



Cognitive Science 47 (2023) e13227

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ISSN: 1551-6709 online

DOI: 10.1111/cogs.13227

# Memory Versus Expectation: Processing Relative Clauses in a Flexible Word Order Language

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Received 9 June 2021; received in revised form 11 September 2022; accepted 12 November 2022

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## Abstract

Memory limitations and probabilistic expectations are two key factors that have been posited to play a role in the incremental processing of natural language. Relative clauses (RCs) have long served as a key proving ground for such theories of language processing. Across three self-paced reading experiments, we test the online comprehension of Hungarian subject- and object-extracted RCs (SRCs and ORCs, respectively). We capitalize on the syntactic properties of Hungarian that allow for a variety of word orders within RCs, which helps us to delineate the processing costs associated with memory demand and violated expectations. Results showed a processing cost at the RC verb for structures that have longer verb-argument distances, despite those structures being more frequent in the corpus. These findings thus support theories that attribute processing difficulty to memory limitations, rather than theories that attribute difficulty to less expected structures.

**Keywords:** Language processing; Relative clauses; Memory models; Predictive processing; Syntactic parsing

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## 1. Introduction

Relative clauses (RCs) comprise some of the best-studied linguistic structures in sentence processing, and in particular, in the processing of syntactic complexity. Our starting point

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Stimuli, data, and the scripts used for data visualization and analysis can be found in the following OSF repository: <https://osf.io/z5pqs/>

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is the asymmetry observed between the English subject-extracted relative clause (SRC) and object-extracted relative clause (ORC): ORC (1-b) is harder to process than SRC (1-a).

- (1) a. The engineer [<sub>RC</sub> who \_ annoyed the analyst] wrote a report about the project.  
 b. The engineer [<sub>RC</sub> who the analyst annoyed \_] wrote a report about the project.

There is a large body of literature investigating this phenomenon, drawing on numerous methodologies, speaker populations, and languages, but it is still an open question what theory of processing difficulty best explains the findings. In particular, three families of accounts that we will focus on in this paper—memory-, expectation-, and thematic role-based accounts—all adequately capture the basic processing asymmetry in RCs in English.

We report on three self-paced reading (SPR) experiments that capitalize on the word order flexibility of Hungarian in order to probe the cross-linguistic applicability of different accounts of RC processing. In Hungarian, the more frequent SRC and ORC structures have longer verb-argument dependencies, making it an ideal testing case, since the predictions of memory- and expectation-based accounts diverge. Our empirical findings suggest that memory-based accounts more adequately capture Hungarian RC processing. Additionally, our results provide some, albeit more mixed, evidence for thematic role-based accounts.

The rest of the paper is structured as follows. In Section 2, we discuss prominent accounts of RC processing (2.1) and introduce the relevant word order properties of Hungarian (2.2). Section 3 reports on the findings of Experiment 1, which manipulated RC-internal word order. Section 4 reports on Experiment 2, which added a biasing context manipulation to the experimental design. Section 5 reports on Experiment 3, which compared subject-modifying RCs to object-modifying ones. Section 6 offers general discussion of the findings of the three experiments. Section 7 concludes.

## 2. Background

In this section, we review accounts of RC processing, focusing especially on memory-based, expectation-based, and thematic role-based accounts. Following that, we discuss the relevant word order properties of RCs in Hungarian.

### 2.1. Accounts of RC processing

While earlier theories posited a universal subject-object asymmetry to explain RC processing, invoking, for example, differences in accessibility (Keenan & Comrie, 1977) or structural asymmetries leading to reanalysis (Frazier, 1985; Frazier & Fodor, 1978), in this paper, we focus primarily on accounts that do not posit such a universal subject advantage. Instead, the accounts we will discuss attribute importance to (1) limitations on memory, (2) probabilistic expectations, or (3) the cost of switching thematic roles. Below, we give an overview of the relevant theories, how they capture the observed basic asymmetry between the processing of SRCs and ORCs in English, and their broader cross-linguistic empirical validity.

Memory-based accounts One family of accounts appeals to linguistic structure and limitations on working memory. For instance, the Dependency Locality Theory (DLT, Gibson, 1998) makes reference to retrieval or integration cost, which increases as the linear distance between codependents (i.e., the filler and the gap or the verb and its arguments, etc.) increases. Because English is an SVO language, ORCs instantiate a longer dependency than SRCs, so processing them results in a greater incurred retrieval cost. Additionally, at the RC verb (*annoyed* in 1), its arguments (*engineer* and *analyst*) need to be integrated. When processing an ORC, there are two noun phrases (NPs) available for integration at the verb; but when processing an SRC, there is only one. Another component of DLT is storage cost, which increases with the number of heads that are predicted at any given point in the structure. At the RC-internal noun phrase in ORCs (*analyst* in 1-b), three incomplete dependencies need to be maintained, namely: (1) the main clause subject (*engineer*) depends on the predicted main verb, (2) *who* depends on the predicted object position of the RC verb, and (3) the RC-internal noun phrase depends on the predicted subject position of the RC verb. In contrast, when processing SRCs, there are never this many incomplete dependencies.

The Activation and Cue-based Retrieval account (Lewis & Vasishth, 2005) makes similar predictions to DLT. A key component of this account is similarity-based interference: in order to integrate the RC verb (*annoyed*) with its arguments, those arguments need to be retrieved from memory. This retrieval involves cue-based competition among the stored elements, that is, among NPs that can act as the subject and object of the verb. In ORCs, two NPs (*engineer* and *analyst*) need to be retrieved and associated with the role of object and subject. But they interfere with each other due to having similar features, for example, being singular and animate, which then results in processing cost. Both DLT and the Activation and Cue-based Retrieval account thus successfully predict a processing cost for ORCs in English, incurred at the RC verb, where retrieval or integration happens. Several studies have indeed provided strong support for memory-based theories, studying RCs not only in English (Ford, 1983; Gordon, Hendrick, & Johnson, 2001; Grodner & Gibson, 2005; King & Just, 1991), but also, for example, in French (Cohen & Mehler, 1996; Holmes & O'Regan, 1981), Basque (Carreiras, Duñabeitia, Vergara, de la Cruz-Pavía, & Laka, 2010), and (less unequivocally) Chinese (Hsiao & Gibson, 2003; Gibson & Wu, 2013).

Expectation-based accounts Expectation-based theories of syntactic complexity emphasize the experience that language users have with different linguistic structures. Two prominent complexity metrics for expectation-based theories are entropy reduction (Hale, 2003, 2006) and surprisal (Hale, 2001; Levy, 2008)—in this paper, we concentrate on the latter. On such an account, processing cost is predicted for unexpected structures, that is, structures that a language user has less experience with. More specifically, it is assumed that comprehenders maintain detailed probabilistic expectations about upcoming linguistic input in context. The lower the likelihood of a word given the preceding context, the more difficult it is to process. Probabilistic expectation can be estimated based on corpus frequencies. For English, the SRC-ORC processing asymmetry has been attributed to the relative frequency of the two constructions: for sentences where both RC noun phrases are full and definite, SRCs are much more common than ORCs (Hale, 2001; Levy, 2008; Real & Christiansen, 2007). Therefore, the surprisal of an ORC is higher than that of an SRC.

In the cross-linguistic context, Levy, Fedorenko, and Gibson (2013, p. 465) make the following generalization (though cf. Safavi, Husain, & Vasishth, 2016): while support for memory-based accounts comes predominantly from studies investigating languages with SVO word order and impoverished morphology (see above), studies of verb-final, morphologically rich languages have yielded results that favor expectation-based theories. Examples of the latter include Hindi (Vasishth & Lewis, 2006), German (Konieczny, 2000; Levy & Keller, 2013), Japanese (Nakatani & Gibson, 2008; Ueno & Garnsey, 2008), Korean (Kwon, Gordon, Lee, Kluender, & Polinsky, 2010), and some mixed findings for Chinese (Jäger, Chen, Li, Lin, & Vasishth, 2015; Wu, Kaiser, & Vasishth, 2017).

**Thematic role-based accounts** Thematic role-based accounts attribute processing cost to switching between the sentential subject's thematic role in the RC and its role in the main clause (MacWhinney & Pléh, 1988; Sheldon, 1974; Staub, Dillon, & Clifton Jr., 2017). Staub et al.'s (2017) account captures the SRC-ORC asymmetry in the following way. In the subject-modifying ORC in (1-b), *engineer* is first assigned a subject thematic role in the main clause, but then an object role in the RC. SRCs, on the other hand, require no such switch: *engineer* is the subject of both the main clause and the RC. This account thus correctly predicts a difficulty for ORCs in subject-modifying RCs. The prediction, however, flips for object-modifying RCs—something we investigate in more detail in Experiment 3. Throughout the paper, in line with Staub et al. (2017), we use “thematic role” switch as a cover term, irrespective of whether this role switch is in fact syntactic or thematic.

It must be noted that though processing cost that arises from the switching of thematic roles could, in principle, be relevant in a variety of syntactically complex sentences, Staub et al.'s (2017) particular experiments investigated only subject-modifying RCs. Specifically, they focused on the processing cost predicted for the main clause verb in subject-modifying ORCs, and found that though this cost is present in some sentences, it is eliminated when there is additional intervening material before the matrix verb. We return to these details in our discussion of Experiment 3.

In sum, despite intense study, the available empirical data still cannot adjudicate among competing theories of RC processing difficulty. As we have seen, in the case of English, all accounts outlined above converge in predicting the basic SRC-ORC processing asymmetry. In brief, SRCs instantiate a shorter verb-argument dependency than ORCs; SRCs are more frequent than ORCs; and ORCs require a switch in thematic roles, while SRCs do not. This highlights the importance of conducting cross-linguistic investigations; depending on the characteristics of a specific language, the predictions of different RC processing accounts may diverge.

## 2.2. Word order flexibility in Hungarian

As we have seen, several influential theories of RC processing correctly capture the SRC-ORC asymmetry observed in English. However, the predictions of the different theories diverge once we take a cross-linguistic perspective. Languages whose word order is flexible, like Hungarian, are especially relevant in this regard, since they might allow for SRCs and ORCs to have variable word order.

The basic word order of Hungarian is SVO, but in fact all six permutations of S, V, and O are possible (É. Kiss, 2002). That is, a transitive verb and its two arguments (*keresi* “seeks,” *János*.NOM “John,” *Marit* “Mary.ACC”) can occur in any of the theoretically possible orders (2). Note that the relevant noun phrases are unambiguously identified as the subject versus object via morphological case-marking: the subject *János* bears nominative case (which has no overt suffix), while the object *Mary* bears the accusative (which is marked by the *-(V)t* suffix)..

(2) John seeks Mary.

- a. János keresi Marit.  
János.NOM seeks Mary.ACC
- b. János Marit keresi.
- c. Marit János keresi.
- d. Marit keresi János.
- e. Keresi János Marit.
- f. Keresi Marit János.

The grammatical functions of subject, object, and so on are not linked to invariant structural positions in the sentence; rather, the different structural positions are associated with logical functions. A Hungarian sentence can be divided into a topic part and a predicate part. The preverbal section of the predicate phrase contains operator positions, for example, a focus constituent, a distributive quantifier position, or negation (É. Kiss, 2002). In this paper, we report on experiments that make use of possible word order differences in Hungarian, while controlling for potential information structural differences.

Utilizing flexibility in word order, we can construct two variants, differing in locality, for both SRC and ORC. Locality is defined as the linear distance between the verb and the extracted argument. The word-order variants where the RC verb directly follows the relative pronoun will be called “local,” and the word orders where a noun phrase intervenes between the relative pronoun and the RC verb will be called “nonlocal.” As shown by the examples below, SRCs (3) can occur either in a VO (local) or OV (nonlocal) configuration (a-b, respectively), while ORCs (4) can occur in VS (local) or SV (nonlocal) configurations (a-b, respectively). For ease of interpretation, throughout this paper, the RC verb will be bolded, and the RC noun phrase will appear in a box. See also Table 1 for a schematic representation of the word orders.

(3) a. SRC, VO (local)

A mérnök, aki idegesítette **az elemzőt**...  
the engineer.NOM who.NOM annoyed the analyst.ACC

b. SRC, OV (non-local)

A mérnök, aki **az elemzőt** idegesítette...  
the engineer.NOM who.NOM the analyst.ACC annoyed

**Both:** ‘The engineer who annoyed the analyst... (wrote a report...).’

Table 1

Schematic summary of the locality manipulation in Hungarian, which is used in Experiments 1–3

Condition	Subject	Rel. pr.	Pre-V NP	RC verb	Post-V NP
SRC local	the engineer	who.NOM		annoyed	the analyst.ACC
SRC nonlocal	the engineer	who.NOM	the analyst.ACC	annoyed	
ORC local	the engineer	who.ACC		annoyed	the analyst.NOM
ORC nonlocal	the engineer	who.ACC	the analyst.NOM	annoyed	

(4) a. ORC, VS (local)

A mérnök, akit idegesített az elemző...  
 the engineer.NOM who.ACC annoyed the analyst.NOM

b. ORC, SV (non-local)

A mérnök, akit az elemző idegesített...  
 the engineer.NOM who.ACC the analyst.NOM annoyed

**Both:** ‘The engineer who the analyst annoyed... (wrote a report...).’

In English, SRCs always instantiate the local and ORCs the nonlocal configuration; but in Hungarian, both SRCs and ORCs can occur in local or nonlocal orders. For such sentences, predictions made by memory-based theories should align with word order instead of extraction site (SRC vs. ORC), with the greatest difficulty in word orders where the verb is furthest away from the head noun, namely, nonlocal orders: (3-b) and (4-b).<sup>1</sup> This manipulation will thus help tease apart the processing accounts outlined above, with special attention to the competing predictions of memory-based and expectation-based accounts.

Previous work on Hungarian has focused on manipulating the thematic roles of both the head NP and the RC NP, testing the possible combinations of Subject-Subject (illustrated in (5)), Subject-Object, Object-Subject, and Object-Object.

