

# **Syntactic dependency formation in sentence processing: A comparative perspective**

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## Introduction

One central goal for our cognitive processes is to make sense of perceptual input. In language comprehension, doing this requires activating long-term lexical and grammatical knowledge to structure and interpret linguistic input. This can be challenging because that input's structure is often incrementally ambiguous or uncertain. Theories of sentence processing model the moment-by-moment cognitive processes that allow comprehenders to meet this challenge and rapidly converge on the most probable structure of the input.

Part of this involves identifying the syntactic dependencies that hold within a span of linguistic input. To form dependencies such as the link between a pronoun and its antecedent, or a displaced *wh*-element and its gap, comprehenders need to integrate information across time. This involves a mixture of forward and backward looking processes. In the forward direction, language users use fine-grained probabilistic information to generate expectations about the structure of upcoming input. In the backwards direction, speakers rely on multiple cues to retrieve previous constituents from memory. Syntactic dependencies are subject to a range of complex linguistic constraints, which significantly complicate these processes. Thus, exactly how speakers use the knowledge of such constraints to guide real-time processing (in both retrieval and prediction) remains an area of active investigation.

Different grammatical systems pose different challenges to comprehenders, and forming robust theories of sentence processing requires us to ask how comprehenders address those various challenges (e.g. Inoue & Fodor, 1995). Despite this, psycholinguistic research overwhelmingly focuses on standard varieties of English and a handful of typologically related Western European languages (Alderete, 2022; Anand, Chung & Wagers, 2011; Kidd & Garcia, 2022; Norcliffe et al., 2015). This limits the generality of the conclusions that can be drawn in sentence processing research, as it does in other areas of cognitive science (Blasi et al., 2022). However, this aspect of the field is improving. Indeed, several lines of research already have rich traditions of comparative cross-linguistic research: For example, research into locality principles in modifier attachment (Grillo & Costa, 2014) or the subject-gap advantage in relative clause processing (Lau & Tanaka, 2021) boast empirically rich cross-linguistic literatures.

In this chapter, we focus narrowly on how comparative psycholinguistic research can inform theories of syntactic dependency formation in comprehension. For reasons of space, we cannot give an exhaustive review of all the literature we survey. Instead, we aim to show that tracing out how syntactic dependency formation unfolds in real-time in grammatically diverse languages can both shed light on long-standing theoretical questions and raise important new questions and issues.

## Backwards dependency formation: Associative memory and cue-driven processing

To form syntactic dependencies in real-time in comprehension, comprehenders must be able to store and update temporary representations of the input, allowing them to integrate the two ends of the dependency. We will somewhat agnostically refer to the cognitive systems that enable this as *working memory* (e.g. Bays et al., 2022; Oberauer, 2009, 2019)<sup>1</sup>. Consider (1):

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<sup>1</sup> Although we are opting to use 'working memory' as a relatively theory neutral term to characterize the relevant cognitive systems, we note that there are important debates about

- (1) The dog that Brian loves came from Tel Aviv.

At the verb *came* in (1), a dependency must be formed with the subject of the sentence. The comprehender must decide which of the two subject phrases held in memory – *the dog*, or *Brian* – is the true subject. Theories of working memory in sentence processing aim to characterize the representations and processes that allow comprehenders to consult the contents of working memory to make this decision.

The working memory systems that subserve this incremental dependency formation do not seem to be qualitatively different than the working memory systems used in other types of higher-order, goal-directed cognitive activity (Caplan & Waters, 2013; Lewis & Vasishth, 2005; Lewis et al., 2006; McElree, 2006; Parker et al., 2017; Wagers & McElree, 2013). Specifically, much research – primarily on English – suggests that the retrieval processes in real-time linguistic processing rely on an associative, content-addressable memory system. The defining feature of such a memory store is that accessing information involves (re-)activating elements in memory as a probabilistic function of how well they match a set of *retrieval cues*, or features that define the target of retrieval. In other words, information is rapidly activated by matching its desired *content*, rather than its *location*, such as its linear position in the input or syntactic position in the structure. This mechanism allows fast access to information ‘on demand’ in processing, allowing comprehension to proceed quickly enough to keep up with the input (Lewis et al., 2006; McElree, 2006). But this speed comes with a cost. Cue-based interference arises whenever items in memory share features with the target of retrieval (e.g. Lewis & Vasishth, 2005; Lewis et al., 2006; Wagers, 2008). If irrelevant items in memory overlap in features with the target, they may impede access to the target by competing with at the point of retrieval, perhaps even being erroneously retrieved.

Overall, there’s good reason to suspect that this retrieval mechanism is a core part of the (neuro-)cognitive architecture of language processing (e.g. Martin, 2016, 2020). From a comparative perspective, however, we want to ask whether (or how) this mechanism can accommodate the grammatical diversity we see in the world’s languages. In what follows, we describe two in-depth case studies on verbal agreement and reflexive dependencies to argue that this broad architectural conclusion holds well in a comparative psycholinguistic context. We hope to show that managing the tension between the computational constraints imposed by the architecture of working memory and the demands of particular grammatical systems can address challenging questions about the nature of the features that comprehenders use to encode and retrieve information in working memory, as well as raise new questions to guide future research.

### ***Retrieval interference in dependency formation: Agreement as a case study***

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whether there is an architecturally distinct working memory system (e.g. Cowan, 2010; Oberauer, 2014, 2019), or if instead long-term memory can serve this functional role (Lewis et al., 2006; McElree, 2006; Caplan & Waters, 2013; Parker et al., 2017).

A banner example of a dependency subject to retrieval interference is subject-verb agreement dependencies in English. Consider the examples in (2):

- (2) a. \*The key<sub>+SG</sub> to the cell<sub>+SG</sub>/cells<sub>+PL</sub> unsurprisingly were<sub>+PL</sub> rusty ...  
b. \*The musician<sub>+SG</sub>/musicians<sub>+PL</sub> who the reviewer<sub>+SG</sub> praise<sub>+PL</sub> so highly will ...

(Examples from Wagers et al., 2009)

At the verb, the comprehender must establish a dependency with the subject (*the key* in 2a or *the reviewer* in 2b). The verb carries number features that could plausibly serve as retrieval cues to reactivate the requisite dependent in memory. However, in (2) the singular subject mismatches the verb in agreement features. The prediction of a cue-based retrieval mechanism is that when a structurally inaccessible distractor overlaps in features with the target (e.g. *cells* or *musicians*), it should interfere with dependency formation.

This prediction seems to be borne out. In English, number feature overlap with a distractor increases errors in production (Bock & Miller, 1991), speeds reading times (Pearlmutter et al., 1999; Wagers et al., 2009; Dillon et al., 2013), diminishes the amplitude of the P600 component (Tanner et al., 2014), slows down decisions about the correct verb form (Staub, 2009, 2010a; Kandel et al., 2022), and increases acceptability in speeded acceptability judgments (Hammerly et al., 2019; Parker, 2019). One component of this *agreement attraction* effect seems to be a cue-based retrieval process underwriting backwards dependency formation, where the partial feature overlap between the verb's retrieval cues and an irrelevant distractor element create cue-based interference in working memory (Badecker & Kuminiak, 2007; Wagers et al., 2009). It is unlikely that this is the only mechanism that contributes to agreement attraction effects. These errors may also be driven by *encoding interference*, that is, difficulty in unambiguously associating number features with their associated nominals in working memory (Eberhard et al., 2005; Hammerly et al., 2019; Yadav et al., 2023). For the purposes of this review, we will focus on retrieval interference. However, we note that the trade-off between encoding and retrieval in creating these effects remains an area of active investigation.

