 2017), or hierarchically intervenes between the derivational agreement mechanism established with the subject and the verb (Franck et al. 2006, 2010). This cluster of findings suggests that retrieval operations are guided by cues to structural prominence (including, but not limited to, Spec-Head relationship,

c-command, hierarchical/linear precedence), indirectly encoded on clausal subjects due to their phrase structural position. While these studies implicate interference during retrieval, recent studies have also argued that interference effects are not the sole product of erroneous retrieval, and may arise due to both retrieval and encoding mechanisms which establish the representation of syntactic nodes in memory (e.g. Villata et al. 2018, Yadav et al. 2023). Such mechanisms are further posited to operate according to a syntactic gating process, particularly attuned to grammaticalized argument-hierarchies and fine-grained syntactic detail (Van Dyke & McElree 2011, Parker & An 2018).

Against this background, the present work seeks to directly investigate several predictions emerging from these studies regarding the use of structural, relational, and thematic information in subject-verb dependency resolution. Previous studies have argued that syntactic cues primarily guide the resolution of the subject-verb dependency in thematic binding and agreement computations, through comparison of interference effects between subjects and objects, direct objects and prepositional objects, and core and oblique arguments, conflating inherent differences across syntactic structure and thematic roles. The aim of the current set of experiments is to evaluate the granularity of syntactic cues, mainly the distinction between specifier positions and complement positions, while maintaining thematic roles constant across structures, thus providing a means to directly investigate how memory mechanisms reference structural and relational information in resolving the subject-verb dependency. Subject retrieval operations have been consistently demonstrated to operate according to morphosyntactic cues to structural position, suggesting that activation levels which determine retrieval probability and latency are sensitive to this dimension of syntactic prominence. Within

the cue-based retrieval model (Lewis & Vasisth 2005, Dotlačil 2021), chunks encoded as specifiers are predicted to elicit increased interference during retrieval, as the effectiveness of the cues to structural position and the strength of the associative match between the retrieval target and the retrieval cues decrease with each additional item that matches such positional cues. Whereas previous works have demonstrated that items in specifier positions standing in a direct hierarchical relationship with the retrieving verb engender interference effects when computing agreement (Franck et al. 2006, 2010; Dillon et al. 2017), the present studies aim to directly address whether the structural and relational features of a chunk encoded as a specifier are independently leveraged by the probing verb's retrieval cues, particularly when the specifier does not stand in a direct hierarchical relationship with the verb. Though non-subject specifiers are not a full match to the set of a verb's subject-retrieval cues, retrieval has been demonstrated to weight structural cues above non-structural cues, including morphological and semantic cues, across a number of long-distance dependencies (Van Dyke 2007, Van Dyke & McElree 2011, Dillon et al. 2013, Arnett & Wagers 2017, Parker & Phillips 2017).

Both experiments reported below leverage the alternation in English between the Double Object and the Prepositional Dative constructions, illustrated in (10a) and (10b), respectively. The relevant dimensions of both structures are fully discussed in the following section.

(10) a. Mary gave Stephen the dog.

b. Mary gave the dog to Stephen.

To preview this discussion, the structures differ in their structural representation of the indirect object, or the thematic Goal, of the ditransitive predicate. Double Object constructions position the indirect object in a specifier position, whereas the Prepositional Dative positions the indirect object as the complement of a preposition. When situated between the subject-verb dependency, these structures allow for a comparison of potential interference effects due to arguments in either specifier or complement positions, keeping constant the representations of (abstract) case, grammatical function, and thematic role. Given that previous works have argued that thematic information on nominal arguments feeds a gating mechanism which subsequently leverages syntactic cues to accept or reject retrieval candidates, maintaining thematic roles between the arguments across the contrasted structures ensures that measures of interference reflect structural differences alone.

Experiment 1 employs a self-paced reading task to measure reading times at the matrix verb in sentences in which the Double Object and Prepositional Dative occurs in a relative clause modifying the subject, reflecting subject-retrieval latencies. Experiment 2 incorporates the design of previous studies on number agreement processing in (un)grammatical sentences (e.g. Bock & Miller 1991, Wagers et al. 2009, Dillon et al. 2013), using acceptability judgments for off-line measures of interference. These studies are discussed in turn.

## 2.1 Experiment 1: Self-Paced Reading with Ditransitive Alternations

### 2.1.1 Design and Predictions

Inhibitory interference effects measured across various experimental reading methodologies have proved fruitful in identifying the relevant cues that guide retrieval operations for a number of long-distance dependencies. Experiment 1 incorporates the designs of Van Dyke & Lewis (2003) and Arnett & Wagers (2017) in a self-paced-reading task to compare the resolution of the subject-verb dependency with intervening Double Object constructions (5a) and their Prepositional Dative alternations (5b).

There are two general classes of syntactic accounts of the Double Object construction: the small clause approach (Johnson 1991, Harley 1995, 2002, Harley & Jung 2015, i.a.) and the applicative approach (Marantz 1993, Bruening 2010, 2021, i.a.). The small clause approach posits that the verb merges with a Possessive Small Clause (SC), in which the indirect object (the Goal) is the specifier to a predicative functional head whose complement is the direct object (the Theme). Conversely, the applicative approach posits an Applicative Phrase (ApplP), in which the indirect object is the specifier to the Appl head, which merges with a lexical verb phrase that introduces the direct object as the complement to the verb (which itself raises to the containing VoiceP or vP). These structures are illustrated in Figures 2.1 and 2.2. Various accounts of the Prepositional Dative frame differ in whether or not the direct object is base-generated in a specifier or complement position (Larson 1988, Bruening 2010, Bruening 2021, i.a.). However, across all accounts, the indirect object surfaces as the complement of a

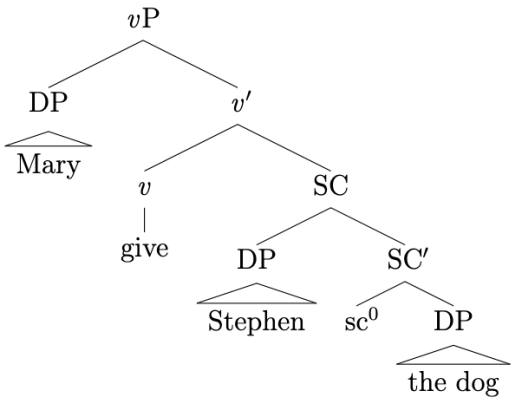


Figure 2.1: Small Clause analysis of Double Object constructions

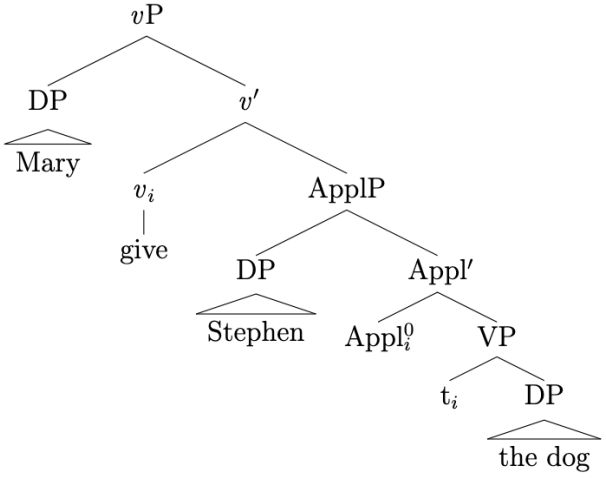


Figure 2.2: Applicative Phrase analysis of Double Object constructions

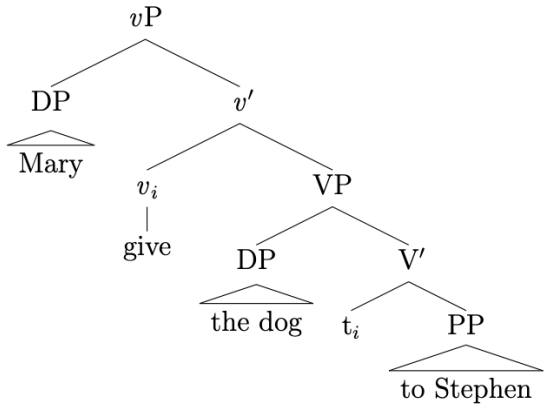


Figure 2.3: Prepositional Dative structure (Harley & Jung 2015)

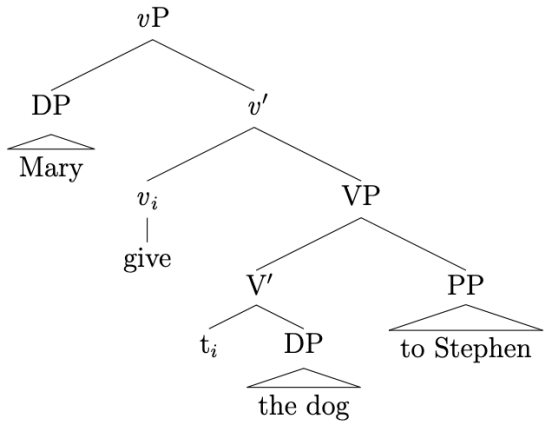


Figure 2.4: Prepositional Dative structure (Bruening 2021)

prepositional phrase, shown in Figures 2.3 and 2.4.

Semantic analyses of the two structures (e.g. Marantz 1993, Bruening 2001, Krifka 2001, Harley 2002, i.a.) have argued that they are not distinct syntactic realizations of the same meaning, but rather, express different meanings all together: the Double Object construction expresses 'caused possession,' whereas the Prepositional Dative expresses 'caused motion,' and predicates which seemingly permit the alternation between the structure are in fact polysemous. These accounts have leveraged various non-alternating examples (e.g. gave me a headache vs. *gave a headache to me, denied

the student the loan vs. *denied the loan to the student) to argue for such lexical restrictions the syntactic alternation. Bresnan & Nikitina (2007), however, provide an extensive corpus analysis which demonstrates that even these apparent exceptions are attested to alternate between the two structures without changing their meaning, and further claim that the two structures can be analyzed as alternate syntactic structures expressing truth conditionally equivalent meanings. In their analysis, the alternation is primarily driven by independently motivated hierarchies of information prominence (including Person, Givenness, Definiteness, Animacy, and Pronominality).

