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Full length article

Delayed structural prediction for relative clauses: A new argument for learning to parse from Santiago Laxopa Zapotec

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ABSTRACT

Comprehenders in many of the world's languages exhibit a preference or a greater ease in comprehending transitive relative clauses (RCs) when associating the dislocated head with a subject position. Some theories relate this preference to an early prediction that an animate head will serve as a subject. We present a picture selection experiment with eye-tracking investigating the role of such predictions in comprehending transitive RCs in Santiago Laxopa Zapotec, an Oto-Manguean language of southern Mexico where RCs are ambiguous unless they contain a resumptive pronoun. Patterns of offline choices and incremental looking suggest that Santiago Laxopa Zapotec comprehenders avoid forming predictive interpretations of the RC head, and do not take its animacy into account in early processing. Instead, comprehenders exhibit a later, animacy-sensitive bias to interpret the RC-internal co-argument as a subject. Overall, we take this pattern as evidence that a comprehender's structural predictions must be somehow dependent on experience-based tuning, while more universal pressures like similarity-based interference remain fixed. The lingering question for theories of cross-linguistic processing is how much of our predictive mechanism is tunable: do we tune just the distribution of expected structures which directs predictions, or also the practice of deploying predictions itself? We discuss how either of these approaches might explain the pattern we observe in Santiago Laxopa Zapotec, and highlight that an answer to this question will depend on continued investigations across a diverse sample of the world's languages.

1. Introduction

In a relative clause (RC) construction like (1), a nominal expression (*band*, the **head**) is modified by a clause containing another position where the head must be interpreted. This second, internal position is typically empty, in which case it is known as a **gap**.

(1) I joined the band [that my grandfather played tuba in _].

Studies on the real-time comprehension of RCs have provided a wealth of insight into the human capacity for sentence processing, including key evidence for three theoretical claims: (a) that comprehenders deploy domain-general memory mechanisms to construct dependencies among elements separated in time, (b) that comprehenders manage uncertainty about the future through early structural prediction,

and (c) that momentary preferences in comprehension may bear the thumbprint of broader cognitive universals about concepts like animacy. These are sometimes presented as competing hypotheses, but we understand them to be mutually-compatible; in fact, each seems to be necessary to explain some portion of how RCs are processed.

Though these three claims have their roots in data from English and other English-like languages, there is a growing body of work investigating RC comprehension across the languages of the world. This has allowed the examination of a variety of structural factors that would be impossible to piece apart if investigations were limited to English, including the role of RC-internal word order, head-RC order, and morpho-syntactic alignment. In doing so, it also provides a critical test of theories which suppose that the dynamics of the human sentence processor come from a core faculty shared across speakers of

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all languages. And indeed, when we view the results of the existing cross-linguistic investigations as a whole, in among important points of variation, we can see remarkable consistency around claims (a), (b), and (c). Just as universals in linguistic structure inspire theories of inherent properties of the language faculty, cross-linguistic consistency in these three generalizations about processing behavior leaves room for theories where the generalizations are inescapable consequences of the way humans comprehend language.

In this paper, we add to this literature by profiling the incremental comprehension of RCs in Santiago Laxopa Zapotec, an Oto-Manguean language of southern Mexico. Even as our results support the universality of claims (a) and (c) above, we observe a novel counter-example to claim (b): comprehenders in Santiago Laxopa Zapotec do not demonstrate early structural prediction in RCs. We take this finding to help refine our understanding of structural prediction, providing evidence that the presence and direction of such predictions is not universally determined, but somehow conditioned by the language at hand.

Our discussion will focus on transitive RCs, where the gap may be in the subject position (2), forming a subject RC (SRC), or in the object position (3), forming an object RC (ORC).

(2) **SRC:** That's the dog [that _ chased the puma].

(3) **ORC:** That's the dog [that the puma chased _].

SRCs are generally less difficult to interpret than ORCs, by several metrics and across a remarkable variety of languages (see Lau & Tanaka, 2021 for a recent review). We will refer to this finding as the **SRC preference**. Claims (a), (b), and (c) have each found success as explanations for various aspects of the SRC preference, highlighting different ways in which ORCs pose particular difficulties.

As for claim (a): Once a comprehender has identified a gap within an RC, they must integrate the meaning of the head, which may be quite distant at that point. It has been frequently suggested that this integration, like a larger class of long-distance dependency resolutions in sentence processing, taxes memory (Gibson, 1998; King & Just, 1991). And in languages like English, ORCs feature gaps which are linearly and structurally more distant from the head than in SRCs; therefore, memory operations for dependency resolution would reasonably be slower and more difficult in those languages' ORCs (Grodner & Gibson, 2005).

Theories of memory demands during RC processing provide a natural explanation for another, more complex finding, that ORC comprehension in English is particularly challenged by argument similarity (Gordon et al., 2001). The strongest evidence for an SRC preference comes from comparing SRCs and ORCs like those in (2)–(3), where the head (*dog*) and its **co-argument** within the RC (*puma*), are similar, i.e. both are singular, definite-marked nouns within the same semantic field. In cases where the co-argument is markedly different from the head noun, e.g. a pronoun like *you*, or a name like *Juana*, comprehenders demonstrate a significantly reduced SRC preference, attributed to reduced difficulty of the ORC (Gordon et al. 2001, 2004, 2006; Humphreys et al., 2016). We'll call this pattern a **similarity asymmetry**. Gordon et al. (2001) propose that similarity asymmetries are a consequence of **similarity-based interference** in memory operations, a phenomenon well-documented in domain-general memory research (Lewis, 1996; Shulman, 1971). If we imagine such interference occurs here, retrieving a distant head from memory should be harder when similar linguistic objects intervene. Results like this are common for a variety of dependencies in sentence processing (Jäger et al., 2017), with theorists variously finding evidence for similarity leading to ineffective retrieval (Jäger et al., 2015; Van Dyke & McElree, 2011, see Lewis & Vasishth, 2005), distorted encoding (Smith et al., 2021; Villata et al., 2018; Yadav et al., 2023, see Oberauer et al., 2012), or difficult maintenance of open dependencies (Ness & Meltzer-Asscher, 2017, 2019).

But not all of the challenges involved in processing an ORC in English seem to be the result of difficult memory operations at the gap, bringing us to claim (b). Because the location of the gap is not known in advance, comprehenders face a higher-than-usual degree of structural uncertainty as they process the pre-gap material within the RC. Frazier (1987) suggests that during parsing, comprehenders may manage this uncertainty by engaging in heuristically-guided structural prediction, postulating the earliest gaps possible, often subject gaps (Stowe, 1986). Later proposals for expectation-based parsing (Hale, 2001; Levy, 2008; MacDonald & Christiansen, 2002; Real & Christiansen, 2007) derive the same structural predictions as a consequence of differences in exposure, given that subject gaps are much more frequent in English (Roland et al., 2007). Both accounts correctly predict an off-line corollary of the SRC advantage: in cases where an RC is globally ambiguous between SRC and ORC interpretations, as is possible in Dutch, an SRC interpretation is highly preferred (Frazier, 1987). Likewise, both predict that ORCs should demonstrate a localized difficulty at the filled subject position, the first place where a subject gap hypothesis must be abandoned. Staub (2010) confirms that this early difficulty is visible in eye-tracking while reading, independent of a later cost attributable to dependency resolution at the gap.

Finally, proponents of claim (c) have built on theories of structural prediction during RC processing to explain a second modulation of ORC difficulty in English based on head animacy. The strongest evidence for an SRC preference obtains when comparing RCs following a human-denoting head like *reporter* (King & Just, 1991). In contrast, Traxler et al. (2002, 2005; see also Mak et al., 2002 in Dutch) observed that the SRC preference is greatly reduced when the head is inanimate, above and beyond the effects of argument similarity noted above.¹ We'll call this pattern an **animacy asymmetry**. Subsequent research has explained animacy asymmetries as a consequence of structural prediction. Sentence completion data suggests that incremental comprehenders specifically expect subject gaps for animate heads, and less so for inanimate heads (Gennari & MacDonald, 2008). If we take such completion patterns to diagnose differences in real-time expectations, they offer a compelling explanation for the above effects, especially because the specific incremental difficulty with animate-headed ORCs can be localized again to rejection of a subject-gap hypothesis at the filled subject (Lowder & Gordon, 2014; Wagers & Pendleton, 2015). Note that an animacy-based prediction for subject gaps may come from universal conceptual associations between higher-animacy entities and subject positions (Bornkessel-Schlesewsky & Schlewsky, 2009; Hopper & Thompson, 1980), or in a purely experience-based account, these predictions may come from observed statistical regularities in others' productions (Gennari & MacDonald, 2008; Real & Christiansen, 2007), which typically favor animate subjects for various reasons (Gennari & MacDonald, 2009; Gennari et al., 2012).

A number of properties make Santiago Laxopa Zapotec RCs different from those associated with the results above, including commonplace global ambiguity between SRCs and ORCs, and a system of grammatical resumptive pronouns which can disambiguate these ambiguities. Nevertheless: if claims (a), (b), and (c) were inherent properties of language comprehension, we should expect to see them each playing a role in Santiago Laxopa Zapotec. To this end, we present data from a picture selection task with eye-tracking (Hammerly et al., 2022), testing for the presence of animacy-based incremental prediction, and for animacy and similarity asymmetries in comprehension difficulty. While we observe similarity asymmetries attributable to expected patterns of interference in memory, there was no evidence that Santiago Laxopa Zapotec comprehenders engaged in early structural prediction. Instead, comprehenders demonstrated more flexible interpretive patterns, with later-developing preferences guided more by the animacy of the co-argument than the animacy of the head.

¹ Mak et al. (2006) probe the interaction of head and co-argument animacy further in Dutch, and make a more nuanced claim, see our discussion.

This pattern of results challenges the claim that the robust predictive SRC preferences expected under claim (b) are intrinsic to human sentence processing. To explain this pattern, we argue, our theory of structural prediction needs to permit a particularly high degree of experience-based tuning.

We explore two accounts that might capture the relevant language-specificity. Under one approach, comprehenders' predictions in Santiago Laxopa Zapotec relative clauses are conditioned not only on general regularities of argument mapping, but also on specific regularities of form present in these particular environments. There is one candidate regularity in the language which could be tempering bias towards SRCs, the presence or absence of a resumptive pronoun. This kind of effect would be unsurprising under modern theories of inferential sentence processing, in which comprehenders are sensitive to any and all statistical regularities in the input (Levy, 2008; MacDonald, 2013), but evidence for such fine-grained distinctions has previously been sparse in the domain of RCs (though cf. Levy et al., 2013). We lack the corpus data needed to test this account in detail, but it offers one type of flexibility that could permit the observed pattern.

We also discuss an alternative dimension of flexibility, considering whether comprehenders might also tune the process of prediction itself to the functional needs of a language, i.e. deciding whether or not to use a given statistical regularity in their predictions. Drawing on recent evidence for the developmental trajectory of prediction behavior in English (Atkinson et al., 2018), we suggest that head-based structural prediction in RC comprehension may be a learned behavior, which is useful in many other languages, but less so in Santiago Laxopa Zapotec due to its particular methods of RC disambiguation. While the present study does not offer empirical distinctions between these hypotheses, we highlight how future cross-linguistic research can help determine which types of experience-based tuning actually define the range of possible comprehension behavior.

2. Cross-linguistic diversity in the processing of relative clauses

As the general focus of sentence processing research has been on English and English-like languages, investigating the field's core phenomena across a more representative sample of the world's languages offers unique opportunities to refine psycholinguistic theories. Perhaps most importantly, cross-linguistic comparison is critical in testing our hypotheses about how and why certain familiar patterns of human behavior emerge. As a particularly influential example, Cueto and Mitchell (1988) showed that high-attachment readings are preferred for ambiguously-attached modifiers in Spanish, the reverse of the English preference for local interpretations (Frazier, 1978). This provided strong evidence against simpler universalist models of attachment heuristics, motivating the development of several more complex hypotheses to avoid stipulating arbitrary language-specificity. The ways in which these later ideas added complexity to theories of processing are representative for the approaches to cross-linguistic variation we see today: on the one hand, one can develop more complicated universalist theories which derive variation from other differences in the particular signal available to the processor (Fodor, 1998, 2002); and on the other hand, one can create theories of language-specific parsing as learned behavior, which consider how experience with a different language could lead to e.g. the selection of different parameters or heuristics (Cueto et al., 1996). While it can be tempting to frame these debates as a battle over the presence or absence of a universal processing mechanism, we aim for a more reconciliatory approach here. After all, even modern descendants of experience-based approaches (e.g. Levy, 2008; MacDonald, 2013) retain the idea that there is some core part of the language processing system that is tuned to language experience, but otherwise invariant. When we view the theoretical landscape in this way, the main research question is not about whether there is a universal mechanism, but instead about the division of labor

between architectural inevitability and learned behavior in our theory of that mechanism.

In this section, we'll profile existing cross-linguistic work on RC processing, most of which has served to test and refine the generalization of an SRC preference, and which has motivated discussion of what is universal and what is language-specific about the way RCs are comprehended. We intend this to serve two purposes, not only providing a more complete background for our investigation, but also serving as a case study for the value of sustained investigation across typologically-diverse languages.

One class of relevant studies has investigated languages where RCs differ only minimally from English, and which provide initial evidence that behaviors generalize across languages. In Dutch and German, relative clauses also follow their heads, but feature a canonical Subject–Object–Verb word order rather than the Subject–Verb–Object order of English. This permits sentences where SRC–ORC ambiguity is only resolved by agreement morphology on the late RC verb, or may remain globally ambiguous. Nevertheless, for such strings, in both languages, ORC parses are still dispreferred and engender more difficulty than SRC parses (Dutch: Frazier, 1987; German: Schriefers et al., 1995). Classic SRC preferences also emerge in RCs with Verb–Subject–Object word order in Modern Standard Arabic (Dodd et al. 2022, 2024). In French, Spanish, Russian, and Hungarian, RCs permit flexibility in word order, again affording particular importance to disambiguating morphology, including case-marked relative pronouns which can disambiguate between SRC and ORC parses at the very onset of the RC. SRC preferences are nevertheless still robust (French: Holmes & O'Regan, 1981), and in some cases, differences in distribution of information in these languages has allowed researchers to observe separable signals of difficulty in ORCs, explained by early violation of expectation at the relative pronoun and independently costly memory operations within the RC (Spanish: del Río et al., 2012; Russian: Levy et al., 2013; task-dependent variation in Hungarian: Orth et al., 2026; Ronai & Xiang, 2023).

Further insight has been possible by examining languages like Mandarin Chinese, where the word order of the head and the RC themselves are reversed, so that heads follow RCs. Such “pre-nominal” RCs are particularly different from English-like “post-nominal” RCs in the expected signature of memory effects. No dependency resolution is possible during the RC, instead, integration is possible only once comprehenders encounter the later head. At this point, it is a subject gap that would require the most distant integration, and so the relative difficulty of memory processes in SRCs vs. ORCs might be expected to reverse. Indeed, some initial studies reported such an ORC preference in Mandarin, suggesting that memory operations are the primary source of difficulty in the processing of pre-nominal RCs (Gibson & Wu, 2013; Hsiao & Gibson, 2003). Nevertheless, the existence of a clear ORC preference has been heavily contested in the subsequent literature (Lin & Bever, 2006; Vasishth et al., 2013). Researchers have hypothesized that the inconsistency of results in Mandarin is partially controlled by the temporary possibility of avoiding an RC parse altogether (Hsiao & MacDonald, 2016; Lin & Bever, 2011). When this possibility is mitigated, we in fact observe SRC preferences in Mandarin (Jäger et al., 2015; Wu et al., 2018), as also seen for pre-nominal RCs in Japanese (Ueno & Garnsey, 2008) and Korean (Kwon et al., 2010). These latter results would suggest that post-nominal and pre-nominal RCs are both characterized by an SRC preference, consistent with an inherent or experience-based ease with subject-gap structures, and inconsistent with the idea that memory costs are the largest source of difficulty in RC processing.

But researchers have been able to probe the influence of head-RC order most effectively in languages which permit both English-like post-nominal and Mandarin-like pre-nominal RCs. Wagers et al. (2018) used a picture selection and touch-tracking experiment to investigate the incremental interpretation of both kinds of RCs in Chamorro, an Austronesian language spoken in the Mariana Islands. They found strong evidence that head-RC order modulated interpretive preferences, with

an SRC preference for post-nominal RCs, but an ORC preference for pre-nominal RCs. Nevertheless, early measures of response consideration from touch-tracking indicated that in both orders, comprehenders were initially attracted to SRC parses. Pizarro-Guevara (2020) compared both orders in a similar way in Tagalog, and reports a similar combination of evidence for a global SRC preference and a competing pressure for ORC parses in pre-nominal RCs. Wagers et al. (2018) suggest that these patterns may result from comprehenders using a combination of universal and language-specific heuristics to minimize memory load and uncertainty as they construct a representation of an unfolding sentence. Under this approach, typical SRC preferences arise in post-nominal RCs because there, a subject-gap structure offers a way to quickly resolve the head-gap dependency and identify the subject of the RC. In pre-nominal RCs, where co-arguments are encountered before heads, pressure to identify the RC subject can end up favoring an ORC parse instead, eliminating or even reversing comprehenders' ultimate preferences.

Elsewhere, another small literature has investigated the influence of morphosyntactic alignment in RC processing. Most of the best-attested languages in the sentence processing literature feature nominative-accusative alignment, in which verbal agreement and case-marking mark all subjects in the same way, and objects of transitive predicates in a second way. But many of the world's languages—including Basque, many Mayan languages, and many of the languages spoken in the Caucasus—feature ergative-absolutive alignment, in which subjects of intransitive predicates pattern together with transitive objects, e.g. receiving absolutive case-marking, while transitive subjects alone behave differently, e.g. receiving ergative case-marking. Some studies on languages with the latter alignment have found no differences in the net difficulty of SRCs and ORCs (the Northeast Caucasian language Avar: Polinsky et al., 2012; the Austronesian language Niuean: Longenbaugh & Polinsky, 2016), or even in some cases an ORC preference (Basque: Carreiras et al., 2010, note that Basque RCs are also pre-nominal; see also evidence from Tollan et al., 2019 for predictive object-gap interpretations for *wh*-questions in Niuean). Still, these findings do not generalize across all ergative-absolutive languages, several of which exhibit robust SRC preferences (the Mayan languages Q'anjob'al and Ch'ol: Clemens et al., 2015; the South Caucasian language Georgian: Foley, 2020; Lau et al., 2023). Polinsky et al. (2012) offer that the observed patterns of preference could be captured as the combination of multiple overlapping pressures, including a typical SRC preference sometimes counteracted by an alignment-specific facilitation for object-gap dependencies derived from the predictive value of observing an ergative subject inside the RC. Language-specific differences in exposure likely have an influence here as well; consider that some of the clearest evidence for an online ORC preference comes from Tongan, an Austronesian language closely related to Niuean in which transitive subject dependencies inside RCs require a less frequent syntactic structure (Ono et al., 2019).²

In all, cross-linguistic investigations of the SRC preference have revealed (a) that evidence for a basic SRC preference is remarkably widespread, but still, (b) that variations between languages in the distribution of information, including differences of word order and finer morphosyntax, have a strong influence on the ultimate patterns of difficulty exhibited by comprehenders of a given language. This picture is consistent with the existence of a universal preference for SRC structures, independent from differences in memory operations, but it nevertheless leaves residual variation which must be explained by some theory of language-specific processing.

Given that comprehenders in different languages are facing distinct challenges in the processing of RCs, it is unfortunate that there has been only minimal cross-linguistic investigation of the similarity and

animacy asymmetries we see in English. The former effect is known to generalize at least minimally outside of English: disrupting similarity with a pronominal co-argument also facilitates ORC comprehension in Russian (Price & Witzel, 2017) and at least for child comprehenders in German (Kidd et al., 2007) and in Hebrew (Arnon, 2010; Friedmann et al., 2009). Similarity asymmetries also have been used to argue for memory-based costs in RC processing in Hindi, where otherwise things would be somewhat murkier due to independent predictive facilitation in some sentences with long dependencies (Vasishth & Lewis, 2006).

There is some evidence that similarity asymmetries exhibit cross-linguistic variation, such that different dimensions of similarity matter more or less based on properties of the language. For Italian children (Adani et al., 2010) and adults (Biondo et al., 2023), it has been observed that similarity in number-marking (e.g. singular, plural) between the head and the co-argument is a source of substantial difficulty in the comprehension of ORCs, but similarity in gender, another grammatically-relevant feature in Italian, has a far weaker effect. Belletti et al. (2012) show that this is not a general pattern across all languages: similarity in gender causes substantial interference effects for RC processing in Hebrew. The authors suggest that it is the features that are relevant for syntactic operations, like subject-verb agreement, in a language which contribute to similarity effects in RC processing (see also Friedmann et al., 2009). In Hebrew, these include gender, but in Italian, they do not.³

Other than these last observations, it's unclear how changeable similarity asymmetries may be across languages. If these patterns are a consequence of the intrinsic constraints faced by domain-general memory operations, we should expect little variation, except where the role of memory may itself vary, as perhaps in pre-nominal RCs. On the other hand, some have suggested that at least the easy interpretation of ORCs with pronominal co-arguments could be reduced to an effect of experience, given that such ORCs are relatively more common in corpus investigations and production experiments (Kidd et al., 2007; Real & Christiansen, 2007; though cf. Roland et al., 2021). Experience-based explanations for similarity asymmetries could predict more substantial cross-linguistic differences, depending on whether the same distributional regularities are apparent in all languages.

The role of head animacy in RC processing is similarly under-explored. The basic animacy asymmetry of Traxler et al. (2002) and Mak et al. (2002) has been replicated in similar languages: in Spanish (Betancourt et al., 2009), in French (Baudiffier et al., 2011), and with German-speaking children (Kidd et al., 2007). There is also some indication that the association between animate heads and subject gaps extends to languages with very different RC structures. Foley (2020) reports a post-hoc analysis of human-, animal-, and inanimate-headed RCs in Georgian, and finds evidence for a cline of SRC preferences, strongest for human heads. The association may even run the other way, from gap positions to features of the head: Wu et al. (2012) and Hsiao and MacDonald (2016) report Mandarin experiments where it seems that comprehenders may have predicted the presence of a human head after encountering a pre-nominal SRC. More recently, Hammerly et al. (2022) extended a similar question in a new domain, using a picture selection task with eye-tracking to explore how comprehenders in the Algonquian language Ojibwe might use the language's distinction between proximate and obviative third-person arguments to predict subject vs. object gaps. The proximate/obviative distinction encodes differences in the prominence of third-person arguments much like animacy, and Hammerly and colleagues show that comprehenders were indeed able to exploit this marking to launch predictions for SRCs specifically in the case of more prominent proximate heads.