Attraction effects are not unique to number or other *phi*-features. English speakers use a variety of cues to form a dependency between a verb and its subject, as indexed by retrieval interference effects: animacy (van Dyke, 2007; Mertzen et al., 2021), structural or case features that define grammatical subjects (van Dyke & Lewis, 2003; Arnett & Wagers, 2017; van Dyke & McElree, 2011; Laurinavichyute & von der Malsburg, 2022), superficial morphological features (Schlueter et al., 2018), and even arbitrary semantic features associated with stereotypical arguments of a given verb (Thornton & MacDonald, 2008; Cunnings & Sturt, 2018; Smith & Vasishth, 2020; see also van Dyke & McElree, 2006). Although there is broad consensus that a mixture of morphological, structural, and semantic cues are used to establish this dependency, many important questions remain outstanding. But this can determine where, and to what degree, we expect to observe interference effects. And perhaps most critically, there are many open questions about the precise content of the cues that mediate dependency formation. Comparative research can shed light on how different grammatical systems may shape the cues used in encoding or retrieval processes in comprehension.

## ***Are attraction effects robustly observed cross-linguistically?***

If agreement attraction phenomena result from fundamental aspects of working memory, then they should be observed widely cross-linguistically. This expectation is borne out: Many different languages have been shown to exhibit agreement attraction effects in at least one experimental paradigm. It has been observed in Dutch (Hartsuiker et al. 2001), German (Hartsuiker et al., 2003), Italian (Vigliocco et al., 1999; Franck et al., 2006; Franck et al., 2008), French (Franck et al., 2002, 2006, 2008), Spanish (Foote & Bock, 2012; Acuña-Farna et al., 2014; Lago et al., 2015; Lago et al., 2022), Romanian (Bleotu & Dillon, 2023), Armenian (Avetisyan et al., 2020), Hindi (Bhatia & Dillon, 2022), Arabic (Lorimor, 2007; Tucker et al., 2015, 2021), Hebrew (Deutsch & Dank, 2009, 2011), Basque (Santesteban et al., 2013), Korean (Kwon & Sturt, 2016), Persian (Franck et al., 2020), Russian (Lorimor et al., 2008; Slioussar, 2018), Slovak (Badecker & Kuminiak, 2007), and Turkish (Lago et al., 2019; Turk & Logacev, 2022) - and this list is far from exhaustive. It has even been observed in French-aligned jabberwocky text (Franck & Wagers, 2020).

However, there appear to be differences in agreement attraction effects across languages. For example, Russian speakers appear to exhibit much smaller agreement attraction effects than do English or Dutch speakers in comparable contexts (Lorimor et al., 2008). And speakers of some languages fail to show agreement attraction in some contexts where speakers of other languages readily exhibit this vulnerability (Chromy et al., 2023). Such cross-linguistic differences are highly informative, but we note that they are difficult to establish without appropriate experimental design and statistical analysis (cf. Vasisht & Gelman, 2021).

To see how language-specific features may influence this phenomenon, consider the role of grammatical case. Badecker and Kuminiak (2007) examined attraction in Slovak gender agreement, asking speakers to complete phrases as in (3) and (4) with whatever continuation comes to mind:

(3)	a. MATCH:	<i>Sluha</i> servant.M.NOM	<i>pre</i> for	<i>palác</i> palace.M.ACC~NOM
	b. MISMATCH-UNAMBIG:	<i>Sluha</i> servant.M.NOM	<i>pre</i> for	<i>hostinu</i> feast.F.ACC
	c. MISMATCH-AMBIG:	<i>Sluha</i> servant.M.NOM	<i>pre</i> for	<i>domácnosť</i> household.F.ACC~NOM
(4)	a. MATCH:	<i>Trest</i> punishment.M.NOM~ACC	<i>za</i> for	<i>zločin</i> crime.M.ACC~NOM
	b. MISMATCH-UNAMBIG:	<i>Trest</i> punishment.M.NOM~ACC	<i>za</i> for	<i>vraždu</i> murder.F.ACC
	c. MISMATCH-AMBIG:	<i>Trest</i> punishment.M.NOM~ACC	<i>za</i> for	<i>krádež</i> theft.F.ACC~NOM

In studies like this, agreement attraction occurs when speakers produce inflected elements that agree with the distractor's gender in MISMATCH conditions. Badecker and

Kuminiak manipulated whether the target and distractor displayed morphophonological case syncretism between nominative and accusative forms. In the examples in (3), the target noun *sluha* is unambiguously nominative: Its accusative form is phonologically distinct (*sluhu*); However, in (4) the target noun *trest* displays nominative-accusative syncretism - the same word form is used for both cases (syncretisms are indicated by the subscript tilde).

Badecker and Kuminiak found essentially no agreement errors when the head noun was case unambiguous (e.g. *sluha* in 3). In contrast, when the head noun was case ambiguous (e.g. *trest* in 4), a much higher rate of agreement errors was observed. The vast majority of these errors occurred when the distractor was also formally case ambiguous (the MISMATCH-AMBIG conditions). In other words, Slovak speakers were most susceptible to agreement attraction when both the target and the distractor displayed nominative-accusative case syncretism.

Badecker and Kuminak proposed that this reflected the cue-dependent reactivation of the subject in working memory in production. If Slovak speakers reactivate the subject in working memory using a cue like [NOM], then the likelihood of correctly retrieving the target should be a function of how much this cue distinguishes the target from the distractor in a given context. If the association between case-syncretic forms and the [NOM] cue is weaker than the association between unambiguously nominative forms and the cue, then the condition in (4c) is expected to show the most errors, because this is where the [NOM] cue distinguishes the two nouns the least effectively. Sims (2015) calls this the *syncretism effect*, and notes that it has also been observed in Russian (Slioussar et al., 2022; see also Nicol & Wilson, 2000) and Croatian (Sims, 2012, discussed in Sims 2015). Similar effects have been reported in German (Hartsuiker et al., 2003). Another striking example comes from Slioussar (2018), who found that genitive singular distractors that were syncretic with nominative plural in Russian created plural agreement attraction – even though their syntactic context rendered them unambiguously singular. Finally, Lago et al. (2019) and Türk and Logacev (2023) show that genitive attractors cause attraction in Turkish, an observation that Lago and colleagues attribute to the association between genitive case and subjecthood in Turkish. However, despite this, such effects are not universal: Lacina and Chromý (2022) fail to find that syncretism effects drive agreement attraction in Czech.

This family of syncretism effects suggests a role for learned, language-specific associations between individual morphemes and the retrieval cues (Badecker & Kuminiak, 2007; Schlueter et al., 2018; Engelmann et al., 2019; but see Slioussar, 2018 for an alternative perspective). By learning the utility of highly diagnostic cues such as morphological case, and leveraging them to guide real-time processing, Slovak speakers achieve very high precision in dependency formation in many contexts: Indeed, Badecker and Kuminiak observed almost no agreement errors when a noun's morphophonological case unambiguously signaled its structural role. Despite this, interference can be seen in contexts where nominative-accusative case syncretism renders the retrieval cues less effective than usual.

It seems natural that case would feature prominently in the real-time resolution of subject-verb dependencies, given the privileged role that case plays in coding grammatical dependencies in many languages. But these effects do not seem to be limited to case. For example, Bleotu and Dillon (2023) show that Romanian speakers show less attraction from bare nominal distractors than distractors with an overt determiner. This makes them less 'subject-like' in the context of Romanian grammar, which generally prohibits bare preverbal subjects

(Dobrovie-Sovín, 2013). Relatedly, Thornton and MacDonald (2008) observed more agreement attraction for elements that were plausible subjects of a given verb. A potential generalization seems to be that the less ‘subject-like’ a distractor is, the less retrieval interference it generates for subject-verb dependency formation, where ‘subject-like’ is defined in language- and potentially even verb-specific terms (see also Arnett & Wagers, 2017; Smith & Vasishth, 2020). To be sure, there remain open puzzles in this area. For instance, Schlueter et al. (2018) argue that retrieval cues need not pick out categorical features of the target; arbitrary features that are statistically associated with a cue might suffice to activate an item in memory. And Avetisyan et al. (2020) do not find that case impacts agreement processing in Armenian, and offer a critical perspective on some of the studies reviewed above.