Regardless of how various proposals incorporate the distinction between 'caused possession' and 'caused motion,' these accounts all maintain that the thematic roles are identical across the two structures (Larson 1988, Bruening 2001, Krifka 2004, Colleman et al. 2010, Bruening 2010, i.a.). In the Double Object construction, the indirect object is the recipient in a transfer of possession and becomes the possessor of the theme, whereas in the Prepositional Dative, the recipient is the goal at the end of a spatio-temporal path traveled by the theme (Collemen et al. 2010, Krifka 2004). Newman (1996) motivates the recipient in a transfer of possession as a goal according to the spatio-temporal dynamics of such events of transference, indicating further that both constructions express an event between the goal and the theme. Typologically, the structures are distinguished according to their alignment configuration in expressing a spatio-temporal event. The Double Object construction is a neutral alignment construction and does not morpho-syntactically distinguish the two arguments from monotransitive themes, whereas the Prepositional Dative is an indirective alignment construction, and treats the ditransitive theme like a monotransitive theme, yet ex-

presses the recipient with a spatial adposition (Haspelmath 2005, 2015). Typological analyses further implicate apparent isomorphisms in expressions of locations, recipients, and spatial goals, such that if a language contains an adposition to mark locations and recipients, this adposition will also mark spatial goals (Blansitt 1988, Newman 1996). Thus, across accounts which posit various syntactic and semantic distinctions between the alternation, and those which claim that the two structures are not, in fact, in alternation, the structure of the underlying events of 'caused possession' and 'caused motion' are taken to cast identical thematic arguments in relation to one another. These considerations motivate the design of Experiment 1, in contrasting the Double Object and Prepositional Dative structures according to their distinct syntactic representations of the indirect object, without thematic alternations between the two structures.

The experimental items, illustrated in (11) below, contain relative clauses with either Double Object (DO) or Prepositional Dative (PP) constructions intervening between the subject-verb dependency, and thus create configurations similar to those used in previous studies used to elicit interference effects at the matrix verb. The matrix subject verb dependency is underlined, and items predicted to elicit interference are italicized. Across items, either the embedded subject (Subj), the indirect object (Goal), or the direct object (Theme) is modified with a single prenominal adjectival modifier, as modification has been demonstrated to involve (re)activation of the modified constituent leading to strengthened encoding in memory, which further facilitates subsequent retrieval (Vasishth & Lewis 2006, Hofmeister 2011, Arnett & Wagers 2017). The non-modified (11a) and (11e) serve as base-lines to compare the processing of Double Object and Prepositional Dative constructions independently of potential effects of

modification. Differences in these conditions may reflect inherent differences between the two constructions, including information structure or prosodic structure, which may independently impact processing.

(11) The clerk who forgot that ...

a. ... *the judge* handed *the nurse* the paper ... was late.

b. ... *the judge* handed *the nurse* the helpful paper ... was late.

c. ... *the judge* handed *the helpful nurse* the paper ... was late.

d. ... *the helpful judge* handed *the nurse* the paper ... was late.

e. ... *the judge* handed the paper to the nurse ... was late.

f. ... *the judge* handed the helpful paper to the nurse ... was late.

g. ... *the judge* handed the paper to the helpful nurse ... was late.

h. ... *the helpful judge* handed the paper to the nurse ... was late.

Adopting the hypothesis that cues to syntactic prominence are encoded on subjects and inform subsequent retrieval operations, the indirect object in Double Object constructions are predicted to be sufficiently subject-like to drive similarity-based interference effects, whereas the structural status of the indirect object in Prepositional Datives constructions is sufficiently distinct from the matrix subject and is not predicted to elicit interference effects. As discussed above, these interference effects are expected to occur at the VP region which initiates retrieval of the subject, realized as longer reading times in this region, and lower accuracy on subsequent comprehension questions.

Within modified Double Object conditions, (11c) is predicted to elicit greater interference effects than (11b), due to the animacy of the indirect object, its status as

the specifier of an intervening phrase, and its strengthened encoding from prenominal modification. These conditions establish the indirect object as sufficiently similar to the matrix subject in animacy and structural prominence, thus driving cue-overload at the verb region when subject retrieval is initiated. The inanimacy of the direct object, conversely, serves to sufficiently distinguish the direct object from the matrix subject, independently of its structural position (Pickering & Traxler 2001). Within modified Prepositional Dative conditions (11f-g), no difference is predicted to emerge, as neither the indirect object nor the direct object are sufficiently subject-like in the sense spelled out above: though the modification serves to strengthen their encoding and representation in memory, both the direct and indirect object only partially match the retrieval cues of the verb, and thus may drive some interference effects though to a significantly smaller extent than (11c). Even if the direct object is assumed to be situated in a specifier position in the Prepositional Dative frame, the direct object can only partially match in cues to the subject, due to the distinction in animacy.

Alternatively, it may also be the case that no significant differences emerge across the Double Object and Prepositional Dative conditions, due to the thematic differences between the intervening elements and the matrix subject. The findings and predictions of Van Dyke & McElree (2011) and Parker & An (2018) suggest that encoding is facilitated for core thematic arguments, providing those arguments with sufficiently detailed syntactic representations as chunks, which further facilitate acceptance or rejection from the candidate set according to (mis)matches in syntactic cues. This account predicts no differences to emerge between Goal-Mod. and Theme-Mod. Conditions across the two structures, as the thematic roles of the arguments remain

identical. Thus, the gating mechanism which distinguishes core and oblique arguments should operate symmetrically in the Double Object and Prepositional Dative structures, regardless of the syntactic distinctions between the structures.

### 2.1.2 Methods

#### 2.1.2.1 Participants

80 native speakers of English were recruited through Prolific (www.prolific.co) to participate in the experiment remotely. All participants voluntarily provided informed consent. Participants were compensated at a rate of $12/hour.

#### 2.1.2.2 Materials

A sample item set is illustrated in (11) above. Experimental materials consisted of 48 items, arranged in a 2 x 4 factorial design crossing STRUCTURE (Double Object, Prepositional Dative) and MODIFICATION (No-Mod., Theme-Mod., Goal-Mod., Subject-Mod.). The 48 items were distributed across eight lists in a Latin Square Design.

Item sets were constructed as follows. All experimental items began with a subject-relative clause sequence: *Det - $N_1$ - who - $V_1$ - that*. Each configuration introduced the matrix subject ($N_1$) and an embedding verb ($V_1$; e.g. *forgot*), which embedded a clausal complement containing the critical Double Object or Prepositional Dative structures. Double Object conditions were constructed with the following sequence: *Det - $N_2$ - $V_2$ - Det - $N_3$ - Det - $N_4$*, where the ditransitive verb is $V_2$, the indirect object or Goal is $N_3$, and the direct object or Theme is $N_4$. Prepositional Dative conditions were constructed using identical lexical items, and differed only in structure,

with the following sequence: *Det - $N_2$ - $V_2$ - Det - $N_4$ - to - Det - $N_3$*. Ditransitive verbs which permit both the Double Object and Prepositional Dative frames were selected to maintain the same lexical items across the two structures.

Within each item set, all four nouns were matched in character length and log frequency (SUBTLEXus database; English Lexicon Project, Balota et al. 2007). The first three nouns ($N_1$ - matrix subject; $N_2$ - embedded subject, $N_3$ - indirect object/Goal) were always animate, and the fourth noun ($N_4$ - direct object/Theme) was always inanimate. 16 animate 'triplets' were selected to occupy the matrix subject, embedded subject, and indirect object positions, and each noun in every triplet rotated through each syntactic position, creating 48 items. In other words, each set of three animate nouns appeared across three distinct item sets, though each noun only surfaced in either of the syntactic positions only once. The experiment was coded to randomize the presentation of the three sets of 16 items, as well as the 16 items within each set, to avoid the sequential presentation of items containing the same three animate nouns. 48 unique inanimate nouns were selected as the direct object for each item set.

Subject-Modification conditions included a prenominal adjectival modifier immediately preceding $N_2$, Goal-Modification conditions included the same adjective ahead of $N_3$, and Theme-Modification conditions included the adjective ahead of $N_4$. As mentioned in the discussion above, the adjectival modification served to distinguish the given DP, thus strengthening its encoding in memory to increase the likelihood of erroneous retrieval of that argument. 48 adjectival modifiers were selected for each item set, and were matched in log frequency.

The spillover region consisted of a two-word prepositional phrase adverbial,

either locative or temporal, which immediately followed the clausal complement. The matrix VP region appeared after the prepositional phrase, and consisted of the auxiliary was and an intransitive predicate. Another locative or temporal prepositional phrase spillover followed the main predicate in each item set.

The 48 experimental items were presented along with 52 filler items. 26 filler sentences were adapted from items in Experiments 2 and 3 of Arnett & Wagers (2017), containing relative clauses with embedded Sentential Complements, Exceptional Case Marking, and Object Control constructions. 26 filler sentences were adapted from the experimental items of Van Dyke & Lewis (2003), containing their high interference items with an embedded clausal subject, and low interference items without an embedded clausal subject. A full list of experimental and filler items is available here.

50 of the items were followed by a yes/no comprehension question. The comprehension questions were designed to probe information about either of the nouns in the sentence, as well as the matrix subject-verb relation. Comprehension questions were evenly balanced for yes and no responses.

#### 2.1.2.3 Procedure

Sentences were presented on participants' personal computers using the web-based platform IbexFarm (Drummond, 2013) in a self-paced word-by-word in-place paradigm. Participants began each trial by pressing the space bar to reveal the first word of the sentence in the center of the screen. Participants were instructed to advance through the sentence at a natural pace by continually pressing the spacebar to remove the current word and reveal the next word of the sentence. After half of the sentences,

participants were presented with a yes/no comprehension question. The presentation of the yes/no answers alternated between left and right, and participants were instructed to press the 'f' key to respond with the answer on the left and the 'j' key to respond with the answer on the right. The order of presentation of items was pseudo-randomized in a Latin Square Design. Four practice items were presented at the beginning of the experiment. The experiment took around 45 minutes to complete.