(5) The boy who sees the girl chases the policeman. Subject-Subject

MacWhinney and Pléh (1988) found that Subject-Subject sentences were the easiest to process and Subject-Object sentences were the hardest, while Object-Subject and Object-Object configurations were of intermediate difficulty. This was taken to support a particular instantiation of thematic role-based accounts (viz., perspective maintenance). Kas and Lukács (2011) found that, among other factors, the interruption of main clauses with an RC led to processing difficulty, and so did greater distance between the verb and its arguments. Overall, these findings support memory-based theories. Existing work on Hungarian clearly differs from ours in terms of its methodology: Kas and Lukács’s (2011) study tested children’s comprehension of RC sentences in an act-out task, and while MacWhinney and Pléh (1988) investigated adult language processing, they measured only whole-sentence reading times (RTs). In order to get a more fine-grained measure of the locus of processing difficulty, we use SPR in our experiments.

There are other languages with similar word order flexibility properties. In Russian, in particular, the default word order of RCs mirrors that of English: SRCs have VO word order, and ORCs have SV word order. But both types of RCs can occur in a scrambled word order, where SRCs have OV word order and ORCs have VS word order. Thus, Russian also potentially allows us to disentangle effects of extraction site from those of word order and dependency locality. Our study is especially similar to Levy et al.'s (2013), who, in a series of SPR experiments, found processing difficulty at the RC verb for structures with a longer verb-argument dependency (OV/SV word orders), in both SRCs and ORCs. This was taken to indicate memory-based processing difficulty. However, in Russian, structures with longer dependencies, in which the RC-internal noun phrase appears before the RC verb, are less frequent than the structures where the RC noun phrase follows the RC verb (Levy et al., 2013)—at least in the case of RCs that contain full NPs. Therefore, the predictions of memory- and expectation-based accounts actually align for Russian, since both predict sentences with the longer dependency to be harder to process. Consequently, Levy et al.'s (2013) finding of processing cost at the RC verb is also compatible with expectation-based theories.

Hungarian is similar to Russian in that extraction site and locality, that is, the local proximity of the RC verb to the relative pronoun, can be varied independently, making it particularly suitable for teasing apart the predictions of memory-based and expectation-based accounts. And critically different from Russian, as we will show in Section 3.3, RCs with longer verb-argument dependencies are more frequent in Hungarian than those with shorter dependencies, making distinct predictions for expectation-based and memory-based accounts for Hungarian RCs. Thus, Hungarian better teases apart memory- and expectation-based theories. We come back to this point of cross-linguistic comparison in more detail in the General discussion (Section 6), comparing our findings to the results of studies that investigated Russian (Levy, Fedorenko, and Gibson, 2013; Price & Witzel, 2017).

Another dimension of word order flexibility important for testing theories of RC processing is headedness: the relative order of the head noun and the RC. As briefly reviewed above, verb-initial and verb-final languages tend to yield results supporting different theories. But especially relevant in this regard are languages that have both head-initial and head-final RCs, since these allow for the manipulation of headedness independent of other properties. For studies investigating such languages, see i.a. Wagers, Borja, and Chung (2018) on Chamorro and Pizarro-Guevara (2020) on Tagalog, who find an SRC advantage in head-initial structures, but an attenuation of this advantage in head-final ones. The current study will only focus on Hungarian head-initial RCs, but we note that Hungarian grammar also allows for RCs to be head-final. We leave the investigation of headedness in Hungarian RCs to future research.

In this paper, we report on the findings of three SPR experiments that capitalized on the word order flexibility of Hungarian. In Experiment 1, we varied extraction site and locality, that is, the distance between the relative pronoun and the RC verb. Experiment 2 is identical to Experiment 1 in its basic word order manipulation, but with the addition of a discourse context that biased participants toward an RC interpretation. In Experiment 3, we compared subject- and object-modifying relative clauses. Overall, our findings strongly support memory-based theories of RC processing, with some evidence for thematic role-based accounts.

### 3. Experiment 1: Locality manipulation

Experiment 1 is an SPR experiment manipulating locality in Hungarian RCs; specifically, we varied extraction site (SRC vs. ORC) and locality (local VO/VS word order vs. nonlocal OV/SV word order).

#### 3.1. Participants

One hundred and ten native speakers of Hungarian participated in an experiment online, and received a compensation in gift cards (value 1000HUF or 3EUR). Participants were recruited on Facebook, via word-of-mouth recruitment and posts in various groups. Based on a background questionnaire, participants who currently live, or have previously spent considerable time outside of Hungary were excluded from analysis. Participants falling outside of the 18- to 35-year-old age range, as well as bilinguals, were also excluded. Data from 81 participants are reported below.

#### 3.2. Materials and procedure

An SPR experiment was conducted online, on the IbexFarm platform (Drummond, 2007). The experiment had a  $2 \times 2$  design. The factor Extraction site had two levels (SRC and ORC) and the factor Locality also had two levels (local and nonlocal). As mentioned, Hungarian allows for the independent manipulation of extraction site (SRC vs. ORC) and verb position. The four sentences below (repeated from (3) to (4)) thus exemplify the four experimental conditions; see also Table 1 for a schematic illustration of these conditions. Following the definition of locality that we adopt, in what follows we will be referring to the sentence type/condition in (6-a) as SRC local, (6-b) as SRC nonlocal, (7-a) as ORC local, and (7-b) as ORC nonlocal. Experimental items were translated and modified from Levy et al. (2013).

##### (6) a. SRC, VO (local)

A mérnök, aki idegesítette az elemzőt hosszú évek óta,  
 the engineer.NOM who.NOM annoyed the analyst.ACC long years since  
 beszámolót írt a projektről.  
 report.ACC wrote the project-about

##### b. SRC, OV (non-local)

A mérnök, aki az elemzőt idegesítette hosszú évek óta,  
 the engineer.NOM who.NOM the analyst.ACC annoyed long years since  
 beszámolót írt a projektről.  
 report.ACC wrote the project-about

**Both:** ‘The engineer who annoyed the analyst for many years wrote a report about the project.’



(7) a. ORC, VS (local)

A mérnök, akit idegesített az elemző hosszú évek óta,  
 the engineer.NOM who.ACC annoyed the analyst.NOM long years since  
 beszámolót írt a projektről.  
 report.ACC wrote the project-about

b. ORC, SV (non-local)

A mérnök, akit az elemző idegesített hosszú évek óta,  
 the engineer.NOM who.ACC the analyst.NOM annoyed long years since  
 beszámolót írt a projektről.  
 report.ACC wrote the project-about

**Both:** ‘The engineer who the analyst annoyed for many years wrote a report about the project.’

All stimuli sentences included RC-final PPs (e.g., *for many years*). This was to provide regions before the main clause (*wrote a report*) that could absorb any spillover effects resulting from the RC-internal manipulation (Levy et al., 2013). Additionally, in written Hungarian, the RC (prescriptively) must be preceded and followed by a comma, and without the PP, the second comma would have appeared in the same SPR region as the critical RC verb or RC-internal noun phrase.

Following Levy et al. (2013), nouns (e.g., *engineer, analyst*) were counterbalanced to occur both in head noun phrase and RC noun phrase positions. This was done in order to avoid a confound between event plausibility (i.e., is an engineer more likely to annoy an analyst, or the other way around?) and extraction site. This doubled the experimental design: each of the above four conditions had two variants with the order of the two noun phrases switched. In other words, there were eight versions of each lexically distinct item set. For the item set illustrated in (6)–(7), for instance, half of the participants saw *the engineer who...* and the other half saw *the analyst who...* In the data analysis, however, we collapsed across this variation in noun phrase position.

Sentences were presented word-by-word: each word appeared in the middle of the screen, and it was replaced by the following word when the participant pressed a key on their keyboard. A binary-choice comprehension question, of the form *Who V-d whom?* (e.g., *Who annoyed whom?*) for experimental items, followed each sentence. The experiment included two practice, 32 experimental, and 38 filler items.

### 3.3. Predictions

Under memory-based accounts, word orders supporting local/shorter verb-argument dependencies would be less costly (VO, VS) than nonlocal ones (OV, SV), irrespective of SRC versus ORC status. That is, (6-a) and (7-a), where there is only one noun phrase available for integration at the verb, are predicted to be less costly to process than (6-b) and (7-b), where there are two noun phrases to integrate at the verb. This cost for nonlocal structures is predicted to manifest on the RC verb, where the arguments of the verb are integrated.

Table 2  
Counts from the part-of-speech-tagged Hungarian National Corpus

Structure	Count
SRC, local	44
SRC, nonlocal	466
ORC, local	26
ORC, nonlocal	50

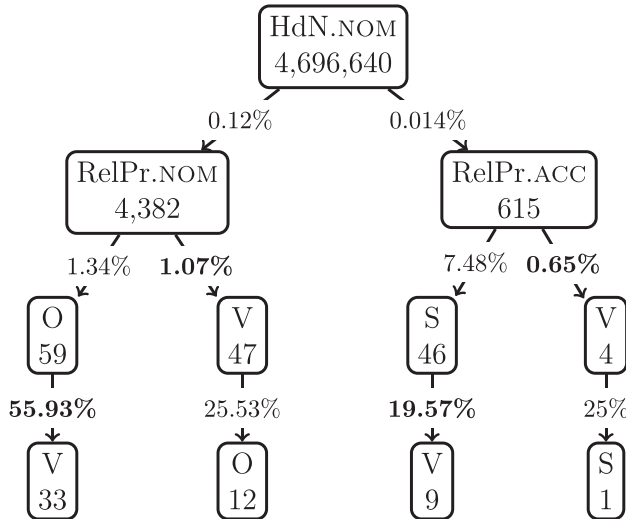


Fig. 1. Incremental counts and probabilities (based on the Hungarian National Corpus).

To check the predictions of expectation-based accounts, we carried out corpus searches in the Hungarian National Corpus (Oravecz, Váradi, & Sass, 2014).<sup>2</sup> Specifically, we searched for sentences that contain a string that matches the critical region of our experimental stimuli. That is, to give an example, we classified a sentence as “SRC, local,” if it contained the following string: (determiner); nominative-marked head noun; (,); nominative-marked 3.SG relative pronoun; 3.SG verb; (determiner) accusative-marked noun—elements in parentheses were optional. The results of our corpus searches can be seen in Table 2. We found that SRCs are overall more frequent than ORCs (510 vs. 76;  $\chi^2=321.43$ ,  $df=1$ ,  $p<.001$ ). Additionally, our corpus findings revealed that nonlocal structures are more frequent than local ones, both for SRCs (466 vs. 44;  $\chi^2=349.18$ ,  $df=1$ ,  $p<.001$ ) and for ORCs (50 vs. 26;  $\chi^2=7.58$ ,  $df=1$ ,  $p<.01$ ).

Though the overall frequency counts are informative, in order to be able to derive predictions for online RTs, we also calculated incremental probabilities, that is, the probability of each word given the sentential context—see Fig. 1. These probabilities were calculated using the following corpus search procedure. For instance, to calculate the probability of transitioning to a nominative-marked relative pronoun (RelPr.NOM in Fig. 1) after a head noun phrase (Hdn.NOM in Fig. 1), a corpus search was carried out for a nominative-marked noun phrase

at the beginning of a sentence (resulting count: 4,696,640), as well as for a string where that noun phrase is immediately followed by the nominative relative pronoun (4382). This gives us 0.12% as the incremental probability. All probabilities reported in Fig. 1 were calculated in this way.<sup>3</sup> As we can see in Fig. 1, transitioning to the nominative-marked pronoun, that is, an SRC parse, has a probability of 0.12%, while the accusative/ORC counterpart is an order of magnitude less likely (0.014%). Expectation-based accounts would, therefore, predict an advantage for SRCs, specifically at the relative pronoun, where case-marking disambiguates SRC versus ORC. Additionally, we can see that within each of SRC (Hdn.NOM-RelPr.NOM...) and ORC (Hdn.NOM-RelPr.ACC-...), transitioning to a verb (V) has a higher probability when an RC-internal noun phrase (S or O) has already been seen: 55.93% versus 1.07% for SRC and 19.57% versus 0.65% for ORC. Given this, expectation-based accounts would predict that nonlocal structures should be easier to process than local ones, with the difference manifesting at the RC verb. These specific predictions about the online incremental processing—namely, a preference for SRCs over ORCs and for nonlocal structures over local ones—are in line with the global frequency counts reported in Table 2.

We note that the corpus findings reported in Fig. 1 and Table 2 are the results of strict search patterns identifying only sentences that are an exact match for (the critical region of) our experimental stimuli. We, therefore, conducted an additional analysis, where we relaxed our search criteria and manually classified a random sample of 200 SRCs and 200 ORCs. This analysis is detailed in Appendix A, and its main results are in line with what is reported above: that there should be a preference for nonlocal structures over local ones.

Finally, the predicted advantage for nonlocal structures at the RC verb can also be described more generally as an expectation-driven antilocality effect (Konieczny, 2000, 2005; Levy and Keller, 2013; Nakatani & Gibson, 2008; Schwab, Xiang, & Liu, 2022; Ueno & Garnsey, 2008; Vasishth & Lewis, 2006, i.a.). In the processing of an RC, once comprehenders have encountered the relative pronoun, they are able to predict an RC verb. Once this prediction is made, any additional material that occurs between the pronoun and the verb sharpens comprehenders' expectations about the location and identity of the verb (see also Levy et al. 2013, p. 464). This ultimately facilitates the processing of the RC verb.

In summary, then, expectation- and memory-based accounts make opposing predictions for the RC verb in particular: expectation-based accounts predict nonlocal structures to be easier, while memory-based accounts predict local structures to be easier—irrespective of SRC/ORC status. Additionally, at the relative pronoun, expectation-based accounts predict an SRC-ORC asymmetry: irrespective of local/nonlocal status, SRCs are predicted to be easier.