Despite these puzzles, we see a fairly coherent picture: In almost every language where researchers have looked for agreement attraction, they have found it (with the notable potential exception of Czech - see Lacina & Chromý, 2022; Chromý et al., 2023). And in general, the factors that determine the distribution of agreement errors within a given language are sensible when one considers the retrieval cues that would plausibly support subject-verb dependency formation in that language. This is consistent with the claim that a similar retrieval mechanism mediates dependency formation across languages, while acknowledging a role for language-specific tuning of this system. Critically, the precise cues that seem to matter vary language by language. This observation comports with the view that language users tune the weights of different cues as a function of their linguistic experience (e.g. Bates & MacWhinney, 1982; MacDonald, 2013), but emphasizes the role that such cues play in directing attention to elements held in working memory in incremental syntactic processing (Yadav et al., 2022).

### **More on retrieval: The challenge of relational constraints**

How broadly is such a retrieval mechanism applied? To start, we might ask whether languages that exhibit object agreement (e.g. Basque) show similar patterns of agreement attraction: It seems they do (Santesteban et al., 2013; Villata & Franck, 2020; Bhatia & Dillon, 2022) - this suggests that the basic cognitive mechanisms for forming subject-verb dependencies extend to object-verb dependencies as well (see also van Dyke & McElree, 2006).

But probing agreement typology even further raises some interesting challenges. Many agreement systems cannot be neatly approximated by identifying single grammatical position as the target of agreement<sup>2</sup>. Instead, the element that controls agreement is determined by considering the features of all the arguments in the clause and their syntactic positions. For

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<sup>2</sup> Indeed, this may be true for *all* agreement systems. Although it is common in the psycholinguistic literature to characterize English as a ‘subject-verb’ agreement language with a fixed grammatical position for the agreement controllers that retrieval can target, some theories of agreement relations reject this view. On these theories, all agreement dependencies are proposed to be the result of relational, structurally defined search operations (e.g. AGREE: Béjar, 2003; Preminger, 2014; Deal, 2015), with apparent language-specific differences in agreement systems arising from how this mechanism interacts with other aspects of a language’s grammatical structure (e.g. Bhatt, 2005). Relatedly, Julie Franck and colleagues have argued that relational notions such as c-command and linear precedence are key determinants of agreement attraction effects (e.g. Franck et al., 2006, 2010), raising the possibility that relational constraints are implicated in the online formation of subject-verb dependencies even in languages like English and French (Arnett & Wagers, 2017; Franck & Wagers, 2020; Franck et al., 2020).

example, some languages show *omnivorous* agreement, with agreement markers indexing a given feature if *either* the subject or object bears a given feature (e.g. Georgian; Nevins, 2011). Still others show a pattern that Bhatia (2019) calls *mixed* agreement: structurally defined alternations between complementary agreement patterns. Consider (5):

(5)

- a. **Sakshi** kutte baag=mẽ Rajesh=ke sa:th ghuma: **rahi: hai**  
 Sakshi.F dog.MPL garden-in Rajesh=GEN.OBL with walk Prog.F be.PRS.SG  
 “Sakshi is walking the dogs in the garden with Rajesh.”
- b. Sakshi=ne **kutte** baag=mẽ Rajesh=ke sa:th ghuma: **-ye**  
 Sakshi=ERG dog.MPL garden=in Rajesh=GEN.OBL with walk-PFV.M.PL  
 “Sakshi walked the dogs in the garden with Rajesh.”

In (5a), the verb agrees with the subject *Sakshi*; in (5b) it instead agrees with the object *kutte* ‘dogs’. The grammatical generalization governing Hindi agreement may be approximately characterized as: *Agree with the structurally most prominent NP not marked for case* (Bhatt, 2005; Bhatia, 2019). Thus, in perfective clauses like (5a) where the subject is marked with ergative case, the object will control agreement if it is unmarked - otherwise default agreement morphology is observed. In progressive clauses like (5b) with unmarked subjects, subject agreement is observed. And if all arguments are overtly case marked, then default agreement is observed.

One consequence of this grammatical generalization is that simple retrieval instructions like *retrieve a subject* or *retrieve an object* will not work in all contexts in Hindi. Instead, determining which NP controls agreement requires joint consideration of all arguments in the clause, which are then ranked to determine which is the structurally highest, unmarked NP. In other words, Hindi agreement processing appears to demand that Hindi speakers access not just *item information* (e.g. the features associated with a single argument), but also *relational information* (e.g. which of the unmarked arguments is the structurally most prominent one).

The distinction between item information and relational information is important, because some evidence suggests that people use different processes when accessing item information and relational information (McElree, 2006). While access to item information is generally thought to be mediated by a cue-based retrieval mechanism (McElree & Doshier, 1989), access to relational information (such as relative temporal order of two items studied) appears to rely on a serial search process (McElree, 2006) - in such a process, the relational information is recovered at the point of retrieval by serially retrieving the relevant items in memory and using the information coded in them to reconstruct the relevant relations between them. In view of the different processes that mediate access to item and relational information in working memory, we should ask: Does the relational nature of Hindi agreement require Hindi speakers to use a qualitatively different set of (serial) memory access processes to resolve agreement (cf. Dillon, 2011), or do Hindi speakers somehow recode relational information as item information, allowing them to deploy simple cue-based retrieval to process verbal agreement?

Bhatia and Dillon (2022) argue for the latter possibility. In a series of forced-choice experiments, they find that Hindi speakers are susceptible to agreement attraction primarily when there is a distractor NP that is itself an agreement controller in a subordinate clause that linearly precedes the critical verb. Bhatia and Dillon argue that this pattern of errors is expected if Hindi speakers proactively encode agreement controllers in memory with a [+CONTROLLER] feature (see Bhatia, 2019, for a discussion of how this feature be incrementally assigned in a structure sensitive manner). If Hindi speakers use this second-order encoding scheme for agreement controllers, then agreement can be resolved by Hindi speakers using simple cue-based retrieval over item information, correctly predicting interference when a distractor bears this feature. One interpretation of this is that Hindi speakers do not resort to a qualitatively different set of memory access processes, such as serial search, but instead use more abstract features to encode and retrieve items in memory, allowing them to circumvent the need to explicitly reconstruct relational information at retrieval. This mechanism would capture the pattern of interference seen in Bhatia and Dillon's study. However, we caution that more direct measurements of retrieval speed are necessary to firmly establish this conclusion (McElree et al., 2003; McElree, 2006).

Thus, even in unambiguously relational agreement systems like Hindi, we see agreement attraction from distractors that are in some sense similar to the agreement controller. This suggests that Hindi speakers resort to abstract features to encode and retrieve agreement controllers in working memory, making rapid dependency formation possible within the constraints of a content-addressable memory (see Bhatia & Dillon, 2022, for further discussion).

We have provided a selective review of agreement attraction effects in a comparative perspective to underline two key points. First, there is good reason to assume that the underlying psychological mechanisms that subserve agreement dependency formation are computationally similar cross-linguistically. This is consistent with an often implicit assumption about the cognitive universality of the underlying working memory architecture. Second, and perhaps less obviously, this comparative research reveals clear cross-linguistic differences in the features that different language users use to encode and retrieve items in working memory, and the weight that they ascribe to those features.

