Seeing events vs. entities: The processing advantage of Pseudo Relatives over Relative Clauses

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Abstract

We present the results of three offline questionnaires (one attachment preference study and two acceptability judgments) and two eye-tracking studies in French and English investigating the resolution of the ambiguity between Relative Clause and Pseudo Relative interpretations. This structural and interpretive ambiguity has recently been shown to play a central role in the explanation of apparent cross-linguistic asymmetries in Relative Clause attachment (Grillo & Costa, 2014; Grillo et al., 2015). This literature has argued that Pseudo Relatives are preferred to Relative Clauses because of their structural and interpretive simplicity. This paper adds to this growing body of literature in two ways. First we show that, in contrast to previous findings, French speakers prefer to attach Relative Clauses to the most local antecedent once Pseudo Relative availability is controlled for. We then provide a direct test for the Pseudo Relatives preference, showing that Relative Clause disambiguation of strings that are initially compatible with a Pseudo Relative interpretation leads to degraded acceptability and longer fixation durations.

Keywords: Universality of Parsing Principles, Ambiguity Resolution, Economy of Computation, Locality, Attachment Preferences, (Pseudo) Relative Clauses.

1. Introduction

One strong hypothesis in psycholinguistics is that language processing is governed by universal mechanisms grounded in principles of optimal computation. From this perspective, crosslinguistic variation in parsing preferences is only apparent and ultimately reducible to grammatical variation. From this perspective, when properly formulated, parsing principles are reducible to the interaction of linguistic structure with basic principles of economy of computation, such as those evidenced in primacy and recency effects. Principles of this sort, which dominate models of language processing and are often observed across cognitive domains, can hardly be construed as acquired. Taking for granted that economy considerations (necessarily of a universal nature)

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are a cornerstone of explanation in psycholinguistics, the debate has therefore typically focused on the relevant level of representation at which economy principles apply and on the complex interaction of economy and faithfulness to a message at each level of representation.

Issues of learnability, discussed in detail in Fodor (1998a,b) further strengthen the universalist perspective: children need to parse the language they hear in order to acquire the grammar of their mother tongue. This will be very hard, if not impossible, if principles of parsing have to be acquired themselves. And principles of parsing can hardly be acquired as long as there is no grammar to base this process on.

The study of sentence processing played a crucial role in shaping this debate and the resolution of syntactic ambiguity contributed crucial insight into the mechanisms underlying structure building and interpretive processes. Parsing principles of minimal effort have been shown to constrain the way we build and navigate complex linguistic structures. Abstracting away from the obvious (often fundamental) differences across models, the underlying principles have been shown to apply in a regular, predictable way across languages with any variation firmly grounded on independent grammatical differences.

There is, however, one domain of research in sentence processing where universality was famously called into question: Relative Clauses attachment (Cuetos & Mitchell, 1988, and much related literature). Relative Clauses (RCs) have featured massively in the psycholinguistics literature, providing an important testing ground for parsing models from early studies on garden-path sentences involving reduced relatives (structure building strategies), to studies comparing local vs. long-distance movement in subject and object relatives (assessing memory mechanisms) to work on RC attachment preferences in various environments/languages (locality of attachment). Cuetos and Mitchell (1988) first observed that speakers of Spanish and English displayed a strikingly different parsing preference in the resolution of syntactic ambiguities involving two potential attachment sites of an RC: while English speakers relied on principles of minimal effort, attaching the RC to the closest potential host (the most local NP *the actress) in (1-a)*); Spanish (and as it later appeared also French, Italian and Dutch a.o.) speakers appeared to violate this principles, showing an overall preference for attachment to the non-local host (*the maid* in (1-b)). The locality principle governing attachment seems therefore to apply differently across languages.

(1) a. Someone shot the maid$_1$ of the actress$_2$ that$_2$ was$_2$ standing on the balcony
b. Alguien disparó contra la criada$_1$ de la actriz$_2$ que$_1$ estaba$_1$ en el balcón

This asymmetry was particularly striking because of its exceptionality and specificity. Spanish and English speakers, in fact, show the same preferences when disambiguating sentences which involve principles governing structure building and filler-gap dependencies, they also show the same tendency to prefer local attachment when constituents other than RCs are tested (e.g. when attaching temporal modifiers in: *John said that Mary left yesterday*). These findings generated a rather vast literature aimed at explaining away the asymmetry. The in depth investigation of RC attachment across languages and structures uncovered a variety of factors that contribute to the disambiguation of RC attachment and the processing of adjuncts more generally. It is now apparent that semantic, pragmatic and prosodic factors all contribute to the disambiguation of sentences involving multiple potential hosts for a RC, and that these factors apply in substantially the same way across languages (for recent reviews see e.g. Grillo & Costa 2014; Hemforth et al. 2015).

An important recent development in this debate came with the discovery that the previous lit-

erature on RC-attachment contained a grammatical confound in the cross-linguistic comparisons (Grillo, 2012). A subset of the languages under study, including Spanish but not English, allow for constructions known as *Pseudo Relatives* (PRs). Faithful to their name, these imposters are string identical to RCs. The two constructions, however, display very different structural, interpretive and prosodic properties (see below for discussion and references). Crucially, there is no attachment ambiguity under the PR parse, as the first NP of a complex NP is the only accessible subject for the embedded predicates, in other words: High Attachment is obligatory with PRs. PRs are found not only in Spanish but also in a number of so-called High Attachment languages (including French, Dutch, Greek and Serbo-Croatian a.o.). PRs, however are not available in Low Attachment languages including English, Basque, Romanian and Chinese. Not recognizing this grammatical distinction necessarily put the burden of explanation of the variation in attachment preferences entirely on the parser, causing the crisis we discussed.

The discovery of this confound led to the formulation of the *PR-first Hypothesis*, which suggests that PRs are both interpretively and structurally simpler than RCs and thus should be preferred by the parser. Recent results on RC-attachment indirectly support this hypothesis by showing a strong effect of PR-availability on RC-attachment: when the PR-confound is controlled for, and only unambiguous RCs are tested, a strong tendency to attach locally is observed across languages and structures. Non-local/High attachment is observed across languages when a PR reading is available.

In the present paper we extend these findings in multiple directions. After a brief introduction on the contrast between PRs and RCs and a short summary of previous experiments on the effects of PR-availability on the resolution of RC attachment ambiguities (Section 1.1), we show that French speakers display a clear preference for Low Attachment when unambiguous RCs are tested and other factors (such as prosody or referentiality) are controlled for (Section 2). As predicted, High Attachment is observed with the same complex DP+RC combinations in environments that license PRs.

This first study sets the stage for the main contribution of this paper: to provide a *direct* test of the PR-first Hypothesis, by evaluating the processing of PRs and RCs in the absence of attachment ambiguities. A straightforward prediction of this account is that forcing a RC-reading in locally ambiguous PR/RC environments should lead to observable processing costs, in terms of e.g. degree of acceptability and reading/fixation time at the disambiguating region. This is because disambiguating in favour of the RC reading would force reanalysis (or re-ranking of parallel parses) of the initial PR-preference. We tested these predictions in two sets of experiments using acceptability judgment tasks (Section 3) and eye-tracking while reading (Section 4). The eye-tracking studies serve a second goal by allowing us to explore the time course of the PR/RC disambiguation. These studies were conducted both in French and English to allow comparing effects of the same variables across PR and nonPR languages.

In line with *PR-first*'s predictions we found that forcing a RC reading in otherwise PR-compatible environments leads to higher complexity as indexed by lower acceptability and longer fixation durations. Importantly, these effects were observed in French (a PR-language) but not in English (a non PR-language), which shows that the relevant variable is PR-availability and not to our manipulations per se. Overall, the results further support the claim that parsing principles are universal: previously reported cross-linguistic differences in parsing preferences are strongly grounded on independently observed grammatical differences and thus epiphenomenal.

1.1. Pseudo Relatives and PR-first

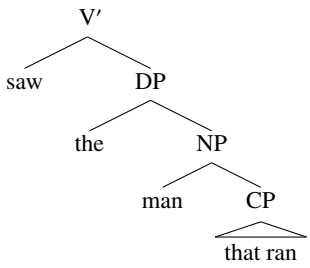
Relative Clauses in the complement position of perceptual verbs in languages like French (2), but not in English, are ambiguous between a RC reading (2-a), and the so-called Pseudo Relative reading (2-b).[1] Despite being string identical, PRs and RCs are both structurally and interpretively different. As shown in (2), and further illustrated in (3) and (4), The CP is embedded within the DP it modifies in RCs but it stands in a sisterhood relation with the same DP in PRs.

(2) a. Jean a vu [$_{DP}$ l' [$_{NP}$ homme [$_{CP}$ qui courait.]]]
J. has seen the man that run.
'John saw the man that ran.'

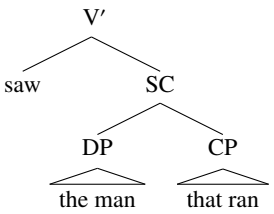
b. Jean a vu [$_{PR}$ [$_{DP}$ l'homme] [$_{CP}$ qui courait.]]
J. has seen the man that ran.
'J. saw the man running.'

c. John saw [$_{PR}$ the man running].

(3) RELATIVE CLAUSE



(4) PSEUDO RELATIVE



This structural difference is accompanied by a sharp interpretive difference: RCs denote properties of entities (5), PRs denote events (6) and roughly correspond to eventive Small Clauses in English (2)[c].[2]

[1] On PRs see e.g. Radford (1975); Kayne (1975); Graffi (1980); Burzio (1986); Cinque (1992); Rizzi (1992); Guasti (1988, 1992); Koenig & Lambrecht (1999); Rafel (1999); Casalicchio (2013); Moulton & Grillo (2015); Grillo & Moulton (2016, Under Review); Grillo & Turco (2016a) among others.

[2] For clarity of presentation, we show a simplified semantics for PRs, for a more detailed discussion on the syntax-semantics of PRs see Moulton & Grillo (2015); Grillo & Moulton (2016). For discussion of how these structural differences are encoded at the prosodic level see Grillo & Turco (2016b).

(5) RC: *John saw the man that runs*

Figure 1: *My Hero*, Zwerink (2011), Public Domain.

∃e [see(e) & EXPERIENCER(e)(John) & STIMULUS(the unique man that ran)(e)]
There is an event of *seeing* and the experiencer of that event is *John* and the stimulus of the event is *the unique man that ran*.