³ Friedmann et al. (2009), Belletti et al. (2012), and Belletti and Rizzi (2013) lay out a way of thinking of these similarity effects as consequences of violating formal principles of feature-intervention in grammar, rather than difficult memory operations.

² Specifically, Tongan SRCs require subject resumptive pronouns (Otsuka, 2000); we will discuss resumptive pronouns in much further detail below.

Nevertheless, this pattern may be variable across languages. Recent studies in Hebrew (Cartner et al., 2023; Geller, 2020) and in Tagalog (Bondoc & Kush, 2024) have noted an absence of animacy asymmetries. If this pattern is the result of animacy-based structural prediction, where could this cross-linguistic variability come from? Some authors have suggested these predictions may reflect a conceptual universal linking animate entities to subject positions, and vice versa (Traxler et al., 2002; Wagers & Pendleton, 2015). In that case, animacy asymmetries should be more or less stable across the world's languages. True variation in this pattern could only be explained by some theory where this asymmetry is somehow conditioned by language experience. Along this line, other authors have previously argued that a preferential link between animate heads and subject gaps could be inherited from systematic tendencies for producers to present animate entities as subjects, or in particular to use animate RC heads with subject gaps (Fadlon et al., 2019; Gennari & MacDonald, 2009; Gennari et al., 2012; Hsiao & MacDonald, 2016; MacDonald, 2013). If predictions are sensitive only to regularities in semantic features and syntactic positions, a language would only depart from the standard animacy asymmetry if it somehow violated these standard asymmetries in speaker behavior. Nevertheless, under more fine-grained theories of experience-based prediction, comprehenders' biases would also be sensitive to other systematic patterns in e.g. the form of different RCs, cues which could lead to more striking variation in predictions.

Our observations in the processing of RCs in Santiago Laxopa Zapotec provide further support that prediction behavior indeed varies across languages, even as other patterns of similarity-based interference and a general preference for human subjects remain more stable. The evidence is difficult for any theory where animacy-guided structural prediction is an architectural inevitability, and invites a few different proposals for how it might emerge as a language-specific behavior. We will offer one tentative explanation based on form-specific prediction, where comprehenders can learn to temper SRC predictions based on other cues, but we will also add and compare an alternative theory which takes an even less universal view. For this alternative, structural prediction itself is a learned behavior, one of many potential strategies identified as useful given the input a processor has experienced. While these proposals disagree on the full extent of possible variability in language processing behavior, they agree that systems for prediction must exhibit a rich sensitivity to particular experience.

3. Relative clauses in Santiago Laxopa Zapotec

Santiago Laxopa Zapotec (Dille' *xhunh*, [di.ʒeʔ ʒuŋ]) is one of many Northern Zapotec languages in the Oto-Manguean family.⁴ It is spoken by at least around 1300 people in the municipality of Santiago Laxopa (*Laxup*), in the Sierra Norte region of Oaxaca, in southern Mexico (Instituto Nacional de Estadística y Geografía, 2020), with an estimated few hundred additional speakers in other parts of Mexico and in the United States. Residents of Santiago Laxopa are typically bilingual with Spanish, the language of trade with other communities and instruction in primary education, but use Zapotec in their daily life, with family and in the local community.

The typical transitive sentence in Santiago Laxopa Zapotec features Verb–Subject–Object word order, as in (4) and (5) (Adler et al., 2018). Word order is critical for disambiguating the role of each argument, as nominal arguments do not carry any case morphology, and verbs only mark agreement with third-person, plural subjects.

- (4) Txhube bi'i xyag=e'nh koch=e'nh.
pull boy=the car=the
'The boy is pulling the car.'

- (5) Txhube koch=e'nh bi'i xyag=e'nh.
pull car=the boy=the
'The car is pulling the boy.'

Santiago Laxopa Zapotec also features a complex inventory of personal pronouns, divided into three persons. Number is distinguished only within the first and second persons (e.g. *lhe* 'you (sg.)' vs. *lhe'e* 'you (pl.)'). Third-person pronouns do not distinguish social gender (masculine vs. feminine), but animacy instead, referring separately to elder humans (*le'*), non-elder humans (*leba'*) non-human animals (*leb*) and inanimate objects (*lenh*) (Toosarvandani, 2023). Subject pronouns generally appear in reduced forms, as a clitic following the verbal content (e.g. =*ba'*, 's/he (non-elder)') (6), while object pronouns generally appear in their full forms, only appearing in reduced forms in certain contexts after a pronominal subject (7) (Foley & Toosarvandani, 2022; Sichel & Toosarvandani, 2025).

- (6) Txhube =ba' koch=e'nh.
pull =he car=the
'He is pulling the car.'
- (7) Txhube bi'i xyag=e'nh lenh.
pull boy=the it
'The boy is pulling it.'

Relative clauses in Santiago Laxopa Zapotec are obligatorily post-nominal (Duff et al., 2022), that is, they follow the head as in English. Unlike English, RCs where the head serves as an argument within the RC feature no relative pronoun or other marker at their left edge.⁵ For instance, an RC can appear simply as a sequence of Verb and Co-Argument after a head (8). In fact, because of the language's Verb–Subject–Object word order, the absence of case-marking on nominals, and the minimal system of agreement morphology, most RCs that feature a gap will be globally ambiguous between SRC (8) and ORC structures (9).

- (8) bi'i xyag=e'nh [txhube _ koch=e'nh]
boy=the pull car=the
'the boy that is pulling the car'
- (9) bi'i xyag=e'nh [txhube koch=e'nh _]
boy=the pull car=the
'the boy that the car is pulling'

Speakers may optionally disambiguate the position of the gap in a RC through the presence of a pronoun in place of the subject or object gap, referring back to the head (10–11). In languages like English, such **resumptive pronouns** (RPs) are generally judged to be unacceptable, but are nevertheless sometimes produced in contexts where a gap would be even less acceptable (Ferreira & Swets, 2005; Morgan & Wagers, 2018; Polinsky et al., 2013; see Meltzer-Asscher, 2021 for a comprehensive review of RPs in processing). But RPs in Santiago Laxopa Zapotec bear more in common with those in languages like Irish and Hebrew, where RPs are produced frequently, and thought to be a grammatically-available alternative to gaps (McCloskey, 2017).⁶ Drawing from corpus and elicited data in Macuiltianguis Zapotec (a closely-related but mutually-unintelligible Northern Zapotec language), Foreman and Munro (2007) suggest that there is even a preference or perhaps an obligation for RCs like (10) with a subject RP over those like (8) with a subject gap.⁷ Preliminary analysis of data from a Santiago Laxopa Zapotec production study confirms that both SRCs and ORCs frequently feature RPs, and subject RPs are particularly common (Duff et al., In preparation).⁸

⁵ RCs with adjunct heads do feature relative pronouns, see (13) for one example.

⁶ In fact, Santiago Laxopa Zapotec shows a wider distribution of RPs than is observed in Irish or Hebrew, where subject RPs are thought to be ungrammatical or more highly restricted.

⁴ While Santiago Laxopa is located in the Ixtlán district of Oaxaca, its closest related languages within Northern Zapotec include the varieties spoken in Villa Alta municipalities like San Bartolomé Zoogocho.

- (10) bi'i xyag=e'nh [txhube =ba' koch=e'nh]
 boy=the pull =he car=the
 'the boy that is pulling the car'
- (11) bi'i xyag=e'nh [txhube koch=e'nh leba']
 boy=the pull car=the him
 'the boy that the car is pulling'

For an incremental comprehender, the timing of disambiguating information in Santiago Laxopa Zapotec RCs is very different from that in English. English comprehenders are alerted to the position where they should interpret the head through the absence of an expected nominal element; in most cases this is obvious as soon as they encounter the word following the gap. In some cases, Santiago Laxopa Zapotec comprehenders receive no disambiguating information at all. In other cases, they are alerted to the position where they should interpret the head through the presence of an RP, either immediately following the RC verb, or else directly after encountering an ambiguous co-argument.⁹

Finally, we note that the internal word order of RCs in Santiago Laxopa Zapotec is highly constrained (Adler et al., 2018). While the language permits some alternative word orders in simple clauses where subjects or objects may come before the verb, in RCs, the Verb–Subject–Object order we have described here is strict. Moreover, unlike languages like English, Santiago Laxopa Zapotec does not feature a passive construction, or any other general syntactic process for suppressing the canonical subject or allowing an object to appear as the subject.¹⁰ Gennari et al. (2012) demonstrate that language-specific constructions for backgrounding the subject in this way are often recruited in the production of RCs with two animate arguments, seemingly to avoid the difficulty of a typical ORC with an animate head (see also Ferreira, 1994; Prat-Sala & Branigan, 2000). In the absence of such constructions, Santiago Laxopa Zapotec speakers and comprehenders may have somewhat different patterns of experience than speakers of more familiar languages.

Sasaki et al. (2021) highlight that the features of Santiago Laxopa Zapotec RCs, and the language's finely-graded system of animacy in particular, make them an interesting place to study the role of animacy in RC comprehension. The authors report four picture selection experiments with eye-tracking, mostly targeting the interpretation of globally-ambiguous RCs with gaps while manipulating the animacy of the head along the language's four-way animacy scale (elder humans > non-elder humans > animals > inanimates). Participants' responses reveal that final interpretations were evenly matched between SRC and

ORC parses, with a surprising absence of any effect of animacy. Eye-tracking data revealed a momentary preference for SRC interpretations just as participants heard the head, but this fleeting boost in attention was not modulated by animacy, and didn't match the expected profile of a firm predictive interpretation. In a supplemental comparison, the authors also report interpretation and eye-tracking data for another set of items featuring subject and object RPs. There, response data suggested that participants had some difficulty interpreting object RPs, especially in one experiment where the head and the co-argument were matched in animacy. These results present an interesting pattern: on the one hand, unambiguous ORCs were difficult in a way consistent with a similarity asymmetry conditioned on animacy (see further discussion in Wagers, 2023); on the other hand, there was no evidence for animacy-conditioned prediction, and only minimal evidence consistent with an SRC preference.

This result is notable, because on its face, there is no single element of Santiago Laxopa Zapotec grammar that would categorically preclude an animacy-conditioned SRC preference—under at least the most universal theories of structural prediction, regardless of the particular VSO word-order, RPs, or global ambiguities, Santiago Laxopa Zapotec RCs should be processed much like any other post-nominal RC. In fact, one might have expected a greater role for animacy, given its prominence as a grammatical feature in the language. In the present study, we aim to provide a closer investigation of these patterns, manipulating animacy with a simpler binary comparison between human and inanimate arguments, while also examining the effect of argument similarity, for ambiguous RCs and RP-disambiguated ORCs, all within the same design.

In trials with ambiguous RCs, if comprehenders use the animacy of the head noun to hypothesize an initial subject-gap structure (Gennari & MacDonald, 2008; Wagers & Pendleton, 2015), we expect to see (i) an animacy asymmetry such that RCs with human heads receive more SRC interpretations, reflected also in (ii) an increase in SRC-consistent gaze patterns triggered by the presence of a human head.

In trials with RP-disambiguated ORCs, if comprehenders are then revising an initial subject-gap prediction, we expect to see (iii) consequences of the same animacy asymmetry, such that RCs with human heads most often receive incorrect SRC interpretations, reflected also in (iv) a slower shift away from SRC-consistent gaze patterns. If comprehenders are relying on some process in memory as they construct their final ORC interpretation, we expect to see a similarity asymmetry, such that RCs with animacy-matched co-arguments (v) most often receive incorrect SRC interpretations and (vi) feature a slower shift away from SRC-consistent gaze patterns.

As we will recount below, of these six predictions, our study provides no evidence for (i), (ii), (iii) or (iv)—that is, we find no evidence for early, animacy-based subject-gap predictions in Santiago Laxopa Zapotec. In contrast, we do observe rapid interpretation of object RPs, sensitive to the expected similarity asymmetry expressed in predictions (v) and (vi). Most interestingly, we also note an unexpected late effect of animacy in the interpretation of these RPs, such that comprehenders constructed ORC parses most easily when the RC-internal co-argument was human. We suggest that these patterns can be explained with recourse to typical notions of similarity-based interference, and a universal conceptual link between animacy and subjecthood, together with some way of explaining why Santiago Laxopa Zapotec comprehenders don't show robust, early-developing, animacy-sensitive SRC predictions. Under one hypothesis we will explore, comprehenders are in fact making nuanced, form-specific predictions, but these predictions happen to be less biased than in other languages, as a consequence of the distribution of RPs in the language. Under the other hypothesis, we reframe structural prediction as a learned parsing behavior. Santiago Laxopa Zapotec, on this approach, doesn't show a role for head animacy in structural prediction for RCs only because Santiago Laxopa Zapotec comprehenders do not engage in early structural prediction for RCs at all.

⁷ Foreman and Munro (2007) also highlight many ways in which other Zapotec languages differ from the widespread optionality we describe here. In San Lucas Quiaviní Zapotec (within the Valley Zapotec family), subject RPs as in (10) are reported to be ungrammatical; while in both Macuilitanguis Zapotec and San Lucas Quiaviní Zapotec, object RPs like (11) are reported to be ungrammatical. In corpora of Colonial Valley Zapotec, a historically-documented variety in the Valley Zapotec family, the authors note subject RPs but not object RPs, seemingly similar to Macuilitanguis Zapotec.

⁸ As discussed in Foreman and Munro (2007), this pattern contradicts the generalization in Keenan and Comrie (1977) that RPs “will be used in proportion to the difficulty of the position being relativized,” where object relativization is thought to be more difficult than subject relativization.

⁹ These are the only possibilities when we consider RCs with two singular nominal arguments. Other features of the grammar allow for disambiguation in cases with pronominal co-arguments or distinctions in plurality.

¹⁰ Gennari et al. (2012) discuss impersonal constructions as a functional alternative to a passive. In Santiago Laxopa Zapotec, impersonal subjects are always expressed by clauses with explicit subject pronouns, unlike the constructions those authors discuss in Spanish and Serbian, which lack explicit subjects. See Ostrove (2021) for discussion of similar facts for pronoun-based impersonal constructions in a (distantly related) Mixtec language.

4. Methods

To test the predictions of animacy-triggered, similarity-sensitive parsing in Santiago Laxopa Zapotec we conducted a picture selection experiment with eye-tracking.

4.1. Participants, procedure, and design

One hundred and two native speakers of Santiago Laxopa Zapotec participated in the experiment.¹¹ Their ages ranged from 18 to 85 years (median age: 40; 28 male). All participated in Santiago Laxopa.

Participants performed a picture selection task using a tablet computer. On each trial, participants were instructed in Zapotec to touch one of two pictures arranged on the screen. Instructions in critical trials used an RC to describe a character in one of the scenes. All instructions, including the explanations of the task for the obtaining of informed consent, were presented auditorily, having been recorded by the third author, a native speaker of Santiago Laxopa Zapotec. The task took 10–15 min on average, after which experimenters verbally administered a demographic questionnaire in Zapotec and/or Spanish.

The form of the critical RC was manipulated according to a core $2 \times 2 \times 2$ design that crossed Dependency Type (DepType), Head Animacy (Head), and Co-Argument Animacy Match (Match). The two levels of Dependency Type were *Gap* and *Object RP*. (*Gap* RCs featured no resumption, and were thus globally ambiguous.¹²) The two levels of Head Animacy were *Non-Elder Human (HU)* and *Inanimate (IN)*. The RC-internal co-argument either *Matched* or *Mismatched* the animacy of the head, such that a *HU Mismatch* RC featured a *HU* head and an *IN* co-argument. Each critical instruction was composed of the carrier frame shown in (12), followed by the RC.¹³

- (12) Udanh fotografia='nh tse ...
touch picture=the of
'Touch the picture of ...'

¹¹ Participants responded to an open call to take part in the study, and no one was turned away—this method succeeded in recruiting widely within the language community, although it was not possible to record eye movement data with all participants, see below for further discussion on the particular construction of the eye movement data set.

¹² To our knowledge, there are no prosodic features which disambiguate between *Gap* RCs with intended SRC and ORC parses. If there were any such features in our stimuli, they did not produce any robust comprehension biases in this study: in Appendix D we report a post-hoc analysis of stimulus-by-stimulus interpretation preferences, which supports the conclusion that individual recordings used were largely homogeneous and evenly biased.

¹³ As one reviewer points out, this carrier phrase means our critical RCs may have been, technically, structurally ambiguous between high modification of *fotografia='nh tse* + Head, and the intended low modification of the Head. As noted above, in some languages it has been proposed that structural biases may prefer a high-attachment structure, as in Spanish (Cuetos & Mitchell, 1988). Perhaps some participants might have been predicting RC structures in which the pictures, not the target individuals, served as the head? We do not know the preferences of Santiago Laxopa Zapotec comprehenders, but we do not expect that Spanish exposure would play a large role in driving a high-attachment preference here, as other bilinguals have largely demonstrated language-specific, monolingual-like preferences in previous work (see Jegerski, 2018; Jegerski et al., 2016 and citations therein). Even if Santiago Laxopa Zapotec comprehenders prefer high modification, we are not particularly concerned for the purposes of this study: this possible problem would only emerge if such a bias was resistant to a general dispreference to attach RCs to inanimate NPs (as seen in Dutch: Desmet et al., 2006), any possible prosodic cues to low attachment in the stimuli (as seen in English: Maynell, 1999, cited in Fodor, 2002), and the overwhelming frequency, plausibility, and salience of low attachment in the task.

The eight critical conditions in one item frame are illustrated in Table 1. Head nouns were always definite, followed by imperfective verb forms and a definite co-argument. After the co-argument, all conditions included a RC-final prepositional modifier (in this item frame, *kwit yegu'nh*, 'near the river').

4.2. Materials

To construct the thirty itemsets in our study, fifteen item frames were first constructed from ten transitive verbs, with five verbs used twice in two frames each. The verbs were selected for their ability to permit all combinations of humans and inanimates acting on humans and inanimates. For example, the verb *shkache'* 'hide' can describe any of the following events: a human blocking another human from view, a human blocking an object from view, an object blocking a human from view, and an object blocking another object from view. Appendix A lists all verbs and nouns used in the experiment.

From each item frame, two itemsets were generated with the same verb. In the first itemset, a critical human noun was the head, and either a critical inanimate noun or a secondary human noun appeared within the RC as a co-argument. In the second itemset, the critical inanimate noun was the head, and either the critical human noun or a secondary inanimate noun appeared within the RC. Thus, Head Animacy was a between-items manipulation. This design choice allowed us to collect more observations from each participant despite a constrained number of plausible verb-argument frames.

The resulting thirty itemsets were presented equally in a Latin square design across five conditions: one of the four critical conditions defined by crossing DepType and Match, or a fifth control condition. Two types of control conditions were constructed to be completely unambiguous, to establish a baseline for RCs which should pose no significant processing difficulty, and to allow confirmation that our methodology was sensitive to expected patterns of incremental interpretation in unambiguous sentences. For half the items, the control condition consisted of an adjunct-gap RC directly modifying *fotografia='nh* 'picture=the', featuring *ga'nh* 'where' (13). These RCs could be unambiguously mapped to the correct picture once the participant heard the first argument in its canonical, post-verbal position; until that point, the signal had no structural ambiguity, and provided no cues which would be expected to bias interpretation. For the other half, the control condition consisted of an RC where the head is interpreted as an argument of the RC verb, as in the critical conditions, disambiguated using a subject resumptive pronoun directly following the verb (14). This latter condition thus ensured that participants encountered some unambiguous SRCs during the experiment. All controls featured arguments mismatching in animacy.

(13) "Where" RC control:

fotografia='nh ga'nh txhube bi'i xyag=e'nh koch=e'nh
picture=the where pull boy=the car=the
'the picture where the boy is pulling the car'

(14) Subject RP control:

fotografia='nh tse bi'i nhu'ulhe='nh shchuchj=ba'
picture=the of girl=the crush=she
yag siy=e'nh
chair=the
'the picture of the girl who (she) is crushing the chair'

The illustrations displayed to the participant always featured the two nouns mentioned in the audio instructions. In one image, the head noun was depicted as the subject, and the co-argument as the object, consistent with an SRC parse. In the other image, the head noun was depicted as the object, and the co-argument as the subject, consistent with an ORC parse. Going forward, we will refer to these as the *SRC image* and the *ORC image*.

Table 1

The eight critical conditions demonstrated within one item frame, crossing Dependency Type, Head Animacy, and Co-Argument Animacy Match.

HU Head									
Mismatch					Co-Argument Animacy Match				
Gap	bi'i xyag=e'nh	txhube	koch=e'nh		bi'i xyag=e'nh	txhube	bi'i nhu'ulhe='nh		
	boy=the	pull	car=the		boy=the	pull	girl=the		
	'the boy who is pulling the car', or 'the boy who the car is pulling'				'the boy who is pulling the girl', or 'the boy who the girl is pulling'				
Object RP	bi'i xyag=e'nh	txhube	koch=e'nh	leba'	bi'i xyag=e'nh	txhube	bi'i nhu'ulhe='nh	leba'	
	boy=the	pull	car=the	him	boy=the	pull	girl=the	him	
	'the boy who the car is pulling (him)'				'the boy who the girl is pulling (him)'				
IN Head									
Mismatch					Co-Argument Animacy Match				
Gap	koch=e'nh	txhube	bi'i xyag=e'nh		koch=e'nh	txhube	kamioneta='nh		
	car=the	pull	boy=the		car=the	pull	truck=the		
	'the car which is pulling the boy', or 'the car which the boy is pulling'				'the car which is pulling the truck', or 'the car which the truck is pulling'				
Object RP	koch=e'nh	txhube	bi'i xyag=e'nh	lenh	koch=e'nh	txhube	kamioneta='nh	lenh	
	car=the	pull	boy=the	it	car=the	pull	truck=the	it	
	'the car which the boy is pulling (it)'				'the car which the truck is pulling (it)'				

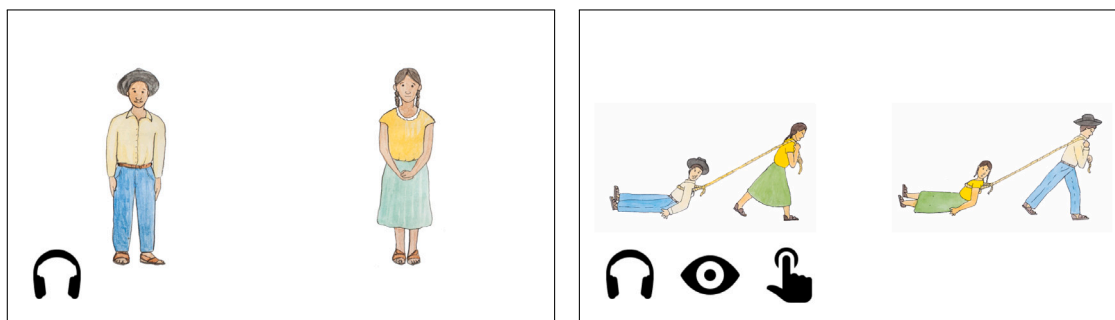


Fig. 1. Participants saw depictions of two individuals or objects, presented with their target descriptions, followed by the critical display, where they were prompted to select the image matching the RC, while their gaze was tracked. These particular images were associated with the item frame profiled in Table 1, in the *HU Match* conditions.