However, the exact cues used in any language, and the principles that determine the weight ascribed to them in any given language, remain poorly understood. Comparative psycholinguistic research highlights this gap in our understanding, and points to a key direction for future research in this area (e.g. Schlueter et al., 2018; Smith & Vasisht, 2020). For example, we see something of a tension between the Hindi results – which point to highly abstract features like 'agreement controller' as cues — and the Russian/Slovak/Romanian results – which point to the utility of surface-level morphophonological cues (see also Schlueter et al., 2018). This contrast suggests an important - though at present tentative - conclusion: There might not be any architectural restriction on what types of information can be used as a cue cross-linguistically. It may simply be that whatever cues are helpful for categorizing items in memory as 'subjects' or 'agreement controllers' are what comprehenders use when resolving these dependencies in real-time processing. Thus, when the presence/absence of an overt determiner (Romanian) or morphophonological reflexes of nominative case (Russian/Slovak) are associated with subjecthood, they are leveraged as cues by speakers of these languages. When there is no single feature that characterizes the target across all contexts (Hindi),

speakers may use second-order features that directly categorize the relevant elements as ‘controller’ in memory. If this is right, then an important next step in this line of research is investigating how language users learn the relevant features for encoding and retrieving items in their language, an important prerequisite for learning to efficiently process their language in the perspective developed here (Omaki & Lidz, 2015; Schlueter et al., 2018; Yadav et al., 2022).

### ***Interference and relational constraints: The challenge of anaphors***

Is a similar mechanism used to establish other types of structure sensitive syntactic dependencies? To address this question, psycholinguists have studied the processing of anaphoric (reflexive) dependencies. Exploring how these dependencies are processed in real-time sheds light on the tension between interference-prone retrieval processes based on item information, and the apparent need to use relational constraints to constrain dependency formation (Dillon, 2011, 2014; Kush, 2013; Kush et al., 2015).

To illustrate this, consider the following example:

(6) Johnny<sub>i</sub> believes that the man<sub>j</sub> that the little boy<sub>k</sub> bit accidentally hurt himself<sub>\*i/j/\*k/\*l</sub>.

At the reflexive anaphor *himself*, the antecedent *the man* must be identified in order to provide the reflexive’s interpretation. The licensing conditions on reflexives are highly structure dependent: The reflexive’s antecedent must be a c-commanding antecedent in a sufficiently local domain (e.g. Chomsky, 1981; Buring, 2005). The locality condition rules out *Johnny* as a potential antecedent in (6), and the c-command condition rules out *the little boy*, explaining the pattern of intuitive interpretive judgments associated with reflexives in examples like this. But constraints such as c-command, or locality, are not straightforward to implement in a cue-based retrieval mechanism, because these describe relations between elements in memory, rather than simple properties of individual elements in memory: *x* c-commands *y*, or *x* is local to *y* (see Kush, 2013; Sturt, 2013 for further discussion).

One foundational question is whether these relational constraints are used in very early processing of the reflexive (Nicol & Swinney, 1989; Sturt, 2003). There is very compelling evidence that comprehenders are rapidly sensitive to the distinction between syntactically accessible antecedents (e.g. *the man* in 6; a *target*) and syntactically inaccessible distractors (e.g. *Johnny* and *the little boy* in 6). For example, cross-modal priming tasks show that semantic associates of grammatical antecedents are selectively primed at the anaphor (Nicol & Swinney, 1989), and reading time measures show exhibit slowdowns when the reflexive’s features mismatch those of the target (Sturt, 2003).

But how do comprehenders manage the (deceptively) simple task of distinguishing the target from distractors at retrieval? That they do is not itself a point of empirical controversy. Yet even so, there is evidence that interference-prone retrieval processes do mediate the formation of reflexive-antecedent dependencies: In some contexts, reflexives are subject to feature-based retrieval interference, though there is considerable empirical debate about to what degree and in what circumstances (Sturt, 2003; Dillon et al., 2013; Jaeger et al., 2017; Parker & Phillips, 2017; Jaeger et al., 2020; Kandel & Phillips, 2022; Keshev & Meltzer-Asscher 2023). But given that distinguishing targets from distractors appears to rely on relational notions of ‘local’ or

'c-commanding' in the statement of the grammatical constraints, we are faced with a puzzle similar to the Hindi agreement pattern. Do comprehenders leverage a qualitatively different search mechanism to reconstruct the relevant relations (e.g. c-command, locality) at retrieval, or do comprehenders code antecedents in working memory in a way that allows them to distinguish targets from distractors using cue-based retrieval (Kush, 2013)?

There are various mechanisms that could allow comprehenders to distinguish target and distractors in memory. One possibility is that the apparent sensitivity to the relational structure is only implicitly coded via the resting activation of different elements in memory across a parse (Wagers, 2008; Franck & Wagers, 2020). On this view, there is no explicit coding of the syntactic position of elements in working memory (c.f. Lewis & Vasishth, 2005). Instead, syntactic structure or linear order gives syntactically local elements a higher activation value in memory. Support for this view comes from Franck & Wagers (2020), who find that c-commanding elements are more readily recognized in probe recognition tasks than non-commanding elements. Such 'resting activation' differences could make the target more likely to be retrieved than the distractor, even if the retrieval cues do not formally distinguish their representations. Computational simulations have shown that this simple activation-based mechanism can qualitatively reproduce the observed behavior without any explicit use of relational cues in verb medial languages (Dillon et al., 2013, 2014).

However, many researchers have proposed that comprehenders do enrich the encodings of elements in memory with structurally defined features that let them formally distinguish syntactically-defined targets and distractors at retrieval using relational constraints. For example, Wagers (2008; see also Franck & Wagers, 2020) propose that memory items bear a feature that indexes their clausal domain, generalizing a mechanism independently proposed for encoding temporal relations in memory to syntactic relations (c.f. Howard & Kahana, 2002). Dillon et al. (2014) and Kush (2014) propose that the comprehenders dynamically track the arguments of the clause they are currently processing and provisionally assign them a 'LOCAL' feature that can be used to track local (c-commanding) subject phrases. In either of these models, the information encoded on the relevant items in working memory is elaborated with contextual information that would support content-addressable access to the target. A final possibility is that comprehenders resort to a serial search process to resolve these dependencies, in a way that mirrors other memory tasks that require the reconstruction of temporal or spatial order (Berwick & Weinberg, 1984; Dillon, 2011).

The post-verbal position of reflexives in English themselves makes it difficult to disentangle these possibilities: If processing the verb provides refreshes or reactivates the representation of the subject, then the easy retrieval of the local subject may simply reflect this heightened activation (Dillon et al., 2013; Kush & Phillips, 2014). To address this possibility, Kush and Phillips (2014) looked at the processing of reciprocals in Hindi, which are subject to similar structural licensing conditions as reflexives. But Hindi's SOV word order ensures that the critical anaphor precedes the verb, meaning that any activation boost conveyed by the verb could not facilitate antecedent retrieval. Nonetheless, Kush and Phillips found no evidence for interference of the sort predicted by cue-based retrieval models. Similarly, Laurinavichyute et al. (2017) leveraged Russian's freer word order to provide a within-experiment test of the role of word order on retrieval interference. They found that when the target and the distractor shared gender features, reading times were slowed for non-gender-marked anaphors in Russian, an

effect they attribute to similarity-based interference at encoding rather than retrieval interference. But they did not see clear retrieval interference effects for either pre-verbal or post-verbal gender-marked anaphors in Russian. These findings suggest that Hindi and Russian speakers can use relational cues to distinguish retrieval targets from distractors even when processing pre-verbal anaphoric dependencies. But again, the empirical literature here is mixed, with some studies in head-final languages reporting interference effects in preverbal reflexive processing (Sezer, 2020, in Turkish; Yong, 2019, in Korean).