#### 2.1.2.4 Analysis

Results were analyzed using the R statistical computing environment and modeled using a series of Bayesian linear mixed-effects models using the brms package (Bürkner 2017), assuming an inverse Gaussian distribution to characterize the relationship between the predictors and RTs (Lo & Andrews 2015) and linear mixed-effects models using the lme4 package (Bates et al. 2014). Extreme reading time observations of less than 50ms and greater than 5000ms were excluded from the analysis. Prior to analysis, RTs were aligned into single-word regions, as in (12), due to inherent differences in word count across the experimental items.

(12) $\text{The}_1$ $\text{clerk}_2$ $\text{who}_3$ $\text{forgot}_4$ $\text{that}_5$ $\text{the}_6$ $(\text{helpful})_7$ $\text{judge}_8$ $\text{gave}_9$ $\text{the}_{10}$ $(\text{helpful})_{11}$ $\text{N}_{12}$ $(\text{to})_{13}$ $\text{the}_{14}$ $(\text{helpful})_{15}$ $\text{N}_{16}$ $\text{last}_{17}$ $\text{week}_{18}$ $\text{was}_{19}$ $\text{late}_{20}$ $\text{to}_{21}$ $\text{the}_{22}$ $\text{appointment}_{23}$.

Within the Modification conditions, coefficient contrasts used a Helmert coding scheme, which compared (i) Goal-Modified sentences with Theme-Modified sentences (i.e. non-subject modification conditions) and (ii) Subject-Modified sentences with the mean of the non-subject modified conditions. This Helmert contrast coding scheme allowed for the comparison of the effects of the modified Goal and Theme conditions, which

crucially differ syntactically across the Double Object and Prepositional Dative constructions. These effects can further be compared with the effect of Subject-Modified sentences, which is independently predicted to emerge due to the wealth of previous findings regarding subject-interference.

To control for differences stemming from processing the region immediately following the clausal complement and immediately preceding the critical VP region (i.e. the spillover following the embedded Double Object or Prepositional Dative structure), the latencies for these preceding words were orthogonalized using a Principal Component Analysis. This process controls for possible sources of variance that may mask effects at the critical VP region, by incorporating the correlational structure with the reading times of the region immediately preceding the VP region.

### 2.1.3 Results

#### 2.1.3.1 Self-Paced Reading Times

Mean reading times for all conditions are plotted in Figure 2.5. As reported throughout the literature, the critical auxiliary initiates subject retrieval, and I focus on this region as the locus of interference effects. Whereas Arnett & Wagers (2017), for example, report interference effects in the spillover region immediately following the auxiliary, they describe this pattern as an artifact of the self-paced moving-window display, in which spillover effects may arise due to readers' forward momentum or predictability of the upcoming predicate due to the series of dashes indicating the position within the sentence and the length of the sentence. Conversely, the in-place display adopted for the current study presents each word individually at the center of the screen, without

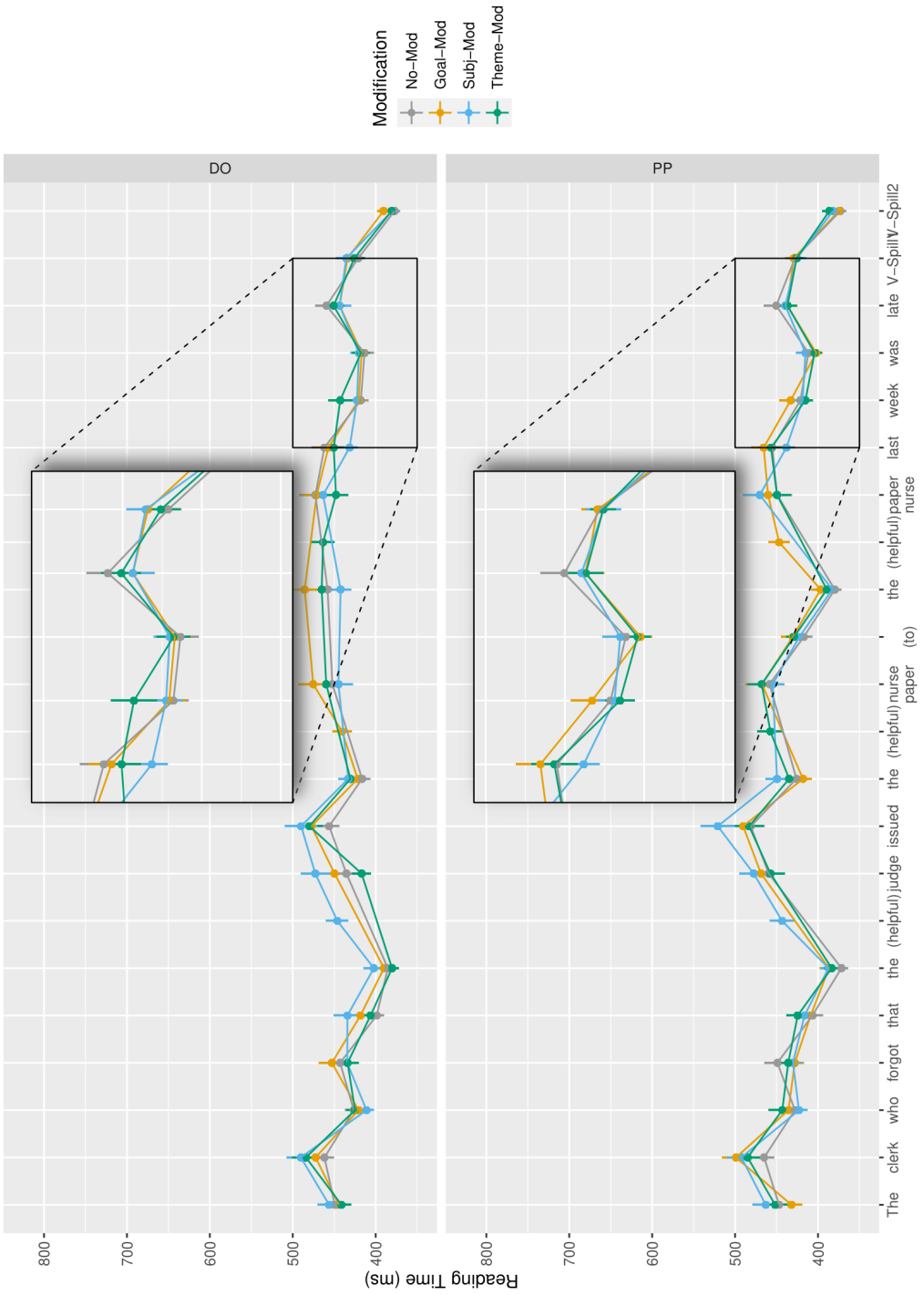


Figure 2.5: Experiment 1 reading times across all conditions, summarizing mean reading times (y-axis) for each experimental region (x-axis), with the critical region magnified. Error bars show standard error

providing any potentially predictive information, and thus requires rapid integration of successive input. I suggest that this self-paced display method reflects localized processing costs, and as such, reading times at the auxiliary are interpreted as measures of processing during subject retrieval operations.

**Self-Paced Reading Times: Non-Modified Conditions** Conditions with non-modified Double Object and Prepositional Dative structures were analyzed separately using a generalized linear mixed-effect model, assuming a Gamma distribution to characterize the relationship between the predictors and RTs (Lo & Andrews 2015), comparing baseline differences between the two structures. At the critical auxiliary, there were no significant differences in reading times across both structures ($t$ = 0.766, $p$ = 0.444). Similarly, no significant differences were observed at the matrix predicate ($t$ = 1.540, $p$ = 0.124), nor the spillover region following the predicate ($t$ = 0.295, $p$ = 0.768). The absence of any reading time differences across the non-modified sentences suggests no baseline differences in processing the two structures. Thus, any differences observed in modified conditions indicate effects due to the strengthened encoding of the modified argument, rather than independent processing differences between the Double Object and Prepositional Dative structures.

**Self-Paced Reading Times: Modified Conditions** Figure 2.6 provides a more detailed view of Modification conditions at the critical region. At the matrix auxiliary in modified condition, there was no main effect of Structure [$\beta$ = -1.13, CI = (-4.00, 1.69)], indicating no reading time differences across all Double Object and Prepositional Dative conditions. However, the critical auxiliary was read reliably slower in Subj-Mod.

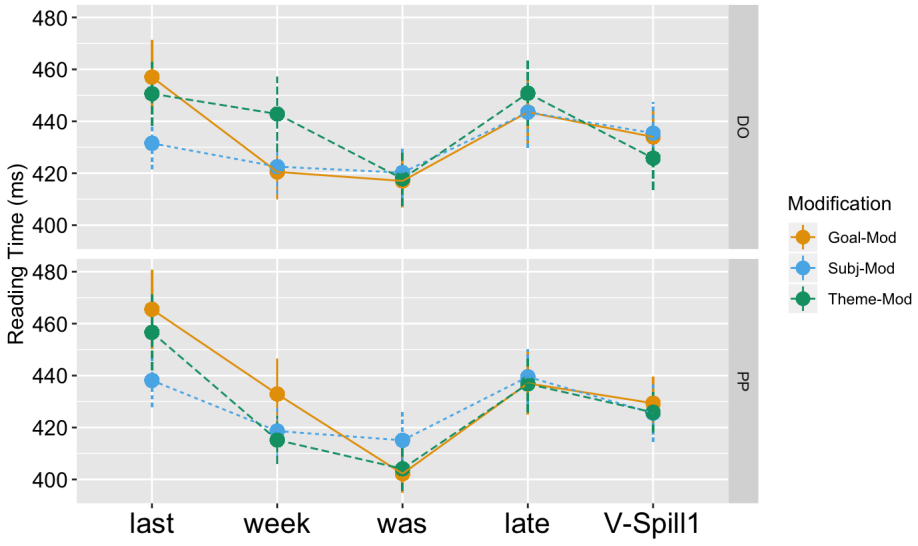


Figure 2.6: Experiment 1 reading times across modified conditions, summarizing mean reading times (y-axis) for each experimental region (x-axis) at the critical region. Error bars show standard error.

conditions than both non-subject modified conditions, across both structures [$\beta$ = 4.64, CI = (0.09, 9.44)]. Contrary to initial predictions, there was a significant interaction between Structure and the difference between Goal-Mod. and Theme-Mod. conditions, such that the critical auxiliary in Goal-Mod. conditions was read slower than in Theme-Mod. conditions, but only in the Prepositional Dative frame [$\beta$ = -6.81, CI = (-13.38, -0.92)]. No significant interaction was observed between Structure and the difference between Subj-Mod. and non-subject modified conditions [$\beta$ = -4.64, CI = (-14.23, 4.42)].