### 3.4. Results and analysis

The overall comprehension question accuracy rate in Experiment 1, averaged over conditions, was 87.5%. Before analysis, trials where the comprehension question was incorrectly answered were excluded. Data points with an RT over 10,000 ms were excluded, removing 0.32% of the data.<sup>4</sup> Fig. 2 shows the RT results from Experiment 1. Note that the plot only includes the word regions (and the spillover region) where different processing accounts predict an effect to occur. For other regions within the RC, please see Fig. B1 in Appendix B

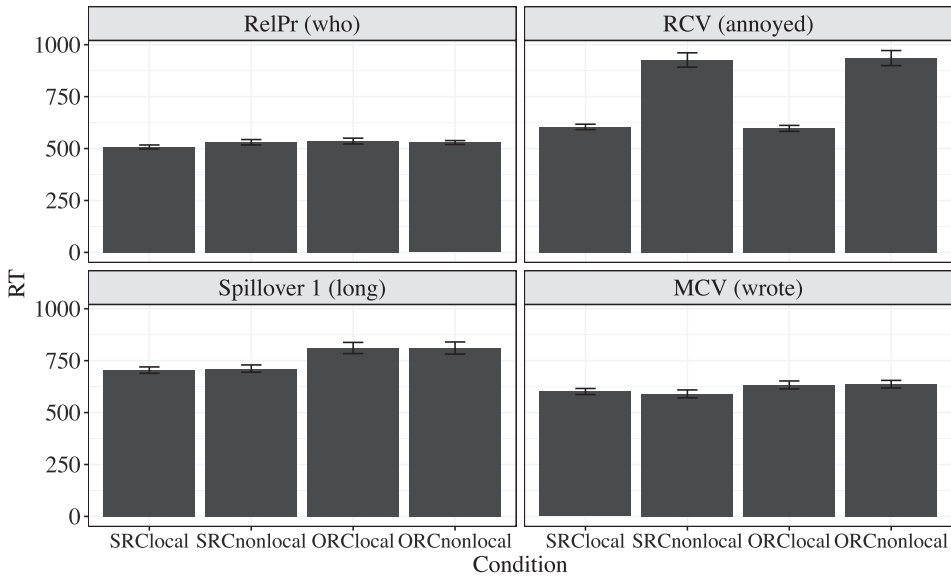


Fig. 2. Experiment 1: Mean reading times for the critical word regions. Error bars represent standard error.

for the word-by-word RT results. For the statistical analysis, RTs were additionally log-transformed.

To analyze RTs, we fit Bayesian mixed effects regression models using the *brms* package from R (Bürkner, 2017). The statistical model included fixed effects of Extraction site (SRC vs. ORC), Locality (local vs. nonlocal), and their interaction, and the full random effect structure including both by-item and by-participant intercepts and slopes.<sup>5</sup> Fixed effects predictors were sum-coded before analysis: ORC:  $-0.5$  and SRC:  $0.5$  within the Extraction site factor; local:  $-0.5$  and nonlocal:  $0.5$  within the Locality factor. To control for spillover effects, RT on the preceding word was also included as a fixed effect in the models. Each word region was analyzed separately. Statistical analyses were conducted for regions where processing accounts predict an effect to occur—see Section 3.3. We also analyzed the region immediately following the critical regions within the RC, that is, the first word in the RC-final PP, where the potential spillover effects would manifest (Spillover 1). We report the posterior parameter estimates ( $\hat{\beta}$ ), the standard error (SE), together with the 95% credible intervals (CrI) and the posterior probability that the parameter value is larger/smaller than 0 ( $P(\beta > 0)$ ;  $P(\beta < 0)$ ). The 95% CrI can be interpreted as there being a 0.95 probability, given our data and prior assumptions, that the true population mean of the relevant parameter lies within this interval. We use this interval as our primary metric for drawing statistical inferences. In particular, if the interval excludes 0, it can be considered as evidence for an effect.

Table 3 shows the results of the statistical analysis for the main regions of interest, with effects highlighted by gray background color. There was some evidence for an effect of Extraction site at the relative pronoun (*who*), albeit weaker than the effects found at other regions. At the RC verb (*annoyed*), we found a strong effect of Locality, such that nonlocal

Table 3

Experiment 1: Results of the Bayesian mixed effects regression model of log-transformed RTs in the critical word regions: parameter estimates, standard errors, 95% CrI, and the posterior probability that the parameter value is larger/smaller than 0

	Estimate ( $\hat{\beta}$ )	SE	95% CrI	Posterior probability
<b>Rel. pronoun (<i>who</i>)</b>				
Extraction site	-0.03	0.01	[-0.05, 0]	$P(\beta < 0) = 0.98$
Locality	0.02	0.02	[-0.01, 0.05]	$P(\beta > 0) = 0.91$
Extraction site $\times$ Locality	0.03	0.03	[-0.03, 0.08]	$P(\beta > 0) = 0.84$
<b>RC verb (<i>annoyed</i>)</b>				
Extraction site	0.01	0.02	[-0.03, 0.05]	$P(\beta > 0) = 0.68$
Locality	0.26	0.03	[0.19, 0.33]	$P(\beta > 0) = 1$
Extraction site $\times$ Locality	0	0.04	[-0.08, 0.08]	$P(\beta > 0) = 0.47$
<b>Spillover 1 (<i>long</i>)</b>				
Extraction site	-0.08	0.02	[-0.12, -0.04]	$P(\beta < 0) = 1$
Locality	0	0.02	[-0.04, 0.05]	$P(\beta > 0) = 0.55$
Extraction site $\times$ Locality	0	0.04	[-0.09, 0.09]	$P(\beta > 0) = 0.51$

Note: Effects of interest are highlighted.

sentences had higher RTs than local sentences. Additionally, in the spillover region (a PP: *long*), there was an effect of Extraction site, such that ORCs had higher RTs than SRCs.

The main clause verb (*wrote*) appeared anywhere in between the seventh and 11th region in the sentence, depending on the item. To factor out the potential effects arising from the main clause verb being in a nonuniform position across items, log-transformed RTs were also residualized to word position before analysis. We found an effect of Extraction site ( $\hat{\beta} = -0.04$ , SE = 0.02, 95% CrI = [-0.08, -0.01],  $P(\beta < 0) = 0.99$ ), such that ORCs had higher RTs than SRCs. But there was no effect of Locality ( $\hat{\beta} = 0$ , SE = 0.02, 95% CrI = [-0.04, 0.03],  $P(\beta < 0) = 0.55$ ) or their interaction ( $\hat{\beta} = -0.01$ , SE = 0.04, 95% CrI = [-0.08, 0.07],  $P(\beta < 0) = 0.58$ ).

### 3.5. Discussion

Our main finding is that at the RC verb (*annoyed*), local (VO, VS) structures were read faster than nonlocal ones (OV, SV), irrespective of SRC/ORC status—in other words, there was a preference for locality. This supports the predictions of memory-, but not expectation-based accounts. Levy et al. (2013), using a similar manipulation in Russian, also found an RT advantage for local sentences at the RC verb. However, as discussed above, local structures are also the more frequent ones in Russian, but not in Hungarian. Hungarian, therefore, better teases apart the predictions of the two competing accounts, and thus provides even stronger support for the memory-based account.

Given that SRCs are overall more frequent than ORCs, expectation-based theories also predict increased RTs for ORCs at the relative pronoun region (*who(m)*), where the SRC versus ORC distinction is made clear by case-marking. Our results provided some but not very strong evidence for this prediction. One possible explanation is that the relative pronoun in Hungarian is simply too short to show an effect. Alternatively, what may be at play is that

the relative pronoun serves two functions: it indicates an RC parse and it further distinguishes SRC from ORC. That is, at the head noun phrase, both main clause and RC continuations are possible, with RCs being much less likely. Given a sentence-initial nominative-marked noun, the likelihood of an RC continuation, that is, the probability that the next word is a relative pronoun, is less than 0.2% (Fig. 1). Nonetheless, at the relative pronoun, a main clause interpretation is ruled out, and the comprehender needs to switch to an unlikely, but now confirmed, RC parse. This means that the surprisal of an RC parse in general is high, irrespective of whether it is an SRC or an ORC. It is then possible that the resulting processing cost overwhelms the processor and obscures more nuanced probability differences between SRC and ORC, which might explain why we did not find a clear SRC-ORC difference at the relative pronoun. This post-hoc hypothesis needs further exploration, which is carried out in Experiment 2.

Lastly, we did observe an overall SRC advantage in later regions: ORCs were read slower in the RC-final postpositional phrase (*for many years*), as well as the main clause verb (*wrote*). The location of the effect is not totally consistent with predictions of an expectation-based account, but it is possible that the expectation-based effect is delayed for some reason. Another possibility is that the effect observed at the main clause points to a thematic role-based account. On such an account, ORCs are harder to process because a (second) thematic switch happens at the main clause verb. We explore this prediction of thematic role-based accounts in a more controlled way in Experiment 3.

## 4. Experiment 2: RC-biasing context

Experiment 1 did not reveal a strong effect at the relative pronoun region, even though case-marking on the relative pronoun signals whether the sentence is an SRC or ORC. SRCs are overall much more frequent than ORCs in Hungarian, and, therefore, expectation-based theories would predict increased RTs at the relative pronoun region in ORCs. However, the lack of a strong effect of Extraction site may be because RC structures are, on the whole, very infrequent in Hungarian. It is possible that participants in Experiment 1 were not expecting an RC continuation after encountering the head noun, making the relative pronoun in general harder to process. This may potentially explain why the more nuanced SRC-ORC frequency difference did not influence processing. To further test whether there is an expectation-based effect on the relative pronoun, Experiment 2 places target sentences in a context that specifically biases toward an RC parse.

### 4.1. Participants

Seventy-six native speakers of Hungarian (recruited via Facebook) participated in an experiment online, and received a compensation in gift cards (value 2000HUF or 6EUR). Based on a background questionnaire, participants who currently live, or have previously spent considerable time outside of Hungary were excluded from analysis. Bilingual participants were also excluded. Data from 67 participants are reported below.

## 4.2. Materials and procedure

Experiment 2 had the same procedure, items ( $N=32$  experimental items) and general design as Experiment 1, that is,  $2 \times 2$  design, crossing Extraction site (SRC vs. ORC) and Locality (local vs. nonlocal). To avoid a confound of event plausibility (is an engineer more likely to annoy an analyst, or the other way around?), the same counterbalancing was employed as in Experiment 1. The additional context manipulation is exemplified below.

(8) **Context story:** Mary is working together with two engineers on a project. She received a report on Sunday, but didn't know which engineer wrote it. She asked her secretary.

a. SRC, VO (local)

A titkárnő azt válaszolta: A mérnök, aki idegesítette az  
the secretary.NOM that.ACC replied the engineer.NOM who.NOM annoyed the  
**elemzőt** hosszú évek óta, volt az, aki beszámolót írt a projektről.  
analyst.ACC long years since was that who report.ACC wrote the project-about

b. SRC, OV (non-local)

A titkárnő azt válaszolta: A mérnök, aki **az elemzőt**  
the secretary.NOM that.ACC replied the engineer.NOM who.NOM the analyst.ACC  
idegesítette hosszú évek óta, volt az, aki beszámolót írt a projektről.  
annoyed long years since was that who report.ACC wrote the project-about

**Both:** 'The secretary replied: The engineer who annoyed the analyst for many years was the one who wrote a report about the project.'

c. ORC, VS (local)

A titkárnő azt válaszolta: A mérnök, akit idegesített az  
the secretary.NOM that.ACC replied the engineer.NOM who.ACC annoyed the  
**elemző** hosszú évek óta, volt az, aki beszámolót írt a projektről.  
analyst.NOM long years since was that who report.ACC wrote the project-about

d. ORC, SV (non-local)

A titkárnő azt válaszolta: A mérnök, akit **az elemző**  
the secretary.NOM that.ACC replied the engineer.NOM who.ACC the analyst.NOM  
idegesített hosszú évek óta, volt az, aki beszámolót írt a projektről.  
annoyed long years since was that who report.ACC wrote the project-about

**Both:** 'The secretary replied: The engineer who the analyst annoyed for many years was the one who wrote a report about the project.'

Participants first saw a screen with a context story (8), and then they proceeded to the SPR trial (8a-d). The context story introduced two individuals of type  $X$  (e.g., *engineer*) and established that a property  $p$  is true of only one of the  $X$  individuals, for example, that they wrote a report. Finally, in the context story, it was asked which of the two  $X$ s is  $p$  (e.g., Mary asked her secretary which engineer wrote a report). SPR sentences included the same Extraction site and Locality manipulation as Experiment 1, but began with three additional

regions before the target sentence, of the form *The Y replied/answered* (e.g., *the secretary replied*). Given the context manipulation, in the secretary's response, a modifier is expected in order to distinguish between the two engineers present in the discourse context. Therefore, the design of this experiment promotes an RC parse (*the engineer who(m)...*), while a main clause interpretation is made less likely. For previous research successfully utilizing similar context manipulations, see i.a. Gibson and Wu (2013), who found that once context eliminates the potential ambiguity with a main clause parse, there is a clear ORC preference in Chinese, as well as Fedorenko, Piantadosi, and Gibson (2012), who found that context reduces within-participants variance, leading to a larger SRC-ORC asymmetry in English than is usually observed in null contexts.

#### 4.3. Predictions

The main predictions of Experiment 1 carry over to Experiment 2. In brief, memory-based accounts predict a cost, that is, increased RTs, for nonlocal structures at the RC verb, where there are two noun phrases available for integration. Expectation-based accounts, on the other hand, predict an advantage for the nonlocal structures at the RC verb, because additional information before the verb helps sharpen predictions about it. This general prediction of antilocality is also supported by corpus-based incremental probabilities.

Expectation-based accounts also predict increased RTs for ORC structures at the relative pronoun—a prediction not clearly borne out in Experiment 1. If the reason why we found no such cost in Experiment 1 is that the overall infrequency of RCs obscures the more nuanced SRC-ORC difference, then we should see this cost manifest in Experiment 2. Because participants are presented with a biasing context preceding the RC sentence, they should now be predicting that RC structure. Therefore, a clearer SRC-ORC difference might arise at the relative pronoun.

#### 4.4. Results and analysis

The overall comprehension question accuracy rate in Experiment 2, averaged over conditions, was 85.4%. Before analysis, trials where the comprehension question was incorrectly answered were excluded. Data points with an RT over 10,000 ms were excluded, removing 0.2% of the data. Fig. 3 shows the RT results from Experiment 2. Similarly to Experiment 1, this plot includes the word regions (and the spillover region) where processing accounts predict an effect to occur. For other regions within the RC, see the word-by-word RT plot (Fig. B2) in Appendix B. For the statistical analysis, RTs were log-transformed. The statistical analysis was identical to that conducted for Experiment 1.