(6) PR: *John saw the man running*

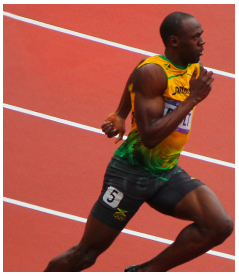


Figure 2: *Run*, Mackintosh (2012), Public Domain.

∃e∃e'[see(e) & EXPERIENCER(e)(John) & STIMULUS(e')(e) & run(e') & AGENT(e')(the man)]
There is an event of *seeing* and the experiencer of that event is *John* and the stimulus of the event is *an event of running by the man*.

Just like eventive Small Clauses (SCs) in English, PRs obey a number of restrictions which do not apply to RCs. The following experiments build on two such factors: constraints on the type of verb licensing PRs and constraints on Tense.

PR-availability #1: Verb Type. Since they denote events, PRs and SCs are allowed under perceptual verbs (which can take both entities and events as complements) (7-a) but not under stative predicates (which only take entity-denoting complements) (7-b):[3]

(7) a. Jean a vu Bolt qui courait.
J. has seen B. that run.IMPF.
'John saw Bolt running.'
b. *Jean vivait avec Bolt qui courait.
J. lived with B. that run.IMPF
'*John lived with Bolt that was running.'

This contrast is even more striking when pronominal objects are used, a manipulation which leads to a perfectly acceptable results under perceptual verbs (8-a) (i.e. when a PR reading is licensed), but complete ungrammaticality under stative verbs (i.e. when only the RC reading is available). This asymmetry is due to the fact that RCs (both restrictive and appositive) can never modify pronominals, a restriction which does not apply to PRs:

(8) a. Jean l'a vu qui courait. PR-only
J. him'has seen that run.IMPF.
'John saw him running.'
b. *Jean vivait avec lui qui courait.
J. lived with him that run.IMPF
'*John lived with him that was running.'

[3]Here and elsewhere we use proper names to disambiguate for the PR reading. Proper names can also head appositive RCs, however it is easy to show that these are also distinct from PRs (see e.g. Radford, 1975, and much related work). PRs for example, do not involve the typical *comma intonation* of appositive, on which see Poschmann & Wagner 2015.

PR-availability #2: Anaphoric Tense. Besides matrix Verb Type, Tense is also restricted in PRs, this restrictions do not apply to RCs and can in turn be manipulated to force a RC reading in otherwise PR-compatible environments.[4] Tense of the embedded clause is anaphoric in PRs. This means that the perception event introduced in the matrix clause and the perceived event introduced by the PR have to happen simultaneously. Simplifying somewhat, Tense specification of the matrix and the embedded clause must match in PRs (8-a). Tense mismatch leads to an ungrammatical structure (9-a). This requirement obviously does not apply to RCs (9-b).[5]

(9) a. *Jean le voit qui courait.
J. him sees.PRES that ran.IMPF
'John sees him that was running.'
b. Jean voit l'homme qui courait. RC-only
J. sees.PRES the'man that ran.PAST
'John sees the man that was running.'

This property of PRs can be used to force a RC reading in PR-compatible environments, turning a global ambiguity into a local ambiguity. (9-c) is locally ambiguous (up to the Tense specification of the embedded verb) between a PR and a RC reading. Tense mismatch, however, forces the RC reading (9-c). Tense in RCs, in fact, is completely independent from that of the matrix predicate and fully referential.

In sum, Matrix Verb Type and Tense can both be used to manipulate PR-availability, which, as we will see, generates important effects on both RC-attachment and preferences, acceptability and fixation durations.

1.2. Effects of PR-availability on RC-attachment

The resolution of the PR/RC ambiguity featured in a number of recent studies which have investigated the role of the selective availability of PRs in explaining apparent cases of cross-linguistic variation in the processing of RC-attachment (Grillo 2012; Grillo & Costa 2014; Grillo et al. 2015). As mentioned in section 1, everything else being equal, speakers of English (among other languages including Basque, Romanian and Chinese) displayed a preference for local attachment of the RC, while speakers of French (and Italian, Spanish and Greek a.o.) preferred non local attachment (1).

The present relevance of PR-availability is easily understood once we consider that the attachment ambiguity disappears under the PR parse (10). Because of standard structural restrictions (c-command), the only accessible subject for the embedded verb is the non-local DP (the son).

(10) J'ai vu $[_{PR}\ [_{DP}$ le fils$_i$ $[_{PP}$ de $[_{DP}$ l'homme$_j$]]] $[_{CP}$ qui$_{i,*j}$ courait.]]
I'have seen the son of the'man that ran.
'I saw the son of the man running.'

[4]Several other restrictions apply selectively apply to PRs and not to RCs, including restrictions on both the inner or outer aspect of the embedded clause. PRs, in fact, require imperfective aspect and are only allowed with eventive verbs or, somewhat more marginally, with states when these describe stage-level predicates (e.g. *to have red eyes*), but are completely unacceptable with individual level predicates (e.g. *to have blue eyes*). Neither restriction obviously applies to RCs: *John lives with the boy that has blue eyes*. For additional work on the role of tense and aspect in RC-processing, see Grillo & Spathas (2014); Aguilar & Grillo (2016).

[5]There are apparent restriction to this involving present under future and present under present perfect, which are discussed in Grillo & Moulton (2016). These are irrelevant for the present experiment which used past under present, which in no way can be construed as a PR.

Grillo (2012); Grillo & Costa (2014) proposed that the RC-attachment preference should covary with PR-availability and hypothesized that PRs are easier to parse than RCs for structural and pragmatic reasons. PRs have impoverished syntax with respect to RCs (e.g. anaphoric Tense), PRs stand in a sisterhood relation with the 'head NP', while RCs are embedded within the same NP, embedding arguably being a more complex configuration. Secondly, PRs convey information relevant for the main assertion of the clause (Frazier, 1990): in fact they can be projected as *arguments* of the main clause (I saw an event), while RCs are always *adjuncts* (I saw an entity, which has a certain property, introduced by the RC itself). Finally, PRs involve less presuppositions than RCs: PRs do not require selection from a pre-established set of entities in the discourse (Crain & Steedman, 1985; Altmann & Steedman, 1988). Similarly, in a sentence like *I saw the boy that was running*, familiarity introduced by the definite determiner extends to the whole NP+RC in the RC parse, but only to the NP in the PR parse. A revision of previous work on RC-attachment, and a number of novel experiments directly manipulating PR-availability in different languages, indeed show a strong correlation between PR-availability and RC-attachment. When PRs are not available, and other relevant factors are controlled for, Low Attachment is found across languages and structures.[6]

Grillo & Costa (2014) report a strong effect of Verb Type on RC-attachment in Italian, with High Attachment observed with perceptual verbs (78.6% High Attachment preference) and Low Attachment with stative verbs (24.2% High Attachment preference). Comparable results were obtained from other PR-languages: Greek (Grillo & Spathas, 2014), Portuguese (Grillo et al. 2012a,b, 2013a,b; Fernandes 2012; Tomaz et al. 2014), Spanish (Grillo et al., 2012b; Aguilar & Grillo, 2016). These are all languages that were previous classified as *High Attachment Languages*. Each one of these studies, however, showed that this classification is epiphenomenal: as predicted by *PR-first*, Low Attachment preference was observed consistently in each of these languages in unambiguous RC environments, High Attachment preference was only observed in PR-compatible environments. Importantly, Grillo et al. (2015) show that predicate semantics/plausibility alone does not account for these results, as the same verb-type manipulation in English (a non-PR language) did not lead to overall High Attachment with either type of verbs.

These results are consistent with the claim that there exists a preference for the PR parse over the RC parse, the so-called *PR-first Hypothesis*. A straightforward prediction of *PR-first* is that Tense Mismatch in the environment of PR-compatible verbs should lead to reanalysis of the initial PR-preference, with observable processing costs. Tense (mis)match, on the other hand, should play no role in the interpretation of the embedded clauses in globally unambiguous RCs (e.g. RCs in the environment of stative verbs). We therefore predict a qualitatively different effect of Tense manipulation in globally unambiguous RC environments.

Before turning to this direct test of *PR-first*, we briefly show that PR-availability also modulates RC-attachment preferences in French. This serves as a pre-test of the effects of PR-availability and also adds to the literature on RC attachment in French.

[6] *PR-first* is certainly not the sole factor determining RC-attachment, previous work showed that this is strongly modulated by of a number of other factors both within and across languages, including *pragmatic* (Gilboy et al., 1995; Frazier & Clifton, 1996), *prosodic* (Fodor, 2002; Hemforth et al., 2015), lexical (Rohde et al., 2011) and independent grammatical properties of the languages under scrutiny, e.g. RCs introduced by Complementizers vs. obligatory Relative Pronouns as in German, Russian and Bulgarian (Hemforth et al., 2000; Grillo & Costa, 2014).

2. Experiment 1: RC-attachment in French

We first want to make sure that Verb Type manipulation (i.e. PR-availability) also modulates RC attachment in French in the same way as it does in other PR-compatible languages.

Materials and Procedure

The experiment contained 24 ambiguous target sentences containing complex NPs of the form NP1 of NP2 followed by a finite CP. These complex NPs were placed in object position of either perceptual verbs (11-a) or stative verbs (11-b). As mentioned above, under perceptual verbs the CP can be either attached as sister of the non-local DP *the son* (PR-reading, no attachment ambiguity) or as RCs, which can in turn be embedded under the local (*the policeman*) or the non-local DP (*the son*). Under stative verbs, the CP can only be construed as a RC, and successively attached High or Low.

(11) a. Marie écoute le fils du policier qui parle. PERCEPTUAL
M. listens.to the son of the policeman that is talking.
'Mary listens to the son of the policeman that talks.'

b. Marie est employée par le fils du policier qui parle. STATIVE
M. is employed by the son of.the policeman that talks.
'Mary is employed by the son of the policeman that talks.'

Target sentences were interspersed with 60 unrelated fillers from other experiments and presented online through the IBEX platform in a latin square design. After reading each sentence participants were asked to complete a sentence describing the event in the embedded clause filling in the blank space in the subject position with either the local or non-local NP. Each participant only saw one version of each targets sentence.

Participants

Sixty-nine native speakers of French participated in the experiment in exchange of a small compensation.