4.3. Apparatus and method

The experiment was presented on Windows Surface Pro tablets running Windows 10. Trials were designed and sequenced using the OpenSesame platform (Mathôt et al., 2012). Audio was presented on Sennheiser HD 202 corded on-ear headphones, while eye movements were collected with a Tobii Pro Nano, sampling at 60 Hz and controlled via the PyGaze library (Dalmaijer et al., 2014).

Fig. 1 illustrates an example trial sequence.¹⁴ At the beginning of each trial, participants saw images of two entities in neutral poses or

orientations, and heard presentations and descriptions of each entity which used a nominal description, as in (15).

- (15) a. *Nhi ze tu bi'i xyag. Nhi ze tu bi'i nhu'ulhe.*
here stand one boy here stand one girl
'Here is a boy. Here is a girl.'
- b. *Lhape gasj=e'nh nyaz bi'i xyag=e'nh.*
hat black=the wear boy=the
'The boy is wearing the black hat.'
- c. *Kamis gache'=nh nyaz bi'i nhu'ulhe=e'nh.*
shirt yellow=the wear girl=the
'The girl is wearing the yellow shirt.'

This was followed by a 2000 ms fixation cross, and then the simultaneous onset of the critical pair of scene illustrations and the critical audio stimulus. Participants had 30 s to select and touch an image, during which time their gaze was monitored. Only one image could be selected on each trial; once a touch was recorded, the trial concluded. Order of entity introduction and left–right order of the critical scenes were fixed per itemset and counter-balanced across the study.

¹⁴ One reviewer points out that this setup is odd in that the preamble presents only one individual who matches each head noun (in this case, one boy, and one girl), and participants then pick between scenes where it seems to be these same individuals participating in the event in different ways (in this case, a scene where that particular boy is pulling that girl, or vice versa). This mismatches the most natural uses of definite-headed relative clauses like “the picture of the boy who is pulling the girl”, where there should be pictures of at least two different boys to pick from. This was likely an obstacle to natural interpretation here. Nevertheless, there is no indication that this pragmatic oddness prevented participants from understanding the RC correctly and quickly.

4.4. Analysis

Eye movement recordings were pre-processed first by excluding all eye tracker samples without a TRUE-valued validity code in either the left or the right eye and then by parsing into fixations using the saccades library (von der Malsburg, 2019) in R. We did not apply a trackloss criterion to trials. Fixations were then categorized, for each participant, into three areas of interest (AOI: left image, right image, center) using the EM algorithm for mixture of univariate normals implemented in the mixtools library (Benaglia et al., 2009).

For 24 participants, eye movement data was not recorded, or it was not possible to distinguish AOIs in the recorded data. This left a sample of 78 participants with eye movement data. Ten of these participants were excluded from analysis based on observations in the field of persistent visual distractions in their immediate environment (this could not always be controlled to the standards required for eye movement analysis). Finally, participants were also excluded based on their choice performance on unambiguous control trials: six of the remaining participants achieved an accuracy of 50% or lower and were excluded. The final sample contained data from 62 participants.

A set of seven region-of-interest (ROI) intervals defined the critical regions in Gap and Object RP sentences: *Pre-critical* (1000 ms window preceding NP1 onset), *Head* (NP1 onset to NP1 offset), *Verb* (V onset to V offset), *Co-Argument* (NP2 onset to NP2 offset), *Pro* (when present, Object RP onset to Object RP offset), *Post-critical 1* (1000 ms window following NP2/RP offset), and *Post-critical 2* (subsequent 1000 ms window).

The dependent variable in our eye-tracking analysis was whether or not participants programmed a new fixation to a given image during each of the seven intervals. Within each trial, fixations were coded with respect to those intervals. Following standard estimations for the time it takes to plan and execute a saccade, the time at which a fixation was programmed was estimated at 200 ms before its measured onset. If the estimated programming time of a fixation fell within an interval, it was counted as a new fixation in that interval.¹⁵ Data were then aggregated per trial, per interval, to a binary response variable for each image, measuring whether that image received any new fixations in that interval on each trial. This roughly follows the analytic strategy of Huang and Snedeker (2020), who observe that this ‘binarization’ analysis is appropriate for small time windows because it better matches the dynamics of how an image is inspected: saccades in visual-world experiments typically occur only a few times per second (Staub et al., 2012), and our acoustic ROIs range between e.g. 400–1200 ms for the Head, Verb, and Co-Argument ROIs.

Left and right images were mapped onto their status as an SRC-consistent image or an ORC-consistent image (which varied by trial). The two resulting binary dependent variables—i.e., whether or not a participant programmed a new fixation to the SRC image, and the ORC image, in each interval—were each modeled using mixed-effects Bayesian logistic regressions with three population-level predictors and all their higher-order interactions. We present two main analyses of those dependent variables here; the exact predictors used differ between the analyses. In a first analysis examining only the ambiguous Gap conditions (the Gap Analysis), we considered the effects of Head Animacy (Head: HU, IN), Co-Argument Animacy Match (Match: Mismatch, Match), and which interpretation the participant indicated for that trial (Interpretation: SRC, ORC). We present these comparisons as an opportunity to investigate the effects of argument animacy on fully

Table 2

Posterior estimates, standard errors, and 95% HPDIs from Bayesian logistic mixed-effects models fit to the probability of choosing the SRC image across the eight critical gap and object RP conditions. Parentheses indicate the level of each factor coded as positive (+0.5).

Effect	Posterior $\hat{\beta}$	Posterior σ_{β}	95% CRI
Intercept	−1.45	0.20	(−1.84, −0.04)
DepType (Obj. RP)	−1.64	0.22	(−2.05, −1.20)
Match (Match)	0.20	0.24	(−0.27, 0.67)
Head (IN)	0.49	0.32	(−0.15, 1.11)
Dep. × Match	0.58	0.30	(−0.02, 1.16)
Dep. × Head	0.92	0.33	(0.26, 1.54)
Match × Head	0.17	0.36	(−0.54, 0.88)
Dep. × M × Head	−0.30	0.41	(−1.10, 0.52)

ambiguous RC inputs. In a second analysis examining only trials on which participants indicated ORC interpretations (the Gap vs. Object RP Analysis), we considered the effects of Head Animacy, Co-Argument Animacy Match, and Dependency Type (DepType: Gap, ObjRP). We present these comparisons as an opportunity to investigate the real-time interpretation of object RPs.

We also analyze participants’ offline RC interpretations, indicated by image selection, as another binary dependent variable, in a single mixed-effects Bayesian logistic regression examining the effects of Head Animacy, Co-Argument Animacy Match, and Dependency Type within our eight critical conditions.

All population predictors were sum-coded (with weights of −0.5 vs. 0.5). Full random effects structure grouped by Subject and Item was included. Models were estimated using the brms library (Bürkner, 2017). We used the default priors in brms (v. 2.18.0), with the exception of all population-level slopes, whose prior was set to Normal(0, 0.5), and the correlations between random effects, set to the Lewandowski-Kurowicka-Joe prior lkj(eta = 2) (Lewandowski et al., 2009). Reported point estimates for parameters ($\hat{\beta}$) are medians over the posterior distributions, and are reported with 95% highest posterior density intervals (HPDIs). Where relevant to comparisons of interest, we also report median marginal estimates ($\hat{P}$) and differences between conditions in the posterior predictive distribution ($\hat{\delta}$), as generated using the hypothesis function in brms.

5. Results

5.1. Interpretation choices

Fig. 2 plots participants’ offline interpretations in critical conditions and Table 2 reports the parameters of a mixed-effects logistic regression fit to choices in those conditions. On the whole, interpretations of ambiguous RCs were roughly equibaised: the SRC image was selected on 37% of Gap trials. This was not due to inattentive or noisy comprehension: the (unambiguously correct) SRC image was selected on 98% of Subject RP and *Where* RC controls. If anything, a 37% rate of SRC interpretation suggests some bias towards the ORC parse, but our statistical analysis suggests that we do not have strong evidence for any departure from chance: calculated for each type of Gap condition, 95% HPDIs in all Gap conditions include 50%, except for RCs with HU heads and HU co-arguments, the only case where we might conclude an ORC bias. We take the general pattern to be one of equibias.

The presence of an object RP was associated with a credible reduction in SRC responses, down to 13% across all Object RP conditions ($\hat{\beta}$ = −1.64; [−2.05, −1.20]_{95%}). We conclude that the task was appropriately sensitive to this known grammatical contrast.

Surprisingly, we observed no simple modulation of these patterns conditioned on head animacy: IN-headed RCs were no less likely to receive an SRC parse ($\hat{\beta}$ = 0.49; [−0.15, 1.11]_{95%}). However, marginal comparisons suggest that head animacy had some relevance in the interpretation of object RPs specifically: inanimate heads induced more

¹⁵ We focus on new fixations following the suggestion of Kingston et al. (2016), who prefer this to more liberal measures, on the grounds that gaze persistence from previous time windows need not be a reflex of information in the current time window. An alternative analysis counting trials with any overlapping fixations is available in the supplementary materials in our OSF repository; the findings do not notably differ from the analysis we report here.

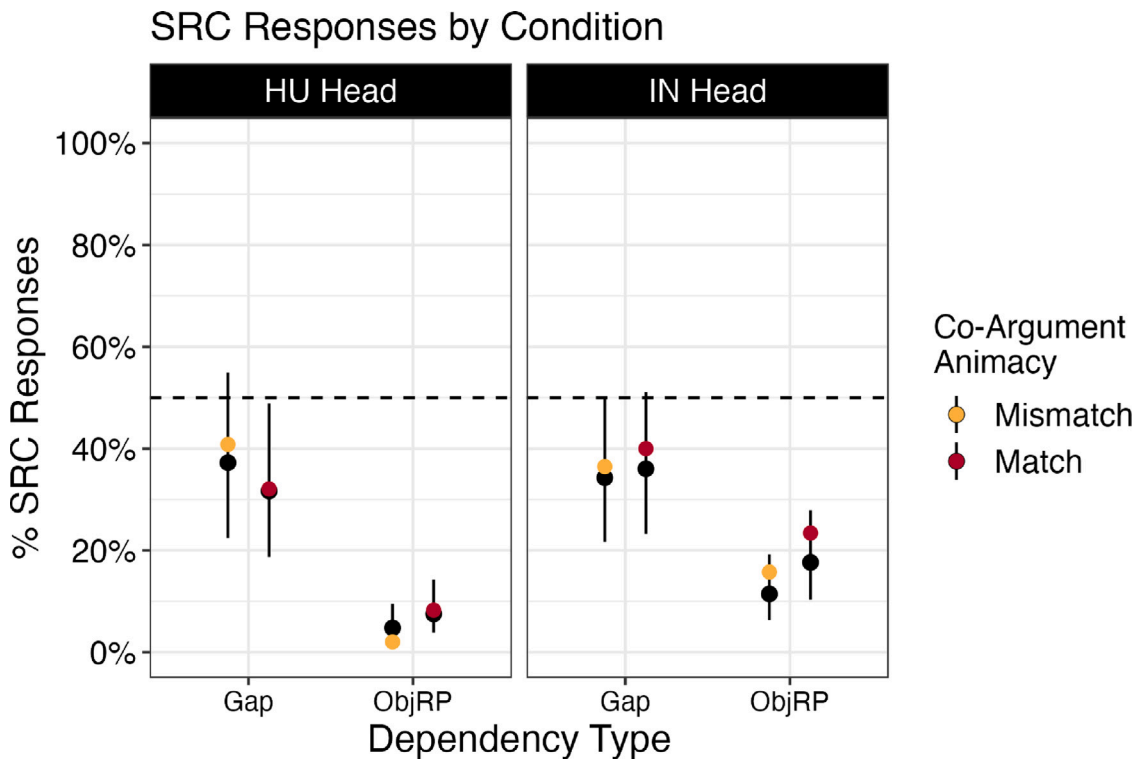


Fig. 2. Participants' relative clause interpretations for critical conditions. Colored dots indicate empirical values, while black dots indicate expected values from a logistic mixed-effects model and their associated 95% HPDIs. (Note that because these intervals are derived from model predictions on a logistic scale, equivalent amounts of model uncertainty are larger on a linear scale for values closer to 50%.)

SRC parses in RP conditions, perhaps diagnosing difficulty comprehending inanimate object RPs ($\delta_{\text{Head|ObjRP}} = 2.81$, $P(\delta > 0) = 0.99$). This is reflected in a credibly positive $\text{DepType} \times \text{Head}$ interaction in the model ($\hat{\beta} = 0.92$; $[0.26, 1.54]_{95\%}$). Co-Argument Animacy Match also conditioned difficulty in object RP interpretation ($\delta_{\text{Match|ObjRP}} = 1.57$, $P(\delta > 0) = 0.98$), driving a trending $\text{DepType} \times \text{Match}$ interaction ($\hat{\beta} = 0.58$; $[-0.02, 1.16]_{95\%}$). Together, these capture the fact that the interpretation of object RPs is much less accurate in IN-headed RCs with IN co-arguments (77%) than in HU-headed RCs with IN co-arguments (98%). Crucially, no such animacy-based modulations are apparent in the ambiguous RCs.

5.2. Gaze patterns in gap conditions

We now move to considering participants' real-time parsing behavior, as indexed by their eye movements. We first report the results of our Gap Analysis, looking at the gaze patterns associated with RCs which were globally ambiguous between SRC and ORC parses, and whether these patterns were modulated by the animacy of the head and co-argument.

Recall that in Gap conditions, the participants selected the SRC vs. ORC image at relatively equal rates, regardless of animacy. The gaze patterns we report provide further insight on how these interpretations emerged on each trial. As we will see, on ambiguous trials, these dynamics were also largely unaffected by animacy.

5.2.1. New fixations on the SRC image

Fig. 3 plots participants' probability of programming a new fixation to the SRC image in each ROI of the ambiguous Gap RCs. Table 3 reports the parameters of a series of mixed-effects logistic regressions predicting new fixation likelihood.

Beginning at the verb, there was a divergence between SRC-responding and ORC-responding trials. Trials in which participants gave an ORC response were less likely to feature new fixations on the

SRC image, weakly trending at the verb ($\hat{\beta} = -0.32$; $[-0.76, 0.13]_{95\%}$) and co-argument ($\hat{\beta} = -0.11$; $[-0.54, 0.31]_{95\%}$) before emerging as credible in the first post-critical region ($\hat{\beta} = -0.72$; $[-1.14, -0.30]_{95\%}$) and the second ($\hat{\beta} = -0.91$; $[-1.41, -0.39]_{95\%}$). Participants seem to have developed a preferred interpretation well before the end of the stimulus.

This interpretation-conditioned divergence was not identical across all conditions, as revealed by marginal comparisons. For instance, at the first post-critical region, it was strongest in trials with IN heads and HU co-arguments ($\delta_{\text{Int.|IN, Mism.}} = -0.92$, $P(\delta < 0) = 0.99$), while similar but somewhat smaller divergences were observed with HU heads and IN co-arguments ($\delta_{\text{Int.|HU, Mism.}} = -0.76$, $P(\delta < 0) = 0.99$), HU heads and HU co-arguments ($\delta_{\text{Int.|HU, M.}} = -0.67$, $P(\delta < 0) = 0.98$), and IN heads and IN co-arguments ($\delta_{\text{Int.|IN, M.}} = -0.55$, $P(\delta < 0) = 0.95$). This asymmetry manifested as a three-way interaction in the model which was nevertheless not credibly positive ($\hat{\beta} = 0.28$; $[-0.57, 1.14]_{95\%}$).

That is, participants arriving at ORC parses tended to be a bit more likely to break from SRC looking patterns at the verb if the co-argument was HU, and/or the co-argument mismatched the animacy of the head. We will return to this pattern below.

Other than this slight asymmetry, these patterns hold unchanged across all argument animacy values, with no other credible effects or interactions observed in the model. Notably, IN heads were not associated with a credible decrease in new SRC fixations at the head ($\hat{\beta} = -0.32$; $[-0.76, 0.11]_{95\%}$) or the following verb region ($\hat{\beta} = -0.15$; $[-0.64, 0.34]_{95\%}$).

5.2.2. New fixations on the ORC image

Fig. 4 demonstrates participants' probability of programming a new fixation to the ORC image during the ambiguous Gap RCs. Table 4 reports the corresponding models.

The same interpretation-sensitive divergence we observed in new fixations to the SRC image emerged here as well: the ORC image received more attention in trials with ORC responses, an effect which

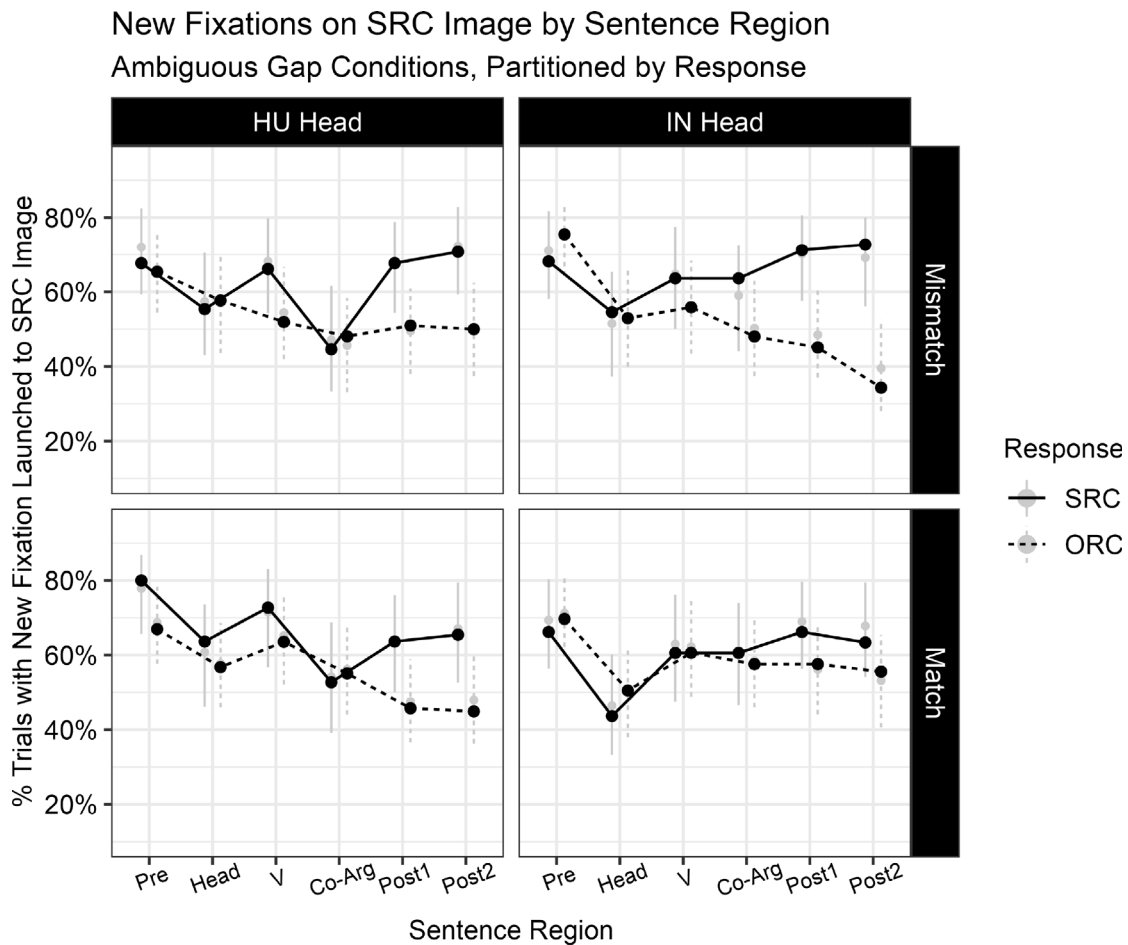


Fig. 3. Participants' probability of programming a new fixation on the SRC image in each analysis region, in critical conditions featuring argument gaps, faceted by head animacy condition (columns) and match condition (rows). Trials with reported SRC interpretations (solid) are plotted separately from trials with reported ORC interpretations (dashed). Fainter gray points and intervals indicate medians and 95% HPDIs from the logistic mixed-effects model.

emerges as credible in the second post-critical region ($\hat{\beta} = 0.81$; $[0.33, 1.28]_{95\%}$).

No other effects or interactions were apparent. In particular, IN heads were not associated with a credible increase in new ORC fixations at the head, where in fact we observe a strong trend in the opposite direction ($\hat{\beta} = -0.38$; $[-0.81, 0.05]_{95\%}$), or the following verb region ($\hat{\beta} = 0.05$; $[-0.43, 0.52]_{95\%}$).

5.2.3. Additional comparisons

From these two analyses, we can also characterize a few general patterns in new fixations to SRC and ORC images. Before head onset, participants generally scanned both images: new fixations were more probable than not for both the SRC image, $\hat{P} = 72\%$, and the ORC image, $\hat{P} = 70\%$. For SRC images, this probability then decreased gradually over the course of the stimulus, reaching a global minimum of $\hat{P} = 54\%$ at the co-argument. Looks to ORC images show a sharper decline immediately at the head, sinking to $\hat{P} = 49\%$, before returning to a higher prominence for the rest of the stimulus. We investigate this general ebb and flow of attention further in a supplementary analysis comparing fixations to identical images across conditions (Appendix B).