At the matrix predicate immediately following the critical auxiliary, there was no main effect of Structure [$\beta$ = -1.43, CI = (-4.93, 1.98)]. There were no significant differences between reading times in Subj-Mod. and non-subject modified conditions [$\beta$ = -1.35, CI = (-4.47, 1.77)], or between Goal-Mod. and Theme-Mod. conditions [$\beta$

= 2.88, CI = ( -2.64, 8.86)] across both structures. However, the significant interaction between Structure and the difference between Goal-Mod. and Theme-Mod. conditions at the auxiliary persisted to the matrix predicate, such that the matrix predicate was read slower in Goal-Mod. conditions, but only in the Prepositional Dative structure [$\beta$ = -10.26, CI = (-16.79, -3.81)]. There was no significant interaction between Structure and the difference between Subj-Mod. and non-subject-modified conditions [$\beta$ = -2.85, CI = (-14.40, 8.75)].

Following the predicate, there was no main effect of Structure [$\beta$ = 1.41, CI = (-1.22, 4.24)]. There were no significant differences between reading times in Subj-Mod. and non-subject modified conditions [$\beta$ = -2.64, CI = (-5.22, 0.01)], or between Goal-Mod. and Theme-Mod. conditions [$\beta$ = 3.30, CI = (-0.96, 8.36)]. The significant interaction between Structure and the difference between Goal-Mod. and Theme-Mod. conditions emerged in the spillover region as well, such that this region was read slower in Goal-Mod. conditions, but only in the Prepositional Dative structure [$\beta$ = -9.19, CI = (-14.24, -4.20)]. Unlike preceding regions, however, there was also a significant interaction between Structure and the difference between Subj-Mod. and non-subject-modified conditions, indicating that the spillover region in Subj-Mod. conditions was read slower than the average of the non-subject-modified conditions, but only in the Double Object conditions [$\beta$ = 9.28, CI = (0.53, 19.41)].

#### 2.1.3.2 Comprehension Question Accuracy

Table 2.1 summarizes mean comprehension question accuracy across the eight experimental conditions. Linear regression reveals no significant effects for experimental

| | **Modification** | | | |
|---|---|---|---|---|
| **Structure** | *No-Mod.* | *Goal-Mod.* | *Subj-Mod.* | *Theme-Mod.* |
| *Double Object* | 73.9% (2%) | 78.5% (1%) | 80.1% (3%) | 82.2% (2%) |
| *Prepositional Dative* | 76% (4%) | 80.6% (4%) | 73.1% (1%) | 74.4% (1%) |

Table 2.1: Experiment 1 mean comprehension question accuracy (with standard error).

factors, or their interaction.

### 2.1.4 Discussion

Experiment 1 suggests that prenominal adjectival modification contributes to the strengthened encoding of items in memory, thereby increasing baseline activation levels, subsequently increasing the probability of erroneous retrieval. Within conditions with such modification, we observe evidence of inhibitory interference attributed to the Goal argument, but only in the Prepositional Dative frame, contrary to initial predictions. Along with this pattern, however, Experiment 1 replicates previous findings in that reading times at the critical region were slower in Subj-Mod. conditions than in both of the non-subject modified conditions, indicating the largest interference effects for retrieval due to intervening subjects.

Crucially, the observed differences in reading times between Goal- and Theme-Mod. conditions across structures are taken to reflect interference effects arising during subject-retrieval operations. The absence of any significant reading time differences between Double Object and Prepositional Datives in the non-modified baseline conditions suggests that the pattern observed in the modified conditions cannot be attributed to independent distinctions in processing the two structures. The presence of the interac-

tion in the modified conditions, however, indicates that the modified nouns benefit from strengthened encoding due to increases in activation, leading to interference when reactivating the subject to resolve the dependency. Within the cue-based retrieval model, pre-nominal modification serves to activate the predicted NP, in order to project a structure with which to attach. Such modification requires successive activation of the projected node, boosting the activation for the modified constituent, resulting in increased availability for subsequent retrieval operations, leading to erroneous retrieval when the modified constituent is not the retrieval target. This process of reactivation serves to strengthen the features associated with the modified constituent, thus increasing the distinctiveness of those features. This can serve to reduce similarity of chunks during encoding, or increase the degree of feature match with the retrieval cues leveraged in the resolution of dependencies (Vasishth & Lewis 2006, Hofmeister 2011, Hofmeister & Vasishth 2014, Arnett & Wagers 2017). The results of Experiment 1 thus provide additional evidence that modification strengthens the encoding of syntactic nodes, which in turn impacts retrieval operating according to activation levels dynamically established during stages of encoding.

Importantly, although the manipulation of modification served its intended purpose of distinguishing particular constituents, making them particularly salient retrieval candidates, the pattern observed in Experiment contradicts initial predictions regarding the syntactic prominence of specifier positions. The critical and spillover regions exhibited longer reading times in Goal-Mod. conditions than in Theme-Mod. conditions, though only in the Prepositional Dative structure, indicating inhibitory retrieval interference attributed to the distinctly encoded goal argument. This pattern

does not indicate similarity-based interference, given that the indirect object in the Prepositional Dative structure only matches in animacy with the matrix subject, and is structurally distinguished as the complement of a preposition. Thus, the results of Experiment 1 indicate that the structural prominence of arguments in specifier positions does not independently engender retrieval interference, and suggest further that subject retrieval operations do not operate according to this syntactic dimension alone. Although the subject-verb dependency has been argued to primarily leverage structural cues, the resolution of this dependency must involve additional cues as well. Dillon et al. (2013), for example, provide experimental and computational modeling evidence which suggests that the retrieval mechanisms which resolve subject-verb agreement dependencies rely on both morphological agreement cues and syntactic cues, whereas the resolution of reflexive anaphor dependencies primarily relies on syntactic cues. Relatedly, Arnett & Wagers (2017) argue that the gradient increase in interference effects across Object Control, ECM, and S-Comp constructions indicates the use of cues to structural position (SpecTP), which distinguishes Object Control structures from ECM and S-Comp structures, and abstract case, which distinguishes the nominative specifier in S-Comp constructions from the accusative specifier in ECM constructions. Although retrieval interference has been attested to arise due to intervening specifier positions (Franck et al. 2006, 2010, Dillon et al. 2017), the results of the present study indicate that the structural prominence of specifiers is not an independent dimension that causes erroneous retrieval. The results of these previous studies thus reflect the particular configuration of the structures leveraged in each design, in which the intervening specifier stands in a direct hierarchical relationship with the agreement-bearing verb. Though the

present study did not confirm initial predictions regarding the prominence of specifiers, we did observe a consistent difference between Subj-Mod. and non-subject modified conditions, with significantly longer reading times in the critical and post-critical regions. This finding is consistent with previous studies, in that interference is observed in items matching in morphological and structural cues to subjecthood, indicating that subject-retrieval is not solely guided by structural cues to syntactic prominence.

Although this pattern is not indicative of similarity-based interference arising in the presence of intervening specifiers, it is also inconsistent with the predictions of the proposal involving a thematic-syntactic gating mechanism (Van Dyke & McElree 2011, Parker & An 2018), in that the indirect object is thematically identical across the two structures. This account predicts no reading time differences to emerge between the Goal-Mod. and Theme-Mod. conditions between the Double Object and Prepositional Dative, as the thematic integration of the arguments with the ditransitive verb inside the relative clause is assumed to encode the core arguments with sufficiently rich representations, facilitating their rejection from the candidate set according to various morphosyntactic cues mismatching with the retrieval cues of the probing verb. The findings of Experiment 1, however, show superficial similarities to the interference patterns which motivated the thematic-syntactic gating proposal of Van Dyke & McElree (2011) and Parker & An (2018). For subject-verb thematic binding, Van Dyke & McElree (2011) contrast their lack of inhibitory retrieval interference from syntactically inaccessible and semantically compatible direct objects with the presence of such inhibitory effects observed by Van Dyke (2007), with similarly syntactically inaccessible and semantically compatible prepositional complements. This contrast served to mo-

tivate the representational distinction between core arguments (direct objects in Van Dyke & McElree (2011)) and oblique arguments (prepositional complements in Van Dyke (2007)), which is hypothesized to capture the different interference profiles of the thematically distinct arguments.