Table 4 shows the results of the statistical analysis for the main regions of interest. There was no effect at the relative pronoun (*who*). At the RC verb (*annoyed*), we found an effect of Locality, as well as an interaction effect, such that nonlocal sentences had higher RTs than local sentences, with this effect being even more pronounced in SRCs than in ORCs. Unlike in Experiment 1, there were no clear effects in the spillover region.

The main clause verb (*wrote*) appeared anywhere in between the 13th and 17th region in the sentence, depending on the item. To factor out the potential effects arising from the



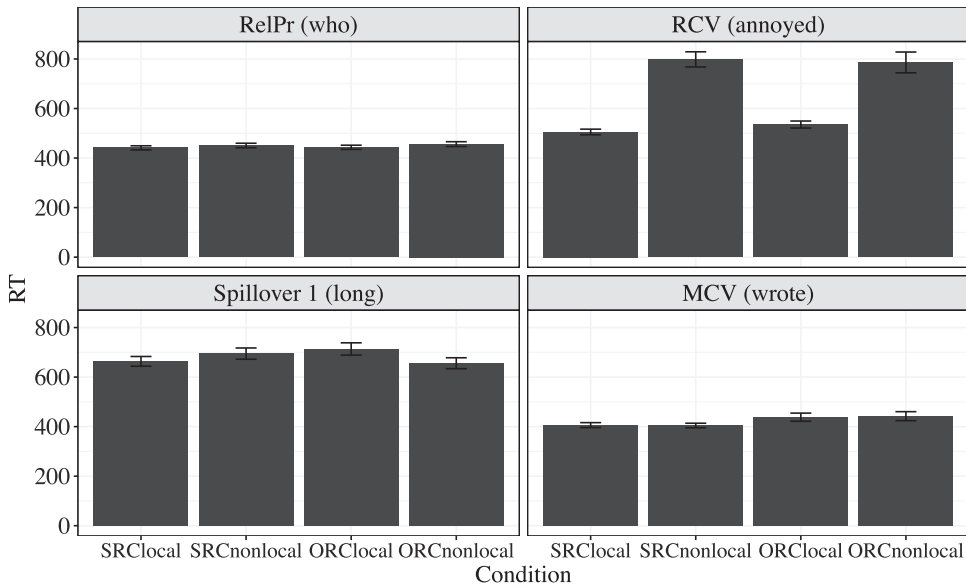


Fig. 3. Experiment 2: Mean reading times for the critical word regions. Error bars represent standard error.

Table 4

Experiment 2: Results of the Bayesian mixed effects regression model of log-transformed RTs in the critical word regions: parameter estimates, standard errors, 95% CrI, and the posterior probability that the parameter value is larger/smaller than 0

	Estimate ( $\hat{\beta}$ )	SE	95% CrI	Posterior probability
<b>Rel. pronoun (<i>who</i>)</b>				
Extraction site	0	0.02	[-0.04, 0.03]	$P(\beta < 0) = 0.56$
Locality	0.02	0.02	[-0.02, 0.05]	$P(\beta > 0) = 0.82$
Extraction site $\times$ Locality	0	0.03	[-0.07, 0.06]	$P(\beta > 0) = 0.45$
<b>RC verb (<i>annoyed</i>)</b>				
Extraction site	0.03	0.03	[-0.02, 0.09]	$P(\beta > 0) = 0.87$
Locality	0.2	0.03	[0.14, 0.27]	$P(\beta > 0) = 1$
Extraction site $\times$ Locality	0.16	0.05	[0.07, 0.25]	$P(\beta > 0) = 1$
<b>Spillover 1 (<i>long</i>)</b>				
Extraction site	0.01	0.02	[-0.04, 0.05]	$P(\beta > 0) = 0.59$
Locality	-0.03	0.03	[-0.08, 0.02]	$P(\beta < 0) = 0.89$
Extraction site $\times$ Locality	0.08	0.05	[-0.02, 0.17]	$P(\beta > 0) = 0.95$

Note: Effects of interests are highlighted.

main clause verb being in a nonuniform position across items, the log-transformed RTs were residualized to word position before analysis. We found no significant effects in this region: Extraction site ( $\hat{\beta} = -0.02$ , SE=0.02, 95% CrI [-0.06, 0.01],  $P(\beta < 0) = 0.89$ ), Locality ( $\hat{\beta} = -0.01$ , SE=0.02, 95% CrI [-0.05, 0.03],  $P(\beta < 0) = 0.69$ ), interaction ( $\hat{\beta} = 0.02$ , SE=0.04, 95% CrI [-0.05, 0.1],  $P(\beta > 0) = 0.73$ ). Nonetheless, there is a numerical trend broadly in line with what we found in Experiment 1: ORCs had higher RTs than SRCs.

#### 4.5. Discussion

In Hungarian, case-marking on the relative pronoun is a strong cue that signals the type of RC: in the sentences tested in our experiments, SRC versus ORC. Given the robust frequency disparity between SRCs and ORCs, with SRCs being more frequent, expectation-based theories would predict a processing cost for ORCs at the relative pronoun. Experiment 1 did not reveal strong evidence for such an effect, and we hypothesized that this may be due to RCs generally being so infrequent that the more nuanced probability differences between SRCs and ORCs are not reflected in RTs. To address this hypothesis, in Experiment 2, we placed RC sentences in a context that biased toward an RC interpretation. This context should counteract a general preference to interpret sentence-initial nominative-marked noun phrases merely as main-clause subjects, make an RC continuation more expected, and make it possible for the differential cost of an SRC versus ORC parse to show up. But despite the context manipulation, our data showed no RT difference between SRCs and ORCs at the relative pronoun region. This suggests that a key prediction of expectation-based accounts of processing difficulty is not borne out in Hungarian RCs. The lack of an effect at the relative pronoun region is, however, in line with prior empirical work. In Russian, just as in Hungarian, SRCs are overall more frequent than ORCs, and case-marking on the relative pronoun reliably distinguishes the two types of RCs. Yet, Levy et al. (2013) also did not find an effect of SRC-ORC disambiguation at the relative pronoun. Additionally, though Price and Witzel (2017) found evidence of processing difficulty at the ORC relative pronoun in their eye-tracking experiment, there were no clear and consistent effects in their SPR experiments.

Importantly, Experiment 2 replicated the key finding of Experiment 1 at the RC verb. In both experiments, we found a strong effect of Locality: nonlocal structures, where two noun phrases are available for integration at the RC verb, incurred a processing cost. Local structures, where only one noun phrase appears before the RC verb, had lower RTs. This finding supports predictions of memory- but not expectation-based accounts. Additionally, we observe a numerical trend at the main clause verb that ORCs were read slower than SRCs, which may point to a thematic role-based theory. We test predictions of thematic role-based accounts more directly in Experiment 3.

### 5. Experiment 3: Subject- versus object-modifying RCs

While Experiments 1 and 2 mainly tested predictions of expectation- and memory-based accounts, Experiment 3 addresses thematic role-based accounts. Recall that an advantage for SRCs was observed in Experiment 1, at the main clause verb and at the RC-final PP region. There was also a numerical trend of this effect at the main clause verb in Experiment 2. This SRC advantage is in line with the predictions of a thematic role-based account (Staub et al., 2017). Importantly, such an account predicts the SRC-ORC asymmetry to flip in object-modifying RCs. Experiment 3, therefore, builds on the previous two experiments by directly testing modification type—that is, whether an RC is subject- or object-modifying—in addition to the previous factors of extraction site and locality.

### 5.1. Participants

Sixty nine native speakers of Hungarian (recruited via Facebook) participated in an experiment online, and received a compensation in gift cards (value 1000HUF or 3EUR). Based on a background questionnaire, participants who currently live, or have previously spent considerable time outside of Hungary were excluded from analysis. Participants falling outside of the 18- to 36- year-old-age range, as well as bilinguals, were also excluded. Data from 60 participants are reported below.

### 5.2. Materials and procedure

The general procedure, as well as the number of items ( $N=32$  experimental items), was identical to Experiment 1. The experiment had a  $2 \times 2 \times 2$  design. In addition to the factors Extraction site (SRC vs. ORC) and Locality (local vs. nonlocal), the factor Modification (subject-modifying vs. object-modifying) was also added. The experimental design is illustrated in the below examples: (9), (11) are SRCs, while (10), (12) are ORCs; the a. variants are local, while the b. variants are nonlocal; (9), (10) are subject-modifying RCs, while (11), (12) are object-modifying RCs.

(9) a. SRC, VO (local), subject-modifying

A játékos, aki lehordta az edzőt a mérkőzést követően,  
 the player.NOM who.NOM berated the coach.ACC the match following  
 meglepte a csapatot.  
 surprised the team.ACC

b. SRC, OV (non-local), subject-modifying

A játékos, aki az edzőt lehordta a mérkőzést követően,  
 the player.NOM who.NOM the coach.ACC berated the match following  
 meglepte a csapatot.  
 surprised the team.ACC

**Both:** ‘The player who berated the coach following the match surprised the team.’

(10)a. ORC, VS (local), subject-modifying

A játékos, akit lehordott az edző a mérkőzést követően,  
 the player.NOM who.ACC berated the coach.NOM the match following  
 meglepte a csapatot.  
 surprised the team.ACC

b. ORC, SV (non-local), subject-modifying

A játékos, akit az edző lehordott a mérkőzést követően,  
 the player.NOM who.ACC the coach.NOM berated the match following  
 meglepte a csapatot.  
 surprised the team.ACC

**Both:** ‘The player who the coach berated following the match surprised the team.’

## (11)a. SRC, VO (local), object-modifying

A csapat meglepte a játékost, aki lehordta az edzőt a  
 the team.NOM surprised the player.ACC who.NOM berated the coach.ACC the  
 mérkőzést követően.  
 match following

## b. SRC, OV (non-local), object-modifying

A csapat meglepte a játékost, aki az edzőt lehordta a  
 the team.NOM surprised the player.ACC who.NOM the coach.ACC berated the  
 mérkőzést követően.  
 match following

**Both:** ‘The team surprised the player who berated the coach following the match.’

## (12)a. ORC, VS (local), object-modifying

A csapat meglepte a játékost, akit lehordott az edző a  
 the team.NOM surprised the player.ACC who.ACC berated the coach.NOM the  
 mérkőzést követően.  
 match following

## b. ORC, SV (non-local), object-modifying

A csapat meglepte a játékost, akit az edző lehordott a  
 the team.NOM surprised the player.ACC who.ACC the coach.NOM berated the  
 mérkőzést követően.  
 match following

**Both:** ‘The team surprised the player who the coach berated following the match.’

Experiment 3 did not use the same items as Experiments 1 and 2, because in those sentences, the main clause object was inanimate (e.g., *report* in *wrote a report*), and, therefore, could not act as a subject in object-modifying RCs. Instead, experimental items were translated and modified from Gibson, Desmet, Grodner, Watson, and Ko (2005). In all sentences, we made sure that (1) the verbs in both the main clause and the RC assign accusative case, so as not to introduce a confound of case-marking; (2) the RC-final PP is uniformly two words (two regions in the SPR task); and (3) the object/subject of the main clause is a “semi-animate” collective noun (e.g., *the team*), so as to avoid including three animate entities in a single sentence. Where the materials of Gibson et al. (2005) did not already meet these criteria, they were modified to do so.

A binary-choice comprehension question followed each sentence. The form of the comprehension question for experimental items was varied: *Who V-d whom?* (e.g., *Who berated whom?*) or *Whom V-d who?* (e.g., *Whom berated who?*) (counterbalanced). This is different from the Experiments 1 and 2, where comprehension questions were always of the form *Who V-d whom?*. We made this change because in Experiments 1 and 2, comprehension questions inherently favored SRCs: to answer a question following an SRC, participants needed to recall the two NPs in the linear order in which they occurred in the sentence. But to answer a question following an ORC, the order of the two NPs needed to be reversed. The design of

Experiment 3 avoids this confound, allowing us to compare and draw conclusions from the rates of comprehension question accuracy across experimental conditions.

### 5.3. Predictions

Predictions concerning the Locality and Extraction site manipulations are identical to those outlined in Experiments 1 and 2. To summarize, memory-based accounts predict processing difficulty for nonlocal structures at the RC verb. Expectation-based accounts predict difficulty for local structures at the RC verb, and for ORCs at the relative pronoun. These predictions hold for both subject- and object-modifying RCs.

Let us now turn to the predictions of thematic role-based accounts. In existing literature focusing on English, the main region of interest has been the main clause verb in subject-modifying RCs (Staub et al., 2017). In a subject-modifying ORC (10), *player* is first assigned a subject role in the main clause, but then an object role in the RC, and finally a subject role again at the main clause verb. Increased RTs are, therefore, predicted at the main clause verb, where the second thematic switch is required. Such an effect was found in Experiment 1, and there was also a numerical trend of this effect in Experiment 2. In contrast, subject-modifying SRCs (9) require no switch: *player* is assigned the subject thematic role in both the main clause and the RC.

Importantly, since Hungarian is a case-marking language, another region of interest is the relative pronoun, in both subject- and object-modifying RCs. Nouns and relative pronouns in our experiments are marked either nominative or accusative, which serves as a cue to their thematic role. In subject-modifying RCs, the head noun *player* has the thematic role of the subject and is in the nominative case. In subject-modifying SRCs (9), it continues to have the role of subject in the RC, and no thematic switch is required. In subject-modifying ORCs (10), on the other hand, *player* takes on an object role in the RC, which is signaled by accusative case-marking on the relative pronoun. This is the first of two thematic switches in subject-modifying ORCs—as discussed above, the second switch occurs at the main clause verb—and is also predicted to result in difficulty. In the case of object-modifying RCs, difficulty is predicted for SRCs. This is because in an object-modifying SRC such as (11), *player* is first assigned an object thematic role in the main clause (signaled by accusative case), but then a subject thematic role in the RC (signaled by the nominative-marked relative pronoun). In object-modifying ORCs (12), however, *player* has the same thematic role of object throughout the sentence, and no switch is required.