The other major pattern apparent from the Gap data is a striking insensitivity to the differences among various animacy configurations. This might give the appearance that listeners were insensitive to the linguistic signal more broadly, or that our methods could not detect signals of incremental comprehension. To address this concern, in Appendix C we report a comparison with our two unambiguous control conditions featuring subject RPs or *where* heads followed by typical

VSO clauses. In both these conditions, we find that our eye movement measures were indeed sensitive to the presence of disambiguating information in the linguistic signal, demonstrating a reduction in new fixations on the inappropriate image in regions immediately following disambiguation. Given this, we are confident that our method is able to detect eye movement signatures of incremental comprehension, and that the observed stability across animacy conditions does not reflect any general insensitivity to the linguistic signal. Similar conclusions can be drawn from our second main analysis, to which we now turn.

5.3. Comparing gaze patterns between gap and object RP conditions

We next consider the effect of an object RP on participants' real-time parsing behavior, as indexed by our Gap vs. Object RP Analysis. Unlike in the Gap conditions, the RP conditions only have one grammatical interpretation. Therefore, in the analyses reported below, we only include trials where a participant responded with the ORC image, regardless of whether it was a Gap or RP condition. This provides an exact comparison between parsing trajectories that lead to the same overt outcome.

This analysis reveals rapid sensitivity to RP disambiguation, but also bring into focus several ways in which head and co-argument animacy modulated participants' paths towards ORC interpretations.

5.3.1. New fixations on the SRC image

Fig. 5 demonstrates participants' probability of programming a new fixation to the SRC image in each ROI of Gap and Object RP trials

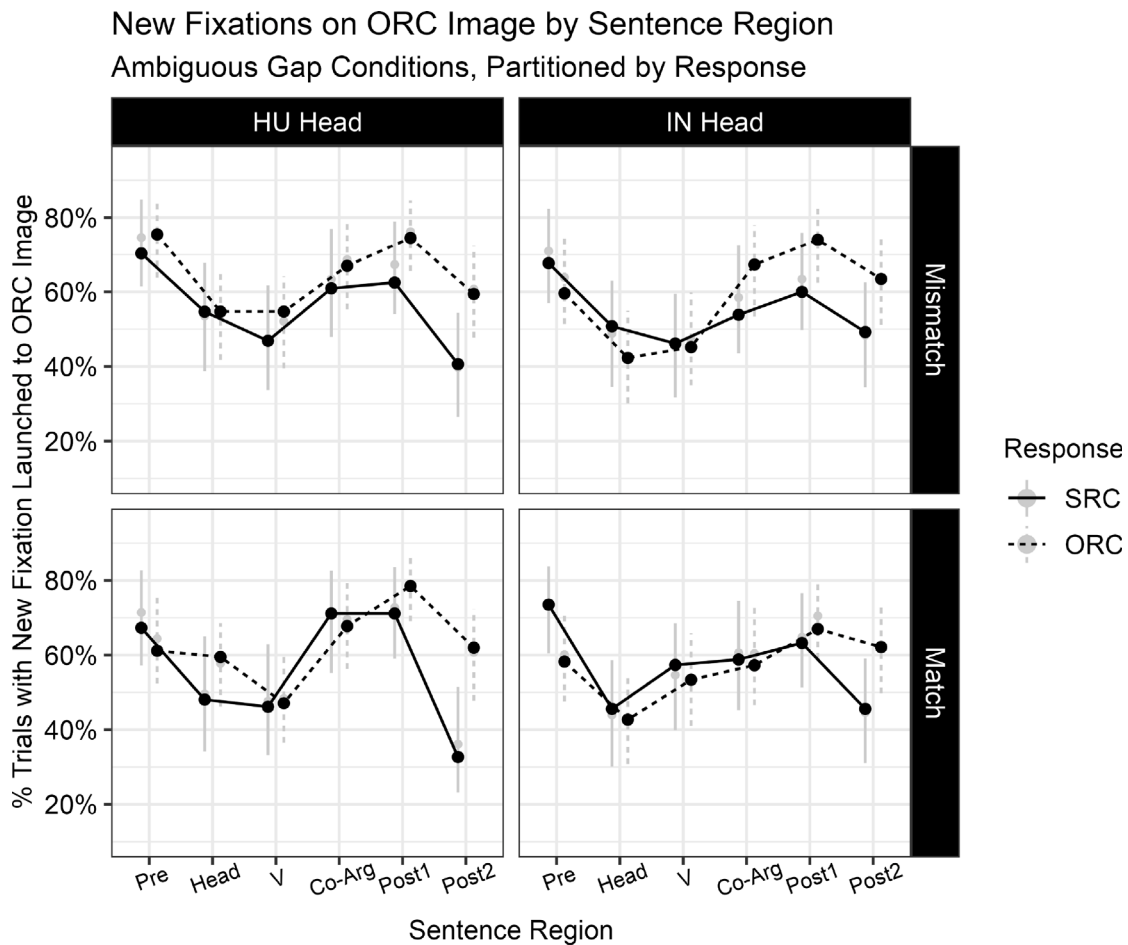


Fig. 4. Participants' probability of programming a new fixation on the ORC image in each analysis region, in critical conditions featuring argument gaps, faceted by head animacy condition (columns) and match condition (rows). Trials with reported SRC interpretations (solid) are plotted separately from trials with reported ORC interpretations (dashed). Fainter gray points and intervals indicate medians and 95% HPDIs from the logistic mixed-effects model.

where participants indicated ORC interpretations. Table 5 reports the corresponding models.

In ObjRP conditions, after the RP, participants became notably less likely to fixate on the SRC image compared to the Gap conditions. This reduction was strongly trending at the first post-critical region ($\hat{\beta} = -0.29$; $[-0.60, 0.03]_{95\%}$), and emerged as credible in the second post-critical region ($\hat{\beta} = -0.67$; $[-1.00, -0.32]_{95\%}$). Participants' online looking behavior was thus sensitive to the presence of an object RP, which adjusted their attention in real time to avoid consideration of ungrammatical interpretations.

Abstracting away from the effect of RP disambiguation, participants in all conditions reduced their new fixations to the SRC image over the course of the stimulus. We take this as a natural consequence of progress towards their ultimate ORC parse, whether that parse was disambiguated or freely selected. When we look at these cases together, we see new effects of animacy that were not apparent in the Gap Analysis: particular arguments lead to differences in the speed of comprehenders' path towards their final interpretation.

First, we note that new SRC fixations fell more slowly in Match conditions, with a trend towards more SRC fixations remaining at the co-argument ($\hat{\beta} = 0.32$; $[-0.05, 0.68]_{95\%}$) and a credible contrast in the first post-critical region ($\hat{\beta} = 0.33$; $[0.03, 0.64]_{95\%}$) and the second post-critical region ($\hat{\beta} = 0.37$; $[0.03, 0.71]_{95\%}$). We take this gaze pattern to indicate slower progress towards a final interpretation when head and co-argument matched in animacy, possibly due to similarity-based interference.

Second, we observe a Match $\times$ Head interaction which is consistently positive throughout the end of the stimulus, credible in the first

post-critical region ($\hat{\beta} = 0.55$; $[0.00, 1.09]_{95\%}$), before receding to a positive trend at the second post-critical region ($\hat{\beta} = 0.49$; $[-0.07, 1.04]_{95\%}$). In the ObjRP conditions, this began trending as early as the disambiguating RP ($\hat{\beta} = 0.51$; $[-0.29, 1.28]_{95\%}$).

The data in these regions is numerically consistent with a potential crossover interaction, where e.g. at the first post-critical region, IN-head trials feature less SRC-consistent looking than HU-head trials in Mismatch conditions ($\hat{\delta}_{\text{Head|Mismatch}} = -0.18$, $P(\delta < 0) = 0.80$), but IN-head trials feature more SRC-consistent looking than HU-head trials in Match conditions ($\hat{\delta}_{\text{Head|Match}} = 0.37$, $P(\delta > 0) = 0.96$). That is, participants' gaze patterns suggest faster and stronger convergence on ORC parses in conditions with HU co-arguments, diagnosing an unexpected online effect of co-argument animacy.

In contrast, we note that no regions displayed the predicted online effect of head animacy, faster and stronger convergence on ORC parses in conditions with IN heads. No such effect was observed at the disambiguating RP ($\hat{\beta} = -0.17$; $[-0.61, 0.27]_{95\%}$), the first post-critical region ($\hat{\beta} = 0.09$; $[-0.23, 0.42]_{95\%}$), or the second post-critical region ($\hat{\beta} = -0.03$; $[-0.46, 0.40]_{95\%}$).

5.3.2. New fixations on the ORC image

Fig. 6 demonstrates participants' probability of programming a new fixation to the ORC image during Gap and Object RP trials where participants indicated ORC interpretations. Table 6 reports the corresponding models.

Surprisingly, we see no particular increase in ORC-consistent gaze patterns driven by the presence of the Object RP, in the first post-critical

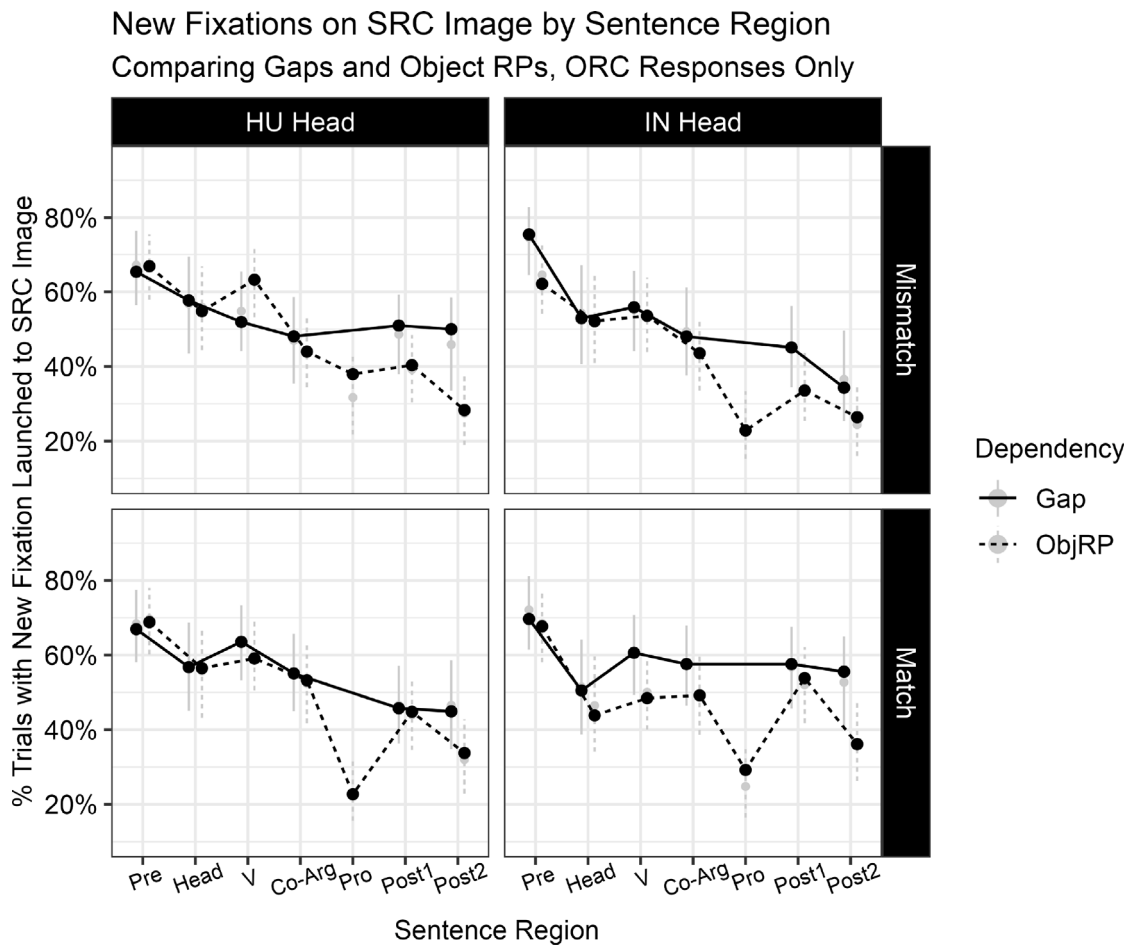


Fig. 5. Participants' probability of programming a new fixation on the SRC image in each analysis region across critical conditions, faceted by match condition (columns) and presence of a resumptive pronoun (rows). Only trials where participants indicated an ORC parse are included in this analysis. Fainter gray points and intervals indicate medians and 95% HPDIs from the logistic mixed-effects model.

region ($\hat{\beta} = 0.14$; $[-0.21, 0.49]_{95\%}$) or the second post-critical region ($\hat{\beta} = 0.04$; $[-0.31, 0.39]_{95\%}$). That is, though we observed above in analysis of fixations on the SRC image that participants began to avoid looks to RP-incompatible images when RPs were present, they do not seem to increase RP-compatible looking. We note that a similar pattern holds in a supplementary analysis of fixations in the control conditions (Appendix C), where disambiguating subject RPs or unambiguous nominal subjects are associated with a quick reduction in new fixations on ORC images but no increase in fixations on SRC images.

Nevertheless, we do observe again here some evidence that ORC-consistent looking patterns are delayed or suppressed in Match conditions, a contrast which was trending at the co-argument ($\hat{\beta} = -0.24$; $[-0.54, 0.07]_{95\%}$), and on the RP when present ($\hat{\beta} = -0.32$; $[-0.74, 0.10]_{95\%}$). A reverse, positive effect of Match is trending at the second post-critical region ($\hat{\beta} = 0.21$; $[-0.10, 0.53]_{95\%}$). We consider that this may reflect a second consequence of slow progress in these conditions, a higher frequency of new fixations on all images in this late time window, as participants in some conditions remain indecisive where others settle firmly on a response. This may also be responsible for some portion of the late Match effect on new SRC fixations discussed in the previous section.¹⁶

¹⁶ See Appendix C for a similar contrast in overall new fixations, where gaze settles in Subject RP and where RC controls faster than ambiguous Gap contrasts. Interestingly, we do not see any evidence for a similar 'settling' contrast in our window of analysis for the present unambiguous Object RP

We also continue to find support for a crossover interaction with Match and Head Animacy, credible at the co-argument ($\hat{\beta} = -0.69$; $[-1.25, -0.12]_{95\%}$). In Mismatch conditions, IN/HU drives more ORC looks than HU/IN ($\hat{\delta}_{\text{Head|Mismatch}} = 0.49$, $P(\delta > 0) = 0.97$), while in Match conditions, IN/IN tends to drive fewer ORC looks than HU/HU ($\hat{\delta}_{\text{Head|Match}} = -0.20$, $P(\delta < 0) = 0.79$).

Finally, we again continue to see no evidence for the predicted main effect of head animacy, such that new ORC fixations emerge more quickly or robustly with IN heads. In fact, IN heads were associated with fewer new ORC fixations at the head ($\hat{\beta} = -0.42$; $[-0.75, -0.09]_{95\%}$), and trended similarly at the RP when present ($\hat{\beta} = -0.37$; $[-0.76, 0.03]_{95\%}$) and the first post-critical region ($\hat{\beta} = -0.25$; $[-0.63, 0.14]_{95\%}$). While we decline to interpret this unpredicted result, it makes clear the absence of the predicted main effect.

5.4. Summary of effects of interest

5.4.1. Subject-gap preference

The SRC preference in SLZ, if present at all, is weaker and qualitatively different than the effect observed in languages like English. Participants' offline interpretations for ambiguous RCs were, if anything, biased towards ORC parses. Gaze analyses revealed some evidence for highly temporary SRC predictions at the head noun and verb, as

conditions vs. Gaps, perhaps because ObjRP items feature a later point of disambiguation.

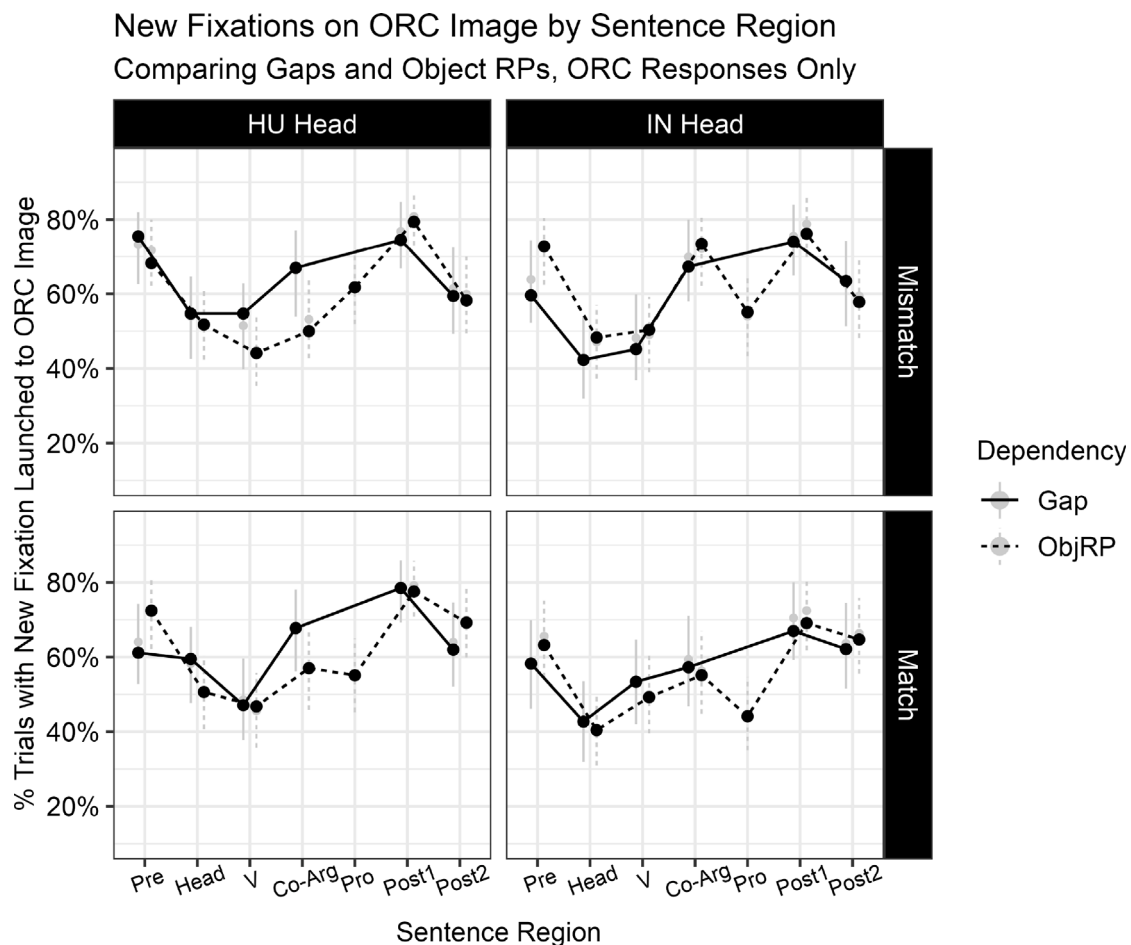


Fig. 6. Participants' probability of programming a new fixation to the ORC image in each analysis region across critical conditions, faceted by match condition (columns) and presence of a resumptive pronoun (rows). Only trials where participants indicated an ORC parse are included in this analysis. Fainter gray points and intervals indicate medians and 95% HPDIs from the logistic mixed-effects model.

indexed by a momentary dip in looks to ORC images. There is mixed evidence as to whether this temporary SRC prediction could be sensitive to head animacy: in the alternative analysis reported in [Appendix B](#), SRC fixations at the head trended more likely when the head was HU, but such a main effect was not observed in any other analysis, and indeed appeared opposite in some regions of the Gap vs. Object RPs analysis. Whatever is driving this momentary preoccupation with the SRC parse, it did not continue as participants heard the co-argument, and, again, was not apparent in offline interpretations.

5.4.2. Post-verbal predictions for object gaps

However, we observe a surprising counterpoint to the classic head-driven SRC prediction effects: co-argument-driven ORC prediction effects. Gaze patterns in the Gap conditions reveal a predominating interest in ORC images beginning at the co-argument, a pattern that is especially clear in the supplementary analysis in [Appendix B](#) comparing looks to the same images across conditions. The shift of attention to an ORC parse at this point in RC comprehension appears to be somewhat stochastic; it is at this point that gaze patterns diagnose divergence between trials with SRC responses and trials with ORC responses, in each condition. That is, in trials with SRC responses, this attention shift was less likely, or weaker.¹⁷

This shift was also modulated by the animacy of the co-argument. First, a simple effect of co-argument animacy is suggested by consistently trending crossover interactions beginning at the co-argument in Gap vs. RP analyses. The consistent pattern, occasionally emerging as credible, was for ORC parses to be most attractive when participants encountered a human co-argument, regardless of head animacy. On the opposite side, consideration of the ORC parse in these regions was reduced in trials where co-argument animacy matched the animacy of the head, the expected similarity asymmetry. The similarity asymmetry in particular persists as a mitigating factor on offline choices for RCs with object RPs, reducing the likelihood of accurate interpretation. These two effects together appear responsible for a gradient degree of attractiveness for ORC parses after the verb: ORC parses were easiest or most attractive for RCs with IN heads and HU co-arguments, and hardest or least attractive for RCs with IN heads with IN co-arguments, while cases of HU + HU and HU + IN occupied a middle ground. The pattern that IN + IN ORCs provoked the slowest interpretations, rather than HU + HU, is a striking demonstration that comprehenders especially desired to align the co-argument with a syntactic position appropriate to its animacy, more so than for the head.

interpret directly post-verbal arguments as subjects. While this general shift is in line with their proposal, it is clear that this is neither a strong nor a general constraint on the language, given that SRC parses appear to remain in competition at this point, and preferences are mediated by the animacy of the co-argument as we discuss.