2.1. Analysis & Results

An overall High Attachment preference (61%) was observed in PR-compatible environments (i.e. under perceptual verbs) and a strong preference for Low Attachment (72%) was observed with unambiguous RCs (under stative verbs). To our knowledge, this is the first experiment showing a preference for local attachment with *unambiguous RCs* in French. This is an important result as it shows that PR-availability might indeed have confounded previous results.

The attachment preference data were analyzed with a Bayesian generalized linear mixed-effects model with a logit link function (Jaeger, 2008) using the *rstan* package (Carpenter et al., 2017; Stan Development Team, 2017) in R (R Core Team, 2017) (R Core Team, 2017). The binary dependent variable of attachment preference was coded as 1 (High Attachment) or 0 (Low Attachment). The levels of the factor Verb were coded as 1 (perceptual) and -1 (stative). With this coding, zero represents the point of "no difference" between the two verb types. Our interpretation of the data will be as follows: if zero is not contained in the posterior distribution of the coefficient parameter ($\hat{\beta}$) we take this as strongly reliable evidence for the effect; if zero is contained in the posterior but lies outside the 95% credible intervals (or CrI, which is the area that covers 95% of the distribution), we will still treat this as reliable evidence for the effect. If

zero lies inside the 95% CrI we will consider the effect as weak and unreliable. In the appendix we provide a detailed motivation for opting for a Bayesian analysis.

The fixed effects part in the model included the main effect of Verb. The random effects part included adjustments for subjects and items of an intercept, the slope for this main effect and the correlation between intercept and slope (Baayen et al., 2008; Barr et al., 2013). The model was run with 4 MCMC chains and 3000 iterations each, of which the first 1500 iterations were used as a warm-up phase. Model convergence was verified by checking visually that the chains converged and by making sure that the $\hat{R}$ statistics for each parameter coefficient was equal to 1 (Gelman et al., 2013).

As can be seen in Figure 2, the model confirms that the evidence for the difference between High Attachment preference in the two verb types is strongly reliable ($\hat{\beta} = 1.13$, 95% CrI = [0.77, 1.52], P($\hat{\beta}$) > 0 = 1). The fact that the posterior distribution lies completely above zero indicates that the preference is higher in perceptual than in stative verbs.

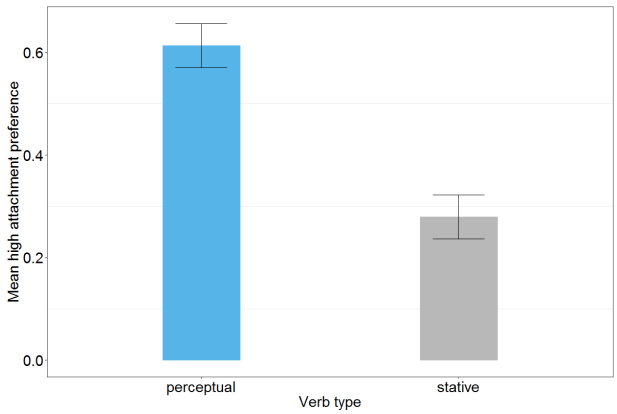


Figure 3: Mean High Attachment preference divided by verb type (with 95% confidence intervals).

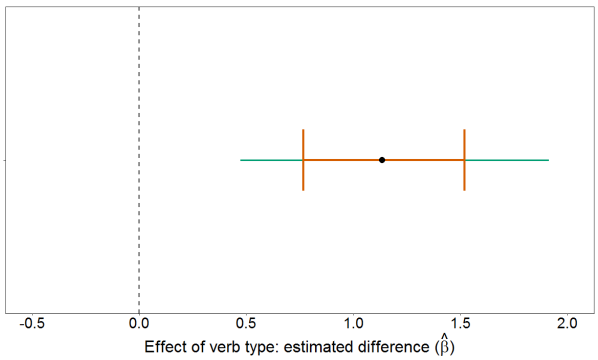


Figure 4: Posterior distribution (with the mean marked as a black dot, and 95% credible intervals) for the effect of High Attachment preference in perceptual vs. stative verbs.

2.2. Intermediate discussion

As in previously reported results for other PR-compatible languages, we have shown that PR-availability strongly modulates RC-attachment also in French. A strong preference for Local attachment is observed with unambiguous RCs (i.e. with stative predicates), supporting the idea that locality principles play a central role across languages. Conversely, a High Attachment preference emerges when PRs are available (i.e. with perceptual verbs). The reasoning is rather simple: since only the non-local NP is an accessible subject in the PR parse, we can explain the strong preference for High Attachment in PR-compatible environments as a preference for the PR parse over the RC parse. Experiment 1, therefore provides further support for the idea that these structures are universally preferred by the parser over RCs.

The set of results discussed so far all provide *indirect* support for a parsing preference for PRs over RCs. Our goal here is to provide a test capable to directly falsify the PR-first Hypothesis. If PRs are indeed preferred to RCs, RC disambiguation of otherwise PR-compatible structures should come with an observable cost.

Several factors can be manipulated to force a RC reading in otherwise PR-compatible environments. One case at point is Tense. As mentioned, Tense is anaphoric in PRs, but not in RCs. In other words, Tense specification of the embedded clause must match the Tense specification of the matrix clause in PRs but not in RCs. .

This allows us to construct minimal pairs which are locally ambiguous between a PR and RC reading up to the Tense specification of the embedded predicate: Matching Tense in (12-a) is compatible with a PR reading, Tense Mismatch will force a RC reading (12-b):

(12) a. Jean a vu la fille qui poussait la femme. PR/RC
J. has seen.PAST the girl that pushed.PAST the woman.
'J. saw the girl pushing the woman/that pushed the woman.'

b. Jean voit la fille qui poussait la femme. RC-ONLY
J. sees.PRES the girl that pushed.PAST the woman.
'J. sees the girl that pushed the woman/*pushing the woman.'

Tense manipulation constitutes an ideal type of disambiguation in that it allows us to keep the whole DP+embedded clause identical across conditions, the only difference across conditions being the Tense specification on the matrix predicate (PAST in the PR-compatible condition vs. PRESENT in the globally unambiguous RC-condition).

In the following sections, we present the results of four experiments testing the effects of Tense (Mis)Match in French (a PR-language) and English (a nonPR language) in PR-compatible and RC-only environments. The first two experiments used acceptability judgments as a proxy for processing complexity. The second set of studies uses eye-tracking while reading with the same stimuli to further investigate the time course of the potential processing difficulty.

If our working hypothesis is on the right track, we should expect to find lower acceptability and longer fixation times for Tense Mismatch than Tense Match *exclusively in otherwise PR-compatible environments*, i.e. only under perceptual verbs and limited to French. The same manipulation should have different effects in a nonPR language like English. Namely, the interaction between matrix verb type and Tense (Mis)Match predicted for French should not be observed in English.

3. Experiments 2: Acceptability of Tense (Mis)Match in French and English

The first set of two experiments testing the interaction of PR-availability and Tense (Mis)Match is an acceptability rating experiment in French and English. Speakers tend to attribute lower acceptability to otherwise perfectly grammatical sentences which involve complex processes, e.g. reanalysis or similarity based interference. The observed difference in acceptability judgments likely reflect this difference in complexity.

Design

In a 2*2 acceptability judgment study we crossed Tense (Mis)Match with (matrix) Verb Type (perceptual vs. stative), the region of interest (NP + embedded clause) and the critical region (embedded verb) were kept identical across conditions. The experiment was conducted in two languages: English, which is a non-PR language, and French, a PR-language. This allows us to independently evaluate the contribution of PR-availability above and beyond the interaction of Tense and Verb Type. The design of the experiment languages was identical across languages.

Participants

Fifty-eight native French speakers (mean age : 29) and 103 native English speakers (mean age: 31) participated in the experiments. Both experiments were run on the Ibex Platform (Drummond 2013 Ibex Farm, http://spellout.net/ibexfarm/). French participants were recruited on the RISC platform, English speakers via Amazon Mechanical Turk.

Material

Both experiments in English and French were a 2*2 design. As shown in Table 1, we manipulated two variables : Verb Type (perceptual / stative) and Tense (match / mismatch). We created 24 items, with 6 items per condition arranged in 4 lists in a standard Latin Square design. Twenty-six fillers in French and twenty-nine fillers in English were added to each list and three practice trials preceded the experiment for each list. The items and the fillers were fully randomized, so that each participant had a different order of the sentences. Both the experimental items and the fillers in French and English were close translations.

Verb Type	**Tense**	**Example item**
Perceptual	Match	*Jean **a vu** la fille qui poussait la femme.* John **saw** the girl that pushed the lady.
	Mismatch	*Jean **voit** la fille qui poussait la femme.* John **sees** the girl that pushed the lady.
Stative	Match	*Jean **était marié à** la fille qui poussait la femme.* John **was married to** the girl that pushed the lady.
	Mismatch	*Jean **est marié à** la fille qui poussait la femme.* John **is married to** the girl that pushed the lady.

Table 1: Example of an item in the four conditions

Procedure

Participants had to judge online the acceptability of each sentence on a scale from 1 (completely unacceptable) to 10 (completely acceptable). Each sentence appeared one at a time on the computer screen with the acceptability scale below it.

Predictions

Based on *PR-first* we should expect to see an interaction between V-Type and Tense in French. More specifically, *PR-first* predicts higher acceptability for (PR-compatible) sentences with Tense Matching than Tense Mismatch under Perceptual verbs. No such effect is predicted for stative verbs. Also, no interaction is expected in English, as a PR interpretation is excluded in this languages and all items describe unambiguous RCs (both locally and globally).

3.1. Results & Analysis

The acceptability judgment data were analyzed with a Bayesian cumulative link mixed-effects model (Agresti, 2012; Christensen & Brockhoff, 2013) using the *brms* package (Bürkner, 2017) in R. The levels of the factor Tense were coded as 1 (match) and -1 (mismatch); the levels of the factor Verb Type were coded also as 1 (stative) and as -1 (perceptual). Data interpretation will be based on the same principle as in Experiment 1.

The fixed effects part included the main effect of Tense and Verb Type, as well as their interaction. The random effects part included adjustments for subjects and items of an intercept, of slopes for these main effects and interactions, and the correlations between intercepts and slopes. We ran the model with 4 chains and 3000 iterations each (the first 1500 iterations used as warm-up). Model convergence was again verified by checking the chains convergence and the $\hat{R}$ statistics for each parameter coefficient. The same analysis procedure was repeated in exactly the same manner for the French and English data.