To summarize, case-marking on the relative pronoun in Hungarian is a cue to whether the thematic role in the RC matches that in the main clause. Increased RTs are, therefore, predicted for that region in subject-modifying ORCs and object-modifying SRCs. Additionally, difficulty is predicted for the main clause verb in subject-modifying ORCs, where a second thematic switch happens.

### 5.4. Results and analysis

Before analysis, trials where the comprehension question was incorrectly answered were excluded. Data points with an RT over 10,000 ms were excluded, removing 0.68% of the data.

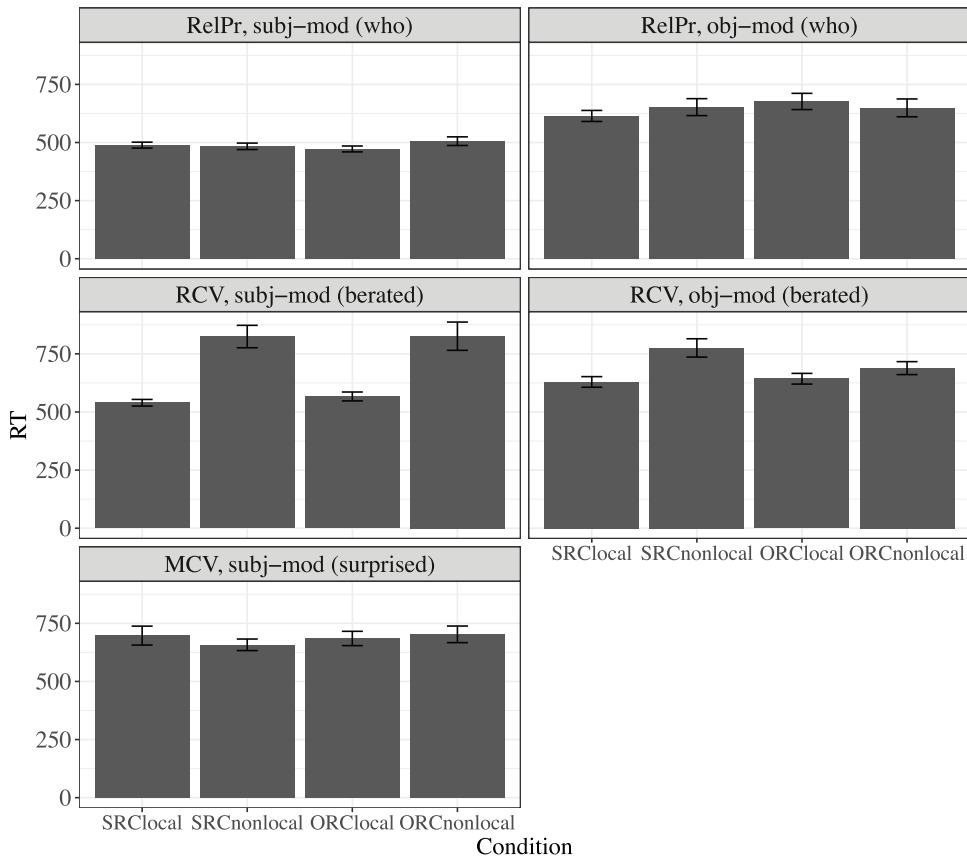


Fig. 4. Experiment 3: Mean reading times for the critical word regions. Error bars represent standard error.

Fig. 4 shows the RT results from Experiment 3, for the word regions and conditions where processing accounts predict an effect. But in Appendix B, we present additional results for the word-by-word RTs (Figs. B3 and B4).

To test the predictions of Memory and Expectation accounts, we fit statistical models predicting log-transformed RTs by Extraction site (SRC vs. ORC), Locality (local vs. nonlocal), Modification (subject-modifying vs. object-modifying), and all relevant interactions, as well as the full random effect structure including both by-item and by-participant intercepts and slopes. Fixed effects predictors were sum-coded before analysis (ORC, local, object-modifying:  $-0.5$ , and SRC, nonlocal, subject-modifying:  $0.5$ ). The models were otherwise identical to those in Experiment 1. Table 5 reports on the results of this analysis for the main regions of interest. As we can see, at the relative pronoun (*who*), there was an effect of Modification: object-modifying sentences had higher RTs than subject-modifying ones. Crucially, however, there was no effect of Extraction site. At the RC verb (*berated*), we found an effect of Locality such that nonlocal sentences had higher RTs than local sentences.

Table 5

Experiment 3: Results of the Bayesian mixed effects regression model of log-transformed RTs in the critical word regions: parameter estimates, standard errors, 95% CrI, and the posterior probability that the parameter value is larger/smaller than 0

	Estimate ( $\hat{\beta}$ )	SE	95% CrI	Posterior probability
<b>Rel. pronoun (<i>who</i>)</b>				
Extraction site	-0.01	0.02	[-0.05, 0.03]	$P(\beta < 0) = 0.71$
Locality	0	0.02	[-0.04, 0.04]	$P(\beta < 0) = 0.48$
Modification	-0.18	0.03	[-0.23, -0.13]	$P(\beta < 0) = 1$
Extraction site $\times$ Locality	0.01	0.04	[-0.07, 0.09]	$P(\beta > 0) = 0.57$
Extraction site $\times$ Modification	0.02	0.04	[-0.06, 0.09]	$P(\beta > 0) = 0.69$
Locality $\times$ Modification	0.02	0.03	[-0.05, 0.09]	$P(\beta > 0) = 0.72$
Extraction site $\times$ Locality $\times$ Modification	-0.1	0.07	[-0.24, 0.05]	$P(\beta < 0) = 0.92$
<b>RC verb (<i>annoyed</i>)</b>				
Extraction site	0.01	0.02	[-0.03, 0.06]	$P(\beta > 0) = 0.72$
Locality	0.16	0.03	[0.11, 0.21]	$P(\beta > 0) = 1$
Modification	0	0.02	[-0.05, 0.04]	$P(\beta < 0) = 0.54$
Extraction site $\times$ Locality	0.08	0.04	[0, 0.17]	$P(\beta > 0) = 0.98$
Extraction site $\times$ Modification	-0.03	0.04	[-0.12, 0.05]	$P(\beta < 0) = 0.76$
Locality $\times$ Modification	0.08	0.05	[-0.02, 0.18]	$P(\beta > 0) = 0.95$
Extraction site $\times$ Locality $\times$ Modification	-0.01	0.08	[-0.17, 0.14]	$P(\beta < 0) = 0.56$

Note: Effects of interest are highlighted.

Next, we turn to testing the predictions of a thematic role-based account. Our main region of interest in both subject- and object-modifying RCs is the relative pronoun (*who*). For the statistical analysis, we coded experimental conditions according to whether they involved a thematic match or mismatch. Conditions with a thematic match are the subject-modifying SRCs and object-modifying ORCs, while conditions involving a thematic mismatch are subject-modifying ORCs and object-modifying SRCs. We then fit a model predicting log-transformed RTs by whether there was a thematic (mis)match. The fixed effects predictor Thematic Role (match vs. mismatch) was sum-coded (match: -0.5 and mismatch: 0.5). The analysis was otherwise identical to the main analyses reported for Experiments 1–3. We found no significant effect of thematic (mis)match on RTs ( $\hat{\beta} = -0.01$ , SE = 0.02, 95% CrI [-0.04, 0.03],  $P(\beta < 0) = 0.61$ ). While our main predictions for thematic role-based accounts were made for the relative pronoun, where case-marking serves as a cue to thematic role, a reviewer additionally suggests that an effect of thematic (mis)match may manifest at the RC verb, which is what triggers thematic integration. We, therefore, conducted the same analysis described in this paragraph for the RC verb region (*berated*), but again found no significant effect ( $\hat{\beta} = 0.01$ , SE = 0.02, 95% CrI [-0.03, 0.06],  $P(\beta > 0) = 0.7$ ).

The main clause verb (*surprised*) is also a critical region for thematic role-based accounts: in subject-modifying RCs, difficulty is predicted for ORCs as compared to SRCs. We, therefore, analyzed the main clause verb data in subject-modifying conditions only, by fitting a statistical model that predicted RTs by Locality, Extraction site, and their interaction (identical to Experiments 1 and 2). However, we did not find the predicted effect of Extraction site

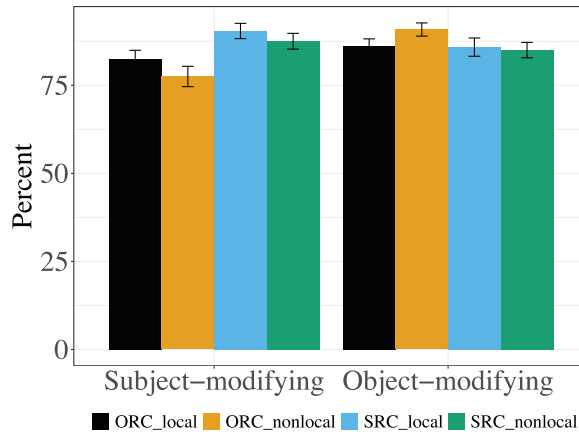


Fig. 5. Experiment 3: Percentage of correctly answered comprehension questions. Error bars represent standard error.

Table 6

Experiment 3: Results of the Bayesian mixed effects logistic regression model of comprehension question accuracy: parameter estimates, standard errors, 95% CrI, and the posterior probability that the parameter value is larger/smaller than 0

	Estimate ( $\hat{\beta}$ )	SE	95% CrI	Posterior probability
(Intercept)	2.14	0.15	[1.84, 2.43]	$P(\beta > 0) = 1$
Extraction site	0.22	0.25	[-0.28, 0.7]	$P(\beta > 0) = 0.81$
Locality	-0.03	0.18	[-0.37, 0.33]	$P(\beta < 0) = 0.57$
Modification	-0.26	0.2	[-0.67, 0.13]	$P(\beta < 0) = 0.9$
Extraction site $\times$ Locality	-0.33	0.36	[-1.04, 0.38]	$P(\beta < 0) = 0.83$
Extraction site $\times$ Modification	1.07	0.34	[0.4, 1.73]	$P(\beta > 0) = 1$
Locality $\times$ Modification	-0.61	0.34	[-1.3, 0.04]	$P(\beta < 0) = 0.96$
Extraction site $\times$ Locality $\times$ Modification	0.7	0.65	[-0.56, 2.01]	$P(\beta > 0) = 0.86$

Note: Effects of interest are highlighted.

( $\hat{\beta} = -0.01$ , SE=0.03, 95% CrI [-0.07, 0.06],  $P(\beta < 0) = 0.57$ ). Locality ( $\hat{\beta} = -0.02$ , SE=0.03, 95% CrI [-0.08, 0.05],  $P(\beta < 0) = 0.69$ ) and the interaction ( $\hat{\beta} = -0.02$ , SE=0.06, 95% CrI [-0.14, 0.11],  $P(\beta < 0) = 0.61$ ) were also not significant.

Finally, we analyzed the comprehension question accuracy results for Experiment 3—see Fig. 5. To analyze comprehension question accuracy, we fit a Bayesian mixed effects logistic regression model, using the brms package from R (Bürkner, 2017). The statistical model included fixed effects of Extraction site, Locality, Modification, and all relevant interactions, as well as the full random effect structure.<sup>6</sup> Fixed effects predictors were sum-coded before analysis (ORC, local, object-modifying: -0.5, and SRC, nonlocal, subject-modifying: 0.5). As Table 6 shows, we found a significant interaction of Extraction site  $\times$  Modification. This effect is driven by SRCs having a higher accuracy than ORCs in subject-modifying RCs ( $\hat{\beta} = 0.76$ , SE=0.25, 95% CrI [0.26, 1.26],  $P(\beta > 0) = 1$ ), but there being no difference between SRCs and ORCs in object-modifying RCs ( $\hat{\beta} = -0.33$ , SE=0.29, 95% CrI [-0.9, 0.27],  $P(\beta < 0) = 0.88$ ).



### 5.5. Discussion

Experiment 3 largely replicates our main finding from Experiments 1 and 2 on subject-modifying RCs, and also extends the same findings to object-modifying RCs. We found increased RTs at the RC verb for nonlocal structures. This result favors memory-based theories of processing difficulty, which predict larger processing cost for nonlocal structures, where more than one noun phrase needs to be retrieved and integrated at the RC verb. At the same time, the findings at the RC verb do not support expectation-based theories, which would predict local RC sentences to be easier to process—based on the corpus findings reported in Section 3.3, and because the intervening noun phrase should sharpen expectations regarding the upcoming RC verb. The other key result of Experiments 1 and 2 replicated in Experiment 3 is the lack of an Extraction site effect on the relative pronoun region. Although null results should be evaluated with caution, the persistence of this null result in all of our experiments nonetheless presents a challenge to expectation-based accounts. Expectation-based accounts predict processing difficulty for ORCs in this region, due to the relative pronoun serving as the first cue that a sentence is an ORC, and ORCs being overall the less frequent structure.

Our main goal in Experiment 3 was to test predictions of the thematic role-based account of RC processing. In Hungarian, the case-marked relative pronoun serves as a cue to thematic roles. In subject-modifying ORCs, the main clause subject (*player*) needs to switch to an object role in the RC, which is signaled by accusative case-marking on the relative pronoun. In object-modifying SRCs, the main clause object (*player*) assumes the role of subject in the RC, and again this switch in thematic roles happens at the nominative case-marked relative pronoun. In contrast, subject-modifying SRCs and object-modifying ORCs require no thematic role switching at the relative pronoun, and are predicted to be easier to process. Crucially, the Experiment 3 RT data revealed no effect of thematic (mis)match at the relative pronoun. Nor was there an effect of thematic (mis)match at the RC verb, which triggers thematic integration. Additionally, in subject-modifying ORCs, there is a second thematic switch at the main clause verb (*surprised*), where *player* assumes a subject role again. However, in Experiment 3, we found no ORC penalty at the main clause verb, even though there was such an effect in Experiment 1, as well as a numerical trend in Experiment 2. In sum, we found no clear evidence of processing difficulty related to thematic (mis)match in the Experiment 3 RT data.