¹⁷ An incremental shift towards ORC interpretations as participants heard the co-argument might offer some support for a parsing pressure hypothesized by [Foreman and Munro \(2007\)](#) in languages like Macuiltianguis Zapotec, to

Table 3

Posterior estimates, standard errors, and 95% HPDIs from Bayesian logistic mixed-effects models fit to the probability of a new fixation on the SRC image in ambiguous gap conditions. Parentheses indicate the level of each factor coded as positive (+0.5).

	Effect	Posterior $\hat{\beta}$	Posterior σ_{β}	95% CRI
Pre	Intercept	0.93	0.15	(0.64, 1.22)
	Match (+)	0.04	0.20	(−0.36, 0.43)
	N1 (IN)	0.02	0.22	(−0.42, 0.45)
	Interpretation (Obj.)	−0.11	0.21	(−0.53, 0.29)
	Match × N1	−0.35	0.33	(−1.00, 0.31)
	Match × Int.	−0.15	0.33	(−0.79, 0.49)
	N1 × Int.	0.52	0.35	(−0.16, 1.20)
	M × N1 × Int.	0.07	0.43	(−0.78, 0.93)
Head	Intercept	0.17	0.14	(−0.10, 0.44)
	Match (+)	−0.04	0.20	(−0.43, 0.36)
	N1 (IN)	−0.32	0.22	(−0.76, 0.11)
	Interpretation (Obj.)	0.02	0.21	(−0.40, 0.43)
	Match × N1	−0.25	0.33	(−0.90, 0.42)
	Match × Int.	−0.02	0.33	(−0.68, 0.64)
	N1 × Int.	0.18	0.33	(−0.47, 0.83)
	M × N1 × Int.	0.19	0.44	(−0.67, 1.05)
Verb	Intercept	0.55	0.14	(0.28, 0.82)
	Match (+)	0.19	0.24	(−0.28, 0.67)
	N1 (IN)	−0.15	0.25	(−0.64, 0.34)
	Interpretation (Obj.)	−0.32	0.23	(−0.76, 0.13)
	Match × N1	−0.22	0.37	(−0.94, 0.51)
	Match × Int.	0.31	0.34	(−0.35, 0.98)
	N1 × Int.	0.25	0.34	(−0.42, 0.92)
	M × N1 × Int.	0.04	0.44	(−0.81, 0.90)
Co-Argument	Intercept	0.16	0.14	(−0.12, 0.43)
	Match (+)	0.28	0.21	(−0.13, 0.70)
	N1 (IN)	0.26	0.23	(−0.19, 0.70)
	Interpretation (Obj.)	−0.11	0.22	(−0.54, 0.31)
	Match × N1	−0.14	0.35	(−0.82, 0.54)
	Match × Int.	0.19	0.33	(−0.46, 0.84)
	N1 × Int.	−0.24	0.35	(−0.92, 0.44)
	M × N1 × Int.	0.10	0.45	(−0.78, 0.99)
Post 1	Intercept	0.38	0.12	(0.14, 0.63)
	Match (+)	0.00	0.20	(−0.38, 0.39)
	N1 (IN)	0.17	0.20	(−0.22, 0.56)
	Interpretation (Obj.)	−0.72	0.21	(−1.14, −0.30)
	Match × N1	0.24	0.33	(−0.41, 0.89)
	Match × Int.	0.22	0.33	(−0.42, 0.87)
	N1 × Int.	−0.02	0.35	(−0.69, 0.66)
	M × N1 × Int.	0.28	0.43	(−0.57, 1.14)
Post 2	Intercept	0.36	0.13	(0.11, 0.62)
	Match (+)	0.04	0.21	(−0.37, 0.46)
	N1 (IN)	−0.08	0.20	(−0.48, 0.32)
	Interpretation (Obj.)	−0.91	0.26	(−1.41, −0.39)
	Match × N1	0.40	0.32	(−0.23, 1.03)
	Match × Int.	0.40	0.34	(−0.27, 1.05)
	N1 × Int.	−0.04	0.35	(−0.73, 0.64)
	M × N1 × Int.	0.44	0.44	(−0.42, 1.29)

5.4.3. Online sensitivity to RPs

Finally, in contrast to the ambivalence to factors like head animacy, it is clear that participants accurately and rapidly used RPs to constrain their interpretations. Offline choices showed that RCs with object RPs were typically interpreted accurately as ORCs, though inanimate heads and cases of matching animacy were associated with increased errors. Gaze patterns show that this disambiguation had concrete and rapid incremental consequences, specifically reducing the attention given to images inconsistent with the RP. Object RPs were associated with an immediate reduction in the post-critical region, even anticipated at the preceding co-argument. Controls with subject RPs were interpreted accurately as SRCs offline, and in our supplementary analysis of gaze data in these items (Appendix C), we see evidence for meaningful uptake of the RP as early as the co-argument following the RP clitic. These effects, to our knowledge the first observations of the incremental interpretation of RPs in the visual-world paradigm, support the con-

Table 4

Posterior estimates, standard errors, and 95% HPDIs from Bayesian logistic mixed-effects models fit to the probability of a new fixation on the ORC image in ambiguous gap conditions. Parentheses indicate the level of each factor coded as positive (+0.5).

	Effect	Posterior $\hat{\beta}$	Posterior σ_{β}	95% CRI
Pre	Intercept	0.83	0.14	(0.55, 1.11)
	Match (+)	−0.18	0.25	(−0.68, 0.31)
	N1 (IN)	−0.20	0.21	(−0.62, 0.21)
	Interpretation (Obj.)	−0.31	0.23	(−0.77, 0.14)
	Match × N1	0.32	0.35	(−0.38, 1.00)
	Match × Int.	−0.31	0.34	(−0.97, 0.35)
	N1 × Int.	−0.31	0.35	(−1.00, 0.38)
	M × N1 × Int.	0.06	0.44	(−0.82, 0.93)
Head	Intercept	−0.04	0.14	(−0.31, 0.23)
	Match (+)	−0.05	0.20	(−0.44, 0.34)
	N1 (IN)	−0.38	0.22	(−0.81, 0.05)
	Interpretation (Obj.)	0.00	0.24	(−0.46, 0.48)
	Match × N1	−0.09	0.32	(−0.70, 0.52)
	Match × Int.	0.26	0.34	(−0.41, 0.93)
	N1 × Int.	−0.34	0.34	(−1.00, 0.33)
	M × N1 × Int.	−0.10	0.44	(−0.96, 0.76)
Verb	Intercept	−0.02	0.14	(−0.30, 0.26)
	Match (+)	0.12	0.20	(−0.27, 0.53)
	N1 (IN)	0.05	0.24	(−0.43, 0.52)
	Interpretation (Obj.)	0.06	0.20	(−0.34, 0.46)
	Match × N1	0.38	0.34	(−0.28, 1.04)
	Match × Int.	−0.14	0.32	(−0.77, 0.49)
	N1 × Int.	−0.09	0.33	(−0.74, 0.56)
	M × N1 × Int.	0.04	0.43	(−0.79, 0.88)
Co-Argument	Intercept	0.62	0.16	(0.30, 0.94)
	Match (+)	0.04	0.21	(−0.38, 0.46)
	N1 (IN)	−0.29	0.26	(−0.79, 0.22)
	Interpretation (Obj.)	0.13	0.24	(−0.36, 0.61)
	Match × N1	−0.28	0.34	(−0.94, 0.39)
	Match × Int.	−0.33	0.36	(−1.02, 0.38)
	N1 × Int.	0.08	0.35	(−0.61, 0.78)
	M × N1 × Int.	−0.07	0.44	(−0.94, 0.78)
Post 1	Intercept	0.91	0.14	(0.63, 1.19)
	Match (+)	0.08	0.20	(−0.31, 0.47)
	N1 (IN)	−0.28	0.23	(−0.74, 0.18)
	Interpretation (Obj.)	0.38	0.22	(−0.06, 0.80)
	Match × N1	−0.25	0.33	(−0.90, 0.41)
	Match × Int.	−0.16	0.33	(−0.80, 0.50)
	N1 × Int.	−0.02	0.34	(−0.68, 0.65)
	M × N1 × Int.	−0.09	0.44	(−0.96, 0.77)
Post 2	Intercept	0.09	0.15	(−0.20, 0.37)
	Match (+)	−0.09	0.22	(−0.51, 0.34)
	N1 (IN)	0.23	0.20	(−0.17, 0.63)
	Interpretation (Obj.)	0.81	0.24	(0.33, 1.28)
	Match × N1	−0.02	0.33	(−0.66, 0.64)
	Match × Int.	0.13	0.33	(−0.52, 0.78)
	N1 × Int.	−0.25	0.34	(−0.92, 0.43)
	M × N1 × Int.	−0.04	0.44	(−0.90, 0.81)

clusion that RPs serve as a powerful and familiar disambiguating cue during the incremental parsing of Santiago Laxopa Zapotec RCs.

6. Discussion

When faced with an RC, Santiago Laxopa Zapotec comprehenders in this experiment seemed to shift from temporary SRC consideration to temporary ORC consideration, an equilibrium which was disrupted only if they encountered a disambiguating RP. In the absence of disambiguation, comprehenders stochastically ended up at a preferred parse without the expected influence of head animacy. Nevertheless, we see the fingerprints of more interesting effects when we examine the trajectory of trials that ended with a voluntary or a disambiguated ORC parse. Eye-movement patterns associated with competing SRC interpretations faded away at different rates across conditions: this shift of attention to ORC interpretations was slowed if head and (expected) co-argument

Table 5

Posterior estimates, standard errors, and 95% HDPIs from Bayesian logistic mixed-effects models fit to the probability of a new fixation on the SRC image in comparable conditions with gaps vs. object RPs. Parentheses indicate the level of each factor coded as positive (+0.5).

	Effect	Posterior $\hat{\beta}$	Posterior σ_{β}	95% CRI
<i>Pre</i>	Intercept	0.81	0.11	(0.59, 1.03)
	Match (+)	0.06	0.16	(−0.26, 0.38)
	N1 (IN)	0.09	0.20	(−0.30, 0.48)
	DepType (RP)	−0.15	0.16	(−0.46, 0.16)
	Match × N1	−0.06	0.29	(−0.63, 0.51)
	Match × Dep.	0.18	0.29	(−0.40, 0.75)
	N1 × Dep.	−0.36	0.27	(−0.90, 0.19)
	M × N1 × Dep.	0.25	0.40	(−0.54, 1.03)
<i>Head</i>	Intercept	0.15	0.14	(−0.12, 0.43)
	Match (+)	−0.09	0.19	(−0.45, 0.28)
	N1 (IN)	−0.21	0.23	(−0.65, 0.24)
	DepType (RP)	−0.09	0.17	(−0.42, 0.25)
	Match × N1	−0.19	0.31	(−0.80, 0.43)
	Match × Dep.	−0.08	0.28	(−0.63, 0.47)
	N1 × Dep.	−0.08	0.29	(−0.64, 0.49)
	M × N1 × Dep.	−0.12	0.40	(−0.91, 0.67)
<i>Verb</i>	Intercept	0.31	0.09	(0.14, 0.49)
	Match (+)	0.08	0.18	(−0.27, 0.43)
	N1 (IN)	−0.22	0.16	(−0.54, 0.10)
	DepType (RP)	−0.07	0.16	(−0.39, 0.24)
	Match × N1	−0.10	0.31	(−0.69, 0.51)
	Match × Dep.	−0.43	0.27	(−0.95, 0.09)
	N1 × Dep.	−0.32	0.28	(−0.87, 0.23)
	M × N1 × Dep.	0.11	0.39	(−0.66, 0.88)
<i>Co-Arg.</i>	Intercept	−0.01	0.09	(−0.19, 0.17)
	Match (+)	0.32	0.18	(−0.05, 0.68)
	N1 (IN)	0.01	0.16	(−0.31, 0.33)
	DepType (RP)	−0.21	0.18	(−0.56, 0.14)
	Match × N1	−0.06	0.31	(−0.67, 0.55)
	Match × Dep.	−0.04	0.27	(−0.57, 0.49)
	N1 × Dep.	−0.16	0.29	(−0.72, 0.41)
	M × N1 × Dep.	−0.08	0.41	(−0.88, 0.72)
<i>RP</i>	Intercept	−1.07	0.15	(−1.39, −0.77)
	Match (+)	−0.17	0.27	(−0.69, 0.35)
	N1 (IN)	−0.17	0.22	(−0.61, 0.27)
	Match × N1	0.51	0.40	(−0.29, 1.28)
<i>Post 1</i>	Intercept	−0.17	0.10	(−0.38, 0.03)
	Match (+)	0.33	0.15	(0.03, 0.64)
	N1 (IN)	0.09	0.16	(−0.23, 0.42)
	DepType (RP)	−0.29	0.16	(−0.60, 0.03)
	Match × N1	0.55	0.28	(0.00, 1.09)
	Match × Dep.	0.27	0.26	(−0.23, 0.78)
	N1 × Dep.	−0.08	0.28	(−0.63, 0.46)
	M × N1 × Dep.	−0.01	0.39	(−0.78, 0.75)
<i>Post 2</i>	Intercept	−0.52	0.14	(−0.79, −0.25)
	Match (+)	0.37	0.17	(0.03, 0.71)
	N1 (IN)	−0.03	0.22	(−0.46, 0.40)
	DepType (RP)	−0.67	0.17	(−1.00, −0.32)
	Match × N1	0.49	0.29	(−0.07, 1.04)
	Match × Dep.	0.05	0.29	(−0.51, 0.62)
	N1 × Dep.	0.08	0.28	(−0.47, 0.62)
	M × N1 × Dep.	−0.28	0.41	(−1.08, 0.53)

matched in animacy—a typical similarity asymmetry—and it was sped up in case of a human co-argument—a highly atypical animacy asymmetry which is nevertheless in line with a preferential link between human arguments and subject positions. The presence of these effects in Santiago Laxopa Zapotec is consistent with theories that take similarity and animacy effects to be the consequences of language-invariant mechanisms like memory operations and conceptual universals.

In contrast, we find no evidence that head animacy, or any pressure to parse RC heads as subjects, robustly influenced any incremental or final interpretations. Why should Santiago Laxopa Zapotec comprehenders aim for a preferred, animacy-aligned parse of the co-argument, while remaining relatively indifferent to the fate of the head, an element which is known to be influential in driving early gap predictions

Table 6

Posterior estimates, standard errors, and 95% HDPIs from Bayesian logistic mixed-effects models fit to the probability of a new fixation on the ORC image in comparable conditions with gaps vs. object RPs. Parentheses indicate the level of each factor coded as positive (+0.5).

	Effect	Posterior $\hat{\beta}$	Posterior σ_{β}	95% CRI
<i>Pre</i>	Intercept	0.75	0.12	(0.50, 1.00)
	Match (+)	−0.24	0.18	(−0.60, 0.13)
	N1 (IN)	−0.24	0.16	(−0.56, 0.07)
	DepType (RP)	0.25	0.18	(−0.11, 0.60)
	Match × N1	−0.07	0.31	(−0.67, 0.53)
	Match × Dep.	0.19	0.30	(−0.39, 0.77)
	N1 × Dep.	0.19	0.31	(−0.42, 0.80)
	M × N1 × Dep.	−0.54	0.41	(−1.33, 0.26)
<i>Head</i>	Intercept	−0.06	0.10	(−0.27, 0.14)
	Match (+)	−0.04	0.15	(−0.34, 0.25)
	N1 (IN)	−0.42	0.17	(−0.75, −0.09)
	DepType (RP)	−0.08	0.16	(−0.39, 0.24)
	Match × N1	−0.20	0.27	(−0.73, 0.32)
	Match × Dep.	−0.25	0.28	(−0.79, 0.30)
	N1 × Dep.	0.24	0.28	(−0.30, 0.78)
	M × N1 × Dep.	−0.03	0.39	(−0.80, 0.74)
<i>Verb</i>	Intercept	−0.05	0.12	(−0.28, 0.19)
	Match (+)	0.04	0.15	(−0.25, 0.33)
	N1 (IN)	0.10	0.19	(−0.26, 0.48)
	DepType (RP)	−0.12	0.15	(−0.41, 0.17)
	Match × N1	0.17	0.26	(−0.35, 0.67)
	Match × Dep.	−0.01	0.26	(−0.53, 0.51)
	N1 × Dep.	0.14	0.26	(−0.37, 0.65)
	M × N1 × Dep.	−0.32	0.39	(−1.08, 0.46)
<i>Co-Arg.</i>	Intercept	0.53	0.13	(0.28, 0.79)
	Match (+)	−0.24	0.16	(−0.54, 0.07)
	N1 (IN)	0.15	0.20	(−0.25, 0.55)
	DepType (RP)	−0.26	0.19	(−0.63, 0.10)
	Match × N1	−0.69	0.29	(−1.25, −0.12)
	Match × Dep.	−0.08	0.29	(−0.64, 0.48)
	N1 × Dep.	0.51	0.31	(−0.12, 1.11)
	M × N1 × Dep.	−0.31	0.40	(−1.09, 0.49)
<i>RP</i>	Intercept	0.16	0.12	(−0.08, 0.40)
	Match (+)	−0.32	0.21	(−0.74, 0.10)
	N1 (IN)	−0.37	0.20	(−0.76, 0.03)
	Match × N1	−0.11	0.33	(−0.77, 0.55)
<i>Post 1</i>	Intercept	1.20	0.14	(0.93, 1.47)
	Match (+)	−0.15	0.17	(−0.49, 0.18)
	N1 (IN)	−0.25	0.19	(−0.63, 0.14)
	DepType (RP)	0.14	0.18	(−0.21, 0.49)
	Match × N1	−0.30	0.29	(−0.87, 0.28)
	Match × Dep.	−0.15	0.29	(−0.72, 0.42)
	N1 × Dep.	0.00	0.30	(−0.59, 0.59)
	M × N1 × Dep.	0.11	0.41	(−0.70, 0.93)
<i>Post 2</i>	Intercept	0.56	0.14	(0.29, 0.83)
	Match (+)	0.21	0.16	(−0.10, 0.53)
	N1 (IN)	−0.03	0.18	(−0.38, 0.32)
	DepType (RP)	0.04	0.18	(−0.31, 0.39)
	Match × N1	−0.12	0.27	(−0.67, 0.42)
	Match × Dep.	0.31	0.28	(−0.24, 0.87)
	N1 × Dep.	−0.13	0.29	(−0.70, 0.44)
	M × N1 × Dep.	−0.04	0.40	(−0.82, 0.74)

in various other languages? We think that this helps narrow the space of possible theories of cross-linguistic variation in the final component of RC processing that we have discussed, structural prediction.

For instance, this finding is largely incompatible with theories where incremental ambiguities are predictively resolved based on a limited set of universal biases or defaults, e.g. about preferential links between certain types of nominals and certain argument positions (Bornkessel-Schlesewsky & Schlesewsky, 2009; Frazier, 1987; Keenan & Comrie, 1977; Wagers & Pendleton, 2015). In the present case, our best candidates for those biases include a preference for human entities to be subjects—something we even see for Santiago Laxopa Zapotec co-arguments—but there is no evidence that this bias drives incremental predictions for human heads.

In the rest of this section, we consider two alternate theories of structural prediction which offer some way to explain this surprising result. Both in some way relativize prediction to a comprehender's experience with their language. On the first approach, all comprehenders engage in experience-based, **form-specific prediction**, adopting incremental expectations for an RC based on language-specific experience with combinations of cues, including the animacy of a given entity, but also the form of the RC, e.g. whether it has yet included any RP. Under this theory, the critical RCs in this experiment do not engender robust head-based SRC predictions because expectations may be tempered by the observed absence of a subject RP. On the second approach, comprehenders may variably deploy **prediction as a learned skill**, forming only certain expectations which help distribute cognitive load during comprehension. Under this theory, robust head-based SRC predictions are absent because early, animacy-based predictions are not useful in this language.

- (16) **Form-specific prediction:** All comprehenders adopt incremental expectations for temporarily ambiguous RCs based on experience, conditioned not only on aspects of content (argument animacy) but also on aspects of form (the presence of a subject RP). When a prediction would match a generally frequent structure, but this structure is not frequent among utterances of the current form, comprehenders will not adopt it.
- (17) **Prediction as a learned skill:** Comprehenders learn to make incremental predictions based on statistically-associated cues like head animacy in order to distribute cognitive load during comprehension. When a prediction would match a generally frequent structure, but this structure would be easily recognized without prediction, comprehenders will not learn to adopt it.

Any empirical comparison between these two options depends on the distribution of particular forms in a typical Santiago Laxopa Zapotec comprehender's experience, at a level of detail that remains hard to estimate. On abstract merits, a theory of form-specific prediction deserves special consideration given many other prominent proposals for widespread statistical prediction in sentence comprehension (e.g. Levy, 2008; MacDonald, 2013). In contrast, the idea of prediction as a learned skill has received less discussion in this literature, and is undoubtedly more complex and less precise. Nevertheless, we find the latter idea attractive for how it relates to other proposals in cognitive science (Cutler, 2012; Howes et al., 2009; Lieder & Griffiths, 2020). We therefore take the time here to treat both proposals in some detail.

6.1. An account based on form-specific prediction

As noted at the beginning of Section 2, evidence for language-specificity in sentence processing behavior has often raised questions about the source of adult-like processing behavior. Could aspects of processing be acquired through experience? Fodor (1998) lays out an argument characteristic of a conservative answer, highlighting the parsimony of a universal comprehension procedure applicable to any grammar, and the appeal of a set of parsing heuristics derived from general principles of computational effort (e.g. Frazier, 1978). One alternative, in fact the main one Fodor argued against at the time, is an account like the "tuning hypothesis" of Mitchell and Cuetos (1991), which suggest that heuristic preferences for ambiguity resolution are learned based on the frequency with which each alternative has proved correct in the learner's experience. Theories descended from this idea of experience-based biases have been widely adopted across sentence processing (Levy, 2008; MacDonald, 2013), and offer one way to explain novel patterns of prediction in a specific language.