As predicted by the PR-first hypothesis, we observed a higher acceptability rate for sentences with a tense match than with a tense mismatch under perceptual verbs in French (Figure 3, right panel). The effect did not show up under stative verbs, for which there was a similar acceptability rate in tense mismatch and tense match trials. The model for the French data indicates that there is evidence for the effect of Verb Type ($\hat{\beta}$ = -0.22, 95% CrI = [-0.39, -0.05], P($\hat{\beta}$) < 0 = 0.99), namely there is 99% certainty for the effect of higher ratings for perceptual verbs than for stative verbs. There was similarly reliable evidence for the effect of Tense ($\hat{\beta}$ = 0.25, 95% CrI = [0.08, 0.42], P($\hat{\beta}$) < 0 = 0.002) and for the interaction of Tense by Verb Type ($\hat{\beta}$ = -0.30, 95% CrI = [-0.46, -0.15], P($\hat{\beta}$) < 0 = 0.99). See Figure 4 for the model outcome.

Importantly, these results were different in English (Figure 3, left panel). As predicted, in this language there was no evidence for the effect of Tense ($\hat{\beta}$ = 0.06, 95% CrI = [-0.04, 0.16], P($\hat{\beta}$) < 0 = 0.12), Verb Type ($\hat{\beta}$ = -0.13, 95% CrI = [-0.27, 0.02], P($\hat{\beta}$) < 0 = 0.96) or their interaction ($\hat{\beta}$ = -0.03, 95% CrI = [-0.15, 0.08], P($\hat{\beta}$) < 0 = 0.72). For all of the effects zero was included in the 95% CrI. See Figure 5 for the model outcome.

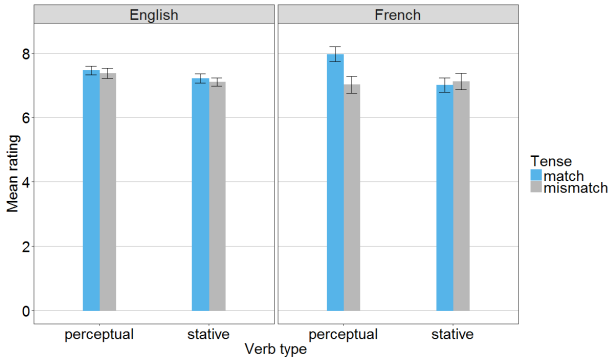


Figure 5: Mean acceptability rate (with 95% confidence intervals) by Tense and Verb Type, in the English and French experiments.

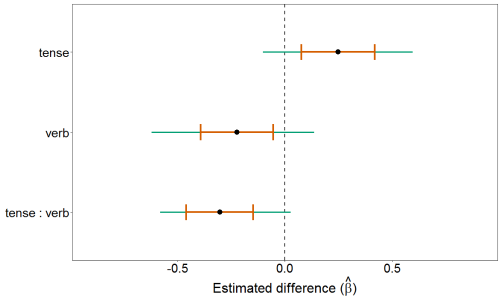


Figure 6: French acceptability judgment experiment: posterior distributions (with the mean marked as a black dot, and 95% credible intervals) for the main effects of Tense and Verb and their interaction.

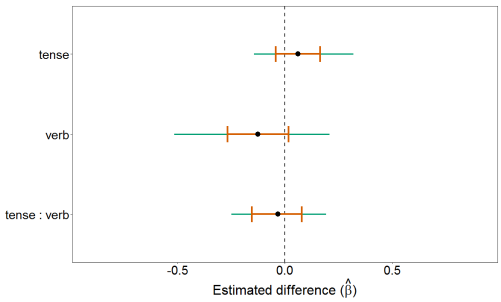


Figure 7: English acceptability judgment experiment: posterior distributions (with the mean marked as a black dot, and 95% credible intervals) for the main effects of Tense and Verb and their interaction.

3.1.1. Discussion

As predicted by PR-first, Tense Mismatch negatively affected acceptability when it forced a RC-reading in an otherwise PR-compatible environment, i.e. under perceptual verbs and only in French. Tense manipulation, however, does not significantly affect acceptability in globally unambiguous RC-only environments. Importantly, this interaction was only observed in French. No effects of Tense and no interaction between Tense and V-Type were found in English. The results thus fully support PR-first predictions: the parser does appear to favour a PR over a RC interpretation. Taken together with previous results from RC-attachment, these results appear to show a preference for secondary predication over restrictive interpretation, or, to put it differently, a preference for *events* over *entities* in the complement of perceptual verbs.

We are now in a position to proceed to the following questions: how does this apparent preference for PRs over RCs unfold online? To address this question we ran two eye-tracking studies using the same stimuli tested in the acceptability study. If our interpretation of the effects is on the right track, we should find longer fixation durations at the disambiguating region (the embedded verb) for Tense Mismatch than Tense Match under perceptual verbs and only for French.

4. Experiment 3: Tracking eye-movement while reading Tense (Mis)Match across languages

4.1. Design

Using the Eye-Tracking methodology, we designed a Reading experiment both in English and French.

4.1.1. Participants

We had two groups of participants, one for the French experiment and one for the English experiment. In the first group, 62 French native speakers living in Paris participated in the French experiment (mean age: 28). For the experiment in English, 50 English native speakers paticipated in the experiment, with 26 living in London, 20 in Glasgow and 4 in Paris (mean age: 26). All participants received either monetary compensation or course credits to participate in the experiment. All participants from both groups were naive as to the purposes of the study.

4.1.2. Materials

Design and materials were the same as for Experiments 2 and 3

A difference from the acceptability studies is that comprehension questions were added to verify that participants were really reading the sentences and were paying attention. Both experiments in French and in English included 16 questions for each list (around 35% of all the trials).

4.1.3. Procedure

Eye fixations were recorded with Eyelink II for French. As for English, eye fixations were recorded with Eyelink 1000 for the experiments in London, and Eyelink II for the experiments in Glasgow and in Paris. The system recorded each participants dominant eye movements while he/she was reading sentences using the Miles test (Miles, 1930). Sentences appeared in 20 font on the screen on a single line for the target items. Each participant had to read the sentence at a natural pace and had to press the spacebar on the keyboard when he/she was finished. They also had to answer a comprehension question after some items by pressing yes/no on the keyboard

(about 35% of all the trials). Each session started with he same three practice items and lasted less than 30 minutes.

4.2. Analysis

In the French experiment, 10 participants had an accuracy rate of less than 85%. Since the questions were very easy, such a low accuracy rate means that these participants were probably not concentrated on the task. We therefore decided to exclude them from the analysis. The rest of the participants had an accuracy rate of about 96%. In the English experiment, 12 participants had an accuracy rate of less than 85%, so we excluded them as well from the analysis, and the rest had an accuracy rate of about 91%

The items were divided into four regions (see Table 2). The critical region concerns the embedded verb (region 3). According to our hypothesis, tense mismatch should generate longer durations at this disambiguating region only in PR-environments (with perceptual verbs) in French, but not in English.

Conditions	**Regions**			
	First Noun + Verb	Second Noun + Complementizer	Verb	End of Sentence
Perception-match	*Jean a vu* John saw	*la fille qui* the girl that	*poussait* pushed	*la femme*. the lady.
Perception-mismatch	*Jean voit* John sees	*la fille qui* the girl that	*poussait* pushed	*la femme*. the lady.
Stative-match	*Jean était marié à* John was married to	*la fille qui* the girl that	*poussait* pushed	*la femme*. the lady.
Stative-mismatch	*Jean est marié à* John is married to	*la fille qui* the girl that	*poussait* pushed	*la femme*. the lady.

Table 2: Example of an item divided into the four region of analysis

The dependent variable we were interested in for the eye-tracking studies was the regression path duration, which reflects the time the reader fixates a particular region, from when she first fixates it until she moves on to fixate the next region (Konieczny, Hemforth, Scheepers & Strube, 1997; Liversedge, Paterson & Pickering, 1998). Other eye-tracking measures, specifically first pass duration and total reading times, did not detect reliable effects (we report these analyses in the appendix).

4.3. Results

We analyzed the regression path duration times with Bayesian shifted lognormal mixed effects models, using the *rstan* package in R. These models arguably account for reading times data in a more appropriate manner (than, for instance, linear mixed-effects models with log-transformed reading times), mainly because these data are right skewed and are bound to be greater than zero (Nicenboim & Vasishth 2018). The levels of the factor Tense were coded as 1 (match) and -1 (mismatch); the levels of the factor Verb were coded as 1 (perceptual) and as -1 (stative). Data interpretation will be based on the same principle as in the previous experiments.

The fixed effects part included the main effect of Tense and Verb, as well as their interaction. Moreover, we included as a main effect (without interactions) the number of characters of each verb as a centered continuous covariate, to control for the length of the verb in the various trials.

Additionally, we included the interaction of the order of presentation of the items (inserted as a centered continuous covariate) with the factor Tense and with the factor Verb. This was done in order to control for any potential learning effects during the experiment and their influence on the experimental manipulations. The main effect of the order of presentation was not included in the model.

The random effects part included adjustments for subjects and items of an intercept, of slopes for the main effects and interaction of Tense and Verb, and the correlations between intercepts and slopes. We ran the model with 4 chains and 3000 iterations each (the first 1500 iterations used as warm-up). Model convergence was verified by checking the convergence of the chains visually and the $\hat{R}$ statistics for each parameter coefficient. The analysis procedure was the same for the French and the English data.

Figure 7 shows the mean regression path duration in each sentence region in the French experiment, and Figure 8 shows the same data from the English experiment. In French, regression path duration at the embedded verb was longer, thus reflecting greater processing difficulty, in sentences with a tense mismatch under perceptual verbs. By contrast, when the verb was stative there was no difference between tense match and mismatch. This is reflected in the strong main effect of Tense ($\hat{\beta}$ = -47.93, 95% CrI = [-97.9, -0.39], P($\hat{\beta}$) < 0 = 0.98) and, more importantly, in the interaction between Tense and Verb Type ($\hat{\beta}$ = -57.86, 95% CrI = [-106.42, -10.44], P($\hat{\beta}$) < 0 = 0.99). For the other model terms there was no evidence for a reliable effect (cf. Table 3). Figure 9 shows the posterior distributions of the fixed-effects parameters in the model for the French data.