Verb-initial languages offer a similar opportunity to investigate the role of relational constraints in establishing reflexive dependencies in real-time. Pizarro-Guevara & Dillon (2022) investigated the processing of reflexive anaphors in Tagalog, which are subject to similar syntactic constraints as English reflexives (Richards, 2013):

- (7) Pinupuri<sub>i</sub> ng dalaga na hinaharana<sub>j</sub> ng tambay gabi-gabi ang kanilang sarili<sub>i/\*j</sub>  
 praise.PV GEN maiden LNK serenade.PV GEN loiterer nightly NOM REFL  
 "The maiden that the loiterer serenaded nightly praised herself."

Because Tagalog's base word order is verb initial, the dependency between the verb and the target antecedent *dalaga* 'maiden' occurs immediately, before the distractor *tambay* 'loiterer' is encountered. Like in Kush and Phillips' Hindi study, there is no processing event that could lead to covert reactivation of the target antecedent prior to the critical anaphor. Pizarro-Guevara and Dillon found that Tagalog readers show sensitivity to feature match with the target, slowing down significantly when the target mismatched the reflexive in number features. However, there was also a main effect of distractor match: Tagalog speakers slowed down when the distractor mismatched the reflexive's features as well.

The general sensitivity to target-reflexive match in both SOV and VSO languages suggests that across the different languages tested, speakers can distinguish the target from distractor by explicitly recruiting relational information to constrain retrieval, since in examples like (7) no other syntactic cues distinguish target from distractor. However, there remains some variability across studies in the degree to which the different researchers saw interference from structurally inaccessible distractors, with perhaps the most pronounced effect of distractor match observed in Tagalog (see Pizarro-Guevara & Dillon, 2022, for further details). Given the substantial differences between the studies and variability in the results, it is perhaps premature to draw strong conclusions about differential sensitivity to structural cues in SOV (Hindi, Turkish, Korean) versus VSO (Tagalog) languages. But further specifying the role that word order itself may play in interference effects in dependency resolution provides a clear, important avenue for future research. This line of work could, in turn, provide detailed mechanistic insight into the claim that ease of dependency formation shapes word order preferences cross-linguistically (Futrell et al., 2020).

Constraints on reflexive dependencies are subject to a fair amount of cross-linguistic variation. This variation also reveals different challenges to the comprehender. Consider the following examples from Mandarin:

- (8) a. Zhangsan<sub>i</sub> zhidao Lisi<sub>j</sub> hai-le ziji<sub>i/j</sub>  
 Zhangsan know Lisi harm-PERF REFL

"Zhangsan knows that Lisi harmed him / himself."

b. Zhangsan <sub>i</sub>	zhidao	wo <sub>j</sub> /ni <sub>j</sub>	hai-le	ziji <sub>-i/j</sub>
Zhangsan	know	1SG/2SG	harm-PERF	REFL

"Zhangsan knows that I/you harmed myself/yourself." (Lyu & Kaiser, 2022; pp. 3)

Reflexive binding in Mandarin differs in two relevant respects from that in English. First, in (8a) we can see that Mandarin reflexives may be bound 'long-distance,' that is, by antecedents outside of their local clause. Second, in (8b), we can see that long-distance binding can be 'blocked' by the presence of a syntactically local first or second person subject.

The blocking constraints on long-distance binding in Mandarin are a clear case of a relational constraint: Whether or not the long-distance binder is appropriate as an antecedent depends on its structural position vis-a-vis the first person indexical (Huang & Liu, 2000). Dillon (2011) and Dillon et al. (2014) asked whether this property might trigger Mandarin speakers to use a processing mechanism more akin to a search process, as it plausibly involves reconstructing relational information (e.g. McElree, 2006). In a multiple-response speed-accuracy tradeoff (MR-SAT) experiment, Dillon and colleagues showed that access to the long-distance antecedent was slower than to the local antecedent (see also Dillon et al., 2016). On the face of it, this seems more compatible with serial search rather than cue-driven retrieval (but see McElree et al., 2003; McElree, 2006; Martin & McElree, 2018; Kush et al., 2019).

Ultimately, however, Dillon and colleagues (2014) argued that the MR-SAT results could be reconciled with a cue-based retrieval model if the cue set that Mandarin speakers use to resolve *ziji* encodes a feature that tracked locality (e.g. local c-commanding phrases: Wagers, 2008; Kush, 2013; Dillon et al., 2014). This model reconciles the observations of Dillon et al. (2014) with the finding that Mandarin reflexives are subject to similarity-based interference effects from grammatically inaccessible distractors (Jäger et al., 2015; Chang et al., 2020). In addition, the degree to which the blocking constraint itself should be understood as truly relational in nature has been challenged in recent work (He & Kaiser, 2014; Lyu & Kaiser, 2021). In particular, Lyu and Kaiser show that the blocking constraint is not categorical in nature and develop a cue-based model of *ziji* resolution where the blocking effect is driven by a mixture of structural cues and cues that target perspective centers (e.g. indexical elements like first-person pronouns).

Thus, even highly relationally constrained Mandarin long-distance reflexive dependencies appear to be resolved on-line using interference-prone retrieval processes, with a mixture of explicitly relational cues and discourse-oriented cues (e.g. point of view; see also Sloggett, 2017). Reflexive processing therefore provides another example where speakers manage relational dependencies in real-time processing not by resorting to qualitatively different memory access mechanisms like search, but instead by adopting abstract features that allow them to encode and resolve relational dependencies efficiently within the computational constraints of a content-addressable working memory. In this case study, we can see how cross-linguistic diversity in word order and in the licensing conditions on reflexive elements permits greater insight into this process than would be possible if only a single language (e.g. English) was the object of psycholinguistic investigation.

## Forward dependency formation: Syntactic prediction

Of course, memory retrieval is not the only mechanism that comprehenders use to form syntactic dependencies. Comprehenders also use forward-looking processes: They predict how the sentence will unfold by integrating the input collected so far with different top-down biases. For example, when encountering a verb, comprehenders use syntactic and world knowledge to predict a plausible object. Altmann and Kamide (1999) showed that upon hearing a verb like *eat* listeners tend to look for an edible object in a visual array of pictures (see also Kaiser & Trueswell, 2004; Knoeferle et al., 2005; Knoeferle & Kreysa, 2012; Arai & Keller, 2013; Rommer, Meyer & Huettig, 2015). Thus, comprehenders predictively generate the internal structure of the VP and a provisional interpretation. Naturally, comprehenders predict words to complete other syntactic dependencies too, for example between a noun and its adjective (Hopp & Lemmerth, 2018), possessor (Stone et al., 2021), or classifier (Grüter et al., 2020). Another type of evidence consistent with forward looking computation is the association between word processing difficulty predictability in context (Levy, 2008a) and/or the extent to which this word narrows down the set of possible further continuations (Hale, 2006; Linzen & Jaeger, 2015).

Comprehenders also predictively form syntactic structure without necessarily anticipating a concrete word. This occurs when the partial input is ambiguous, in which case comprehension proceeds without waiting for disambiguation in the input. To the extent that we find consistent parsing decisions in such conditions, these decisions likely reflect predictive biases. Studies of ambiguity resolution indeed have revealed consistent patterns, demonstrating knowledge of grammatical constraints, frequency of linguistic forms, context and real-world plausibility, as well as strategies for minimizing structure building (Frazier, 1979; Frazier & Rayner, 1982; Tanenhaus et al., 1995; Pickering & Traxler, 1998; Mitchell, et al., 1995; Garnsey et al., 1997; Trueswell, Tanenhaus, & Kello, 1993; Levy, 2008a; a.o).