In particular, such accounts can predict equibaised interpretations of an ambiguity in a given context if comprehenders' experience in such contexts was itself unbiased. Could it be the case that there are equally many SRCs and ORCs in Santiago Laxopa Zapotec production? On a

first pass, this seems implausible. Wherever they have been investigated in a corpus, transitive subject dependencies with full co-arguments have been observed to be much more common than transitive object dependencies with full co-arguments (e.g. English: Reali & Christiansen, 2007; Roland et al., 2007; Russian: Levy et al., 2013; Hungarian: Ronai & Xiang, 2023; Mandarin: Vasishth et al., 2013; Basque: Carreiras et al., 2010).¹⁸ Santiago Laxopa Zapotec does lack one important secondary factor that is known to support the dominance of SRCs in the input, having no productive passive-like construction which could reorganize the thematic alignment of a lexical predicate so that typically-non-subject arguments are expressed as subjects. Gennari and MacDonald (2009) and Gennari et al. (2012) highlight that speakers in many languages use such constructions to avoid producing ORCs. Without such a construction, Santiago Laxopa Zapotec speakers may produce more ORCs than English speakers;¹⁹ nevertheless, we find it unlikely that this completely offsets SRC dominance. There is some preliminary evidence that differences in passivization preferences within RCs do not prevent (animacy-based) SRC prediction as a rule. Gennari et al. (2012) show that Spanish speakers are much less likely to use passives in RCs than English speakers, given the availability of impersonal constructions as a second alternative. Even though these impersonals do not allow speakers to adjust syntactic structures in favor of subject gaps, Spanish still exhibits a robust SRC preference, and a robust animacy asymmetry (Betancourt et al., 2009).

However, under the strongest versions of these accounts (e.g. Levy et al., 2013; MacDonald, 2013), an experienced comprehender making complete use of statistical regularities in the input would not be predictively completing RC dependencies just based on the features of the head, but would be sensitive to any other early, informative features of the input. In Santiago Laxopa Zapotec, one such cue may be the presence or absence of a subject RP directly after the verb.²⁰ The majority of SRCs in the language feature an RP—e.g., in a recently-conducted picture-description study from our research group (Duff et al., *In preparation*), 92% of 162 elicited transitive SRCs included a subject RP.²¹ Even given a large overall bias towards SRCs in the input, once a sophisticated statistical comprehender recognizes the absence of a subject RP, they would begin making more fine-grained predictions conditioned just on their experience with other RCs which lacked a subject RP. Within this subset, it could easily be the case that ORCs are as frequent as (RP-less) SRCs, or indeed more frequent.

¹⁸ Many other sources report SRC predominance in corpora, but we cannot verify whether they limited their searches to only transitive or nominal-co-argument sentences, e.g. Dodd and Morgan (2022) on Arabic. We limit ourselves to such cases here because they match the items of our study. As it happens, this choice is consequential in at least some languages. Intransitive RCs are quite common, so when you count them as SRCs, a language like English seems to have a robust predominance of SRCs (Wagers & Pendleton, 2015). But looking at all transitive RCs, at least some English corpus counts are equibaised between SRCs and ORCs (Gordon & Hendrick, 2005, see also Longenbaugh & Polinsky, 2016 on Niuean and Avar and Levy et al., 2013 on Russian). If our participants in our study learned to anticipate specifically transitive RCs with nominal co-arguments, the cross-linguistic generalization would expect that they should predict an SRC; otherwise, it may be that their particular predictions would modulate over time as they encounter first the head, then the transitive verb, and then the nominal co-argument—but an ultimate SRC preference in offline interpretations would still be expected.

¹⁹ There are good reasons to expect that resumption would provide an alternative tool for producers to mitigate the difficulties of ORC production. Fadlon et al. (2019) find that in difficult RCs with an animate agent and an animate patient, where English speakers routinely passivize, Hebrew speakers use optional RPs especially often.

²⁰ We thank a reviewer for raising this suggestion.

²¹ These RCs were elicited with pictures depicting reversible actions, like those in the present study; it may be the case that in the absence of plausibility cues, producers were under an atypical pressure to disambiguate through an RP, meaning this overestimates the rate of resumption in typical speech. Nevertheless, such reversible actions match the materials in the present study.

Table 7
How comprehension may proceed through the RCs in our study if comprehenders made form-specific predictions as hypothesized, together with related observations from eye-tracking and response data.

Processing Santiago Laxopa Zapotec RCs, under form-specific prediction		
Position	Proposed computations	Related observations
Head	Comprehenders may anticipate an RC due to the repetitive structure of our stimuli, and the presence of multiple possible referents for the head noun on its own. Experience favors an SRC interpretation (and thereby an upcoming subject RP), most so for HU heads.	Slight and brief tendency for more new SRC fixations, see Section 5.2 and a closer look in Appendix B. Predicted animacy asymmetries only register as a trend in Appendix B, although cf. Section 5.3.2.
Verb	First explicit cue to the presence of an RC. Head-based predictions continue to accumulate.	Early preferences continue as weak trends, see Section 5.2, Appendix B.
Verb + 1	Directly after the verb, comprehenders may encounter a subject RP or a full nominal co-argument.	
SubjRP	They receive confirmation of an expected SRC parse, easily retrieving the head in the absence of other recently-encountered nouns, and easily completing a structure which may be preferred due to experience.	Rapid decline in ORC fixations visible on following region (Appendix C) and near-ceiling accuracy (Section 5.1) in SubjRP controls.
Co-Arg	The absence of a subject RP changes the balance of predicted structures. Preference will begin to shift stochastically towards an ORC parse. The animacy of this particular argument will be a highly accessible cue to influence that preference, and the construction of either parse will be delayed if the co-argument shares features with the head, increasing the difficulty of the necessary memory operations.	General preference for ORC images (Appendix B), but response-conditioned divergence begins (Section 5.2.1), larger for HU co-arguments and smaller if Match (Section 5.3).
Co-Arg + 1	The latter cases may continue after the co-argument with an object RP or a clause-final prepositional phrase.	
ObjRP	They receive confirmation of an ORC parse. The final adoption of this interpretation will be easiest in conditions where preference had already most accumulated for an ORC parse, or else where it will be easiest to begin consideration of another parse.	Rapid decline in SRC fixations in subsequent regions (Section 5.3.1), with continued effects of Co-Arg animacy and Match as above, and less accurate ObjRP interpretations if Match (Section 5.1).
Post	They know there will be no further disambiguating information between an SRC and an ORC, and the currently preferred parse should be adopted shortly.	Culmination of response-conditioned divergence (Section 5.2).

Unfortunately, to determine the exact predictions of this hypothesis, we would need a better understanding of the rate of free production of SRCs and ORCs, in all their forms, which is not possible without an annotated corpus of Santiago Laxopa Zapotec speech. Still, with some version of the reasonable assumptions above, this approach seems to yield one nice result, that comprehenders’ predictions should pivot sharply upon observing the absence of a subject RP. Indeed, at the co-argument in our Gap and ObjRP sentences, comprehenders do begin exhibiting a much stronger interest in the ORC parse (best illustrated in Appendix B). More particular assumptions would be necessary to explain other aspects of the data. Why in particular should we fail to observe a credible SRC preference before the missing subject RP, modulated based on the animacy of the head? As with the predominance of SRCs over ORCs in RC exposure, it does not seem particularly likely that Santiago Laxopa Zapotec input contradicts the general cross-linguistic animacy asymmetry in RC exposure (English: Gennari & MacDonald, 2009; Kidd et al., 2007; Wagers & Pendleton, 2015; German: Kidd et al., 2007; Mandarin: Hsiao & MacDonald, 2016; Tagalog: Bondoc & Kush, 2024)—particularly as a preferential status for HU subjects seems to drive the interpretation of the co-argument in the same RCs. Instead, under this approach, one might dismiss the absence of an early SRC preference in our gaze measures as a consequence of a limited time window: between the introduction of the RC (unambiguous at the onset of the verb)²² and the evidence of a subject RP’s absence (unambiguous shortly after the onset of the co-argument), this design only allowed for about 600–800ms of gaze data, while we were able to track later evidence of interpretation for at least 2000 ms during the post-critical regions.

In Table 7, we outline the moment-to-moment processing that this form-based prediction account would expect for our stimuli, with reference back to the patterns we observe in our study.

²² Given that the prior context of our items required a DP continuation, to our knowledge, the noun + verb string could only be completed as an RC.

Notice that in this table we describe a relative ease for SRC parses cued by subject RPs. We did not see any evidence that SRC parses were robustly preferred in the absence of any cues, as they seem to be for late-disambiguated RCs in e.g. Dutch (Frazier, 1987) or German (Schriefers et al., 1995). Nevertheless, filler items with subject RPs were interpreted nearly perfectly (98% SRC responses), much better than our critical items with object RPs (87% ORC responses). Some of this asymmetry may have been due to additional memory costs associated with the presence of an intervening co-argument, but it also may be attributable to the (memory-independent) SRC preference noted across languages in Section 2. Perhaps these preferences were drowned out in ambiguous RCs by the temporary prominence of the co-argument at the point of interpretation, or by the additional biases we consider here particular to gapped RCs.

6.2. An account based on prediction as a learned skill

While sophisticated variants of experience-based biases remain the highest-profile theories that could link processing differences to differences of exposure, we think these data may also lend themselves to an alternative, more extreme view. In this approach, comprehenders do not merely tune biases for ambiguous input, but they may instead tune many free elements of the procedure for incremental comprehension, including whether or not to use a candidate cue to launch a prediction.

We take inspiration for such an account from various sources outside of adult sentence processing. For instance, this greatly resembles proposals by Cutler et al. (2004) and Cutler and Pasveer (2006) on incremental lexical recognition, in which comprehenders of different languages might pay differential attention to the same cue, auditory correlates of stress, based on its gradient utility for lexical disambiguation (see Cutler, 2012 for a review; see also the large literature on stable individual variability in cue adoption for segmental perception, e.g. Idemaru et al., 2012; Kong & Edwards, 2016; Shultz et al., 2012).

This view also emerges from a growing strain of work in developmental sentence processing, in which researchers have provided evidence that children differ from adults not only in the direction of

their biases, but also in the overall ways in which they form and deploy those biases. For instance, children, like adults, exhibit hallmarks of incremental decision-making for some structural ambiguities (Trueswell et al., 1999), but while these decisions are sensitive to fine patterns of lexical co-occurrence, they are far less sensitive than adults to information from the referential context (Snedeker & Trueswell, 2004; see reviews in Snedeker, 2013 and Omaki & Lidz, 2015). Trueswell and Gleitman (2004) suggest that children may rely on certain cues differentially over time, discovering more complex or less valuable cues only as they become more expert in language processing.

An experience-based developmental trajectory for language processing as a skill mirrors proposals for the development of other complex behaviors, where learners are able to converge on similar patterns of behavior without prior knowledge or conscious deliberation, e.g. learning how to heuristically integrate multiple types of information in a decision problem (Erev & Barron, 2005; Rieskamp & Otto, 2006), how to distribute reliance between internal and external representations of information in so-called ‘cognitive off-loading’ tasks (Gray & Fu, 2004; Gray et al., 2006; Howes et al., 2016; Weis & Wiese, 2019), or how to use the motor system to achieve goals in an unpredictable environment (Haith & Krakauer, 2013; Nagengast et al., 2009). One approach in cognitive psychology (e.g., Howes et al., 2009; Lewis et al., 2014; Lieder & Griffiths, 2020), growing out of Anderson’s (1990, 1991) tradition of rational analysis, has suggested that individuals converge on strategies that achieve optimal tradeoffs between effort and reward, given cognitive limitations and the nature of our environment, through domain-general optimization procedures like reinforcement learning (Sutton & Barto, 2018). For examples relevant to language processing where computational modeling validates the possibility that the dynamics of skilled behavior could emerge through individual learning, see Reichle and Laurent (2006) on eye-movements during reading, and Lewis et al. (2014) and Brasoveanu and Dotlacil (2021) on lexical decision tasks.

New evidence from child processing of English supports the idea that early structural prediction in particular may emerge from this kind of optimization. Atkinson et al. (2018) report the results of a visual-world eye-tracking study on the incremental interpretation of English *wh*-questions by adults, and 5-year-old and 6-year-old children. Participants were asked questions after a story, and their gaze anticipation of potential answers was used to measure whether they predicted earlier object gaps more so than optional prepositional gaps (Sussman & Sedivy, 2003), as expected under accounts of structural prediction in long-distance dependencies. While eye-tracking measures revealed robust predictions for adults, and later-developing predictions for 6-year-olds, the 5-year-old participants did not seem to engage in any prediction for an object gap, even though a corpus analysis suggests that 5-year-olds have appropriate patterns of exposure to derive an object-gap preference. The authors suggest that this pattern might emerge from flexible optimization; in particular, structural prediction in these structures may be more risky than it’s worth for younger children, as they are known to face particular difficulty with re-analyzing structural commitments (Trueswell et al., 1999).

What value might there be for structural prediction in English, that drives comprehenders to predict more greedily once their mechanisms for recovery have improved? We suggest that in English, predicting the gap of a question or a relative clause offers a way to distribute processing load throughout a sentence, and avoid having to reconcile many aspects of interpretation all at once. Consider the SRC in (18).

(18) ... the boy that_① pulled_② the car ...

If an English comprehender adopted a wait-and-see strategy once they recognized the RC at position ①, they would carry forward requirements to locate the RC gap, and identify the subject of the RC. At position ②, observing the verb, they must engage in several processes to represent the current input: recognizing that verb and its meaning,

but also reacting to the empty subject position by encoding a subject gap associated with the RC head, and retrieving the RC head as the subject of the RC verb. On the contrary, if the comprehender predicted a subject gap once they recognized the RC at position ①, they can predictively encode a subject gap associated with the just-encountered head. At position ②, at the verb, all that remains is to recognize the verb itself, and link it to the prepared subject, no differently than encountering a verb following a subject in a typical declarative. Of course, this is merely a cartoon representation of these processes, and presumably some overlap would be unavoidable, but prediction would still result in a less peaky distribution of effort. Avoidance of peakiness would be rational under the assumption that comprehenders are to some extent involved in a race against time to represent input (Christiansen & Chater, 2015): resolving several components of processing simultaneously, at speed, may cause problems for those components or catastrophically delay the next processes down the line. This idea is closely related to the hypothesis that communicative efficiency pressures language producers to avoid peaks in information density (see Aylett & Turk, 2004 and much subsequent work), with the main difference being that here, we are considering how a comprehender might adjust their own parsing strategies to serve a similar goal.

Note that naive structural prediction of a subject gap does of course incur the risk of reanalysis whenever the RC has a different structure. Still, the robust regularities in the distributions of SRCs and ORCs make predictive completion, especially aided by animacy, a relatively safe bet: per Wagers and Pendleton (2015), in English news texts, a prediction of an SRC following an animate head would be right 90% of the time.

In contrast, structural prediction does not appear to be so clearly motivated for RCs in Santiago Laxopa Zapotec. Consider the RP-disambiguated SRC in (19).

(19) ... the.boy pulled_① =he_② the.car ...

The first point at which a comprehender can certainly recognize a RC is at position ①, having encountered a post-nominal verb. A comprehender that chooses to wait and see, in this case, must wait for the subject (as they do in most simple clauses) but also must wait to identify the position of the gap. Both of these remaining processes are then triggered by the RP at position ②. While head retrieval and subject-verb processing would therefore overlap, unlike in English these processes would be initiated by the presence of a positive cue, separate from the additional costly-to-process lexical content of the clause.²³ Moreover, unlike in English, SRC/ORC disambiguation triggered by the input is not universal. A comprehender who avoids a gap prediction at position ① in (20) may be free to continue postponing analysis at position ②, completing an SRC or ORC parse only when they are confident.²⁴ In Santiago Laxopa Zapotec RCs, the possibility of a sudden glut of processing demands is therefore both (a) reduced in intensity due to the nature of resumptive pronouns as a disambiguating cue and (b) reduced in frequency of occurrence, given that some strings remain globally ambiguous. We think this could explain why comprehenders do not engage an early prediction strategy based on animacy.

²³ See detailed discussion in Meltzer-Asscher (2021) regarding whether the head retrieval triggered by RPs might itself be somehow facilitated compared to gaps. Evidence points both ways, and is perhaps best reconciled by imagining that RPs may facilitate certain aspects of processing, but only when they occur in positions which comprehenders did not predict to be empty (i.e. where comprehenders did not predict a gap). If comprehenders in Santiago Laxopa Zapotec do avoid gap prediction, this may be one such case.

²⁴ Compare evidence from Frazier and Rayner (1987) that comprehenders will apparently postpone parses in situations of high uncertainty triggered by syntactic category ambiguity. We assume that this longer timeline of parsing labor is available only under ambiguity; that is, there is no way for an English comprehender to adopt the same longer timeline to prevent peakiness in the comprehension of an unambiguous SRC.

Table 8
How comprehension may proceed through the RCs in our study if comprehenders did not engage in any early predictions as hypothesized by an account of prediction as a learned skill, together with related observations from eye-tracking and response data.

Processing Santiago Laxopa Zapotec RCs, under form-specific prediction		
Position	Proposed computations	Related observations
Head	Comprehenders may anticipate an RC due to the repetitive structure of our stimuli, and the presence of multiple possible referents for the head noun on its own. An SRC interpretation may be considered, perhaps most for HU heads, but it does not receive any commitment.	Slight and brief tendency for more new SRC fixations, see Section 5.2 and a closer look in Appendix B. Animacy asymmetries would be taken as negligible, perhaps in line with the inconsistent trends in Appendix B, and Section 5.3.2.
Verb	First explicit cue to the presence of an RC. The beginnings of a clause structure may be formed, but still no commitments are made regarding the role of the head.	Only the continuation of earlier weak preferences, see Section 5.2, Appendix B.
Verb + 1	Directly after the verb, comprehenders may encounter a subject RP or a full nominal co-argument.	
SubjRP	They begin constructing an SRC parse in earnest, easily retrieving the head in the absence of other recently-encountered nouns, and easily completing a structure which may be preferred due to experience.	Rapid decline in ORC fixations visible on following region (Appendix C) and near-ceiling accuracy (Section 5.1) in SubjRP controls.
Co-Arg	Given two possible structures, preference may begin accumulating between these stochastically, perhaps with an initial bias towards considering an ORC parse, where the argument currently in the focus of attention is the subject. The animacy of this particular argument will be a highly accessible cue to influence that preference, and the construction of either parse will be delayed if the co-argument shares features with the head, increasing the difficulty of the necessary memory operations.	General preference for ORC images (Appendix B), but response-conditioned divergence begins (Section 5.2.1), larger for HU co-arguments and smaller if Match (Section 5.3).
Co-Arg + 1	The latter cases may continue after the co-argument with an object RP or a clause-final prepositional phrase.	
ObjRP	They must begin constructing an ORC parse, regardless of the current state of preference. This construction will be easiest in conditions where preference had already most accumulated for an ORC parse, or else where it will be easiest to begin consideration of another parse.	Rapid decline in SRC fixations in subsequent regions (Section 5.3.1), with continued effects of Co-Arg animacy and Match as above, and less accurate ObjRP interpretations if Match (Section 5.1).
Post	They know there will be no further disambiguating information between an SRC and an ORC, and the currently preferred parse should be adopted shortly.	Culmination of response-conditioned divergence (Section 5.2).

(20) ... the.boy pulled^① the.car^② ...

In Table 8, we outline the moment-to-moment processing that this account of prediction as a learned skill would expect for our stimuli, with reference back to the patterns we observe in our study.

Note that under this account, we suggest that commitment to a particular parse only begins once comprehenders encounter the co-argument. At this point, the animacy of both arguments may be weighed as comprehenders form a preference for an SRC or an ORC parse, but it seems plausible that a recency bias leads to the co-argument's observed dominance, while nevertheless it is the combination of both arguments that fuels delays in interpretation attributable to similarity-based interference of some kind. In either of these accounts, we remain here agnostic as to whether this interference is a matter of overloaded cues (Lewis & Vasishth, 2005), faulty encodings (Oberauer et al., 2012), or difficult maintenance of the head (Ness & Meltzer-Asscher, 2017), although we note that an account where interference principally challenges re-analysis (e.g. Wagers, 2023) would be incompatible with this second approach, given the assumption that comprehenders lack previous commitments at this point.

This overall profile is one which admits the importance of several overlapping processes which must be accomplished in RC comprehension, distributed in time according to the temporal profile and strength of information in a given language. In this way, it is very similar to the approaches adopted in Wagers et al. (2018) and Hammerly et al. (2022), only admitting one additional source of cross-linguistic variance. Wagers et al. (2018) suggest that Chamorro comprehenders may avoid strong predictions in pre-nominal RCs, because the limited information available about the head (merely its existence) makes a gap prediction relatively risky. Here we derive a similar lack of prediction, but must resort not to a lack of information (the head is, after all, known), but instead a lack of strategic value. One way to summarize our proposal here is that rather than pursuing a maximally well-formed incremental parse at every step of the input (as those authors suggest), comprehenders aim to pursue a maximally well-formed incremental parse only to the extent that it would be useful.

6.3. Comparing these accounts

In the end, both a universal form-specific prediction account and a language-specific delay in prediction are capable of explaining the particular lack of an overarching SRC preference during comprehension of these RCs. One distinction between these accounts seems to rest on how one wants to explain the lack of animacy asymmetries during early ambiguous regions of the stimulus, and the inflection point towards robust ORC preferences at the co-argument. Under form-specific prediction, assuming a certain distribution of forms in experience, one can nicely explain the turn towards ORCs, but must write off the absence of earlier predictions as a measurement problem. Under our second account, one can fully account for the absence of early predictions, but must attribute the ORC shift at the co-argument to some general notion of current-nominal prominence.

Zooming out a bit, the strongest argument against the latter approach is a theoretical one, that it is too flexible to admit both powerful experience-based prediction, and optionality in whether a processor exercises this prediction. While we think it is plausible that not every incremental comprehender recruits all normatively-predictive information from experience in the same way,²⁵ we agree this is a highly powerful theoretical step.

To motivate these extra degrees of freedom more convincingly, a defense of this account should hope to find further cases of languages where early structural prediction in RCs may similarly be avoided in cases where it offers little value.²⁶ Based on our discussion of

²⁵ One potentially-relevant case of such variation already comes from the literature on task effects and “good-enough processing”: see Ferreira and Patson (2007) and Karimi and Ferreira (2016) for review, and see also Brothers et al. (2017) for particular evidence of task variation in prediction.