As for main clause region in subject-modifying RCs, however, it must be noted that the lack of a robust effect may be due to the inclusion of a postpositional phrase (*after the match*). Staub et al. (2017) found processing cost at the main clause verb for ORCs, as compared to SRCs; but they also showed that this difficulty was eliminated when additional material intervened between the object gap and the main clause verb. In our experiment, stimuli always contained such intervening material, and the main clause verb never occurred immediately after the RC verb. Therefore, our finding that in subject-modifying RCs, there was no RT difference at the main clause verb between SRCs and ORCs is in line with Staub et al. (2017). Additionally, Experiment 3 had twice as many conditions as Experiments 1 and 2, yet it had slightly fewer participants. It is, therefore, possible that the reason we did not find evidence for a thematic role-based account is that Experiment 3 lacks sufficient statistical power. More

future work is needed to investigate whether the effect predicted by the thematic role account could be detected.

At the same time, however, we did observe an effect of subject- versus object-modification in comprehension question accuracy: SRCs have higher accuracy than ORCs, but only in subject-modifying RCs. This result is partially consistent with the thematic role-based accounts. On the one hand, a thematic role-based account predicts an SRC advantage in subject-modifying RCs. Therefore, the comprehension accuracy results in Experiment 3 suggest that thematic-role assignments may affect late-stage sentence comprehension difficulty. On the other hand, however, a thematic role-based account also makes the prediction that in object-modifying RCs, it should be ORCs that have higher accuracy, and this was not confirmed by our data.

## 6. General discussion

### 6.1. Summary of findings

Across three SPR experiments, we capitalized on the word order flexibility properties of Hungarian and varied extraction site (SRC vs. ORC), locality (distance of the verb from the extracted argument), and modification type (subject- vs. object-modifying RC). A number of key findings have emerged that bear on different theories of RC processing.

First, we found that processing cost is higher for nonlocal RC structures. Specifically, RTs were higher on the RC verb when the RC-internal noun phrase occurred before it than when it occurred after it. This finding provides strong support for memory-based accounts of RC processing, which attribute increased cost to the encoding, retrieval, or integration of an increased number of arguments, over a greater linear distance. Importantly, in Hungarian, the RCs where both dependent noun phrases precede the RC verb, which are predicted to be costly by memory-based accounts, are predicted to be preferred under expectation-based accounts (Section 3.3). That is, the predictions of memory- and expectation-based accounts diverge, making Hungarian particularly suitable for teasing apart the two accounts. Our finding of increased RTs at the RC verb provides support for memory-based accounts, and against expectation-based accounts.

In addition to the RC verb region, another critical region in Hungarian RCs is the relative pronoun region, for which expectation-based accounts make a strong prediction: namely, that SRCs should have an advantage. But taking our three experiments together, we find no RT differences between SRCs and ORCs on the relative pronoun. This finding comes despite the fact that SRCs are considerably more frequent than ORCs, and case-marking on the relative pronoun is an unambiguous cue for distinguishing SRCs from ORCs. The lack of an effect on the relative pronoun thus presents another challenge to the expectation-based accounts. In fact, not only are SRCs more frequent than ORCs, but the relative frequencies are even more skewed in Hungarian than they are in English. Therefore, the null result cannot be due to an insufficiently robust SRC-ORC frequency differential. This contrasts with Russian,

where SRCs are more frequent than ORCs, but relatively less so than in English (Levy et al., 2013), and where the ORC penalty on the case-marked pronoun was also not reliably present (Levy et al., 2013; Price & Witzel, 2017). In summary, we do not find evidence supporting expectation-based theories in RTs at either the RC verb region, or the relative pronoun region.

Lastly, our experiments revealed some, albeit more mixed, evidence for thematic role-based accounts, which predict an SRC advantage in subject-modifying RCs, but an ORC advantage in object-modifying RCs. We found that in subject-modifying RCs, ORCs had longer RTs than SRCs at the main clause verb, which is where the comprehender needs to make a thematic switch from object to subject. However, this pattern was only found in Experiments 1 and 2, and not in Experiment 3. In Experiment 3, we also tested object-modifying RCs and analyzed the critical relative pronoun region, but found no conclusive evidence in favor of the thematic role-based account in the RT data. However, offline comprehension accuracy results from Experiment 3 show an SRC advantage only in subject-modifying RCs, suggesting that thematic role switching influences late-stage comprehension processes.

## 6.2. *Alternative accounts of the RC verb effect*

Before going into the theoretical implications of our findings, let us first address potential concerns regarding spillover. The main effect at the RC verb that we interpret as a memory-based locality effect could receive a more superficial description. Namely, it could be argued that the pattern we observe is that RTs are faster in the region immediately following the relative pronoun, which is the RC verb in local structures, but the RC-internal noun phrase in nonlocal ones. This then results in the pattern that the RC verb in the local structures was read faster than the RC verb in the nonlocal structures. The relative pronoun is both short and frequent, raising the possibility that the relatively fast RTs we observe in the region following it are a result of spillover (see i.a. Roland, Mauner, & Hirose, 2021 on the role of spillover in SPR). Nonetheless, one reason to doubt this alternative account is that RTs are generally slow in our experiments, at about 500 ms on the relative pronoun. We note that the Hungarian RTs we observe in our experiments are considerably longer than is commonly reported for English, though they are more in line with Russian SPR data from Levy et al. (2013) and Price and Witzel (2017). Moreover, in our main analysis, the RT from the previous region was already included as a predictor in the statistical model. But to further clarify the potential issue of spillover arising from the RC verb occupying different positions in local and nonlocal sentences (region 3 vs. 4 in the SPR task), we also conducted two additional statistical analyses.

The first analysis was identical to the ones reported in the Results sections, but with the important addition that RTs were also residualized to word position prior to the Bayesian data analysis. This step could help factor out the effect of word position. Here, we find the same effects as the ones reported in the main analysis: for Experiment 1, there is an effect of Locality ( $\hat{\beta}=0.27$ ,  $SE=0.03$ , 95% CrI=[0.2, 0.34],  $P(\beta>0)=1$ ), but not of Extraction site ( $\hat{\beta}=0.01$ ,  $SE=0.02$ , 95% CrI=[-0.03, 0.06],  $P(\beta>0)=0.68$ ) or their interaction ( $\hat{\beta}=0$ ,  $SE=0.04$ , 95% CrI=[-0.08, 0.08],  $P(\beta>0)=0.48$ ). For both Experiments 2 and 3, we also conducted the

Table 7

Summary of the Roland et al. style spillover analysis: Analyzed regions, preceding word (categorical predictor), predictor representing memory-based accounts, and predictor representing expectation-based accounts

Region	Preceding word-predictor	Memory-predictor	Expectation-predictor
Rel. pronoun	subject	0	SRC: 0 ORC: 1
RC noun phrase	local: RC verb nonlocal: rel. pronoun	0	0
RC verb	local: rel. pronoun nonlocal: RC noun phrase	local: 0 nonlocal: 1	local: 1 nonlocal: 0
Spillover 1	local: RC noun phrase nonlocal: RC verb	0	0

similar additional analysis on the RC verb. The results there are also completely in line with the results reported in the main analyses for those two experiments.

In the second additional analysis, we conducted a spillover analysis following Roland et al. (2021) (see especially their Table 7), which is aimed at investigating and factoring out any systematic influence that a word has on the following word, collapsing over experimental conditions. The analysis from Roland et al. (2021) is informative for the current purpose because their investigation, focusing on the SRC/ORC asymmetry in pronominal versus full NP RCs in English, also necessitated comparing words that occupied different positions in different experimental conditions. Specifically, we adapted their analysis to reanalyze data from our Experiment 1, using observations from the following four critical regions: relative pronoun (*who*, region 2), RC-internal noun phrase (*the analyst*, region 3 or 4 depending on condition), RC verb (*annoyed*, region 3 or 4 depending on condition), and spillover region (first word after the RC, *long*, region 5). We fit a Bayesian mixed effects regression model with three types of predictors, which incorporated information about the preceding region for each word, as well as predictors corresponding to the effects of memory- and expectation-based models. The first predictor is a categorical predictor that specifies what the previous region is: a subject noun phrase versus a relative pronoun versus an RC-internal noun phrase versus an RC verb. The second predictor reflects the memory-based predictions outlined in Section 3.3. Since the memory-based effect was predicted to slow down RTs on the RC verb in the nonlocal conditions, this predictor was coded as 1 for the RC verb in nonlocal conditions, and 0 for all other regions. The third predictor, reflecting the main predictions of expectation-based accounts, was coded as 1 for the relative pronoun in ORCs, as well as the RC verb in local sentences; and 0 for all other regions. Table 7 summarizes the three predictors for this analysis.

The model outcome showed an effect of the preceding word, confirming that RTs were indeed significantly affected by a spillover effect. But more importantly, even with the presence of the spillover effect, the effects of the memory and expectation-based predictors were still in line with the main analysis we presented earlier: we found an effect of the

Memory-predictor ( $\hat{\beta}=0.11$ ,  $SE=0.04$ , 95% CrI=[0.03, 0.2],  $P(\beta>0)=1$ ), but there was no effect of the Expectation-predictor ( $\hat{\beta}=-0.01$ ,  $SE=0.01$ , 95% CrI=[-0.03, 0.02],  $P(\beta<0)=0.71$ ). Altogether, both the additional analysis using residualized RTs, as well as the analysis adapted from Roland et al. to specifically control for the spillover effect, suggest that the main effect observed at the RC verb is not attributable solely to spillover. Instead, they support the interpretation in terms of locality-driven processing difficulty.

It is also possible that what is driving the results at the RC verb is not memory retrieval per se, but rather the cost of verb-argument integration. The descriptive generalization here is that an RC verb is read slower when all of its arguments are present, that is, in the nonlocal condition. And the same effect can be argued to appear on the RC-internal noun phrase, which is read slower when it is postverbal, that is, in the local condition. These effects might be explained by processing cost associated with interpreting the phrase once all the arguments of its head are present. Overall, however, we take such a verb-argument integration cost to also be broadly indicative of memory-based effects. Further manipulations of Hungarian RC sentences, for example, including a modifier before the RC verb to absorb any potential spillover, or varying the plausibility of the RC verb's arguments to modulate integration cost, could help clarify the precise source of the processing cost we observe, but we leave these experiments to future work.

### 6.3. RC processing in flexible word order languages: Hungarian versus Russian

Hungarian is similar to Russian in that both languages have flexible word order within the RC. However, in Russian, the structures that are predicted to be costly by memory-based accounts are also the more frequent ones, meaning that the predictions of memory-based and expectation-based accounts are more aligned for that language. Below, we discuss in more detail how our results compare to existing work on Russian.

Levy et al.'s (2013) SPR experiments, which our Experiment 1 closely mirrors in its design, revealed increased RTs at the RC verb for structures with a longer dependency, suggesting memory-based processing difficulty. But, as mentioned, because in Russian the structures with a longer dependency are also the less frequent ones, it is possible that this effect reflects the spillover of expectation-based cost from the RC noun phrase. Levy et al. (2013) also found that highly infrequent RC-initial object noun phrases led to increased RTs, which was taken to be evidence of expectation-based processing difficulty. However, as Price and Witzel (2017) point out, this effect can also be viewed as reflecting working memory processes, specifically the encoding cost of holding two NPs in memory before integrating them at the verb. Price and Witzel's (2017) investigation of Russian RCs focused in particular on SRCs and ORCs that have the longer dependency, that is, sentences we refer to as "nonlocal." In their SPR experiments, the authors manipulated whether the RC-internal noun phrase was a pronoun or a full noun phrase, and compared RCs to complement clause baselines. They found processing difficulty at the RC verb, in line with Levy et al. (2013). But the same processing cost was not found for sentences where the RC contained a pronoun instead of a full NP, which crucially have different relative frequencies. Additionally, evidence of expectation-based processing cost was found at the embedded noun phrase, where sentences with less frequent

word orders resulted in longer RTs. In sum, both studies of Russian have revealed evidence that is potentially consistent with both memory- and expectation-based theories of processing. While our study of Hungarian is in line with the main finding of Levy et al. (2013) and Price and Witzel (2017), namely that processing cost at the RC verb increases with the number of noun phrases coming before it, this result is primarily indicative of memory-based processing difficulty and does not provide support for expectation-based theories.

It is important to note that Price and Witzel (2017) also conducted an eye-tracking experiment that tested nonlocal SRCs and ORCs with full NPs. Though identical in design to one of their SPR experiments, the eye-tracking experiment did not replicate the finding of processing cost at the RC verb. In fact, the opposite pattern of results was found: RCs showed facilitation when compared to their complement clause baselines. As Price and Witzel (2017) highlight, this can be interpreted as an expectation-driven antilocality effect, whereby the presence of both arguments (head noun and RC-internal noun) creates a strong expectation for the RC verb. To explain the discrepancy between their SPR and eye-tracking findings, the authors point to task-specific processing demands. Specifically, they argue that SPR places greater demand on working memory resources, which is why effects related to memory processes (i.e., the cost observed at the RC verb) are most readily observed in that task. In light of these considerations, future work should also employ eye-tracking to investigate the processing of Hungarian RCs.

#### 6.4. *Memory versus expectation from a cross-linguistic perspective*

Our experiments directly pitted against each other memory- and expectation-based accounts: expectation-based accounts predict an antilocality effect at the RC verb in Hungarian, while memory-based accounts predict a locality effect. We found strong evidence of the latter effect in Hungarian RCs, in line with a growing body of cross-linguistic studies that also find that when memory and expectation are put in opposition, expectation-based effects tend to be lessened. For instance, Safavi et al. (2016) found evidence against (surprisal-based) expectation in Persian complex predicates, which consist of a pre-verbal noun and a verb. In these structures, once the noun has been read, the identity of the verb is strongly predictable. The authors found that such strongly predictable verbs were indeed read faster than verbs which occur in simple noun-verb predicate configurations, and whose identity is, therefore, not predictable. However, this study also found a locality effect: increasing verb-argument distance led to slower RTs, and crucially, strong predictability did not neutralize this locality effect. Overall, then, the Persian data are also most consistent with a memory-based account of verb-argument dependency resolution.