We will call these types of eager structure building processes *syntactic prediction*. We use this term to capture the types of structure projection mentioned above: syntactic features of upcoming input, and the incremental interpretation of syntactic ambiguity. For reasons of space, we leave out prominent avenues of prediction research which ask how lexically specified prediction is (e.g. DeLong, Urbach & Kutas, 2005; Ito et al., 2020; Ness & Meltzer-Asscher, 2016) and whether word prediction reflects discourse congruence or passive association processes (e.g. Federmeier & Kutas, 1999; Nieuwland & Van Berkum, 2006). We will also not discuss production processes, though these too involve preemptive structure building in interesting ways cross-linguistically (e.g. Momma et al., 2016; Sarvasy et al., 2022). And finally, we set aside many important questions, such as whether comprehenders are highly incremental in constructing syntactic analyses in all contexts (e.g. Karimi & Ferreira, 2016), whether the syntactic representations constructed are always globally syntactically coherent (e.g. Tabor et al., 2004), and detailed questions about the time course of generating syntactically sophisticated predictions about upcoming words (e.g. Chow et al., 2015). Instead, we will focus on evaluating three main issues in a comparative context: crosslinguistic robustness of this predictive processing, sensitivity to grammatical constraints in real-time, and possible shared biases across languages.

## ***The balance between forward and backward looking processing across language systems***

The cost-effectiveness of prediction could depend, for example, on word order properties. As we saw, at least in English, subject-verb dependencies rely on backwards dependency formation (retrieval of the subject argument when processing the verb). But this picture might change when we examine, for example, languages with SOV word order. Speakers of head-final languages, like Hindi or Japanese, have to maintain more material in memory prior to the verb (see Ueno & Polinsky, 2009, for discussion), relative to speakers of head-medial languages like English. Early approaches to sentence processing emphasized the role of the phrasal head, and of linking arguments to the verb, in driving parsing decisions (Pritchett, 1988; 1991). These head-driven parsing approaches proposed that nodes of the incrementally built structure cannot be projected until their head appears in the input. This means that in head-final languages internal arguments cannot be attached to the partial tree until very late in the sentence; in other words, speakers of SOV languages might not form dependencies in as eager a manner as speakers of SVO languages.

However, experimental findings have demonstrated that the parser projects syntactic structure prior to the verb in SOV languages. Despite uncertainty about the verb, Japanese speakers make decisions as to attachment of ambiguous dative arguments (Kamide & Mitchell, 1999) and gap position of scrambled wh-phrases (Aoshima, Phillips, & Weinberg, 2003). As direct evidence for pre-verbal prediction, Kamide, Altmann, and Haywood (2003) showed that Japanese speakers use case marking to predict upcoming arguments, instead of a verb's selectional restriction. In their study, a nominative NP and a dative one prompted listeners to postulate a transfer event and expect a compatible theme. Similar types of predictions were later exhibited in other verb-final languages with rich case systems, including German (Knoeferle et al., 2005) and Turkish (Özge, Küntay, & Snedeker, 2019). Such findings suggest that processing relies on forward-looking mechanisms across languages, although different cues (e.g. case, or verbal subcategorization information) may guide the predictions.

Following this, it was then argued that SOV languages might even rely on predictive structure building to a greater extent than SVO languages. This view partly leans on findings regarding structural forgetting. Structural forgetting arises in double center embedded sentences such as (10). English speakers perceive these complex sentences as more acceptable when one of the three final verbs is omitted, as in (10b) (Gibson & Thomas, 1999; see Huang & Phillips, 2021 for similar NP omissions in Mandarin), despite the fact that this omission leaves one subject (*the kids*) without a corresponding predicate and one filler (*the dog*) unlicensed by a gap. This grammaticality illusion (also called the missing VP illusion) does not arise in SOV languages like Dutch (Frank et al., 2016) and German (Vasishth et al., 2010). This robustness against structural forgetting is often described as adaptation to prediction of clause final verbs (Vasishth et al., 2010).

- (10) a. The dog<sub>i</sub> [that the kids<sub>j</sub> [that the woman scolded t<sub>j</sub> today] like t<sub>i</sub> a lot] wagged his tail.  
b. The dog<sub>i</sub> [that the kids<sub>j</sub> [that the woman scolded t<sub>j</sub> today] wagged his tail.

Another type of evidence for robust prediction in SOV languages is faster processing of non-local, relative to local, verb-argument dependencies. These so-called anti-locality effects have been observed in German (Konieczny, 2000), Hindi (Vasishth and Lewis, 2006; Husain et al., 2014), and Japanese (Nakatani and Gibson, 2010). Since non-local dependencies often require increased backward-looking processing efforts, the facilitation has been explained in terms of prediction. Levy (2008a) suggests that additional pre-verbal dependents can allow for more accurate predictions about the contents of the verb and its linear position. Vasishth and Lewis (2006) proposed that the additional dependents repeatedly reactivate a stored predicted V node and thus facilitate later access to it.

Yet more recent findings challenge the idea that parsing in SOV languages relies mostly on prediction. Husain et al. (2014) and Safavi et al. (2016) show evidence from Hindi and Persian, respectively, that increased dependency length can slow down processing at head-final verbs under certain conditions, in direct contrast to anti-locality effects (see also Ranjan et al., 2022). In addition, Apurva & Husain (2021) found evidence against the hypothesis comprehenders form more accurate verb predictions in longer dependencies in Hindi (contra Levy's proposal). Lastly, Bhatia and Husain (2022) show that in some cases bottom-up considerations can take priority even in head final languages. They show that Hindi speakers are vulnerable to shallow processing and local coherence, effects that have been observed in English in the past. Overall, these suggest that prediction in verb-final languages is not infallible.

On the other side of the coin, recent evidence shows that top-down biases can be so strong as to override the bottom-up input even in SVO languages. Evidence of this sort has been exhibited in English (Gibson et al., 2013), Hebrew (Keshev & Meltzer-Asscher, 2021), Russian (Poliak et al., 2023), and Mandarin Chinese (Zhan et al., 2017). For example, Keshev and Meltzer-Asscher show that Hebrew speakers will override subject-verb agreement cues in the input to impose a more frequent syntactic structure. This fits with the overarching idea of noisy-channel processing (Levy, 2008b): readers are aware of possible production and perception error, and therefore may allow prior expectations to shift the interpretation of a sentence away from the perceived input. This might suggest that comprehension relies on predictive processing and bottom-up cues to similar extents across languages, even though word order drastically changes the cues that can be used predictively.

### ***Prediction of long-distance dependencies and language-specific well-formedness***

Syntactic prediction targets not only verb-argument relations but also long distance dependencies like extraction and reference resolution. Comprehenders seek to resolve these dependencies (with a gap or antecedent) as soon as possible once a dependency is initiated (with a filler or a pronoun correspondingly). And in doing so they exhibit sensitivity to intricate grammatical constraints.

For example, given a partial input with a filler-gap dependency (11), a gap could arise in positions (11a-c). As the gap is null, only after mapping all the realized arguments in the sentence, final conclusions about a gap position can be drawn. Yet, the parser forms a dependency between the filler and an early potential gap position (11a) before verifying that it is vacant. This has been reflected in listeners' anticipatory looks to compatible answers (Sussman & Sedivy, 2003), and in difficulty of reading nouns that occupy a potential gap position (Stowe,

1986). This has been observed in several languages including English (Stowe, 1986), French (Bourdages, 1992), Italian (de Vincenzi, 1991), Dutch (Frazier & Flores d'Arcais, 1989), German (Schlesewsky, Fanselow, Kliegl, & Krems, 2000), Japanese (Aoshima, Phillips, & Weinberg, 2004), and Hebrew (Keshev & Meltzer-Asscher, 2017).