In the present study, however, a similar interference pattern emerges according to the syntactic distinctions between direct objects and prepositional objects, although the interfering arguments are thematically identical: the Goal in Prepositional Dative structures, as a prepositional complement, engenders inhibitory interference during subject retrieval, whereas the Goal in Double Object structures, superficially akin to a monotransitive direct object, does not give rise to such inhibitory interference. The core insights of the Van Dyke & McElree (2011) syntactic-gating mechanism can be maintained in tandem with the findings of Experiment 1, as well as the experimental findings of Van Dyke (2007) and Van Dyke & McElree (2011), if such a mechanism does not distinguish between thematic arguments, but between proximal and distal arguments of predicates. Put differently, this would incorporate a temporal dimension in encoding, such that arguments encoded in close proximity to the verb are immediately integrated to fulfill the argument structure requirements of the predicate before such thematic information fades from the focus of attention (McElree 2006). These proximal arguments benefit from sufficiently detailed encoding in relation to the predicate, and thus provide the gating mechanism with adequate mismatching cues to facilitate rejection from the set of potential retrieval candidates. As the verb recedes from the focus of attention during incremental parsing, so does the thematic information of the predicate, and subsequently encountered arguments are not sufficiently encoded in relation to the

argument structure of the predicate. Though the to-be-attached prepositional phrase reactivates the VP node to attach to the structure in the Prepositional Dative frame, this syntactic relation does not serve to change the depth of encoding of the goal, which remains deficient in its representation as a chunk. As this argument does not provide adequate mismatching syntactic cues for the gating mechanism, this argument remains within the set of retrieval candidates, causing similarity-based interference according to the remaining overlapping features with the target (here, animacy and/or compatibility with the predicate). In this account, the thematic encoding of arguments according to the argument structure of a predicate provides arguments with detailed representations that feed the syntactic gating mechanism, as in the original account of Van Dyke & McElree (2011), however, the thematic-argument structure of the predicate is subject to temporal decay, and when this information is no longer in the focus of attention, subsequently encountered arguments are attached structurally, but do not benefit from strengthened thematic encoding. This encoding mechanism is consistent with the findings of Experiment 1, as well as that of Van Dyke (2007) and Van Dyke & McElree (2011).

As discussed above, Parker & An (2018) directly investigate the predictions of the original Van Dyke & McElree (2011) gating mechanism, using a within-subjects comparison of direct object and prepositional object distractors in an agreement attraction paradigm, finding facilitatory intrusion effects for ungrammatical sentences with oblique arguments in prepositional phrases but no such effects stemming from core arguments in direct object position. Parker & An claim further that this pattern is attributed to the detailed encoding of core thematic arguments rather than the struc-

ture of the prepositional phrases, providing evidence that oblique agents in passivized relative clauses do not cause facilitatory interference effects in ungrammatical sentences. These claims regarding contrasting interference profiles for core and oblique arguments are difficult to maintain, however, as the thematic roles of the arguments within the three structural contexts are not controlled when manipulating the distinct structures. The comparison between direct objects and prepositional objects in Experiment 1 of Parker & An (2018) manipulates both syntactic structure and thematic role, though the authors argue the different interference profiles arise due to thematic distinctions. Experiment 3 of Parker & An (2018) investigates the passive structure, but does not directly contrast this structure with the prepositional phrases from their Experiment 1 in a within-subjects design, providing no adequate baseline with which to compare interference effects. The absence of interference effects in the passive constructions may also be due to independent differences between the target and the distractor within the items, precluding feature overlap which would license erroneous retrieval. Experimental items consisted of inanimate relative clause heads with animate distractors in the passive by-phrases, and matrix predicates which were only compatible with inanimate external arguments. These distinctions may have prevented interference to arise, independently of the syntactic-gating mechanism proposed to underpin the results of Experiment 3 of Parker & An (2018). Experiment 2 does not address all of these concerns with the findings of Parker & An (2018), but serves to provide a more direct comparison by investigating intrusion effects in Double Object and Prepositional Dative structures, maintaining thematic roles constant across distinct syntactic environments in order to better evaluate the locus of interference and the nature of the gating mechanism active

during encoding.

## 2.2 Experiment 2: Agreement Attraction with Ditransitive Alternations

Experiment 1 demonstrated effects of inhibitory interference attributed to the modified indirect object only in Prepositional Dative constructions, with no such interference observed in Double Object structures. These findings suggest a temporal dimension to thematic encoding and syntactic gating, such that Goal argument in the Double Object constructions is integrated immediately with the verb, according to its argument structure, and is encoded with sufficient syntactic cues for the gating mechanism to rule out this argument as a potential retrieval candidate. In Prepositional Dative structures, however, the Goal argument cannot be immediately encoded in relation to the verb due to its linear and hierarchical distance, and does not benefit from the strengthened encoding that facilitates rejection according to the gating mechanism, and remains active as a viable retrieval candidate. The findings from Experiment 1 provide evidence of inhibitory interference during retrieval, and Experiment 2 seeks to investigate whether such configurations similarly give rise to facilitatory interference, as predicted according to cue-based retrieval models. Thus, Experiment 2 adopts the constructions from Experiment 1 to investigate the acceptability of sentences in which the subject and verb (mis)match in number, and whether the presence of an intervening Goal argument matching in number with the verb licenses an illusion of grammaticality in ungrammatical sentences, as consistently observed in off-line and on-line measures of

number agreement processing.

### 2.2.1 Design and Predictions

The items for Experiment 2 are modified from the item sets created for Experiment 1, using only the Goal-Mod. sentences across both the Double Object and Prepositional Dative structures. These items use the same sets of nouns as in Experiment 1, and all include singular subjects modified with subject relative clauses introducing the ditransitive verb phrase. The two structures are crossed with the number of the intervening indirect object (Singular, Plural) and the grammaticality of the verb (Grammatical/Singular, Ungrammatical/Plural). An example itemset is given in (13), and a full list of the materials for Experiment 2 is available here.

(13) The realtor who sold ...

a. ...the ordinary pianist the cottage ...was energetic ...

b. ...the ordinary pianists the cottage ...was energetic ...

c. ...the ordinary pianist the cottage ...were energetic ...

d. ...the ordinary pianists the cottage ...were energetic ...

e. ...the cottage to the ordinary pianist ...was energetic ...

f. ...the cottage to the ordinary pianists ...was energetic ...

g. ...the cottage to the ordinary pianist ...were energetic ...

h. ...the cottage to the ordinary pianists ...were energetic ...

Following the results of Experiment 1, we predict no facilitatory intrusion effects in the ungrammatical sentences with intervening Double Object constructions, due to the im-

mediate integration of the Goal fulfilling the argument structure of the verb, permitting the rejection of the Goal according to its mismatching syntactic cues. In Prepositional Dative constructions, however, the modified Goal is predicted to interfere with agreement processing and retrieval, as was observed in Experiment 1, such that presence of a plural Goal in ungrammatical sentences in the Prepositional Dative frame will lead to greater rates of acceptance in ungrammatical sentences. Across structures, no differences are predicted to emerge in ratings of grammatical sentences, as observed in similar studies on number agreement processing (Wagers et al. 2009, Dillon et al. 2013, Yadav et al. 2023).

### 2.2.2 Methods

#### 2.2.2.1 Participants

40 native speakers of English were recruited through Prolific (www.prolific.co) to participate in the experiment remotely. All participants voluntarily provided informed consent. Participants were compensated at a rate of $12/hour.

#### 2.2.2.2 Procedure

Sentences were presented on participants' personal computers using the web-based platform IbexFarm (Drummond, 2013) one word at a time in the center of the screen with rapid serial visual presentation reading (RSVP; Potter, 1988), at a rate of 300ms per word. Following the completion of each sentence, a response screen appeared for 3 seconds in which participants rated the sentence as either 'Acceptable' or 'Unacceptable.' Participants pressed the 'f' key to respond 'Acceptable' and the 'j' key to

respond 'Unacceptable.' Participants were instructed to read each sentence carefully, and provide intuitive judgments on whether the sentences sounded like natural examples of English sentences they could imagine using or comprehending without difficulty. Participants were asked to provide their judgments quickly according to their natural intuitions. The response screen disappeared after 3 seconds if participants were too slow to provide their responses, and they continued onto the next item. The order of presentation of items was pseudo-randomized in a Latin Square Design. Four practice items were presented at the beginning of the experiment. The experiment took around 25 minutes to complete.

### 2.2.3 Results

#### 2.2.3.1 Acceptability Judgments

Figure 2.7 summarizes the proportion of responses as 'Acceptable' across the eight experimental conditions. Proportions were analyzed using a generalized logistic mixed-effects model with the three experimental factors (Structure, Distractor Number, Grammaticality). There was a main effect of grammaticality ($t$ = -17.256, $p <$ 0.001), reflecting greater proportion of 'Acceptable' ratings for grammatical sentences over ungrammatical sentences. As visualized in Figure 2.7, there was also an interaction between distractor number and grammaticality ($t$ = -4.022, $p < 0.001$), indicating that participants were more likely to accept ungrammatical sentences in the presence of a plural distractor. The size of this interaction also drives a main effect of distractor number ($t$ = -2.769, $p < 0.01$), reflecting a greater proportion of 'Acceptable' ratings in sentences with plural distractors. There were no other significant effects of the exper-

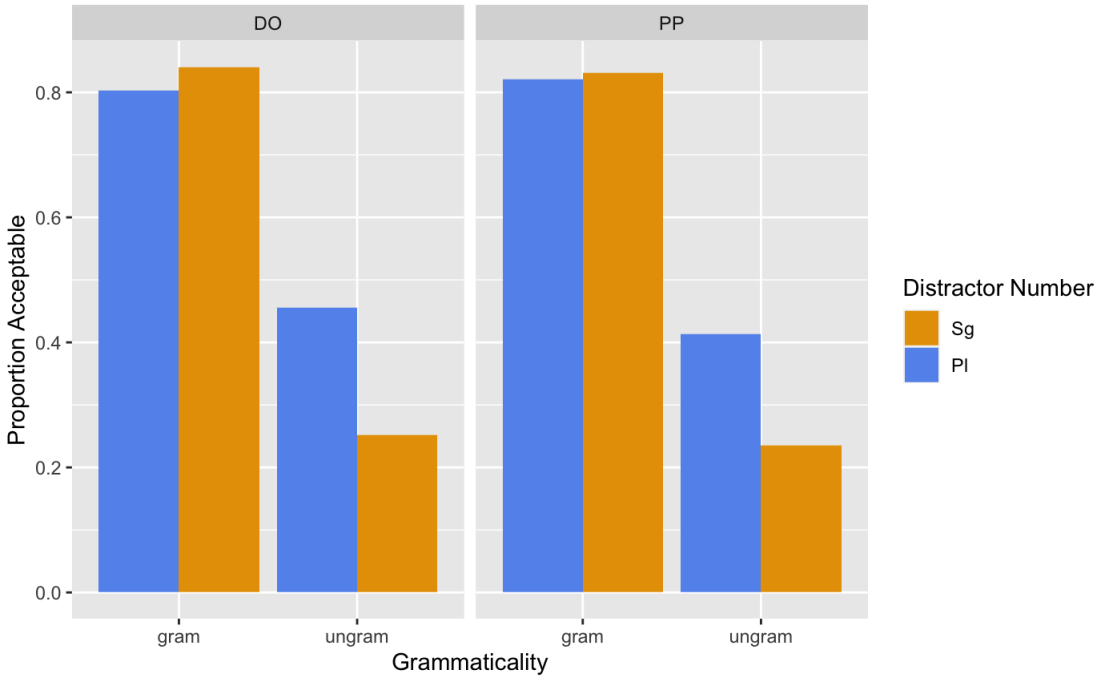


Figure 2.7: Proportion of 'Acceptable' responses in Experiment 2

imental factors, or their interactions. Crucially, this includes the predicted three-way interaction between structure, distractor number, and grammaticality ($t = 0.51$, $p = 0.61$), indicating no differences in effects of intrusion in ungrammatical sentences between Double Object and Prepositional Dative structures.