German presents another case study for teasing apart competing predictions of memory- and expectation-based accounts, with overall mixed evidence. Concretely, Levy and Keller (2013) found antilocality effects in German verb-final structures, specifically in main clauses and SRCs where the verb is preceded by a dative argument. At the same time, within the same language, they also found locality effects: the otherwise observed antilocality effect disappeared when the preverbal material in the SRC also contained an adjunct. The authors argued that this may have been due to the preverbal material being longer: the resulting increased working memory load may have cancelled out the dative argument's facilitatory effect. We

must note that a similar explanation for the absence of antilocality effects cannot, however, be given for our findings. In the Hungarian sentences, the preverbal material was not especially lengthy, and contained only a single noun phrase; yet, we found no effects of expectation-based processing. Additionally, more recent work by Vasishth, Mertzen, Jäger, and Gelman (2018) failed to replicate Levy and Keller's (2013) antilocality results, suggesting that further research is needed to establish whether the claims regarding antilocality effects in German hold up.

In the processing of English RCs, one domain where expectation- and memory-based theories do not align is pronominal RCs. English SRCs are more frequent than ORCs when the RC-internal NP is a full NP, but when looking at RCs where the RC-internal NP is a pronoun, ORCs are found to be more frequent than SRCs (Reali & Christiansen, 2007). Expectation-based accounts, therefore, predict a reversal in processing cost for pronominal RCs: while in RCs that contain a full NP, SRCs should be easier to process, pronominal RCs should show the opposite pattern. Indeed, Reali and Christiansen (2007) found that in pronominal RCs, it is ORCs that are easier to process, providing support for expectation-based processing. In recent work, however, Roland et al. (2021) argue that what appeared to be an ORC advantage in pronominal RCs in earlier work is due to spillover. Instead, these authors find an SRC advantage in both full NP and pronominal RCs; pronominal ORCs do present processing difficulty, and that difficulty increases when the RC-internal NP is a full NP. These findings are most consistent with memory-based accounts. Overall, then, the cross-linguistic picture suggests that in cases where expectations and memory limitations are in conflict, clear evidence that would favor expectation-based processing remains elusive.

## 7. Conclusion

In conclusion, the results of the present study provide strong support for memory-based accounts of RC processing: we found locality-driven processing difficulty, rather than expectation-driven facilitation. We also found some evidence for thematic role-based accounts of processing. As such, based on novel cross-linguistic observations, our findings shed new light on the long standing questions of RC processing.

## Acknowledgments

For helpful discussion and feedback at various stages of this project, we would like to thank the editor and anonymous reviewers, Brian Dillon, Daniel Lam, Jon Sprouse, Adrian Staub, Yi-Ting Huang, and the audiences at CUNY 2019, CUNY 2020, and LAGB 2019. We are especially grateful to Jeff Witzel for his input at CUNY 2019. We are grateful to all the Hungarian participants who completed and circulated our experiments, and especially to Eszter Lévai and Réka Mándoki for their help with participant recruitment. This paper is based upon work supported by the National Science Foundation under Grant No. #BCS-1451635, and by the University of Chicago Humanities Division Council. All mistakes and shortcomings are our own.

## Notes

- 1 While we have defined locality in terms of linear distance, there is another, related difference between local and nonlocal RCs. In local structures, there is only one noun phrase (*engineer*) available for integration at the verb, while in nonlocal ones, two noun phrases (*engineer, analyst*) intervene before, and need to be integrated with, the verb. While these two ways of defining locality are conceptually distinct, they both predict increased processing difficulty for nonlocal RCs.
- 2 The Hungarian National Corpus contains 187.6 million words. It is divided into five subcorpora by regional language variants: the vast majority (164.7 million words) from Hungary, the rest being Slovakia, Subcarpathia, Transylvania, and Vojvodina. It is also divided into five subcorpora by text genres, in million words: 71 press, 35.5 literature, 20.5 science, 19.9 official, and 17.8 personal. The corpus is part-of-speech (POS) tagged, but not structure tagged. Due to the case-marking properties of Hungarian, searching for the relevant case-marked POS strings can ensure that we only find the relevant RC structures. An example of a POS-search string is “(Det) N.NOM (,) Rel.Pronoun.NOM V.3sg (Det) N.ACC,” which we used to identify local SRC structures.
- 3 The corpus searches reported in Fig. 1 were slightly more conservative than the ones reported in Table 2. Specifically, to calculate the incremental probabilities, we conducted corpus searches that always included obligatory determiners before the NPs. Additionally, we focused on sentences where the head noun was the first word of the sentence. These searches thus provided a closer match with our experimental stimuli, and consequently, the resulting counts are overall lower, for example, 12 local SRCs in Fig. 1 versus 44 in Table 2. Nonetheless, the overall predictions derived are identical for the two analyses.
- 4 A reviewer points out that this exclusion criterion is less stringent than what is typically adopted in the literature (Kush & Dillon, 2021; Müller & Mari, 2021; Singh, Fedorenko, Mahowald, & Gibson, 2016, i.a.). For this reason, we reanalyzed our findings from all three experiments, excluding data points with an RT below 100 or above 3000 ms. Using this cutoff, only an additional 1% of the data are removed, and crucially, the major results and conclusions reported in the paper remain identical.
- 5 The parameter values for the brms models (in all analyses) are the following:
 

```

model=brm(formula = logRT ~ Locality * ExtractionSite + PreviousWordlogRT
+ (1 + Locality * ExtractionSite | Participant)
+ (1 + Locality * ExtractionSite | Item),
data = data, family = gaussian(),
prior = c(prior('normal(6,3)', class='Intercept'),
set_prior('normal(0,1)', class='sigma'),
set_prior('normal(0,1)', class='b'),
set_prior('normal(0,1)', class='sd'),
set_prior('lkj(2)', class='cor')),
warmup=1000, iter=2000, chains=4,
control=list(adapt_delta=0.99, max_treedepth=12))

```



6 The parameter values for the brms model are the following:

```

model=brm(formula = Response ~ Locality * ExtractionSite * Modification
+ (1 + Locality * ExtractionSite * Modification | Participant)
+ (1 + Locality * ExtractionSite * Modification | Item),
data = data, family = bernoulli(link=logit),
prior = c(prior('normal(0,0.5)', class='Intercept'),
set_prior('normal(0,1.5)', class='b'),
set_prior('lkj(2)', class='cor')),
warmup=1000, iter=2000, chains=4,
control=list(adapt_delta=0.99, max_treedepth=12))

```

7 The concern that some data were missed arises for the local versus nonlocal distinction, but not for the SRC versus ORC one. SRC/ORC status is unambiguously signaled by case-marking on the relative pronoun, and, therefore, our previous searches already identified all such sentences.

## References

- Bürkner, P.-C. (2017). brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software*, 80(1), 1–28.
- Carreiras, M., Duñabeitia, J. A., Vergara, M., de la Cruz-Pavía, I., & Laka, I. (2010). Subject relative clauses are not universally easier to process: Evidence from basque. *Cognition*, 115(1), 79–92.
- Cohen, L., & Mehler, J. (1996). Click monitoring revisited: An on-line study of sentence comprehension. *Memory & Cognition*, 24(1), 94–102.
- Drummond, A. (2007). Ibex Farm. <http://spellout.net/ibexfarm>.
- É Kiss, K. (2002). *The syntax of Hungarian*. Cambridge Syntax Guides. Cambridge University Press.
- Fedorenko, E., Piantadosi, S., & Gibson, E. (2012). Processing relative clauses in supportive contexts. *Cognitive Science*, 36(3), 471–497.
- Ford, M. (1983). A method for obtaining measures of local parsing complexity throughout sentences. *Journal of Verbal Learning and Verbal Behavior*, 22(2), 203–218.
- Frazier, L. (1985). Syntactic complexity. In D. R. Dowty, L. Karttunen, & A. M. Zwicky (Eds.), *Natural language parsing: Psychological, computational, and theoretical perspectives*, Studies in Natural Language Processing (pp. 129–189). Cambridge University Press.
- Frazier, L., & Fodor, J. D. (1978). The sausage machine: A new two-stage parsing model. *Cognition*, 6(4), 291–325.
- Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*, 68(1), 1–76.
- Gibson, E., Desmet, T., Grodner, D., Watson, D., & Ko, K. (2005). Reading relative clauses in English. *Cognitive Linguistics*, 16(2), 313–353.
- Gibson, E., & Wu, H.-H. I. (2013). Processing Chinese relative clauses in context. *Language and Cognitive Processes*, 28(1–2), 125–155.
- Gordon, P. C., Hendrick, R., & Johnson, M. (2001). Memory interference during language processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 27(6), 1411–1423.
- Grodner, D., & Gibson, E. (2005). Consequences of the serial nature of linguistic input for sentential complexity. *Cognitive Science*, 29(2), 261–290.
- Hale, J. (2001). A probabilistic Earley parser as a psycholinguistic model. In *Proceedings of the 2nd Meeting of the North American Chapter of the Association for Computational Linguistics on Language Technologies*, NAACL '01 (pp. 1–8). Stroudsburg, PA: Association for Computational Linguistics.

- Hale, J. (2003). The information conveyed by words in sentences. *Journal of Psycholinguistic Research*, 32(2), 101–123.
- Hale, J. (2006). Uncertainty about the rest of the sentence. *Cognitive Science*, 30(4), 643–672.
- Holmes, V., & O'Regan, J. (1981). Eye fixation patterns during the reading of relative-clause sentences. *Journal of Verbal Learning and Verbal Behavior*, 20(4), 417–430.
- Hsiao, F., & Gibson, E. (2003). Processing relative clauses in Chinese. *Cognition*, 90(1), 3–27.
- Jäger, L., Chen, Z., Li, Q., Lin, C.-J. C., & Vasishth, S. (2015). The subject-relative advantage in Chinese: Evidence for expectation-based processing. *Journal of Memory and Language*, 79–80, 97–120.
- Kas, B., & Lukács, A. (2011). Processing relative clauses by Hungarian typically developing children. *Language and Cognitive Processes*, 27(4), 500–538.
- Keenan, E. L., & Comrie, B. (1977). Noun phrase accessibility and universal grammar. *Linguistic Inquiry*, 8(1), 63–99.
- King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language*, 30(5), 580–602.
- Konieczny, L. (2000). Locality and parsing complexity. *Journal of Psycholinguistic Research*, 29(6), 627–645.
- Konieczny, L. (2005). The psychological reality of local coherences in sentence processing. In *Proceedings of the 27th Annual Conference of the Cognitive Science Society* (pp. 1178–1183).
- Kush, D., & Dillon, B. (2021). Principle B constrains the processing of cataphora: Evidence for syntactic and discourse predictions. *Journal of Memory and Language*, 120, 104254.
- Kwon, N., Gordon, P. C., Lee, Y., Kluender, R., & Polinsky, M. (2010). Cognitive and linguistic factors affecting subject/object asymmetry: An eye-tracking study of prenominal relative clauses in Korean. *Language*, 86(3), 546–582.
- Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition*, 106(3), 1126–1177.
- Levy, R., Fedorenko, E., & Gibson, E. (2013). The syntactic complexity of Russian relative clauses. *Journal of Memory and Language*, 69(4), 461–495.
- Levy, R. P., & Keller, F. (2013). Expectation and locality effects in German verb-final structures. *Journal of Memory and Language*, 68(2), 199–222.
- Lewis, R. L., & Vasishth, S. (2005). An activation-based model of sentence processing as skilled memory retrieval. *Cognitive Science*, 29(3), 375–419.
- MacWhinney, B., & Pléh, C. (1988). The processing of restrictive relative clauses in Hungarian. *Cognition*, 29(2), 95–141.
- Müller, M.-L., & Mari, M. A. (2021). Definite descriptions in the light of the comprehension vs. acceptance distinction: Comparing self-paced reading with eye-tracking measures. *Frontiers in Communication*, 6, 634362.
- Nakatani, K., & Gibson, E. (2008). Distinguishing theories of syntactic expectation cost in sentence comprehension: Evidence from Japanese. *Linguistics*, 46(1), 63–87.
- Oravecz, C., Váradi, T., & Sass, B. (2014). The Hungarian Gigaword Corpus. In *Proceedings of the 9th International Conference on Language Resources and Evaluation (LREC'14)*, Reykjavik, Iceland: European Language Resources Association (ELRA).
- Pizarro-Guevara, J. S. (2020). *When human universal meets language specific* [PhD thesis]. UC Santa Cruz.
- Price, I. K., & Witzel, J. (2017). Sources of relative clause processing difficulty: Evidence from Russian. *Journal of Memory and Language*, 97, 208–244.
- Realí, F., & Christiansen, M. H. (2007). Processing of relative clauses is made easier by frequency of occurrence. *Journal of Memory and Language*, 57(1), 1–23.
- Roland, D., Mauner, G., & Hirose, Y. (2021). The processing of pronominal relative clauses: Evidence from eye movements. *Journal of Memory and Language*, 119, 104244.
- Safavi, M. S., Husain, S., & Vasishth, S. (2016). Dependency resolution difficulty increases with distance in Persian separable complex predicates: Implications for expectation and memory-based accounts. *Frontiers in Psychology*, 7, 403.
- Schwab, J., Xiang, M., & Liu, M. (2022). Anti-locality effect without head-final dependencies. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 48(3), 446–463.

- Sheldon, A. (1974). The role of parallel function in the acquisition of relative clauses in English. *Journal of Verbal Learning and Verbal Behavior*, 13(3), 272–281.
- Singh, R., Fedorenko, E., Mahowald, K., & Gibson, E. (2016). Accommodating presuppositions is inappropriate in implausible contexts. *Cognitive Science*, 40, 607–634.
- Staub, A., Dillon, B., & Clifton Jr, C. (2017). The matrix verb as a source of comprehension difficulty in object relative sentences. *Cognitive Science*, 41(S6), 1353–1376.
- Ueno, M., & Garnsey, S. M. (2008). An ERP study of the processing of subject and object relative clauses in Japanese. *Language and Cognitive Processes*, 23(5), 646–688.
- Vasishth, S., & Lewis, R. L. (2006). Argument-head distance and processing complexity: Explaining both locality and antilocality effects. *Language*, 82(4), 767–794.
- Vasishth, S., Mertzen, D., Jäger, L. A., & Gelman, A. (2018). The statistical significance filter leads to overoptimistic expectations of replicability. *Journal of Memory and Language*, 103, 151–175.
- Wagers, M. W., Borja, M. F., & Chung, S. (2018). Grammatical licensing and relative clause parsing in a flexible word-order language. *Cognition*, 178, 207–221.
- Wu, F., Kaiser, E., & Vasishth, S. (2017). Effects of early cues on the processing of Chinese relative clauses: Evidence for experience-based theories. *Cognitive Science*, 42, 1101–1133.