- (11) Who<sub>i</sub> is Brian advising...
- a. t<sub>i</sub> at the department?
  - b. Maayan to meet t<sub>i</sub> at the conference?
  - c. that we try to invite t<sub>i</sub> to the party?

In binding dependencies, predictive dependency formation can be seen if the pronoun appears prior to its antecedent (12). Such cataphoric pronouns initiate an active search for an antecedent much like the active filler's search (van Gompel & Liversedge, 2003). This is reflected in an increased processing difficulty for an early gender-mismatching noun (e.g. *man* in 12). The gender mismatch cost suggests that the comprehenders attempted to interpret the pronoun as referring to this noun, even though the antecedent can appear later. This has been observed in English (van Gompel & Liversedge 2003), Russian (Kazanina & Phillips, 2010), Japanese (Aoshima et al., 2009), Korean (Kwon & Sturt, 2013), Italian (Fedele & Kaiser, 2014), Dutch (Pablos et al., 2015), German (Patterson & Felser, 2019), and Norwegian (Giskes & Kush, 2021).

- (12) While she was eating lunch, the man talked to Anna about cats.

Notably, these predictions are sensitive to grammatical constraints. Active gap search for example adheres to island constraints (e.g. Stowe, 1986; Traxler & Pickering, 1996; see Phillips (2013) for an overview; but c.f. Chaves & Dery, 2019), and antecedent search adheres to binding principles (Kazanina et al., 2007; Kush & Dillon, 2021; but c.f. Patterson & Felser, 2019). The reverse is not true - movement constraints do not restrict the active antecedent search (Yoshida et al., 2014). This suggests that gap or antecedent predictions reflect initial structure building, rather than general heuristics such as 'immediately use any referent' or 'quickly assume what the gist is'.

This view leads us to expect that syntactic prediction would unfold differently in different languages, based on language-specific grammatical constraints. Does prediction operate under a unique set of pressures in each language? Or are some pressures shared (e.g. limits on working memory) and prioritized over language-specific constraints? The fact that final interpretation is sensitive to a unique set of constraints in each language is not questioned. However, psycholinguistic research has to establish whether prediction reflects a coarse first-pass based on cross-linguistically shared principles, or a sophisticated application of the grammatical possibilities in a given language.

The picture from research on reference resolution seems mixed. Wagers, Chung, and Borja (2022) might suggest a significant role of idiosyncratic constraints in prediction of Chamorro binding. They find an unintuitive interpretive bias - a preference for a reflexive over a disjoint reading for ambiguous pronouns. This contrasts with preferences in other languages (e.g. Ivan et al., 2021). Wagers and colleagues propose that the Chamorro pattern can partly

reflect an interaction between early parsing commitment and a grammatical constraint preventing the disjoint object from outranking the subject in animacy and topicality. Trying to satisfy this requirement when the input includes only a verb and an ambiguous object pronoun could mean betting on the option which would license a wider variety of subjects - a reflexive reading. Wagers and colleagues suggest that this interpretation lingers even though the full sentence licenses both disjoint and reflexive reference. If this analysis is on the right track it suggests that idiosyncratic constraints highly restrict predictive dependency formation.

Kazanina and Phillips (2010), on the other hand, suggested that a cross-linguistically robust principle affects prediction more prominently than a language-specific constraint, based on a study of Russian cataphora. They found that Principle C blocks the antecedent search, but not the Russian-specific constraint (forcing non co-reference between subjects of simultaneous agentive events). They suggest that Russian-specific constraint applies as a late filter choosing between candidates rather than as a restriction on the initial generation of candidates. This could be either because of the idiosyncratic nature of the while-clause restriction or to its pragmatic nature (see Keshev & Meltzer-Asscher, 2020, for independent evidence as to the different time course or diffusibility of predictions based on pragmatic and syntactic licensing).

The picture emerging from filler-gap dependencies has more clearly indicated a sensitivity to unique grammatical properties in syntactic prediction. Keshev and Meltzer-Asscher (2017) and Keshev (2017) found that in Hebrew resumptive pronouns and parasitic gaps can improve the acceptability of RC islands. This contrasts with the pattern in English (Alexopoulou & Keller, 2007; Phillips, 2006). In line with that, Keshev and Meltzer-Asscher showed that comprehenders predict gap/resumptive sites within Hebrew RC islands, contra findings on the English gap-search (Traxler & Pickering, 1996; Phillips, 2006). Keshev and Meltzer-Asscher trace this syntactic prediction difference to the availability of grammatical last resort strategies and show that the gap/resumptive search is blocked in Hebrew too when resumption and parasitic gaps cannot salvage the dependency. This suggests that parser is sensitive to language-specific and construction-specific conditions on resort strategies.

The search for a gap is sensitive to language-specific predictive cues, not only to variations in island constraints. In Chamorro some wh-dependencies trigger agreement morphology on the verb, a phenomenon called wh-agreement. This agreement marking, which directly follows the extracted phrase given Chamorro's verb-initial word order, can provide unambiguous cues for the grammatical position of the gap - subject, object, or oblique. Wagers, Borja, and Chung (2015) showed that this agreement cue (and its absence) guides interpretation in real time: During the incremental processing, Chamorro comprehenders immediately link a wh-filler with a gap site compatible with the wh-agreement, but defer to commit to a gap site that licenses optional wh-agreement in absent of agreement.

Similar findings have been observed in Tagalog (Pizarro-Guevara & Wagers, 2020), another verb-initial Austronesian language. In Tagalog, voice morphology interacts with extraction, and can allow early commitment to the thematic role of the extracted element: A wh-element has to take the agent role if the verb displays agent voice, but a patient role is possible if the verb is marked for patient voice. Pizarro-Guevara and Wagers found that Tagalog comprehenders attend to voice morphology in the real-time and are even sensitive to the cross-construction differences in the strength of the voice restriction (using it differentially in wh-questions and topicalizations).

Overall, grammatical systems offer very different types of cues that comprehenders could use to form predictions, and pose different licensing pressures on the parser. These yield cross-linguistic differences in how predictions are formed. Yet, processing is similar across languages in that comprehenders incrementally deploy syntactic and probabilistic knowledge to predict upcoming input. Prediction can therefore be taken to exhibit a cross-linguistic processing principle - maximize incremental well-formedness (Wagers et al., 2018), while language-specific grammatical principles define what well-formedness is.

### **Filler-gap dependencies as a test case for cross-linguistically shared biases**

The preceding section emphasizes the vital role of language-specific grammatical features in syntactic prediction. Another arena of investigation in the comparative study of sentence processing attempts to trace universal processing pressures (e.g. Grillo & Costa, 2014; Lau & Tanaka, 2021). One potential pressure is a bias for parsing ambiguous nouns as subjects, and a useful test case of that is the processing of relative clauses. In these structures, comprehenders often favor subject gaps over object gaps. This is reflected, among others, in the final interpretation of ambiguous relative clauses in Dutch (Frazier, 1987) and German (Schriefers, Friederici, & Kuhn, 1995). In unambiguous relatives, the advantage of subject relatives over object relatives is reflected in a decreased processing cost (adult processing) or better comprehension (children). This arises in typologically different languages: English (King & Just, 1991; Gordon, Hendrick, & Johnson, 2001; Grodner & Gibson, 2005; Forster, Guerrero, & Elliot, 2009; a.o), Spanish (Betancort, Carreiras, & Sturt, 2009); Italian (Arosio, Guasti, & Stucchi, 2011), French (Cohen & Mehler, 1996); German (Bader & Meng, 1999), Georgian (Lau et al., 2023), Avar (Polinsky et al., 2012), Hebrew (Arnon, 2010; Keshev & Meltzer-Asscher, 2021), Japanese (Ueno & Garnsey, 2008), Korean (Kwon et al., 2010), Tagalog (Pizarro-Guevara, 2020), and Santiago Laxopa Zapotec (Sasaki et al., 2022).