#### 2.2.3.2 Response Times

Figure 2.8 plots the mean response times in providing both judgments of 'Acceptable' and 'Unacceptable' across the eight experimental conditions. Response times were analyzed using a generalized linear mixed-effect model, assuming a Gamma distribution to characterize the relationship between the predictors and RTs (Lo & Andrews 2015). The predictors in the model included the experimental factors (Structure, Distractor Number, Grammaticality) and response type (Acceptable, Unacceptable). There

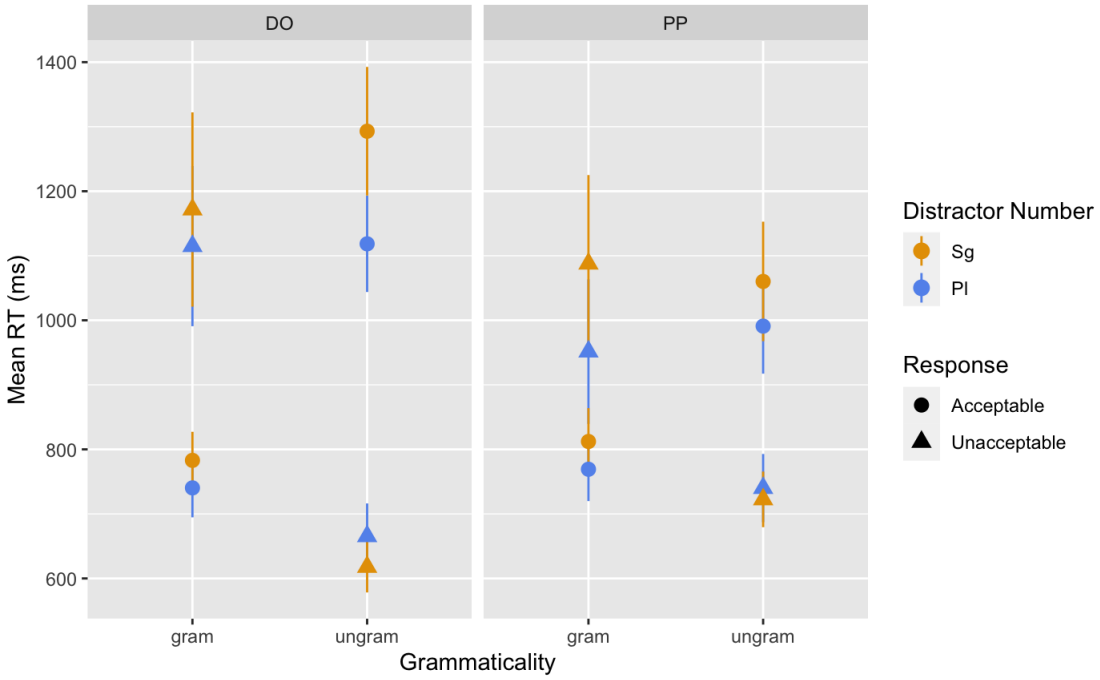


Figure 2.8: Experiment 2 mean response times for 'Acceptable' and 'Unacceptable' responses, across eight experimental conditions. Error bars show standard error.

was an interaction between grammaticality and response type ($t = 3.144$, $p < 0.002$), such that response times were slower in accepting grammatical sentences than in rejecting ungrammatical sentences. This suggests that more information and processing is required to evaluate a sentence as grammatical, and conversely, that less information and processing is necessary to identify a sentence as ungrammatical (i.e. only the presence of a verb mismatching in number with the subject). There was a significant three-way interaction between structure, grammaticality, and response type ($t = 2.004$, $p < 0.05$), indicating that participants were slower in accepting grammatical sentences with the Double Object structure than in the Prepositional Dative structure. There was also a four-way interaction between structure, distractor number, grammaticality and response type trending significant ($t = -1.66$, $p = 0.095$), indicating that in ungrammat-

ical sentences with plural distractors, participants were marginally slower in responding 'Unacceptable' in Prepositional Dative conditions than in Double Object conditions, suggesting greater difficulty in rejecting ungrammatical sentences. There were no other significant effects of the experimental factors or their interactions.

### 2.2.4 Discussion

Experiment 2 replicates the classic agreement attraction effect (Pearlmutter et al. 1999, Wagers et al. 2009, Dillon et al. 2013), whereby plural distractors in ungrammatical sentences improve acceptability judgments relative to singular distractors. Relatedly, no intrusion effects are observed in grammatical conditions, replicating the grammaticality asymmetry, as predicted in contemporary models of number agreement phenomena (Yadav et al. 2023). The facilitatory effect in acceptability in ungrammatical conditions, however, was not shown to differ significantly across the Double Object and Prepositional Dative structures, contrary to the predictions following the results of Experiment 1. In reaction times, however, there emerged a trend suggesting greater intrusion effects in the Prepositional Dative structure than in the Double Object structure. As shown in Figure (8), participants are both faster in accepting ungrammatical sentences with plural distractors and slower in rejecting ungrammatical sentences with plural distractors in the Prepositional Dative condition than in the Double Object condition. Though the complex interaction was not statistically significant, this pattern suggests that the plural distractor exhibits a marginally stronger intrusion effect in the Prepositional Dative structure, licensing the illusion of grammaticality such that accepting ungrammatical sentences with plural distractors is facilitated, and the

corresponding rejection is inhibited.

The off-line and and on-line measures from Experiment 2 only partially corroborate the findings of Experiment 1, in which inhibitory interference was observed for modified goal arguments in Prepositional Dative constructions, but not in Double Object constructions. Conversely, the acceptability judgements in Experiment 2 show clear facilitatory effects of plural goal arguments in ungrammatical sentences with both the Prepositional Dative and Double Object structures, whereas the reaction time measures hint at greater facilitatory effects in the Prepositional Dative structure. These findings are not compatible with the modified gating mechanism proposed in the discussion of Experiment 1, as this proposed mechanism predicts strengthened encoding of the goal in the Double Object construction through immediate thematic integration with the predicate, allowing the gating mechanism to rule out this argument from the set of retrieval candidates. Such a mechanism only predicts interference to arise from the goal in the Prepositional Dative, given its distal relationship with the verb. Experiment 2 does not support these predictions. The extension of the inhibitory interference effects in the Prepositional Dative structures from Experiment 1 to the facilitatory interference effects in the same structures in Experiment 2, however, is significant in directly demonstrating the related predictions of the cue-based retrieval model. Reconciling these patterns with the patterns for the Double Object construction across Experiments 1 and 2, however, suggests that distinct mechanisms or cue weightings may be involved in resolving the different subject-verb dependencies, thematic binding and number agreement. These issues are discussed in the General Discussion below.

# 3

# General Discussion

## 3.1 Summary of Results

The present study investigated the resolution of two related subject-verb dependencies, thematic binding and number agreement, across a self-paced reading task and an acceptability judgment task with items in which Double Object and Prepositional Dative structures intervened on the subject-verb dependency. These structures were leveraged due to their distinct syntactic representations of the thematic goal argument: in the Prepositional Dative, the goal is a prepositional complement, and in the Double Object, the goal is the specifier of a functional projection below the little v layer. Although previous studies studying dependency resolution have suggested that morphosyntactic cues are weighted above thematic-semantic cues in resolving subject-verb dependencies (Van Dyke & Lewis 2003, Van Dyke & McElree 2011, Dillon et al. 2013, Arnett & Wagers 2017), these works have primarily shaped their claims on the basis of retrieval differences with subject and objects intervening on the subject-verb

dependency, which are known to differ structurally and thematically, and relatedly, alter the event structure and semantic interpretation of sentences claimed to be minimally distinct. The ditransitive alternation in English between the Double Object and Prepositional Dative constructions provide an ideal testing grounds for evaluating claims about syntactic and thematic-semantic cues, as the structures represent the goal argument distinctly (as either a specifier or complement), while maintaining thematic roles and semantic interpretations constant.