²⁶ Elsewhere in the literature, one can sometimes see claims of this nature made in the processing of simple transitive clauses in languages with relatively free word order. For instance, in a visual-world study on Hungarian, Müller

Santiago Laxopa Zapotec, a good place to start would be with other languages that have frequent global ambiguities between SRCs and ORCs. Dutch offers one such case, with SOV RCs that are often globally ambiguous if the head and its co-argument match in number. On the one hand, we know that despite this ambiguity, Dutch comprehenders exhibit a robust SRC preference in offline interpretations of HU–HU RCs (Frazier, 1987), unlike Santiago Laxopa Zapotec.²⁷ On the other hand, Mak et al. (2006) argue that in Dutch, this bias does not come from early head-based prediction, and instead, comprehenders delay their parse until they have observed both the head and the co-argument, much as they seem to do in Santiago Laxopa Zapotec. In particular, they observed that reading-time evidence for an online SRC prediction—difficulty when subject-verb agreement disambiguated to an ORC parse—was particular to certain combinations of head and co-argument animacy: comprehenders seemed to avoid SRC predictions in IN–HU ORCs, but they still exhibited difficulty consistent with an SRC prediction for IN–IN ORCs. Future work, including evidence from visual-world eye-tracking, should clarify whether this is indeed because Dutch comprehenders delay their structural predictions as Mak and colleagues propose, but if so, it would be in line with our approach to Santiago Laxopa Zapotec.²⁸

Another, closer comparison could come from Dodd and Morgan (2022) and Dodd et al. (2024), who present studies on the reading of VSO RCs in Modern Standard Arabic, where global ambiguity is also possible and RPs are a frequent tool for disambiguation. Despite the similarity to Santiago Laxopa Zapotec, in those experiments comprehenders nevertheless suffered difficulty with ORCs that the authors attribute to an experience-based preference for SRCs, which would be consistent with structural prediction. To our knowledge, no studies have probed the possibility of head-based prediction in particular in Arabic; this could prove to be a valuable minimal comparison with the present study. See also Hebrew, where optional RPs are not required for disambiguation but are also possible for comparable ORCs, and where recent reading studies (Carter et al., 2023; Geller, 2020) have indeed noted the absence of clear animacy asymmetries in subject gap predictions.²⁹ But the idea that all and only languages with global SRC/ORC ambiguities or widespread RPs should demonstrate this pattern is, of course, too simplistic; any approach should ideally also be able to account for the apparent lack of animacy predictions in Tagalog (Bondoc & Kush, 2024), where RCs must feature a gap, and typical corpus asymmetries would provide a clear bias towards SRCs in the case of an animate head.

One final avenue for distinguishing these accounts comes from Wagers and Pendleton (2015), who note an interesting contrast between the observed frequency of SRCs with inanimate heads in English corpus

data (90%, trailing rates with animate heads only slightly), and English comprehenders' apparent absence of online SRC predictions in incremental comprehension of inanimate-headed RCs. Such data is more compatible with any account where incremental prediction isn't a one-to-one consequence of biases of experience. While we cannot at present make such comparisons between normatively-rational prediction rates and actual prediction rates in Santiago Laxopa Zapotec, this type of analysis might be informative in other cross-linguistic work where corpus data is available.

6.4. Alternatives and limitations

Before we conclude, we address possible concerns regarding our absent effect of structural prediction, including related to diversity of age and language experience as potential alternative explanations, and reflect on the overall plausibility of an effect in this design.

Our sample features participants from a wider age-range than often observed in studies on adult language comprehension, which most often recruit from populations below the age of 30. A priori, one might wonder whether older participants are less likely to demonstrate robust predictive looking patterns in this type of study, leading to the absence of any clear effect in our data. To examine whether this might be the case, we conducted a post-hoc analysis of just the half of our participants at or below the median age of 40. Results are available in our supplementary materials, and were closely in line with those that we report for the complete sample, indicating that the lack of prediction was not specific to just older adults. In fact, such a prediction would have been exactly the reverse of observations for effects of age in the comprehension of English RCs. Across self-paced listening (DeDe, 2015) and eye-tracking while reading (DeDe & Kelleher, 2021), older adults show not a reduced but an exaggerated animacy asymmetry. This finding matches nicely with the hypothesis that these asymmetries are tied to a flexible strategy of predictive comprehension, given claims that older adults are thought to rely more on predictions during comprehension (Choi et al., 2017; Rayner et al., 2006), even as those predictions are relatively narrow compared to younger adults (Haeuser et al., 2022).

Our sample also features participants with a wide array of different language experiences. While all participants were bilingual, reflecting the broader Santiago Laxopa Zapotec speaking population, some indicated in a post-experiment questionnaire that they acquired Zapotec later in life or that they used more Spanish than Santiago Laxopa Zapotec in most parts of their life. We can imagine two ways a participant's particular multilingual language experience could affect predictive behavior in Santiago Laxopa Zapotec comprehension, in principle. On one hand, participants with relatively higher amounts of Spanish use may have reduced exposure to the kind of information that supports structural prediction in Santiago Laxopa Zapotec. But alternatively, participants with higher Spanish exposure might be more likely to recruit comprehension behaviors that are common in Spanish, including structural prediction (Betancourt et al., 2009; del Río et al., 2012). To examine whether either hypothesis might be true, we conducted a post-hoc analysis of just those 35 participants who indicated they acquired Zapotec before the age of 10 and used Spanish more than Santiago Laxopa Zapotec in at most one aspect of their daily life. Results are available in our supplementary materials, and were again closely in line with those that we report for the complete sample, indicating that the lack of prediction was not specific to just participants with greater use of Spanish (or vice versa).

Is it possible that, independently of these population-specific alternatives, the method we adopt here might lack sensitivity to detect the kind of predictions that we are interested in? This seems on the whole, unlikely. Predictive interpretations for these kinds of long-distance dependencies are known to be robust in in-lab eye-tracking experiments with adults (Atkinson et al., 2018; Sussman & Sedivy, 2003). And similar tasks run in similar settings delivered robust evidence for early

et al. (2021) report that regularities of word order are not used to predict that an initial nominal will serve as a subject, given the availability of case information shortly afterward. See also Malko et al. (2025), who describe an absence of animacy effects in a visual-world experiment on transitive clauses in the Pama–Nyungan language Pitjantjatjara.

²⁷ A reviewer suggests that this could reflect a difference between these ambiguities in VSO RCs on one hand, and SOV RCs on the other, if languages may generally prefer not to posit gaps between a pronounced co-argument and its verb, a generalization of the Subject Parsing Constraint of Foreman and Munro (2007) (see also Bever, 1970). This is worthy of further investigation, although we note that one would also have to explain why e.g. other VSO RCs, as in Arabic, seem to exhibit strong SRC preferences.

²⁸ Still, it is striking that SRC interpretations still win out strongly in Dutch studies, unlike what we have seen in Santiago Laxopa Zapotec.

²⁹ It is very unlikely that Hebrew comprehenders avoid structural prediction wholesale: Results of some reading studies in Hebrew suggest that comprehenders may even predict the presence of a gap or an RP, and struggle with the alternative, see sources reviewed in Meltzer-Asscher (2021). Nevertheless, it could still be the case that comprehenders avoid English-like head-based prediction of subject gaps, specifically.

subject-gap prediction in Ojibwe RCs (Hammerly et al., 2022), and object-gap prediction in Niuean *wh*-questions (Tollan et al., 2019), not to mention evidence for early subject-gap prediction in Chamorro RCs using touch-tracking, a presumably coarser measure (Wagers et al., 2018). Nevertheless, it is true that this kind of evidence has not been attested, to our knowledge, for animacy-fueled subject-gap predictions in English, the case where other evidence makes us the most confident that such predictions exist. One close case comes from a study by Stern et al. (2019), who find visual-world evidence for an SRC preference in Spanish for fluent Spanish–English bilinguals, although this is limited to a finding of faster disambiguation rather than any evidence of earlier prediction. Another close case from the existing literature is a recent study by Macdonald et al. (2020), who target the same asymmetries as the present study, animacy-based SRC prediction and animacy-based similarity asymmetries for English-speaking children and adults. Nevertheless, one key difference is the notions of animacy which they manipulate, featuring only non-human animals and inanimates, two cases very nearby to each other in human conceptions of animacy (Yamamoto, 1999). They report no clear evidence for an animacy-related SRC preference for children or adults, but this may be a result of the particular categories probed. They nevertheless did observe a clear similarity asymmetry, with adults struggling to interpret unambiguous RCs with animacy-matched arguments much as we observe in our study. In the absence of an exact comparison case, the absence of prediction here must bear some caveat, but evidence of early prediction abounds in various other studies, making that caveat relatively small.

Comparing then, to the evidence which exists for previous eye-tracking evidence of subject gap prediction, we do note that the particular timing of our visual and audio stimuli may have biased against the chance to observe robust predictions. In Hammerly et al. (2022), before the onset of audio stimuli, participants could take advantage of a 4s familiarization period to scan an array of three images. In Tollan et al. (2019), participants interacted with an array of physical objects before the critical question. In contrast, in our study, after an initial period where participants were introduced to the relevant participants in the events to come (both human and inanimate characters), the critical scenes were presented together with the onset of audio. The head of the RC began on average about 1.5s after this onset. If at this point, comprehenders were still performing an initial survey of the images, this may have prevented task-directed gaze patterns of the kind our analysis assumes. Although this is possible, we do note that comprehenders must have achieved satisfactory awareness of both scenes by at least the co-argument, in order to begin showing effects of interpreting the subject RP (see Appendix C). Nevertheless, there is no indication of any effect of head animacy at this point. An alternative possibility is that even though visual processing of the novel images did not block goal-oriented eye movements, it took attention away from the audio stimulus, to the point where participants were not engaging closely enough with interpretation in order to demonstrate predictive behavior. This worry is somewhat assuaged by the fact that Wagers et al. (2018), using touch-tracking, were still able to find evidence for incremental prediction despite using the same simultaneous presentation timing. Nevertheless, future studies using a similar paradigm could best address these concerns by investigating whether familiarization periods indeed help improve attention to subsequent audio stimuli.

6.5. Conclusions

We see two key results from the present investigation of incremental interpretation of RCs in Santiago Laxopa Zapotec. Both offer insight into the source of asymmetries in RC comprehension attested in other languages. First, despite a variety of notable differences from the languages most previous work has focused on, real-time processing behavior in Santiago Laxopa Zapotec bears the fingerprints of a familiar difficulty with similarity, and a familiar predilection for parsing animate nouns as subjects. Both patterns seem to come from cognitive

processes that underlie the comprehension of RCs regardless of the language in question. But language-specific features shape the way in which that latter animacy effect emerges in Santiago Laxopa Zapotec, modulating the ease of constructing an interpretation late in comprehension, rather than modulating early structural predictions. This, we offer, is because Santiago Laxopa Zapotec comprehenders exhibit predictions that are in some way language-specific, with the crucial difference from other languages either being the presence of a potential soft anti-SRC cue (the absence of a subject RP), or the low utility of early prediction (given the nature of ambiguity and disambiguation in these RCs). The accounts we consider agree that language processing must in some sense be tuned to the specific properties of a language. They differ in how many aspects of that system they take to be tunable, whether merely the expected distribution of structures that supports a mechanism of prediction or in fact the deployment of prediction itself. Exactly how tunable our theory of processing should be, we think, can only be addressed if we continue investigating patterns of comprehension across an appropriately diverse sample of the world's languages.

CRediT authorship contribution statement

John Duff: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Delaney Gomez-Jackson:** Writing – review & editing, Investigation. **Fe Silva Robles:** Writing – review & editing, Resources, Investigation. **Maziar Toosarvandani:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Matthew Wagers:** Writing – review & editing, Visualization, Supervision, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Ethics and consent

All human subjects experimentation reported here was deemed exempt by the UC Santa Cruz Institutional Review Board. All participants provided informed consent.

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Declaration of competing interest

The authors have no competing interests to declare.

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Appendix A. Items

See Table 9.

Table 9

Verbs and nouns used in each of the fifteen item frames. Mismatch conditions were created by combining critical HU and IN nouns, while Match conditions featured e.g. critical HU heads with matched HU co-arguments.

Verb		Critical HU		Critical IN		Matched HU Co-Arg.		Matched IN Co-Arg.
<i>tsyacha'</i>	lean	<i>bi'i xyag</i>	boy	<i>yawag</i>	axe	<i>bi'i nhu'ulhe</i>	girl	<i>yag ta'a</i> lumber
<i>tsey</i>	burn	<i>bi'i xyag</i>	boy	<i>yich</i>	paper	<i>bi'i nhu'ulhe</i>	girl	<i>yag</i> tree
<i>tsjano</i>	follow	<i>bi'i nhu'ulhe</i>	girl	<i>koch</i>	car	<i>bi'i xyag</i>	boy	<i>juget</i> toy
<i>shchuchj</i>	crush	<i>bi'i xyag</i>	boy	<i>yej</i>	rock	<i>bi'i nhu'ulhe</i>	girl	<i>koch</i> car
<i>tsgakw</i>	cover	<i>bi'i xyag</i>	boy	<i>yetj</i>	sugarcane	<i>bi'i nhu'ulhe</i>	girl	<i>lon</i> tarp
<i>shchuchj</i>	crush	<i>bi'i nhu'ulhe</i>	girl	<i>yag siy</i>	chair	<i>bi'i xyag</i>	boy	<i>yitw</i> pumpkin
<i>tsey</i>	burn	<i>bi'i nhu'ulhe</i>	girl	<i>yag</i>	tree	<i>bi'i xyag</i>	boy	<i>yel</i> corn plant
<i>shkache'</i>	hide	<i>bi'i nhu'ulhe</i>	girl	<i>yix</i>	plant	<i>bi'i xyag</i>	boy	<i>yesw</i> pot
<i>tsyacha'</i>	lean	<i>bi'i xyag</i>	boy	<i>le'eze</i>	wall	<i>bi'i nhu'ulhe</i>	girl	<i>yag</i> tree
<i>tsgakw</i>	cover	<i>bi'i xyag</i>	boy	<i>yesw</i>	pot	<i>bi'i nhu'ulhe</i>	girl	<i>lats yiche</i> blanket
<i>txhube</i>	pull	<i>bi'i xyag</i>	boy	<i>koch</i>	car	<i>bi'i nhu'ulhe</i>	girl	<i>kamioneta</i> truck
<i>shkache'</i>	hide	<i>bi'i nhu'ulhe</i>	girl	<i>da'a bep</i>	rain cape	<i>bi'i xyag</i>	boy	<i>lats yiche</i> blanket
<i>chige</i>	push	<i>bi'i xyag</i>	boy	<i>koch</i>	car	<i>bi'i nhu'ulhe</i>	girl	<i>kamioneta</i> truck
<i>dzesbis</i>	make wet	<i>bi'i nhu'ulhe</i>	girl	<i>yesw</i>	pot	<i>bi'i xyag</i>	boy	<i>manger</i> hose
<i>shchille</i>	press	<i>bi'i xyag</i>	boy	<i>le'eze</i>	wall	<i>bi'i nhu'ulhe</i>	girl	<i>yag</i> tree

Appendix B. Comparing gaze patterns on the same images across conditions

Image pairs featuring HU and IN arguments were identical in HU Mismatch and IN Mismatch conditions. We exploit this fact to perform a secondary analysis of how new fixations to images which depict an event with a HU subject and images which depict an event with an IN subject varied across conditions. Trials with SRC and ORC interpretations were not differentiated for this analysis. Fig. 7 demonstrates new fixations on each image by region, conditioned on how the depicted subject is mentioned within the RC stimulus. Table 10 reports the corresponding models.

To begin, we observe that these two classes of images had a small difference in their basic tendency to attract new fixations. In the 1000 ms before the onset of the head, images depicting inanimate notional subjects (and human notional objects) attracted more attention ($\hat{\beta} = 0.39$; [0.01, 0.77]_{95%}). This property has been previously noted in similar experiments, possibly a consequence of the atypicality of inanimates affecting humans (Malko et al., 2025). Nevertheless, once the linguistic stimulus becomes relevant, beginning at the head, we observe relative equilibrium of attention to the images themselves.

Instead, beginning at the head, we see evidence that the linguistic stimulus drives differential attention. The HU-subject image received somewhat less attention in conditions where that subject was not mentioned as the head, at the head ($\hat{\delta}_{\text{SubjMention|DS=HU}} = -0.31$, $P(\delta < 0) = 0.86$) and the following verb ($\hat{\delta}_{\text{SubjMention|DS=HU}} = -0.40$, $P(\delta < 0) = 0.92$). For IN-subject images, this effect is not apparent at the head ($\hat{\delta}_{\text{SubjMention|DS=IN}} = 0.02$, $P(\delta < 0) = 0.48$), and appears weaker at the verb ($\hat{\delta}_{\text{SubjMention|DS=IN}} = -0.28$, $P(\delta < 0) = 0.86$). This could be evidence for a complex animacy effect on predictive SRC parses, such that images were more attractive at the head noun when they depicted that head noun as subject, particularly for images where that subject was HU. This is in line with the hypothesis that predictive SRC parses are more likely for HU heads, but whatever the source of this effect, it is weak at best; note that the model did not estimate a credibly positive interaction between head depiction and depicted subject animacy at the head ($\hat{\beta} = 0.33$; [-0.32, 0.95]_{95%}) or at the verb ($\hat{\beta} = -0.12$; [-0.50, 0.73]_{95%}). This possible animacy asymmetry is also very short-lived. Credibly at the co-argument ($\hat{\beta} = 0.44$; [-0.10, 0.95]_{95%}) and also trending at the first post-critical region ($\hat{\beta} = 0.60$; [0.10, 1.05]_{95%}),

Table 10

Posterior estimates, standard errors, and 95% HDPIs from Bayesian logistic mixed-effects models fit to the probability of a new fixation on an image in ambiguous gap conditions featuring arguments with mismatched animacy. Parentheses indicate the level of each factor coded as positive (+0.5).

	Effect	Posterior $\hat{\beta}$	Posterior σ_{β}	95% CRI
Pre	Intercept	0.84	0.15	(0.55, 1.12)
	Depicted Subject Animacy (IN)	0.39	0.19	(0.01, 0.77)
	N1 Depiction (Object)	-0.04	0.21	(-0.46, 0.39)
	DSA $\times$ N1 Dep.	0.14	0.34	(-0.54, 0.81)
Head	Intercept	0.09	0.13	(-0.16, 0.34)
	Depicted Subject Animacy (IN)	0.11	0.20	(-0.28, 0.50)
	N1 Depiction (Object)	-0.15	0.24	(-0.61, 0.33)
	DSA $\times$ N1 Dep.	0.33	0.32	(-0.32, 0.95)
Verb	Intercept	0.14	0.11	(-0.07, 0.34)
	Depicted Subject Animacy (IN)	0.14	0.22	(-0.30, 0.56)
	N1 Depiction (Object)	-0.34	0.22	(-0.81, 0.11)
	DSA $\times$ N1 Dep.	0.12	0.31	(-0.50, 0.73)
Co-Arg	Intercept	0.31	0.15	(0.01, 0.61)
	Depicted Subject Animacy (IN)	0.23	0.23	(-0.23, 0.69)
	N1 Depiction (Object)	0.54	0.21	(0.13, 0.95)
	DSA $\times$ N1 Dep.	-0.10	0.36	(-0.81, 0.62)
Post 1	Intercept	0.59	0.10	(0.39, 0.80)
	Depicted Subject Animacy (IN)	-0.02	0.26	(-0.53, 0.50)
	N1 Depiction (Object)	0.48	0.25	(-0.02, 0.96)
	DSA $\times$ N1 Dep.	0.19	0.31	(-0.41, 0.78)
Post 2	Intercept	0.19	0.11	(-0.02, 0.39)
	Depicted Subject Animacy (IN)	-0.26	0.23	(-0.70, 0.19)
	N1 Depiction (Object)	0.03	0.21	(-0.38, 0.44)
	DSA $\times$ N1 Dep.	0.10	0.31	(-0.52, 0.71)

both images received more attention in conditions where the depicted subject was mentioned as the co-argument. In general, images seem to have been particularly attractive as the participants encountered the noun matching the image's depicted subject, an effect which was especially strong for the co-argument. This echoes the general time-course for SRC and ORC fixations demonstrated in the primary analyses, where SRC images receive maximal attention at the head, and ORC images at the co-argument.

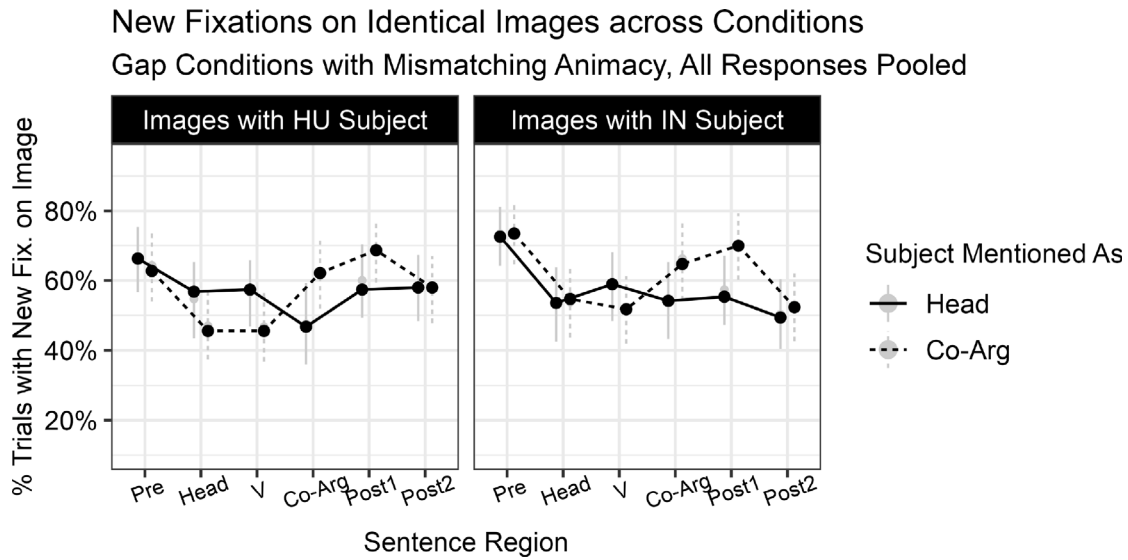


Fig. 7. Participants' probability of programming a new fixation to an image in each analysis region, in critical conditions featuring argument gaps and arguments mismatching in animacy, faceted by the animacy of the image's depicted subject. Looks to images in trials where the image subject was mentioned as the RC head (solid) are plotted separately from trials where they were mentioned as the RC co-argument (dashed). Fainter gray points and intervals indicate medians and 95% HPDIs from the logistic mixed-effects model.