We also checked the various effects on the regression path duration prior to the critical region. Only region 2 (second noun and Complementizer) is relevant for this purpose, since in region 1 reading times are expected to be influenced by Verb Type. Specifically, this region was longer for stative verbs than for perceptual verbs (cf. Table 2). By contrast, region 2 was identical across conditions. In region 2, we only found some weak evidence for an effect of word length ($\hat{\beta}$ = 35.01, 95% CrI = [6.35, 64.13], P($\hat{\beta}$) < 0 = 0.0097), which does not depend on the experimental manipulation of interest. There was no evidence for the other effects (cf. Table 3).

Region	**Effect**	**Estimate ($\hat{\beta}$)**	**95% credible intervals**	**P($\hat{\beta}$) < 0**
Second Noun + Complementizer (region 2)	Tense	7.08	[-45.15, 59.81]	0.39
	Verb Type	-5.07	[-65.79, 54.97]	0.56
	Word Length	35.01	[6.35, 64.13]	0.0097
	Tense : Verb Type	-8.29	[-63.16, 47.94]	0.61
	Item Order : Tense	-0.29	[-4.05, 3.49]	0.56
	Item Order : Verb Type	0.35	[-3.55, 4.23]	0.43
	Item Order : Tense : Verb Type	0.57	[-3.13, 4.33]	0.39
Verb (region 3)	Tense	-47.93	[-97.9, -0.39]	0.98
	Verb Type	-12.19	[-55.83, 32.02]	0.71
	Word Length	6.74	[-12.05, 25.21]	0.24
	Item Order : Tense	1.75	[-1.28, 4.87]	0.13
	Item Order : Verb Type	2.09	[-0.98, 5.12]	0.09
	Item Order : Tense : Verb Type	3.11	[-0.02, 6.24]	0.03

Table 3: French: Results of Bayesian linear mixed-effects models in region 2 and 3

Importantly, in English the time it takes to read the verb was not influenced by Tense, neither under perceptual nor under stative verbs. For none of the fixed-effects model terms was there evi-

dence for a reliable effect (cf. Table 4). This can be seen by examining the posterior distributions for the different parameters, plotted in Figure 10.
In region 2 in English, like in French, there was only evidence for a main effect of word length ($\hat{\beta}$ = 39.94, 95% CrI = [16.54, 63.54], P($\hat{\beta}$) < 0 = 5e-04), independently of the relevant experimental factors. All the other effects in the model were non-reliable (cf. Table 4).

Region	Effect	Estimate ($\hat{\beta}$)	95% credible intervals	P($\hat{\beta}$) < 0
Second Noun + Complementizer (region 2)	Tense	-58.84	[-142.11, 110.32]	0.93
	Verb Type	20.78	[-62.58, 104.18]	0.31
	Word Length	39.94	[16.54, 63.54]	5e-04
	Tense : Verb Type	10.18	[-72.56, 89.89]	0.39
	Item Order : Tense	1.10	[-4.45, 6.75]	0.34
	Item Order : Verb Type	-0.56	[-6.29, 5.14]	0.57
	Item Order : Tense : Verb Type	0.09	[-5.38, 5.86]	0.49
Verb (region 3)	Tense	31.32	[-24.59, 89.17]	0.14
	Verb Type	-34.66	[-90.49, 21.98]	0.89
	Word Length	-2.38	[-21.10, 15.85]	0.59
	Tense : Verb Type	-22.91	[-79.65, 34.01]	0.79
	Item Order : Tense	0.31	[-3.61, 4.11]	0.44
	Item Order : Verb Type	3.27	[-0.56, 7.20]	0.05
	Item Order : Tense : Verb Type	2.14	[-1.88, 6.12]	0.14

Table 4: English: Results of Bayesian linear mixed-effects models in region 2 and 3

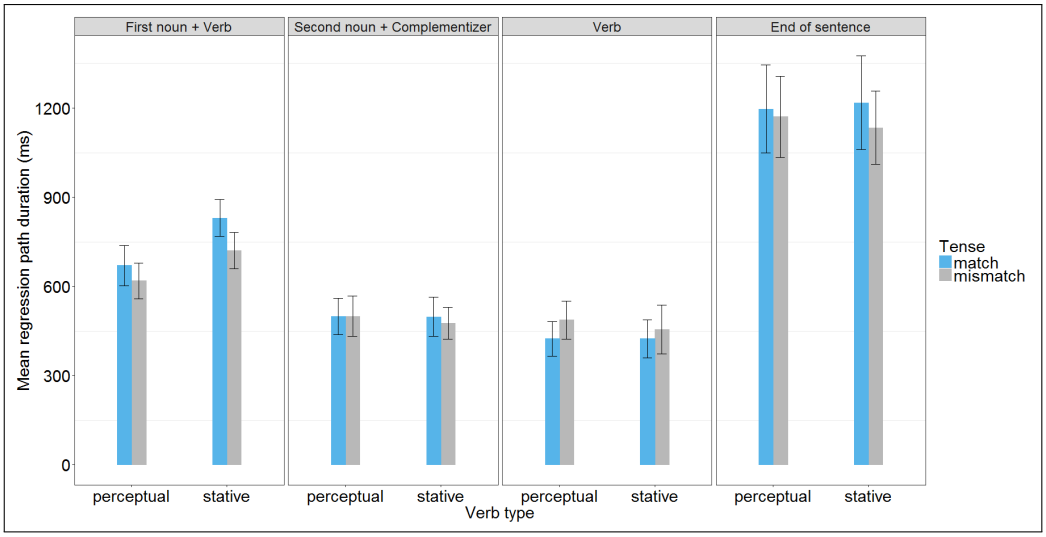


Figure 8: French eye-tracking experiment: regression path durations (with 95% confidence intervals) in the various sentence regions, divided by Tense and Verb Type.

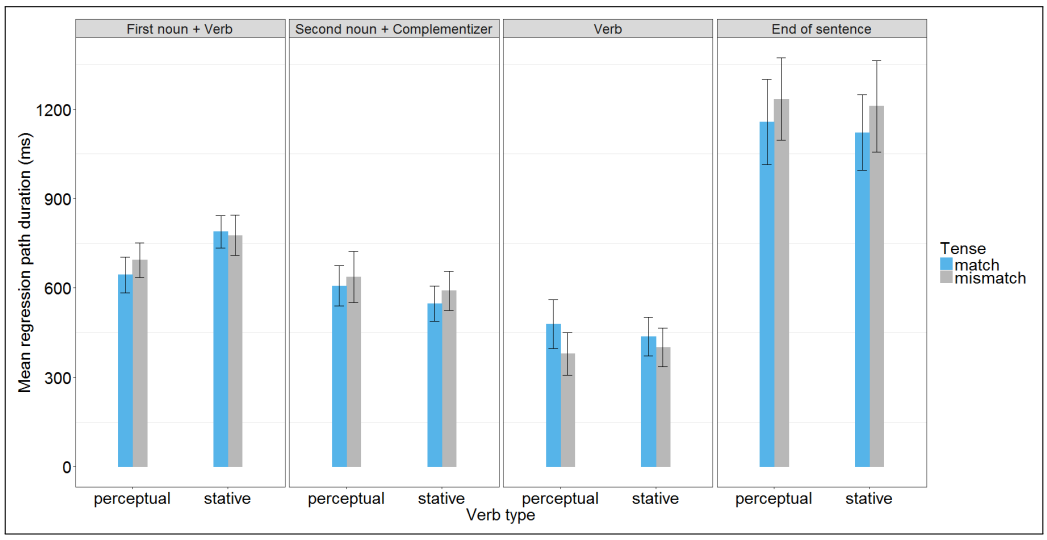


Figure 9: English eye-tracking experiment: regression path durations (with 95% confidence intervals) in the various sentence regions, divided by Tense and Verb Type.

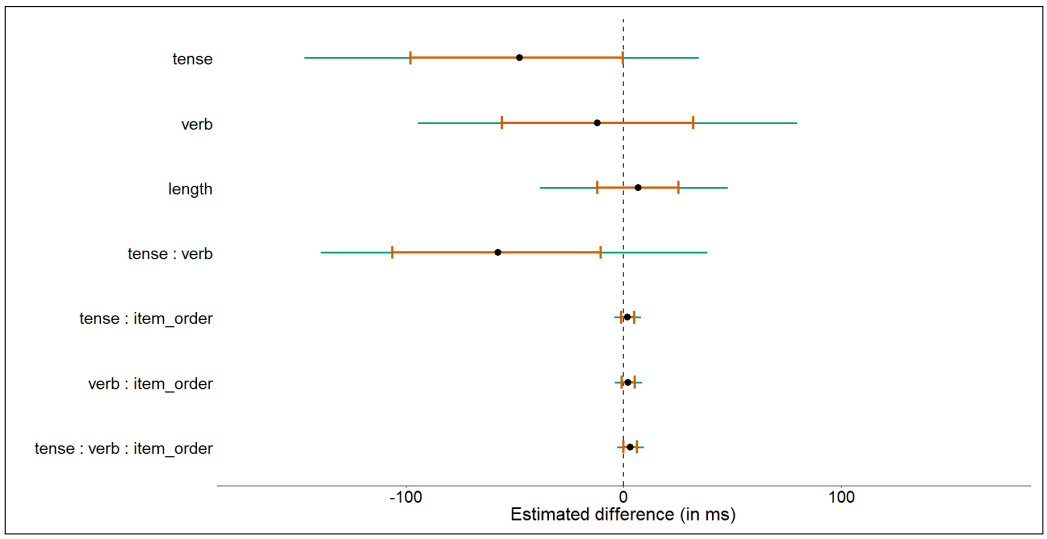


Figure 10: French eye-tracking experiment: posterior distributions (with the mean marked as a black dot, and 95% credible intervals) for the model parameters in the fixed effects part.