## APPENDIX: A

In our main corpus analyses reported in Section 3.3, we relied on restrictive search patterns aimed at identifying RCs that are a very close match for the critical region of our experimental stimuli. There is a potential concern that by using restrictive search patterns, some of the relevant structures were missed.<sup>7</sup> In order to provide further evidence for the biases identified in Section 3.3, namely that nonlocal RCs are preferred over local ones, we conducted an additional analysis. For this analysis, we searched the Hungarian National Corpus for the following sentences: a sentence-initial determiner, followed by a nominative-marked noun, followed by an optional comma, and then followed by a relative pronoun that is either nominative-marked (SRCs) or accusative-marked (ORCs). This search identifies all SRCs ( $N=4382$ ) and ORCs ( $N=615$ ) from the corpus, and is essentially the data from the second layer of Fig. 1 (RelPr.NOM and RelPr.ACC). We then randomly selected 200 sentences from each of these groups, and hand coded them according to what type of RC they represented.

As compared to the main analyses of Section 3.3, we relaxed our criteria and also counted sentences that are not a direct match for the experimental stimuli. For instance, we counted RCs that had a complex noun phrase as the RC-internal NP, such as *The owner who collected world war weapons...* In such structures, only the final word of the object is accusative-marked (i.e., only *weapons*, not *world war*), and, therefore, they would not have been identified by our previous corpus searches. Table A1 presents the results of the manual classification. As before, V denotes the RC verb, O the RC object, and S the RC subject. X denotes material other than V/O/S such as adjuncts, for instance, prepositional phrases, as in *The poet, who on this mountain awaited the mail...*, which was classified as “HdN.NOM RelPr.NOM X V O.”

The “nontransitive” category for SRCs includes sentences that are intransitive or copular, for example, *The father, who is proud of his self-discipline...*, and more generally sentences where there was no accusative-marked direct object, for example, *The God, who with-you argues...*, where *you* bears the instrumental case (note that Hungarian is standardly taken to have at least 18 cases). It also includes (a small number of) sentences where there was an

accusative-marked direct object, but it was not the object of the main verb of the RC, for example, *The expert, who specific company names.ACC didn't want to mention....* The “no overt subject” category for ORCs includes sentences where the subject is pronominal but has undergone pro-drop, for example, *The girl, who <you> loved.2SG so much....*, and ones where the verb is in the third person plural active form, which is how Hungarian expresses passive meanings, for example, *The man, who <they> pronounced.3PL dead....* These kinds of sentences were deemed too different from any of our experimental stimuli to be counted in one of the V and O/S containing categories. Lastly, the “other” category refers to sentences for which the corpus search yielded various outcomes that do not form a natural class.

Regarding the results reported in Table A1, following our definition throughout the paper for what counts as a local versus nonlocal RC, we should focus on sentences where the relative pronoun is directly followed by the V and S/O (or S/O and V), with no additional material intervening in any place. This narrows the results down to the first two rows of the table. We can see that for SRCs, there were 11 local and 23 nonlocal sentences, while for ORCs, there were 0 local and 15 nonlocal ones. But it is also possible to take a more permissive view of what makes a structure local versus nonlocal. For this, we turn to the general antilocality idea described in Section 3.3: once comprehenders have encountered the relative pronoun, they can predict the RC verb. Given this, any material that intervenes before the RC verb helps sharpen expectations about it, and should facilitate processing. Therefore, we can classify as “nonlocal” any sentence where there is material intervening between the relative pronoun and the verb, even when that material is not (just) the RC-internal NP (S/O). Defining locality this way, the counts derived from Table A1 are the following: for SRCs, there were 11 local and 45 nonlocal structures, while for ORCs, there were 0 local and 45 nonlocal structures. Given either classification, then, the findings of this additional corpus analysis are consistent with what we argued in Section 3.3, namely that nonlocal RCs are more frequent than local ones in Hungarian.

Lastly, a reviewer notes that our experimental design can be interpreted as manipulating not locality per se, but VO/VS versus OV/SV word order. This would then suggest that we should

Table A1  
Results of the manual classification of 400 randomly selected RCs

SRC	Count	ORC	Count
HdN.NOM RelPr.NOM V O	11	HdN.NOM RelPr.ACC V S	0
HdN.NOM RelPr.NOM O V	23	HdN.NOM RelPr.ACC S V	15
HdN.NOM RelPr.NOM X V O	15	HdN.NOM RelPr.ACC X V S	8
HdN.NOM RelPr.NOM X O V	2	HdN.NOM RelPr.ACC X S V	3
HdN.NOM RelPr.NOM V X O	0	HdN.NOM RelPr.ACC V X S	0
HdN.NOM RelPr.NOM O X V	4	HdN.NOM RelPr.ACC S X V	18
HdN.NOM RelPr.NOM X V X O	1	HdN.NOM RelPr.ACC X V X S	0
HdN.NOM RelPr.NOM X O X V	0	HdN.NOM RelPr.ACC X S X V	1
nontransitive	96	no overt subject	95
other	48	other	60
<b>total</b>	<b>200</b>	<b>total</b>	<b>200</b>

analyze corpus results in terms of the relative ordering of the verb and its arguments. Though we believe that focusing on whether there is intervening material between the relative pronoun and the verb better reflects the predictions of expectation-based accounts than focusing on VO versus OV order, this analysis is also worth exploring. As Table A1 shows, among SRCs, there were 27 VO and 29 OV sentences, while among ORCs, we found eight VS and 37 SV sentences. This suggests that if we define “local” word orders as VO/VS and “nonlocal” as OV/SV, then the frequency advantage for nonlocal sentences becomes less pronounced for SRCs than under previous definitions, though it is still robust for ORCs. Nonetheless, a processing advantage for local conditions, which is the main finding of our experiments, is still not predicted by an expectation-based account, since local structures are at most as frequent, and not more frequent than, nonlocal ones. This suggests that our findings remain better explained by memory-based accounts.

## APPENDIX: B

Visual inspection of Fig. B4 reveals an unexpected effect on the RC-internal noun phrase in the object-modifying RCs. Specifically, in the nonlocal condition (“RCNPpre”; *the analyst*), RTs were numerically higher for SRCs than for ORCs: SRC mean RT=704 ms (SE=44); ORC mean RT=613 ms (SE=23). This may be interpreted as the spillover of processing difficulty from the immediately preceding relative pronoun, where a thematic role-based account predicts an SRC penalty. However, the observed effect at the RC-internal noun

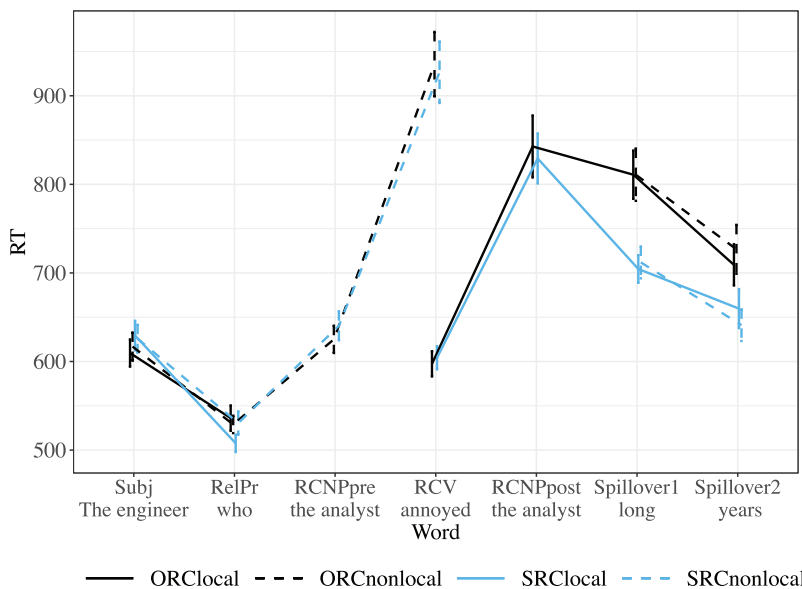


Fig. B1. Experiment 1: Mean reading times by region for the first six words. Error bars represent standard error. The position of the RC noun phrase (RCNP) with respect to the RC verb (RCV) depends on whether it is in a local or nonlocal condition. The spillover regions represent a postpositional phrase.

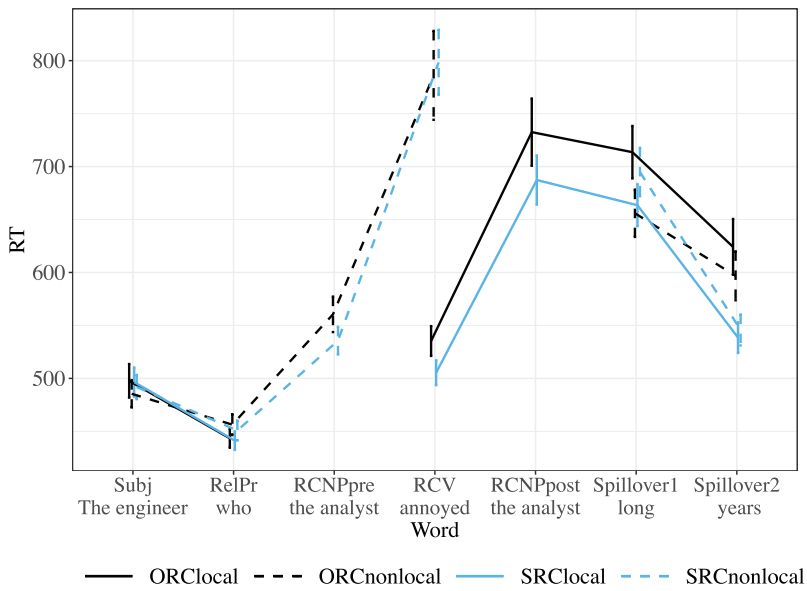


Fig. B2. Experiment 2: Mean reading times by region for the first six words. Error bars represent standard error. The position of the RC noun phrase (RCNP) with respect to the RC verb (RCV) depends on whether it is in a local or nonlocal condition. The RCfinal regions represent a postpositional phrase.

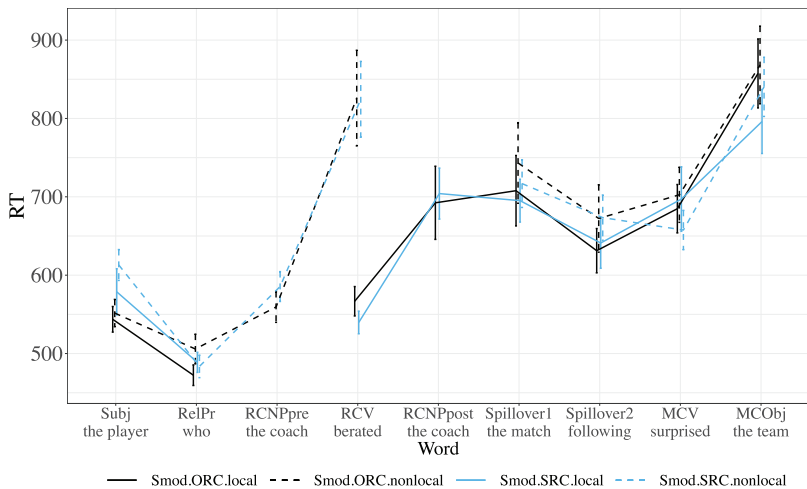


Fig. B3. Experiment 3: Mean reading times by region for subject-modifying RCs. Error bars represent standard error. The position of the RC noun phrase (RCNP) with respect to the RC verb (RCV) depends on whether it is in a local or nonlocal condition. The RCfinal regions represent a postpositional phrase.

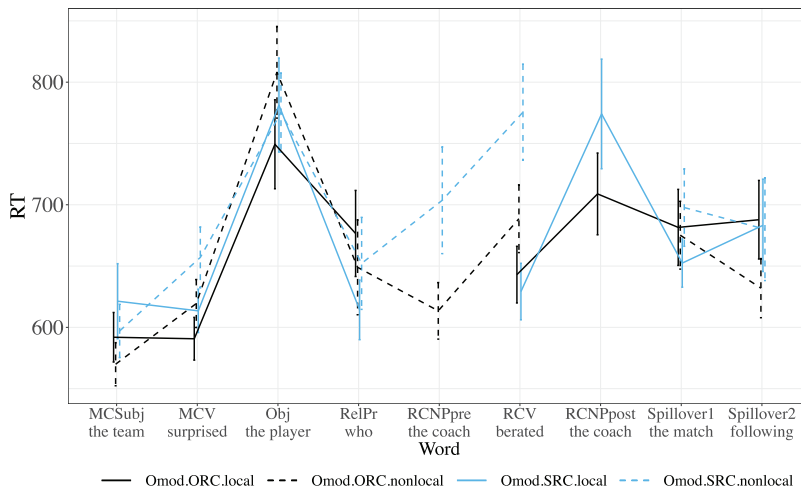


Fig. B4. Experiment 3: Mean reading times by region for object-modifying RCs. Error bars represent standard error. The position of the RC noun phrase (RCNP) with respect to the RC verb (RCV) depends on whether it is in a local or nonlocal condition. The RCfinal regions represent a postpositional phrase.

phrase is not statistically reliable (Extraction site ( $\hat{\beta}=0.06$ ,  $SE=0.04$ , 95% CrI  $[-0.03, 0.14]$ ,  $P(\beta>0)=0.92$ ). Additionally, local RCs do not show a similar trend in the relevant spillover region. In local structures, the region immediately following the relative pronoun is the RC verb (*berated*), meaning that if there is spillover cost from the relative pronoun, we might expect that to also result in elevated RTs at the RC verb for local SRCs. However, local SRCs did not have higher RTs than local ORCs at the RC verb: SRC mean RT=629 ms ( $SE=23$ ); and ORC mean RT=643 ms ( $SE=23$ ).