Appendix C. Gaze patterns in control conditions

To provide more context for our critical online effects, we also present a *post hoc* analysis of eye movements during correct-responding trials for the two types of control trials, Subject RP and *where* RCs, compared to comparable Gap conditions (Mismatch, featuring SRC responses). Note that this relies on a somewhat smaller set of data than our critical analyses: participants saw a maximum of 3 of any control type in each form, and typically gave SRC responses to only 3 of their 6 Mismatch Gap trials. In this analysis, we use Helmert-coding to treat the three levels of RC type, with the first contrast (ControlType) comparing between Where (−1) and SubjRP (+1), and the second (DepType) comparing between both control conditions (−1) and the Gap conditions (+2). We apply the analysis only in regions which had similar duration in all conditions: the 1000 ms pre-critical region, the verb, the co-argument (parsed in all these cases as the object), and the two 1000 ms post-critical regions.

We know subject RPs and *where* RCs were associated with a marked increase in SRC interpretations³⁰ in the offline task. This interpretation shows up quickly in the eye movement record as a rapid reduction in their new fixations on the (inappropriate) ORC image after the point of disambiguation—in SubjRP conditions, this was the subject RP, and in *where* RCs, this was the nominal subject. Fig. 8 demonstrates participants' probability of programming a new fixation to the ORC image in these trials, and Table 11 reports the corresponding models. Greater tendency for new fixations on the ORC images in Gap trials over control trials manifests as a trending effect of DepType at the immediately following co-argument ($\hat{\beta} = 0.15$; $[-0.07, 0.38]_{95\%}$), emerging as a credible effect at the first post-critical region ($\hat{\beta} = 0.35$; $[0.11, 0.61]_{95\%}$), and the second post-critical region ($\hat{\beta} = 0.36$; $[0.14, 0.58]_{95\%}$).

There was no main effect or interaction with head animacy in any region. In particular, ORC looks were not overall less common with HU heads, and the disambiguation contrast did not appear to be weaker in HU head conditions, as might be expected if participants in Gap conditions were predisposed to an SRC parse in such cases.

³⁰ Note that while we continue to use the terms “SRC interpretation” and “ORC interpretation” here, in *where* RCs the correct interpretation, leading to the “SRC” response, did not involve an SRC parse. In these general cases, the “SRC” image depicts the first nominal in the RC acting as a subject.

Table 11

Posterior estimates, standard errors, and 95% HDPIs from Bayesian logistic mixed-effects models fit to the probability of a new fixation on the ORC image in subject RP and *where* RC filler trials vs. comparable argument gap trials. Parentheses indicate the level of each factor coded as positive (+0.5).

	Effect	Posterior $\hat{\beta}$	Posterior σ_{β}	95% CRI
Pre	Intercept	0.63	0.17	(0.30, 0.98)
	ControlType (Where v. SubjRP)	0.18	0.16	(−0.14, 0.50)
	DepType (Controls v. Gap)	0.21	0.13	(−0.02, 0.48)
	N1 (IN)	0.06	0.26	(−0.46, 0.58)
	CType × N1	−0.21	0.28	(−0.76, 0.34)
	DType × N1	−0.07	0.22	(−0.50, 0.35)
Verb	Intercept	−0.23	0.13	(−0.49, 0.02)
	ControlType (Where v. SubjRP)	−0.05	0.16	(−0.37, 0.28)
	DepType (Controls v. Gap)	0.03	0.10	(−0.17, 0.23)
	N1 (IN)	−0.13	0.23	(−0.58, 0.31)
	CType × N1	−0.25	0.27	(−0.78, 0.27)
	DType × N1	0.07	0.19	(−0.30, 0.45)
Co-Argument	Intercept	0.06	0.14	(−0.23, 0.34)
	ControlType (Where v. SubjRP)	−0.09	0.16	(−0.40, 0.23)
	DepType (Controls v. Gap)	0.15	0.11	(−0.07, 0.38)
	N1 (IN)	−0.29	0.25	(−0.77, 0.21)
	CType × N1	0.29	0.27	(−0.25, 0.82)
	DType × N1	0.01	0.20	(−0.39, 0.40)
Post 1	Intercept	−0.02	0.20	(−0.41, 0.38)
	ControlType (Where v. SubjRP)	0.10	0.20	(−0.30, 0.50)
	DepType (Controls v. Gap)	0.35	0.13	(0.11, 0.61)
	N1 (IN)	0.03	0.31	(−0.57, 0.63)
	CType × N1	0.08	0.31	(−0.54, 0.70)
	DType × N1	−0.17	0.23	(−0.63, 0.28)
Post 2	Intercept	−0.88	0.19	(−1.25, −0.52)
	ControlType (Where v. SubjRP)	−0.08	0.21	(−0.49, 0.34)
	DepType (Controls v. Gap)	0.36	0.11	(0.14, 0.58)
	N1 (IN)	−0.14	0.29	(−0.70, 0.43)
	CType × N1	0.03	0.33	(−0.61, 0.69)
	DType × N1	0.25	0.21	(−0.16, 0.66)

We can also examine new fixations to the SRC image, but there is less to observe there. Fig. 9 demonstrates participants' probability of programming a new fixation to the SRC image in each ROI for HU and IN heads in these trials. Table 12 reports the corresponding models.

Here we observe some evidence that these conditions drove more SRC-consistent looking. During the co-argument the Gap conditions

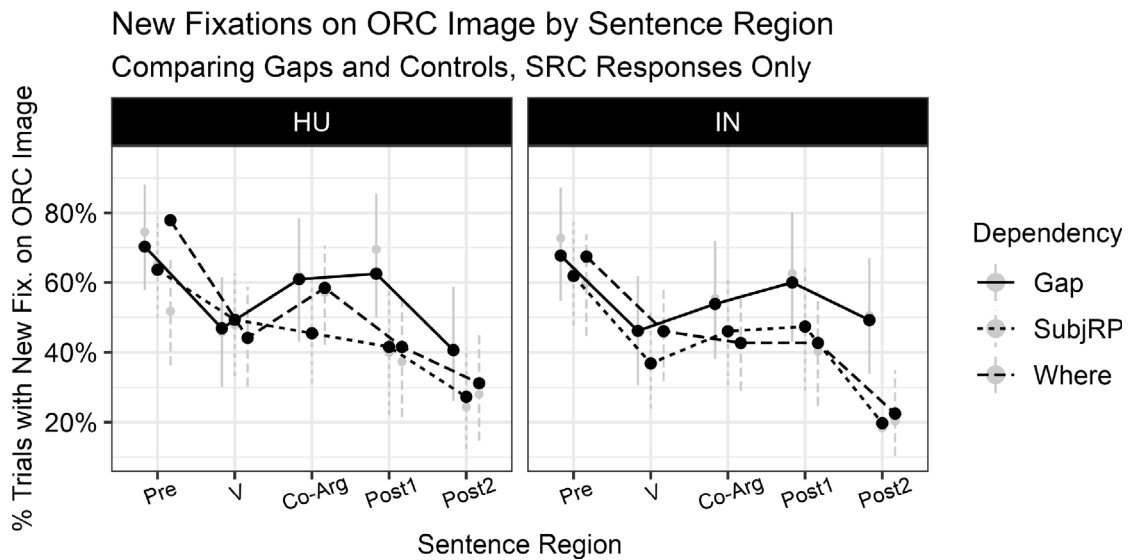


Fig. 8. Participants' probability of programming a new fixation to the ORC image in each analysis region, for subject resumptive pronoun and *where* RC filler trials vs. comparable argument gap trials, faceted by head noun animacy. Only trials where participants indicated an SRC parse are included in this analysis. Fainter gray points and intervals indicate medians and 95% HPDIs from the logistic mixed-effects model.

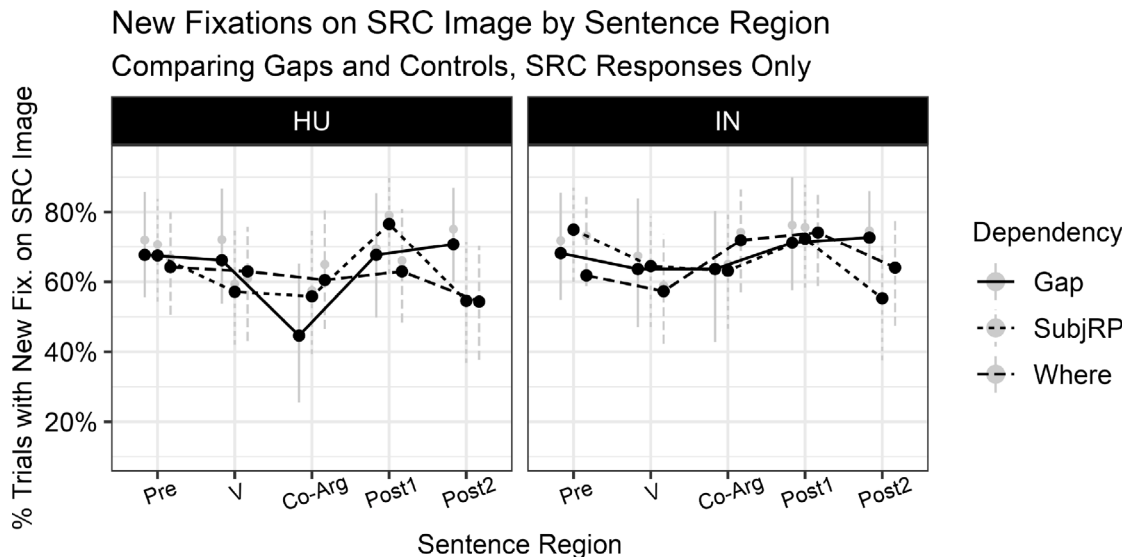


Fig. 9. Participants' probability of programming a new fixation to the SRC image in each analysis region, for subject resumptive pronoun and *where* RC filler trials vs. comparable argument gap trials, faceted by head noun animacy. Only trials where participants indicated an SRC parse are included in this analysis. Fainter gray points and intervals indicate medians and 95% HPDIs from the logistic mixed-effects model.

tended to show fewer new SRC fixations ($\beta = -0.16$; $[-0.42, 0.09]_{95\%}$). In the second post-critical region, we see a reverse effect, that Gap conditions showed more new SRC fixations ($\beta = 0.27$; $[0.07, 0.49]_{95\%}$). Taken together with the ORC fixations, this seems to indicate that participants in the Gap condition made more new fixations in this time window, consistent with the idea that they had settled less firmly on a single preferred interpretation.

These results suggest a few concrete generalizations about the time-course of comprehending unambiguous linguistic material in this study. First, participants comprehending unambiguous instructions reduced new looks to incompatible images rather than increasing new looks to compatible images. Second, these patterns of avoidance emerged quickly online, trending consistently by the audio region following disambiguation. Third, at the tail end of our temporal window, unambiguous stimuli also resulted in an overall reduction in new fixations to any image, compared to ambiguous stimuli. These patterns help

contextualize the similar results observed with our critical ObjRP conditions. They also help contrast between participants' online sensitivity to grammatically disambiguating cues in these conditions vs. the absence of any robust incremental effect of head animacy.

Appendix D. Considering potential prosodic disambiguation in gap conditions

In the design and analysis of this study, we have assumed that RCs with no RP in Santiago Laxopa Zapotec are systematically ambiguous. This is primarily on the basis of native speaker judgments: we have observed that speakers are willing to endorse the same sequence of words as a RC which appropriately describes a head noun which is acting as a subject, or acting as an object; we also have seen speakers on occasion produce the same sequence of words (without an RP) themselves, to describe both of these scenarios.

Table 12

Posterior estimates, standard errors, and 95% HDPIs from Bayesian logistic mixed-effects models fit to the probability of a new fixation on the SRC image in subject RP and *where* RC filler trials vs. comparable argument gap trials. Parentheses indicate the level of each factor coded as positive (+0.5).

	Effect	Posterior $\hat{\beta}$	Posterior σ_{β}	95% CRI
Pre	Intercept	0.94	0.17	(0.62, 1.28)
	ControlType (Where v. SubjRP)	0.08	0.19	(-0.29, 0.45)
	DepType (Controls v. Gap)	0.01	0.12	(-0.22, 0.26)
	N1 (IN)	0.18	0.28	(-0.38, 0.73)
	CType $\times$ N1	-0.03	0.31	(-0.64, 0.57)
	DType $\times$ N1	-0.10	0.21	(-0.52, 0.33)
Verb	Intercept	0.58	0.19	(0.22, 0.95)
	ControlType (Where v. SubjRP)	0.04	0.18	(-0.31, 0.40)
	DepType (Controls v. Gap)	0.14	0.13	(-0.10, 0.40)
	N1 (IN)	-0.03	0.29	(-0.61, 0.55)
	CType $\times$ N1	0.15	0.31	(-0.46, 0.75)
	DType $\times$ N1	-0.10	0.22	(-0.54, 0.34)
Co-Argument	Intercept	0.49	0.17	(0.16, 0.83)
	ControlType (Where v. SubjRP)	-0.19	0.20	(-0.59, 0.21)
	DepType (Controls v. Gap)	-0.16	0.13	(-0.42, 0.09)
	N1 (IN)	0.51	0.29	(-0.08, 1.08)
	CType $\times$ N1	-0.06	0.33	(-0.71, 0.58)
	DType $\times$ N1	0.13	0.26	(-0.38, 0.65)
Post 1	Intercept	1.04	0.21	(0.63, 1.46)
	ControlType (Where v. SubjRP)	0.18	0.20	(-0.22, 0.57)
	DepType (Controls v. Gap)	-0.01	0.15	(-0.29, 0.29)
	N1 (IN)	0.19	0.28	(-0.36, 0.75)
	CType $\times$ N1	-0.30	0.33	(-0.93, 0.35)
	DType $\times$ N1	0.08	0.24	(-0.39, 0.56)
Post 2	Intercept	0.56	0.18	(0.20, 0.92)
	ControlType (Where v. SubjRP)	-0.09	0.18	(-0.44, 0.26)
	DepType (Controls v. Gap)	0.27	0.11	(0.07, 0.49)
	N1 (IN)	0.13	0.27	(-0.40, 0.65)
	CType $\times$ N1	-0.18	0.31	(-0.80, 0.45)
	DType $\times$ N1	-0.08	0.19	(-0.46, 0.30)

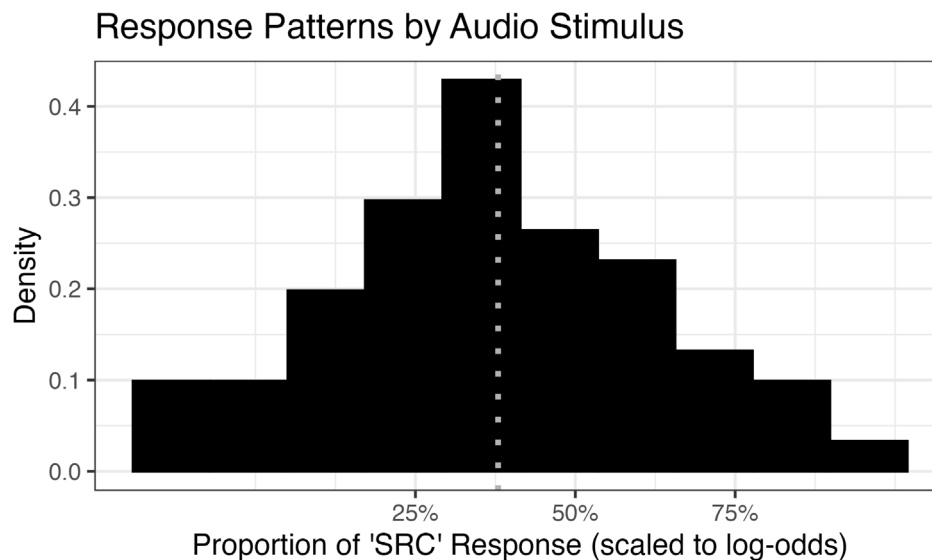


Fig. 10. The distribution of “SRC” response rates per individual audio stimulus in the Gap conditions. The dotted vertical line indicates the mean.

Nevertheless, in many cases of purported global ambiguities in other languages, speakers and listeners consider certain prosodic markings as a strategy for disambiguating a sequence of words towards one interpretation or another (Wagner & Watson, 2010), e.g. boundary placement as a cue for modifier attachment height in English (Maynell, 1999, cited in Fodor, 2002; Speer et al., 2011), or boundary placement and intonational tune as a cue for the relative scope of sentential negation and *because* in English (Hirschberg & Avesani, 2000; Kitagawa & Fodor, 2006).

One might wonder whether there are any distinguishing cues available to Santiago Laxopa Zapotec speakers and listeners for prosodically disambiguating RP-less RCs. To the best of our knowledge from our general study of the language, there are no such cues, at least none which are used systematically. Nevertheless, we consider the possibility of such cues to be an important question, with consequences for the interpretation of our study. If there were cues which we did not control for in our stimuli, they might have pushed participants in one direction or the other for each particular stimulus. In that case, the apparent

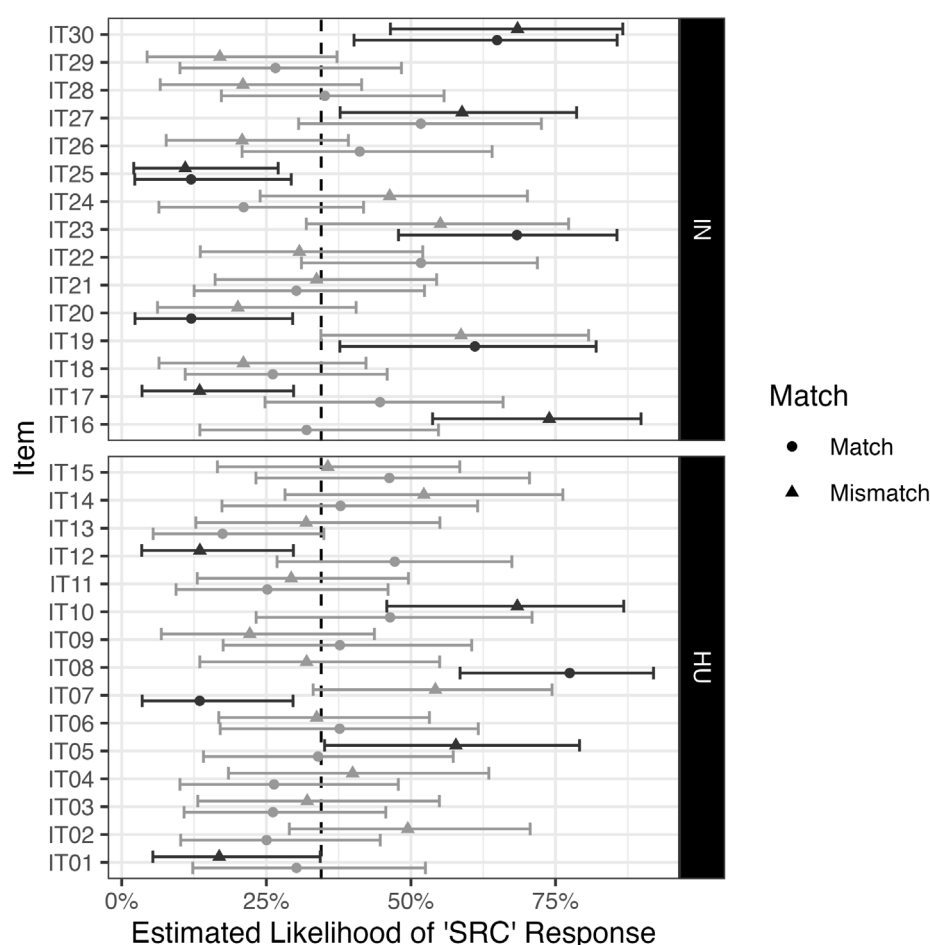


Fig. 11. The estimated likelihood of “SRC” response rates per individual audio stimulus in the Gap condition, organized per item and Match condition. Points reflect posterior means from the mixed-effects model, while error bars reflect 95% highest-density posterior intervals, and the dotted line reflects the global expected likelihood. Stimuli for which HDPIs did not include the global expected value are highlighted in black.

patterns of ambiguity in responses and eye movements may actually be due to a blend of largely SRC-biased and ORC-biased stimuli.

We can rule out this possibility on the basis of an examination of stimulus-wise variability in our response data for trials in the Gap condition. The response patterns for our individual recorded stimuli are not bimodally distributed between SRC-biased and ORC-biased categories, but instead clustered around a typical value of about 40% “SRC” responses (Fig. 10). To measure the extent of this homogeneity more closely, we used brms to fit an intercept-only binomial regression with random intercepts by stimulus, and considered the relationship between the posterior 95% HDPIs for each stimulus as compared to the expected value for an unknown stimulus (the fixed global intercept). Of the 60 stimuli that entered this analysis, the large majority (44) patterned close to the typical value, with HDPIs which included the global intercept (Fig. 11). Most stimuli, we conclude, did not feature any particular bias, from prosody or otherwise.

A remaining 16 stimuli suggested some exceptional bias towards or away from an SRC interpretation, including 3 stimuli which received unanimous ORC interpretations. We investigated these items more closely to better understand the source of these biases. In the first place, we observe that many of them show some consistent pattern attributable to the plausibility of certain verb-argument relations. For instance, across multiple stimuli, participants very rarely accepted “pot” or “sugarcane” as a subject of “cover”, and across another set of stimuli, we observe that they routinely preferred interpretations where a *da’a bep* (*capisallo* in Spanish, a textile used for rain protection, typically made out of reeds in the region around Santiago Laxopa) “hid” a

person, over the reverse interpretation. Such multi-stimulus plausibility patterns seem to explain the direction of the bias in 11 of the 16 more biased stimuli, including all of those unanimously interpreted as ORCs. Qualitative prosodic investigation of the remaining 5 recordings suggests no systematic patterns that could explain their bias.

While we cannot fully rule out that there are prosodic strategies available in Santiago Laxopa Zapotec to disambiguate RCs without RPs, we are confident from this analysis that the recordings used in our study did not feature any substantial uncontrolled prosodic variability which would explain the overall variability in interpretations. Instead, stimuli generally elicited a homogeneous, even mixture of interpretations.

Data accessibility statement

Data, stimuli, analysis scripts, fitted models, and supplementary analyses are available in a repository hosted by the Open Science Foundation, available at <https://doi.org/10.17605/OSF.IO/8JTNZ>.

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