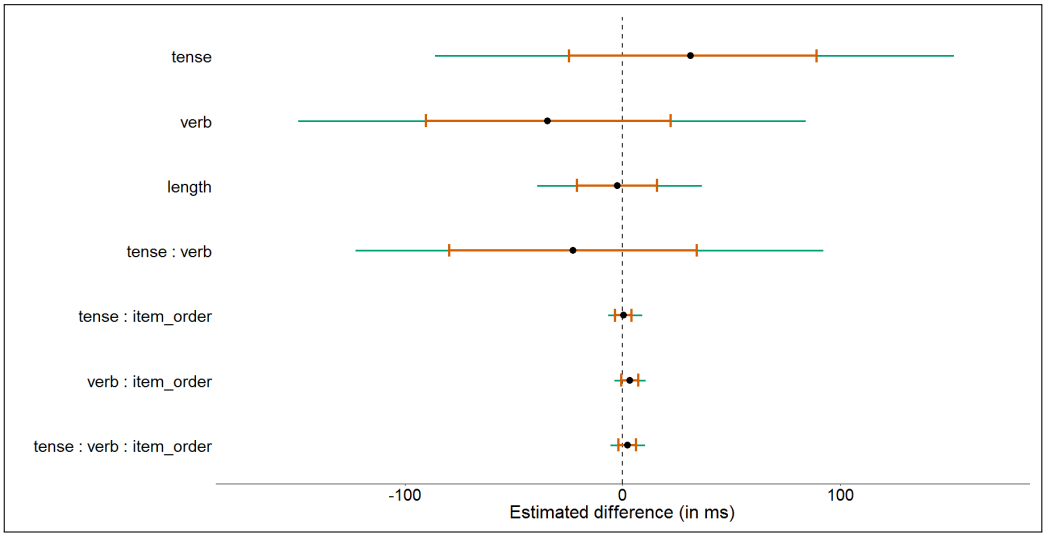


Figure 11: English eye-tracking experiment: posterior distributions (with the mean marked as a black dot, and 95% credible intervals) for the model parameters in the fixed effects part.

In sum, the results from the eye-tracking studies in French and English add to the previous experiments in two ways: first, we replicated the finding of a tense matching advantage for perpceptual verbs in French but not in English. This further indicates that the preference for the PR interpretation is active at the earliest stages of processing.

5. Discussion and Conclusions

We set out to investigate the processing of the PR/RC ambiguity, with the double goal of clarifying the timing of this disambiguation and of testing the PR-first hypothesis, i.e. the claim that the parser displays a structural preference for PRs over RCs. Previous results, based on RC attachment preferences, indirectly supported this hypothesis. Resolution of this ambiguity in the absence of attachment ambiguities, however, had not been tested directly so far.

We presented three sets of experiments: one online sentence completion task assessing effects of PR-availability on RC-attachment in French, two online acceptability judgment tasks and two eye-tracking while reading studies. Each experiment nicely adds to the results of the previous one, providing an increasingly clear picture on the processing of embedding RCs and PRs.

The first experiment on effects of PR-availability on RC-attachment adds to previous work in this domain and further supporting PR-first. Once PR-availability is controlled for, using matrix verbs that only select for entities as complements, Low Attachment preference is observed also in French, a language which previously had consistently been shown to display High Attachment preference for RCs. When PRs are made available, using perceptual matrix verbs, which can also select events, the usual High Attachment preference is observed, as previously shown for Italian, Portuguese and Spanish, but not for nonPR languages like English (Grillo et al., 2015). This first study, aside from adding an important piece to the RC-attachment literature, provides a baseline for the following studies crossing Verb Type and Tense. Having established that PR-availability plays a role in the processing of embedded finite clauses in French, we moved

on to ask whether this effect will also be observed in the absence of attachment ambiguities and, if so, how does it unfold in time.

To this aim, we designed an acceptability judgment task which capitalizes on a well-known asymmetry between PRs and RCs: the constraint on PR Tense to be anaphoric to/match that of the matrix clause. We compared acceptability jugments of (perfectly grammatical) embedded clauses which either matched or mismatched the matrix clause in Tense specification. The (mis)matching clauses were embedded within either perceptual or stative verbs. We reasoned that a PR preference might generate a higher preference/acceptability for PR-compatible (Tense Matched) embedding, over PR-incompatible (Tense Mismatched) embedded clauses. As RCs do not require Tense Matching, we did not expect any effects. We further predicted the effect to be language dependent: a disadvantage for Tense Mismatch under perceptual verbs should only be observed in PR-languages (e.g. French), but not in nonPR languages (e.g. English), insofar as it is dependent on PR-availability and not tied to e.g. an interaction of the semantics of the matrix predicate and Tense (mis)match.

The results fully support our predictions, showing an interaction between Verb Type and Tense in the desired direction and only for French. A mismatch in Tense between the matrix and embedded predicates leads to significantly lower acceptability under perceptual verbs. Since all the target sentences used in this experiment are perfectly grammatical, we attribute the lower acceptability to the processing cost of reanalysis (from the originally preferred PR to the more complex RC) triggered by the tense mismatch.
Finally, we conducted two eye-tracking studies in French and English, using the same design and materials from the acceptability studies. This final set of experiments further strengthens the interpretation of the acceptability judgments studies and contributes a valuable insight into the timing of the PR/RC ambiguity resolution. We were able to replicate the *Tense Matching Advantage* observed uniquely in French under perceptual verbs in eye-fixations at the disambiguating region. *Shorter* regression path durations were found for Tense Match than Tense Mismatch at the embedded verb exclusively under perceptual verbs and only in French but not in English. These results are consistent with the proposed preference for PRs over RCs and indicate that this is a syntactic preference present at the earliest stages of parsing and not determined by later intepretive components.
Taken together, our results provide strong *direct* support for the *PR-first Hypothesis*. A preference for PRs emerges from both differences in acceptability judgments (of otherwise perfectly grammatical sentences) and eye-fixation durations. Forcing a RC reading of otherwise PR-compatible sentences leads to lower acceptability and longer regression path duration. PR-availability also leads to a stronger preference for High Attachment of RCs in French, and crucially its unavailability leads to Low Attachment, supporting a universal preference to attach incoming materiel to the most local host as one of the central factors in RC-attachment ambiguities.
These results further show that cross-linguistic asymmetries in parsing preferences of RC-attachment are epiphenomenal and greatly modulated by PR-availability Grillo (2012), among other grammatical factors (Gilboy et al., 1995; Frazier & Clifton, 1996; Hemforth et al., 2000, 2015).

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Appendix A. Items French completion task

Mean % of HA is indicated for each item.

1.	a. Jean voit le fils du médecin qui bricole.	53.84
	Pierre partage la maison avec le fils du médecin qui bricole.	68.75
2.	a. Kelly entend la grand-mère de la fille qui fait le ménage.	38.88
	b. Kelly travaille avec la grand-mère de la fille qui fait le ménage.	0
3.	a. Jean entend le professeur du garçon qui chante.	50
	b. Jean court avec le professeur du garçon qui chante.	0
4.	a. L'écrivain regarde la tante de la fille qui jongle.	15
	b. L'écrivain est marié à la tante de la fille qui jongle.	5.26
	d. La maison de la tante de la fille qui jongle est jolie.	0
5.	a. Marie écoute le fils du policier qui murmure.	92.3
	b. Marie est employée par le fils du policier qui murmure.	53.33
6.	a. Marie observe l'ami du député qui cuisine.	70.58
	b. Marie est fiancé à l'ami du député qui cuisine.	20
7.	a. Jeanne surprend la domestique de l'actrice qui vole.	75
	b. Jeanne s'entraîne avec la domestique de l'actrice qui vole.	23.07
8.	a. L'avocat surprend le chauffeur du voisin qui nage.	42.10
	b. L'avocat s'entraîne avec le chauffeur du voisin qui nage.	31.57
9.	a. David observe la fille de la domestique qui s'entraîne.	92.30
	b. Marc est divorcé de la fille de la domestique qui s'entraîne.	25
10.	a. Alain observe la nièce de l'infirmière qui patine.	84.21
	b. Alain est lié à la nièce de l'infirmière qui patine.	44.44
11.	a. Jeanne photographie le collègue du boucher qui court.	75
	b.Jeanne danse avec le collègue du boucher qui court.	38.46
12.	a. Cathy regarde l'ami du juge qui peint.	80
	b. Cathy est fiancée à l'ami du juge qui peint.	15.78
13.	a. Lily imagine l'amie de la fleuriste qui travaille.	42.85
	b. Lily fait la fête avec l'amie de la fleuriste qui travaille.	68.75
14.	a. Rachel rêve de l'ami du frère qui boit.	21.05
	b. Rachel est marié à l'ami du frère qui boit.	15
15.	a. David dessine le petit-fils de l'homme qui fume.	66.66
	b. David est employé par le petit-fils de l'homme qui fume.	30.76
16.	a. Philippe filme l'agent de l'acteur qui ronfle.	60
	b. Philippe passe du temps avec l'agent de l'acteur qui ronfle.	15.78
17.	a. Le pompier enregistre le cousin de l'avocat qui siffle.	64.28
	b.Le pompier est employé par le cousin de l'avocat qui siffle.	31.25
18.	a. Léa aperçoit l'ami du cordonnier qui danse.	73.68
	b. Léa est fiancée à l'ami du cordonnier qui danse.	35
19.	a. Sally photographie la belle-fille de l'infirmière qui étudie.	56.25
	b.Sally collabore avec la belle-fille de l'infirmière qui étudie.	57.14
20.	a. Le chanteur regarde le frère du PDG qui saigne.	90
	b. Le chanteur étudie avec le frère du PDG qui saigne.	27.77

21. a. Le policier filme l'amie de la sur qui tricote. 69.23
    b.Le policier est marié à l'amie de la sur qui tricote. 50
22. a. L'architecte imagine la sœur de la collègue qui danse. 36.84
    b. L'architecte est divorcé de la sœur de la collègue qui danse. 5
23. a. David voit le professeur de l'ami qui pilote. 46.66
    b. David fait la fête avec le professeur de l'ami qui pilote. 14.28
24. a. Le voisin écoute le fils du concierge qui chante. 89.47
    b. Le voisin va à l'université avec le fils du concierge qui chante. 31.57

Appendix B. Items for French *acceptability* and *eye-tracking* studies

Mean acceptability rate is indicated for each item.