Given that the resolution of the subject-verb dependency has been argued to primarily leverage morphosyntactic cues, and further, that syntactically prominent specifiers have been demonstrated to interfere with agreement computations in particular configurations (Franck et al. 2006, 2010, Dillon et al. 2017), the present study was concerned with directly evaluating whether the syntactic prominence of an argument in a specifier position was an independent syntactic dimension that guided subject-verb dependency resolution. Neither experiment in the present study provided support for this hypothesis. Results from a self-paced reading task in Experiment 1 demonstrated effects of inhibitory interference during subject retrieval attributed to the goal argument, but only in the Prepositional Dative structure, in which the goal is a prepositional complement, contrary to initial predictions. However, Experiment 1 did demonstrate predicted inhibitory interference effects attributed to the intervening subject, replicating previous findings of such similarity-based interference (Lewis 1996, Van Dyke & Lewis 2003, McElree 2000, Van Dyke & McElree 2011). Results from a speeded acceptability judgment task in Experiment 2 utilizing an interference paradigm to elicit agreement attraction (Bock & Miller 1991) showed facilitatory effects in ungrammatical sentences,

such that ungrammatical sentences with singular subjects and plural verbal agreement were judged to be acceptable to a greater extent in the presence of an intervening plural goal argument than in the presence of a singular goal. Though replicating well-attested findings of number agreement processing (Wagers et al. 2009, Dillon et al. 2013, Lago et al. 2015, Yadav et al. 2023), Experiment 2 did not pattern with Experiment 1, in that significant intrusion effects in acceptability judgments were observed across both Double Object and Prepositional Dative structures, providing no support to the initial hypothesis regarding the prominence of specifiers as in Experiment 1. In line with the results of Experiment 1, however, reaction time measures in the acceptability judgment task revealed an intriguing statistical trend, reflecting marginally faster acceptance rates for ungrammatical sentences with a plural distractor and slower rejection rates for ungrammatical sentences with a plural distractor in the Prepositional Dative structure, as compared with the Double Object construction. These patterns of results are not immediately consistent with any existing account of the memory architectures that subserve dependency resolution more broadly.

## 3.2 Modification

Stepping aside from the central question of this study on syntactic cues, Experiment 1 provided additional evidence for the strengthened encoding of modified constituents, which serves to facilitate subsequent retrieval operations. In the non-modified conditions, no significant reading time differences were observed at the critical and spillover regions across the two structures, however, in the conditions with modified

arguments, modified subjects were shown to inhibit retrieval operations to a greater extent than non-subjects, and within the modified non-subjects, the modified goals elicited greater inhibitory effects on retrieval relative to modified themes, though only in the Prepositional Dative structure.

These findings are neatly understood within cue-based retrieval models, such that the elaboration of a constituent serves to boost its baseline activation and distinguish the modified chunk in memory, thereby increasing the likelihood of retrieving this constituent (Hofmeister & Vasishth 2014, Arnett & Wagers 2017). Vasishth & Lewis (2006) argue that modification preceding the to-be-encountered constituent preactivates the node with which it must attach, increasing the baseline activation levels of the projected structure before the constituent itself is encountered. Incorporating the constituent within the projected node further increases the activation of the entire structure, and this directly impacts retrieval operations, in which retrieval latencies retrieval probabilities are inversely proportional to activation levels. These successive (re)activations strengthen the encoding of the features defining the modified structure, which serve to increase the distinctiveness of this item in memory. Although certain accounts argue that strengthening the featural representations of distractors disrupts the adequate featural encoding of the target (Nairne 1990, Oberauer & Kliegl 2006), the results of Experiment 1 are consistent with the retrieval-based account, as the effect is shown to arise during retrieval, and is shown to exhibit a greater impact for fully cue-matching subjects than partially-matching non-subject arguments (Arnett & Wagers 2017). However, this experiment was not designed to distinguish between these encoding-based and retrieval-based accounts.

## 3.3 Syntactic Gating

The pattern of inhibitory interference from Experiment 1, in which the modified goal in the Prepositional Dative engendered a slowdown at the subject retrieval site, and the pattern of facilitatory interference in Experiment 2, in which the plural goal licensed an illusion of grammaticality in ungrammatical sentences with both Double Object and Prepositional Dative structures, challenge existing accounts of the memory architectures which guide dependency resolution. Experiment 1 did, however, replicate patterns of inhibitory interference from subjects intervening with the subject-verb dependency (Van Dyke 2003, McElree 2005, Van Dyke & McElree 2011, a.o.), as is predicted by cue-based retrieval models, given the extent of overlapping cues between the matrix subject and the embedded subject matching the retrieval cues of the probing verb. Due to the fan effect of the ACT-R architecture, the increasing number of items associated with the retrieval cues of the verb reduces the associative strength between the cues of the target and the retrieval cues, as activation levels are distributed across all items matching the set of retrieval cues. The model thus predicts the similarity-based interference observed in Experiment 1.

The surprising pattern to emerge from Experiment 1 concerns the slowdowns observed during retrieval, attributed to modified goals in the Prepositional Dative structure, contrary to initial predictions on the prominence of specifiers, and this dimension of similarity with clausal subjects. The presence of such inhibitory interference in Prepositional Dative structures relative to Double Object structures mirrors the cluster of findings in Van Dyke (2007) and Van Dyke & McElree (2011), in which interveners in

direct object position were not shown to interfere with subject-verb thematic binding, whereas interveners in prepositional complement positions did exhibit such inhibitory effects on thematic binding. On the basis of this pattern, Van Dyke & McElree (2011) propose an account in which a syntactic gating mechanism modulates retrieval candidates according to their thematic argument status. Core thematic arguments are encoded with distinct and detailed representations, due to their prominent role in establishing the meaning of a sentence, providing the gating mechanism with sufficient syntactic cues to facilitate acceptance or rejection from the set of retrieval candidates. Conversely, oblique arguments, as those in prepositional phrases, for example, are not encoded with detailed representations, and do not provide the gating mechanism with sufficient mismatching cues to reject from the candidate set. This account thus predicts interference from oblique thematic arguments, and no interference from core arguments, as attested across Van Dyke (2007) and Van Dyke & Lewis (2011).

As noted above, the results of Experiment 1 only superficially track with such an account: the goal argument is shown to interfere with subject retrieval in the Prepositional Dative frame, in which the argument is a prepositional complement, but the same argument does not exhibit such inhibitory slowdowns relative to the theme in the Double Object construction. In the discussion of Experiment 1, a gating mechanism sensitive to proximal and distal arguments of a verb phrase was proposed to account for the apparent symmetry between the present findings and those of the previous studies, although the results of Experiment 2 provide evidence against such a mechanism. Unlike Experiment 1, the difference in interference profiles across structures was not observed in Experiment 2, which found facilitatory effects in ungrammatical sentences

with both constructions. This pattern does not superficially align with the parallel findings of Experiment 1 of Parker & An (2018), who observe facilitatory interference in ungrammatical sentences with prepositional complement distractors, but not direct object distractors, and argue in favor of the thematic-syntactic gating mechanism proposed by Van Dyke & McElree (2011).

## 3.4 Thematic Integration

The results of Experiment 1 and 2 may be understood, however, without positing a gating mechanism that mediates thematic integration. Rather, this may reflect the rapid availability of thematic-argument structure upon encountering the verb and the immediate assignment of thematic roles, which are subject to decay when the verb is no longer in the focus of attention (Rayner, Carlson, & Frazier 1983, Carlson & Tanenhaus 1988, Clifton, Speer, & Abney 1991, Schütze & Gibson 1999, Altmann 1999, Frazier & Rayner 1982, Liversedge et al. 1998, Boland 2005, King, Andrews, & Wagers 2012, Tollam, Massam, & Heller 2018). Research on attachment ambiguities (e.g. Rayner, Carlson, & Frazier 1983), argument-modifier ambiguities (e.g. Clifton, Speer, & Abney 1991), and passive-active ambiguities (e.g. Trueswell et al. 1994) has consistently demonstrated that verbs immediately activate their thematic-argument structures, and assign corresponding roles immediately, exhibiting a preference to build structures and dependencies that realize this argument structure (Schütze & Gibson 1999, Tollam, Massam, & Heller 2018). The availability of this information can decay, however, when the verb is no longer in the focus of attention (McElree 2006). For example, King,

Andrews, & Wagers (2012) demonstrated effects of this decay in the context of reflexive dependencies, which have been argued to resist interference effects in contrast to subject-verb dependencies that retrieve the same argument (Badecker & Straub 2002, Dillon et al. 2013, cf. Parker & Phillips 2017). Previous studies on the resolution of reflexive dependencies, however, utilized direct object reflexives adjacent to the matrix predicate, which activates argument structure information and retrieves the matrix subject that is simultaneously the retrieval target of the reflexive dependency. This predicts no intrusion to occur from distractor antecedents when the reflexive is adjacent to the predicate, as was previously observed, and predicts interference to arise for reflexives separated from the predicate. King et al. observed such a pattern with ditransitive matrix verbs, alternating whether or not the reflexive was adjacent to the predicate or not in Double Object vs Prepositional Dative structures as in (14), and found that predicate adjacent reflexives were not subject to interference from local distractors, whereas predicate separated reflexives were.

(14) a. The bricklayer who employed Helen shipped herself sacks of mortar.

b. The bricklayer who employed Helen shipped sacks of mortar to herself.

The patterns observed in Experiments 1 and 2 may suggest that thematic structure is immediately accessed for a given verb, allowing for the immediate assignment of thematic roles for adjacent elements, but this thematic structure is subject to decay, and more distal nominals are not adequately integrated into the thematic structure of the predicate. Predicates are encoded with thematic role specifications, and seek nominal constituents to thematically integrate. Nominal arguments are assumed to be

encoded with a bundle of features characterizing this integration, which I refer to as $\pm\theta$, minimally expressing the assigned thematic role of the nominal expression. Presumably, all nominal arguments are encoded with a -$\theta$ feature by default, until thematic integration occurs, thus 'valuing' the feature. I follow Rissman, Rawlins, & Landau (2015) in assuming that not all ditransitive/dative verbs discretely encode three arguments, and that different predicates will exhibit gradient effects with regard to the thematic integration proposal spelled out below. For verbs like *send*, which do not obligatorily require a goal argument, thematic information is assumed to decay to a greater extent than for verbs like *give*, which require integration of the goal. For obligatory-goal verbs like *give*, integrating the theme is required, whereas the representation of the goal may be underspecified, and is thus subject to gradient effects in encoding (Rissman et al. 2015). Relatedly, the presence of the animate goal in the Double Object construction requires the integration of both arguments, as Double Object structures cannot omit a theme whereas certain Prepositional Dative structures permit omission of the goal, though the strength of such thematic integration is still subject to decay after the verb is no longer in the focus of attention.