Different factors conspire to make subject gaps easier than object gaps. The subject-gap advantage can result from lower costs in backward-looking dependency formation: a dependency with an object gap and the filler (in some languages as English) is longer (Gibson, 1998; Lewis & Vasishth, 2005). The subject-gap advantage can also reflect a forward-looking expectation for the filler to take the subject position: An prior bias for minimizing dependency length (Staub et al., 2018; Futrell et al., 2020; Konrad et al., 2021), for statistical prevalent gaps (Hale, 2001; Levy, 2008a; Jaeger et al., 2015), or for identifying the subject early on.

Typological variation in word order has been informative in teasing apart these different accounts. While in English, relative clauses follow the noun that they modify, in Mandarin, for example, they precede it. This ordering sets the distance between the filler and the gap. This can reverse backward-looking memory demands: In languages with prenominal relatives subject gaps have to span longer dependency length. Evidence for the subject gap advantage has been mixed in Mandarin (for review see Lau & Tanaka, 2021), yet this seems to be at least partly due to a temporary ambiguity with a main clause parse. Where such confounding factors are controlled, the subject-gap advantage seems to arise (Wu, Kaiser, & Vasishth, 2017; Jaeger et al., 2015). These suggest that memory based accounts alone cannot account for the subject gap advantage in all languages. On the other hand, findings from Russian which has flexible word order suggest an advantage for verb-initial relative clauses, either with a subject or with an

object gap (Levy, Fedorenko, & Gibson, 2013). This suggests evidence for the role of dependency length, on par with memory-based accounts. It seems that costs of backward and forward dependency formation both contribute to such effects (Staub, 2010).

It also seems that the expectation for subject gaps cannot be entirely reduced to the frequency of subject extraction in a language: The subject-gap advantage has also been observed when object gaps are more frequent (in Tagalog: Pizarro-Guevara, 2020). An informative comparative evidence for the types of prediction involved in this subject-advantage comes from the processing of prenominal and postnominal relatives in Chamorro (Wagers, Borja, & Chung, 2018). Wagers and colleagues (2018) found that final interpretations of ambiguous relative clauses (13) depended on the clause-head ordering: Chamorro speakers overwhelmingly prefer the subject-gap reading for postnominal relatives, but slightly prefer the object gap reading for prenominal ones. Yet, a subject-gap advantage still lingers in response times even for these prenominal relative clauses.

(13) a. Ambiguous postnominal RC:

atyu	na	lâhi	[i	ha	chichiku	i	patgun]
That	LINKER	man	[COMP	AGR	kiss	the	child]

b. Ambiguous prenominal RC:

atyu	[i	ha	chichiku	i	patgun]	na	lâhi
That	[COMP	AGR	kiss	the	child]	LINKER	man

‘that man who is kissing the child’ or ‘that man who the child is kissing’

Wagers and colleagues (2018) propose that two forces shape incremental processing in these Chamorro relative clauses - a pressure to identify a gap quickly (licensing the extraction), and a pressure to identify the subject. In postnominal relatives these two operate together to produce a strong subject gap preference. But in prenominal relatives the two contrast - since the head noun appears only after the clause, assigning the subject role to the first noun means overriding the subject gap. This produces more defeasible preferences and a contrast between response times (reflecting the initial subject gap parse) and final interpretations (reflecting the later reanalysis). Ultimately, it seems that a mixture of pressures conspire to produce the full cross linguistic pattern. A bias for interpreting ambiguous nouns as the subject is likely to play some role in this. This bias is also observed independent of extraction, in languages with flexible word order (in Mandarin Chinese - Wang et al., 2009) or with null subjects (in Turkish - Demiral, Schlesewsky, & Bornkessel-Schlesewsky, 2008).

However, the pressure to identify the subject could be more intricate and tied to agenthood and prominence rather than to syntactic position. This view is compatible with the effect of animacy on the subject bias. Inanimate nouns, which are less likely to be agents, are also less likely to be favored as a subject interpretation in relative clauses (Mak, Vonk, & Schriefers, 2002; Traxler et al., 2002, 2005; Gennari & MacDonald, 2008; Wagers & Pendleton, 2016) as well as in simple transitive sentences (Wang et al., 2009). There seems to be a general expectation for early agents, even when this contrasts with voice morphology as evident in misinterpretation of English passives (Ferriera, 2003) and in anticipatory looks of Tagalog listeners (Sauppe, 2016; but see Garcia et al., 2021). The subject-gap bias is also sensitive to

another type of grammatically coded prominence - the distinction between proximate and obviate third-persons in Ojibwe (Hammerly, Staub, & Dillon, 2022). Thus, the subject advantage in nominative languages could reflect the typological referential hierarchy identified (Silverstein, 1976): The parser attempts at aligning higher-ranked nouns (animate or proximate ones) with the agent role in real time comprehension (Bornkessel-Schlesewsky & Schlewsky, 2009).

On the other hand, the subject-gap bias could reflect a bias for the position that the sentence is most likely to include. Ergative-absolutive languages do not morpho-syntactically part arguments to subjects and objects. Instead, the major distinction in these languages is between agents (ergatives) and other arguments, including both intransitive subjects and object themes of transitive events (absolutives). Some findings from ergative-absolutive languages suggest a subject gap advantage (Avar: Polinsky et al., 2012; Mayan Ch'ol and Q'anjob'al: Clemens et al., 2015) while others show an object gap advantage (Basque: Carreiras et al., 2010). Tollan and colleagues (2019) found that Niuean comprehenders exhibit an 'absolutive' gap advantage - favoring a gap in either an object position or as the core argument of an intransitive event. Tollan and colleagues propose that the overarching principle behind the expectation of 'nominative' gaps and 'absolutive' gaps is a bias favoring the category that is most likely to occur in a given language system. While it is unclear whether preferences for parsing a noun as a subject reflects a bias for agentivity-alignment or for the most likely nominal category, findings from the processing of relative clauses have been overall highly informative in identifying widely shared biases that guide predictive resolution of syntactic dependencies.

## **Conclusion**

Theories of the underlying psychological mechanisms used in language processing are typically assumed to be cross-linguistically general. Our overview shows this assumption is generally supported by empirical investigations in comparative psycholinguistics: Eager, predictive processing, and interference-prone retrieval processes seem to be key components of syntactic dependency formation cross-linguistically. These shared psychological mechanisms lead to broad cross-linguistic similarities in how dependency formation unfolds in real-time.

However, comparative research in real-time dependency formation further refines our understanding of these mechanisms. Comparative research on agreement and reflexive processing has advanced our understanding of how comprehenders encode hierarchical grammatical relations in working memory, as well as the type of cues that drive dependency formation in real-time. Comparative research has also highlighted shared processing biases across languages, bringing us closer to a complete understanding of the underlying principles that drive eager dependency formation in comprehension. Yet despite these advances, we hope to have shown that such cross-linguistic research highlights gaps in our current understanding, and points the way for further research on dependency formation from a cross-linguistically informed perspective.

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