1. a. (match-perception) Pierre a vu le garçon qui arrosait la fille avec le tuyau. 75
   b. (mismatch-perception) Pierre voit le garçon qui arrosait la fille avec le tuyau. 75
   c. (match-stative) Pierre a été ami avec le garçon qui arrosait la fille avec le tuyau. 62
   d. (mismatch-stative) Pierre est ami avec le garçon qui arrosait la fille avec le tuyau. 79
2. a. (match-perception) Léa a entendu le clown qui imitait le magicien. 76
   b. (mismatch-perception) Léa entend le clown qui imitait le magicien. 74
   c. (match-stative) Léa a été fiancée au clown qui imitait le magicien. 80
   d. (mismatch-stative) Léa est fiancée au clown qui imitait le magicien. 80
3. a. (match-perception) Le policier a surpris le juge qui discutait avec le ministre. 85
   b. (mismatch-perception) Le policier surprend le juge qui discutait avec le ministre. 73
   c. (match-stative) Le policier a couru avec le juge qui discutait avec le ministre. 69
   d. (mismatch-stative) Le policier court avec le juge qui discutait avec le ministre. 66
4. a. (match-perception) L'écrivain a regardé le journaliste qui menaait le sénateur. 81
   b. (mismatch-perception) L'écrivain regarde le journaliste qui menaait le sénateur. 72
   c. (match-stative) L'écrivain s'est entraîné avec le journaliste qui menaait le sénateur. 76
   d. (mismatch-stative) L'écrivain s'entraîne avec le journaliste qui menaait le sénateur. 72
5. a. (match-perception) Marie a écouté le ministre qui critiquait le président. 85
   b. (mismatch-perception) Marie écoute le ministre qui critiquait le président. 77
   c. (match-stative) Marie a été mariée au ministre qui critiquait le président. 79
   d. (mismatch-stative) Marie est mariée au ministre qui critiquait le président. 80
6. a. (match-perception) Sarah a aperu le policier qui frappait le chauffeur. 94
   b. (mismatch-perception) Sarah aperoit le policier qui frappait le chauffeur. 63
   c. (match-stative) Sarah a divorcé du policier qui frappait le chauffeur. 69
   d. (mismatch-stative) Sarah divorce du policier qui frappait le chauffeur. 66
7. a. (match-perception) Jeanne a vu le professeur qui cherchait l'étudiant. 85
   b. (mismatch-perception) Jeanne voit le professeur qui cherchait l'étudiant. 62
   c. (match-stative) Jeanne a été fiancée au professeur qui cherchait l'étudiant. 53
   d. (mismatch-stative) Jeanne est fiancée au professeur qui cherchait l'étudiant. 71
9. a. (match-perception) Léa a observé le bijoutier qui irritait le client. 75
   b. (mismatch-perception) Léa observe le bijoutier qui irritait le client. 73
   c. (match-stative) Léa a collaboré avec le bijoutier qui irritait le client. 71
   d. (mismatch-stative) Léa collabore avec le bijoutier qui irritait le client. 72
10. a. (match-perception) Le détective a filmé le commerant qui trompait le fournisseur. 82
    b. (mismatch-perception) Le détective filme le commerant qui trompait le fournisseur. 73
    c. (match-stative) Le détective a été employé par le commerant qui trompait le fournisseur. 69
    d. (mismatch-stative) Le détective est employé par le commerant qui trompait le fournisseur. 54

12. a. (match-perception) Léa a espionné le professeur qui accueillait le doyen. 81
    b. (mismatch-perception) Léa espionne le professeur qui accueillait le doyen. 78
    c. (match-stative) Léa a vécu avec le professeur qui accueillait le doyen. 78
    d. (mismatch-stative) Léa vit avec le professeur qui accueillait le doyen. 75
13. a. (match-perception) Léo s'est représenté la serveuse qui agaait la dame. 57
    b. (mismatch-perception) Léo se représente la serveuse qui agaait la dame. 62
    c. (match-stative) Léo se représente la serveuse qui agaait la dame. 76
    d. (mismatch-stative) Léo est marié à la serveuse qui agaait la dame. 74
14. a. (match-perception) Thomas a regardé la vendeuse qui aidait la cliente. 87
    b. (mismatch-perception) Thomas regarde la vendeuse qui aidait la cliente. 69
    c. (match-stative) Thomas a été fiancé à la vendeuse qui aidait la cliente. 73
    d. (mismatch-stative) Thomas est fiancé à la vendeuse qui aidait la cliente. 74
15. a. (match-perception) David a rencontré la danseuse qui courait avec la chanteuse. 72
    b. (mismatch-perception) David rencontre la danseuse qui courait avec la chanteuse. 68
    c. (match-stative) David a été ami avec la danseuse qui courait avec la chanteuse. 70
    d. (mismatch-stative) David est ami avec la danseuse qui courait avec la chanteuse. 74
18. a.(match-perception) Léa a enregistré la conductrice qui insultait la victime. 94
    b. (mismatch-perception) Léa enregistre la conductrice qui insultait la victime. 67
    c. (match-stative) Léa a logé chez la conductrice qui insultait la victime. 69
    d. (mismatch-stative) Léa loge chez la conductrice qui insultait la victime. 65
19. a. (match-perception) Sally a entendu la soprano qui impressionnait la ballerine. 72
    b. (mismatch-perception) Sally entend la soprano qui impressionnait la ballerine. 64
    c. (match-stative) Sally a été amie avec la soprano qui impressionnait la ballerine. 74
    d. (mismatch-stative) Sally est amie avec la soprano qui impressionnait la ballerine. 74
20. a. (match-perception) Le chanteur a écouté la présidente qui critiquait la journaliste. 81
    b. (mismatch-perception) Le chanteur écoute la présidente qui critiquait la journaliste. 66
    c. (match-stative) Le chanteur a collaboré avec la présidente qui critiquait la journaliste. 67
    d. (mismatch-stative) Le chanteur collabore avec la présidente qui critiquait la journaliste. 70
21. a. (match-perception) Le caméraman a observé la chirurgienne qui aidait la sage-femme. 86
    b. (mismatch-perception) Le caméraman observe la chirurgienne qui aidait la sage-femme. 73
    c. (match-stative) Le caméraman est sorti avec la chirurgienne qui aidait la sage-femme. 69
    d. (mismatch-stative) Le caméraman sort avec la chirurgienne qui aidait la sage-femme. 77
24. a. (match-perception) Le chorégraphe a épié la scénariste qui encourageait la pianiste. 74
    b. (mismatch-perception) Le chorégraphe épie la scénariste qui encourageait la pianiste. 70
    c. (match-stative) Le chorégraphe a été hébergé par la scénariste qui encourageait la pianiste. 65
    d. (mismatch-stative) Le chorégraphe est hébergé par la scénariste qui encourageait la pianiste. 72

Appendix C. Items English *acceptability* and *eye-tracking* studies

Mean acceptability rating is indicated for each item.

1. a. (match-perception) Peter saw the boy that sprayed water over the girl. 76
   b. (mismatch-perception) Peter sees the boy that sprayed water over the girl. 75
   c. (match-stative) Peter was friends with the boy that sprayed water over the girl. 82
   d. (mismatch-stative) Peter is friends with the boy that sprayed water over the girl. 83
2. a. (match-perception) Leah heard the clown that imitated the magician. 77
   b. (mismatch-perception) Leah hears the clown that imitated the magician. 72
   c. (match-stative) Leah was engaged to the clown that imitated the magician. 77
   d. (mismatch-stative) Leah is engaged to the clown that imitated the magician. 78

3. a. (match-perception) The policeman was pointing at the judge that argued with the minister. 81
   b. (mismatch-perception) The policeman is pointing at the judge that argued with the minister. 76
   c. (match-stative) The policeman was jogging with the judge that argued with the minister. 72
   d. (mismatch-stative) The policeman is jogging with the judge that argued with the minister. 72
4. a. (match-perception) The writer was watching the journalist that threatened the senator. 73
   b. (mismatch-perception) The writer is watching the journalist that threatened the senator. 74
   c. (match-stative) The writer was training with the journalist that threatened the senator. 78
   d. (mismatch-stative) The writer is training with the journalist that threatened the senator. 69
5. a. (match-perception) Mary listened to the minister that criticized the president. 74
   b. (mismatch-perception) Mary listens to the minister that criticized the president. 75
   c. (match-stative) Mary was married to to the minister that criticized the president. 79
   d. (mismatch-stative) Mary is married to to the minister that criticized the president. 77
6. a. (match-perception) Sarah caught sight of the policeman that hit the driver. 87
   b. (mismatch-perception) Sarah catches sight of the policeman that hit the driver. 78
   c. (match-stative) Sarah was divorced from the policeman that hit the driver. 71
   d. (mismatch-stative) Sarah is divorced from the policeman that hit the driver. 83
7. a. (match-perception) Jean saw the professor that looked for the student. 76
   b. (mismatch-perception) Jean sees the professor that looked for the student. 58
   c. (match-stative) Jean was engaged to the professor that looked for the student. 54
   d. (mismatch-stative) Jean is engaged to the professor that looked for the student. 59
8. a. (match-perception) Jack observed the postman that attacked the neighbour. 78
   b. (mismatch-perception) Jack observes the postman that attacked the neighbour. 76
   c. (match-stative) Jack worked with the postman that attacked the neighbour. 79
   d. (mismatch-stative) Jack works with the postman that attacked the neighbour. 77
9. a. (match-perception) Leah was watching the jeweller that irritated the customer. 69
   b. (mismatch-perception) Leah is watching the jeweller that irritated the customer. 74
   c. (match-stative) Leah was working for the jeweller that irritated the customer. 78
   d. (mismatch-stative) LLeah is working for the jeweller that irritated the customer. 76
10. a. (match-perception) The detective filmed the shopkeeper that cheated the supplier. 78
    b. (mismatch-perception) The detective films the shopkeeper that cheated the supplier. 71
    c. (match-stative) The detective was employed by the shopkeeper that cheated the supplier. 70
    d. (mismatch-stative) The detective is employed by the shopkeeper that cheated the supplier. 68
11. a. (match-perception) Peter was photographing the butler that attacked the gardener. 75
    b. (mismatch-perception) Peter is photographing the butler that attacked the gardener. 83
    c. (match-stative) Peter was living with the butler that attacked the gardener. 70
    d. (mismatch-stative) Peter is living with the butler that attacked the gardener. 78
12. a. (match-perception) Leah spied on the professor that met the dean. 70
    b. (mismatch-perception) Leah spies on the professor that met the dean. 69
    c. (match-stative) Leah lived with the professor that met the dean. 74
    d. (mismatch-stative) Leah lives with the professor that met the dean. 62
14. a. (match-perception) Tom was watching the shop assistant that helped the customer. 82
    b. (mismatch-perception)Tom is watching the shop assistant that helped the customer. 75
    c. (match-stative) Tom was engaged to the shop assistant that helped the customer. 75
    d. (mismatch-stative) Tom is engaged to the shop assistant that helped the customer 78
15. a. (match-perception) David was meeting the dancer that jogged with the singer. 73
    b. (mismatch-perception) David is meeting the dancer that jogged with the singer. 78
    c. (match-stative) David was friends with the dancer that jogged with the singer. 66
    d. (mismatch-stative) David is friends with the dancer that jogged with the singer. 74