For thematic binding, subject retrieval operations target nominal arguments that are not yet thematically integrated, bearing the -$\theta$ cue. This cue is combined in a non-linear fashion with syntactic and semantic cues, and is weighted above these individual cues, but does not outweigh the combination of morphosyntactic and semantic cues, such that arguments bearing the -$\theta$ feature interfere with subject-retrieval operations, though to a lesser extent than arguments bearing the +$\theta$ cue that overlap in several morphosyntactic cues to subjecthood. Such a system may account for the

patterns observed in Experiment 1. The embedded subject elicited the most robust interference effects, as predicted by the cue-overlap with the matrix subject in structural position (+SpecTP) and Case (+Nom), which outweigh the embedded subject's $+\theta$ cue, assigned upon thematic integration with the matrix predicate. In the Double Object construction, no significant differences during retrieval were observed between the interfering modified goal and the interfering modified theme, which is captured by the mismatch in the retrieval cues to structural position, case, and thematic integration. In the Prepositional Dative construction, however, the modified goal was shown to elicit greater processing difficulty than the modified theme during retrieval, indicative of inhibitory interference, which can be modeled by assuming (i) that the thematic information of the ditransitive predicate rapidly decays following the integration of the theme and (ii) the goal argument in the distal prepositional phrase is not thematically integrated with the predicate. The Prepositional Dative goal would then remain a viable retrieval candidate with the $-\theta$ feature, reducing the associative strength between the matrix subject and the retrieval cues, thus decreasing the likelihood of successful retrieval of the target.

(15) a. The clerk$_{\{-\theta,\ +\text{Subj}\}}$ who forgot that the judge$_{\{+\theta,\ +\text{Subj}\}}$ sent the paper$_{\{+\theta,\ -\text{Subj}\}}$ to the nurse$_{\{-\theta,\ -\text{Subj}\}}$ last week was late$_{\{-\theta,\ +\text{Subj}\}}$.

b. The clerk$_{\{-\theta,\ +\text{Subj}\}}$ who forgot that the judge$_{\{+\theta,\ +\text{Subj}\}}$ sent the nurse$_{\{+\theta,\ -\text{Subj}\}}$ the paper$_{\{+\theta,\ -\text{Subj}\}}$ last week was late$_{\{-\theta,\ +\text{Subj}\}}$.

This account with the $\pm\theta$ feature is consistent with the findings of Van Dyke (2007) and Van Dyke & McElree (2011) following a similar logic, such that intervening di-

rect objects do not interfere with thematic-binding operations given their immediate thematic integration with the embedded predicate, whereas intervening prepositional complements can interfere in the absence of such thematic integration.

Subject retrieval operations in computing number agreement similarly rely on the $\pm\vartheta$ cues, though the morphosyntactic number feature is weighted above the cue to thematic integration. Although thematic binding and number agreement are distinct grammatical functions, such a cue weighting permits both subject retrieval operations to utilize the same set of retrieval cues. In ungrammatical sentences with plural verbs, neither the singular subject or the plural distractor are a full match for the retrieval cues, and in a subset of trials, retrieval will proceed erroneously, thus licensing the illusion of grammaticality upon retrieving the plural distractor in computing agreement. With cues to morphosyntactic number features, thematic integration, and structural position, this system predicts gradient facilitatory effects in ungrammatical sentences, conditioned by the degree of featural overlap of each constituent with the retrieval cues. Though plural Double Object distractors are thematically integrated, and mismatch the structural cues to subjecthood, facilitatory interference effects are a product of the privileged weight of the number cue, which increases the activation for constituents associated with the plural feature, correspondingly increasing the likelihood of erroneous retrieval. Plural Prepositional Dative distractors are not thematically integrated, and benefit from increases in activation due to the greater degree of featural-match, predicting stronger facilitatory effects. In grammatical conditions, no differences are predicted between plural and singular distractors, according to hybrid models of number agreement processing (e.g. Yadav et al. 2023): with plural distractors, the number

representation of the plural distractor percolate up to distort the representation of the subject in a subset of trials causing inhibition upon encountering the singular verb, and with singular distractors, the fan effect reduces the activation of the singular subject similarly causing inhibition at retrieval, thus eliminating differences between conditions.

(16) a. *The judge$_{\{\text{-PL, -}\theta\text{, +SUBJ}\}}$ who sent the paper$_{\{\text{-PL, +}\theta\text{, -SUBJ}\}}$ to the nurses$_{\{\text{+PL, -}\theta\text{, -SUBJ}\}}$ last week were late$_{\{\text{+PL, -}\theta\text{, +SUBJ}\}}$.

b. *The judge$_{\{\text{-PL, -}\theta\text{, +SUBJ}\}}$ who sent the nurses$_{\{\text{+PL, +}\theta\text{, -SUBJ}\}}$ the paper$_{\{\text{-PL, +}\theta\text{, -SUBJ}\}}$ last week were late$_{\{\text{+PL, -}\theta\text{, +SUBJ}\}}$.

This system is consistent with the findings of Dillon et al. (2013), who observe facilitatory effects from distractors in direct object position. This is not a complete account of number agreement, however, and cannot neatly incorporate the findings of Parker & An (2018), which directly contrast with the findings of Dillon et al. (2013) and do not reflect interference effects from distractors in direct object position. The Dillon et al. findings, however, have recently been replicated in a large-scale replication study with 181 new participants, indicating reliable facilitatory effects from direct object distractors (Jäger et al. 2020, Yadav et al. 2022). Relatedly, Parker & An (2018) do not find interference effects from distractors in embedded subject position, which is surprising given the consistent findings of interference from subjects across subject-verb dependencies (Van Dyke & Lewis 2003, Van Dyke & McElree 2011, Wagers et al. 2009, a.o.). Although the thematic-integration account sketched above cannot straightforwardly account for the patterns observed by Parker & An (2018), there may be independent motivations that warrant replication of their experiments, to develop

a more comprehensive account of the encoding mechanism sensitive to thematic and syntactic information.

## 3.5 Combinatorics and Reliability

The thematic integration proposal posits that both subject-verb dependencies, thematic binding and number agreement, leverage the same set of cues, though the cues are weighted such that different cues guide the two retrieval processes. Such a model is consistent with the model of language processing proposed by Martin (2016), which integrates psycholinguistic theory with neurobiological architectures of perception. This model posits that parsing operates according to processes of cue combination, which combines non-redundant cues via summation, and cue integration, which weights cues by estimates of their reliability as cues to the retrieval target, based on prior experience and expectations. As in the early cue-based retrieval model (Van Dyke & Lewis 2003, Lewis & Vasishth 2005), the set of retrieval cues determine which representations in the input are activated, and the model of Martin (2016) assumes further that cue reliabilities determine the strength of evidence in favor of a particular representation. In this system, cue-overload is determined by the degree to which a set of cues diagnoses a unique representation, whereby processing load arises due to poor estimates of reliabilities, leading to erroneous activation of ungrammatical or unlicensed representations.

The proposed system of thematic integration is consistent with this notion of cue reliability, central to Martin's (2016) model of sentence processing, in that thematic-binding and number-agreement retrieval operations are guided by the cues most reliable

for correctly retrieving the target. That thematic-binding and number-agreement computations cannot necessarily be disentangled suggests that the two processes are made possible through a stochastic evaluation of the reliability of the relevant cues, according to the contextually determined demands upon retrieval. In Experiment 1, all of the nouns intervening between the subject and the verb are singular, but crucially differ in their thematic integration and syntactic environment, which suggests that thematic integration and structural cues will be most reliable in identifying the unique retrieval target. Put differently, morphological agreement cues, such as cues to number, will not serve to appropriately distinguish the chunks in memory, thus contributing to low reliability for purposes of thematic-binding. Conversely, in Experiment 2, the nouns interfering between the subject and verb differ in their morphological number, and the task of computing agreement and evaluating grammaticality require the retrieval cues to distinguish the target from distractors according to cues to number. Thematic-binding operations are peripheral to the task of computing number agreement, and thus cues to morphological number will be more reliable than thematic integration cues. This is reflected in the judgment results of Experiment 2, such that plural distractors in both the Double Object and Prepositional Dative structures elicit facilitatory interference effects, though the interpretation of Experiment 1 suggests that the structures differ in the strength of thematic integration of the arguments. However, thematic binding must also occur at the verb, even though cues to thematic integration are not effective in distinguishing potential retrieval candidates when computing number agreement. The RT trend in Experiment 2 suggests that plural distractors in the Prepositional Dative structure facilitate acceptance and inhibit rejection of ungrammatical sentences to a

greater extent than plural distractors in the Double Object structure, and may reflect lingering effects due to thematic binding operations, in which the Prepositional Dative distractor is erroneously retrieved as in Experiment 1.

Assuming a process of stochastic determination of cue reliability according to grammatical function and individual level variability in cue weighting (Yadav et al. 2022) allows for an understanding of the present results, and may explain the contrasting intrusion profiles observed in Dillon et al. (2013)/Jäger et al. (2020) and Parker & An (2018) such that agreement computation occurs in tandem with thematic binding, and the cues used to retrieve the subject are probabilistically determined. Though quite speculative, this would suggest that the participants of the Parker & An (2018) studies vary in their cue-weights, and adopt distinct criteria for determining the reliable cue, and the strength of that cue, in uniquely identifying and retrieving the target. Such a claim, however, requires further replication of the Parker & An studies, as well as Approximate Bayesian Computation to evaluate individual levels of cue weighting, which has proved effective in estimating individual level parameters for participants in the Dillon et al. (2013) and Jäger et al. (2020) studies (Yadav et al. 2022). This may be a fruitful avenue for further research in understanding the calculation of cue combinatorics and reliability, and the dynamic updating of such calculations according to distinct grammatical functions across retrieval operations.

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