18. a. (match-perception) Leah was recording the driver that insulted the victim. 84
    b. (mismatch-perception)Leah is recording the driver that insulted the victim. 74
    c. (match-stative) Leah lived with the driver that insulted the victim. 74
    d. (mismatch-stative) Leah lives with the driver that insulted the victim. 77
19. a. (match-perception) Sally heard the soprano that impressed the ballerina. 72
    b. (mismatch-perception) Sally hears the soprano that impressed the ballerina. 76
    c. (match-stative) Sally was friends with the soprano that impressed the ballerina. 71
    d. (mismatch-stative) Sally is friends with the soprano that impressed the ballerina. 76
20. a. (match-perception) The singer heard the manager that criticized the journalist. 68 b.
    (mismatch-perception) The singer hears the manager that criticized the journalist 68
    c. (match-stative)The singer worked with the manager that criticized the journalist. 80
    d. (mismatch-stative) The singer works with the manager that criticized the journalist. 73
21. a. (match-perception) The cameraman was watching the surgeon that helped the midwife. 69
    b. (mismatch-perception) The cameraman is watching the surgeon that helped the midwife. 74
    c. (match-stative) The cameraman went out with the surgeon that helped the midwife. 80
    d. (mismatch-stative) The cameraman goes out with the surgeon that helped the midwife. 80
22. a. (match-perception) The architect saw the girl that pushed the lady. 80
    b. (mismatch-perception) The architect sees the girl that pushed the lady. 74
    c. (match-stative) The architect was friends with the girl that pushed the lady. 74
    d. (mismatch-stative) The architect is friends with the girl that pushed the lady. 73
23. a. (match-perception) David caught sight of the manager that bothered the clerk. 80
    b. (mismatch-perception) David catches sight of the manager that bothered the clerk. 70
    c. (match-stative) David was trained by the manager that bothered the clerk. 64
    d. (mismatch-stative) David is trained by the manager that bothered the clerk. 64
24. a. (match-perception) The choreographer spied on the scriptwriter that encouraged the piano player. 63
    b. (mismatch-perception) The choreographer spies on the scriptwriter that encouraged the piano player. 69
    c. (match-stative) The choreographer housed the scriptwriter that encouraged the piano player. 70
    d. (mismatch-stative) The choreographer houses the scriptwriter that encouraged the piano player. 47

Appendix D. Justification of the choice of a Bayesian analysis

The Bayesian framework for data analysis allows the incorporation of previous information (prior) into the experimental data that have been collected, yielding a new probability distribution (posterior) that indicates how the prior information should be updated in the light of the observed data (Kruschke 2015; Kruschke & Liddell 2017). The advantages of Bayesian analysis over the traditional frequentist methods are discussed in detail in numerous publications (Wagenmakers 2007; Kruschke 2013, 2015; McElreath 2016; Nicenboim & Vasishth 2016; Sorensen et al. 2016). Here we will only briefly mention some of the motivations for opting for this method.

The most important characteristic of Bayesian analysis is a straightforward interpretation of the results. The posterior distribution of a main effect or an interaction provides information on how reliable the evidence of the effect or interaction is. This contrasts with Null Hypothesis Significance Testing methods which provide information on the null hypothesis (i.e., the possibility that there is no effect) and not on the hypothesis actually being tested by the experimenter (Vasishth & Nicenboim 2016). Moreover, uncertainty around effects is expressed in a Bayesian framework by means of credible intervals (CrI), which contain a certain portion of the posterior distribution, thus providing direct information on the results. By contrast, traditional

confidence intervals provide information on sampling techniques (Wagenmakers 2007; Hoekstra et al. 2014; Morey et al. 2016; Nicenboim & Vasishth 2016; Vasishth & Nicenboim 2016).
Another benefit, specific to the use of (generalized) linear mixed-effects models, is flexibility of model fitting. Linear mixed-effects models are known to be most reliable with large amounts of data (**?**Matuschek et al. 2017). Small data sets can be a problem, especially when fitting maximal models, namely models with the maximal structure of random effects allowed by the design (Barr et al., 2013), because of convergence problems. Bayesian model fitting, by contrast, does not fail because of model complexity.
Finally, the arguably most appropriate model for reading times data, which are right skewed and are constrained by nature to be greater than zero, is a shifted lognormal model (Nicenboim & Vasishth, 2018). Fitting such a model is, to the best of our knowledge, still impossible if not using the Bayesian analysis program *Stan* (Carpenter et al., 2017) and the R package *rstan* (Stan Development Team, 2017).

Appendix E. Analysis results with other eye-tracking measures

Region	Effect	Estimate ($\hat{\beta}$)	95% credible intervals	P($\hat{\beta}$) < 0
Second Noun + Complementizer (region 2)	Tense	11.19	[-24.52, 46.16]	0.27
	Verb Type	4.49	[-30.47, 42.12]	0.41
	Word Length	27.79	[14.76, 41.15]	0.0003
	Tense : Verb Type	16.28	[-17.08, 50.99]	0.17
	Item Order : Tense	-0.54	[-2.88, 1.92]	0.67
	Item Order : Verb Type	2.12	[-0.63, 4.89]	0.06
	Item Order : Tense : Verb Type	0.09	[-2.29, 2.46]	0.47
Verb (region 3)	Tense	-3.43	[-32.89, 25.10]	0.59
	Verb Type	-15.45	[-45.43, 13.79]	0.84
	Word Length	13.97	[2.35, 25.97]	0.01
	Tense : Verb Type	4.72	[-24.59, 33.82]	0.37
	Item Order : Tense	-0.23	[-2.27, 1.79]	0.59
	Item Order : Verb Type	2.07	[0.006, 4.20]	0.02
	Item Order : Tense : Verb Type	-0.57	[-2.57, 1.40]	0.71

Table E.5: French data: Results of Bayesian linear mixed-effects models in region 2 and 3, using first pass reading times as dependent variable.

Region	Effect	Estimate ($\hat{\beta}$)	95% credible intervals	P($\hat{\beta}$) < 0
Second Noun + Complementizer (region 2)	Tense	-16.03	[-87.38, 52.93]	0.66
	Verb Type	22.65	[-56.67, 104.38]	0.29
	Word Length	82.69	[46.94, 123.42]	8.333333e-05
	Tense : Verb Type	-49.42	[-123.33, 26.18]	0.90
	Item Order : Tense	0.79	[-4.19, 5.75]	0.38
	Item Order : Verb Type	2.69	[-2.61, 8.02]	0.16
	Item Order : Tense : Verb Type	2.61	[-2.52, 7.89]	0.16
Verb (region 3)	Tense	-28.46	[-92.28, 39.96]	0.81
	Verb Type	-10.14	[-80.78, 58.07]	0.61
	Word Length	47.23	[17.64, 78.29]	0.0005
	Tense : Verb Type	-20.05	[-86.07, 46.16]	0.73
	Item Order : Tense	1.61	[-3.08, 6.11]	0.24
	Item Order : Verb Type	2.31	[-2.42, 7.33]	0.17
	Item Order : Tense : Verb Type	1.57	[-3.08, 6.19]	0.24

Table E.6: French data: Results of Bayesian linear mixed-effects models in region 2 and 3, using total reading times as dependent variable.

Region	Effect	Estimate ($\hat{\beta}$)	95% credible intervals	P($\hat{\beta}$) < 0
Second Noun + Complementizer (region 2)	Tense	-20.76	[-78.29, 34.22]	0.76
	Verb Type	-45.19	[-105.47, 16.75]	0.92
	Word Length	25.91	[9.79, 43.03]	0.002
	Tense : Verb Type	34.56	[-21.04, 91.01]	0.11
	Item Order : Tense	0.74	[-3.11, 4.77]	0.35
	Item Order : Verb Type	3.20	[-0.73, 7.09]	0.06
	Item Order : Tense : Verb Type	-1.77	[-5.74, 2.13]	0.81
Verb (region 3)	Tense	-2.98	[-35.28, 29.76]	0.57
	Verb Type	-17.23	[-51.89, 16.32]	0.84
	Word Length	3.81	[-5.53, 12.87]	0.20
	Tense : Verb Type	-28.71	[-62.34, 4.34]	0.96
	Item Order : Tense	0.16	[-2.08, 2.48]	0.45
	Item Order : Verb Type	0.06	[-2.31, 2.38]	0.48
	Item Order : Tense : Verb Type	1.45	[-0.89, 3.81]	0.11

Table E.7: English data: Results of Bayesian linear mixed-effects models in region 2 and 3, using first pass reading times as dependent variable

Region	Effect	Estimate ($\hat{\beta}$)	95% credible intervals	P($\hat{\beta}$) < 0
Second Noun + Complementizer (region 2)	Tense	41.75	[-56.31, 146.08]	0.21
	Verb Type	9.55	[-95.86, 113.14]	0.42
	Word Length	85.91	[51.46, 123.90]	0.0001
	Tense : Verb Type	35.35	[-65.45, 136.41]	0.25
	Item Order : Tense	-2.67	[-9.78, 4.29]	0.77
	Item Order : Verb Type	3.27	[-3.56, 10.13]	0.17
	Item Order : Tense : Verb Type	-4.87	[-11.95, 2.12]	0.91
Verb (region 3)	Tense	3.07	[-76.28, 78.45]	0.46
	Verb Type	-54.74	[-136.38, 23.85]	0.91
	Word Length	53.46	[16.90, 90.87]	0.002
	Tense : Verb Type	46.35	[-32.19, 122.85]	0.12
	Item Order : Tense	-0.50	[-5.75, 5.01]	0.58
	Item Order : Verb Type	1.33	[-4.38, 6.97]	0.32
	Item Order : Tense : Verb Type	-3.72	[-8.99, 1.62]	0.91

Table E.8: English data: Results of Bayesian linear mixed-effects models in region 2 and 3, using total reading times as dependent variable