Eye-tracking Evidence for Frequency and Integration Cost Effects in Corpus Data

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Introduction – Experimental approach

Advantages of experimental approach:

- controlled conditions
- established reliability and validity

Drawbacks of experimental approach:

- sentences presented out of context
- constructed manually by the experimenter
- bias: do subjects develop special strategies when presented with the same construction many times? (even when there are fillers)
- only few items from any experiment

Main objectives of this work

Use an eye-tracking corpus as complementary evidence to experimental data

- reading in context; sentences occur in natural context
- “real” language, naturally occurring text
- more data points (for frequent constructions)
- test on many different constructions
- but: less controlled conditions

Test predictions for reading times on relative clauses from

- SPLT (Syntactic Prediction Locality Theory, (Gibson, 1998))
- Transitional probabilities (McDonald & Shillcock, 2003)

Question: Can we find well-established complexity effects in corpus data?

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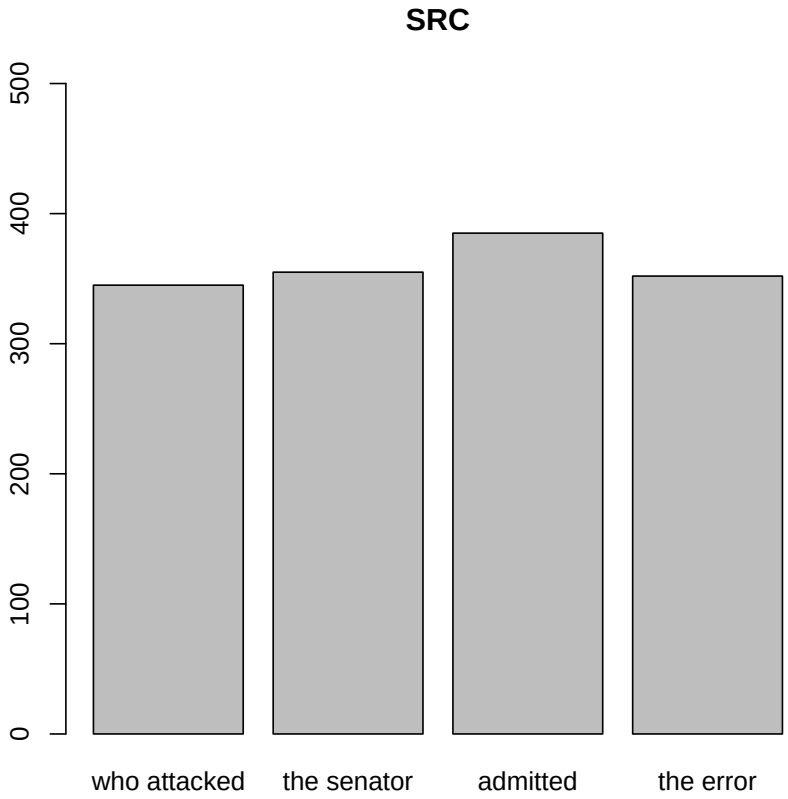
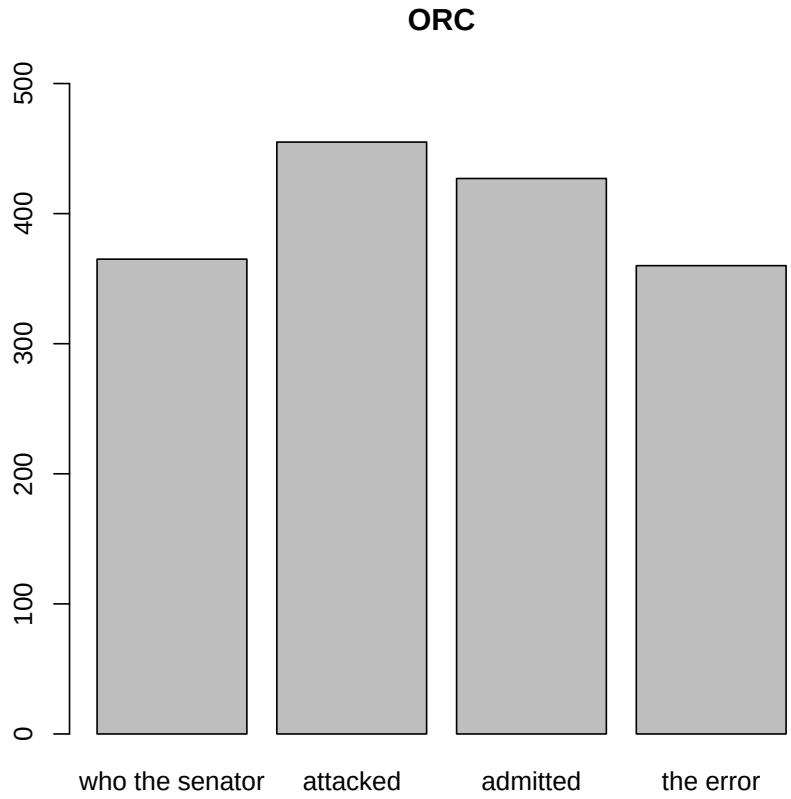
Overview

1. Subject vs. Object Relative Clauses
2. Background: Theories predicting RC reading times
3. The Dundee Corpus
4. Methods: Multiple Hierarchical Linear Regression
5. Results
6. Conclusions

Processing Difficulty and Relative Clauses

Reading times longer on object relative clauses (ORCs) than on subject relative clauses (SRCs), e.g. (King & Just, 1991; Gibson, 1998).

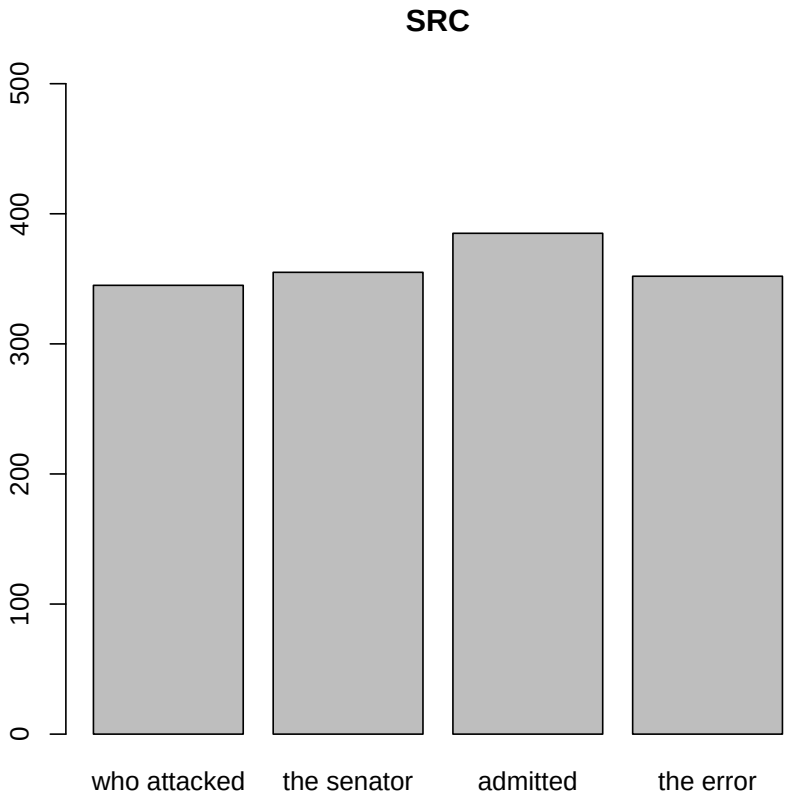


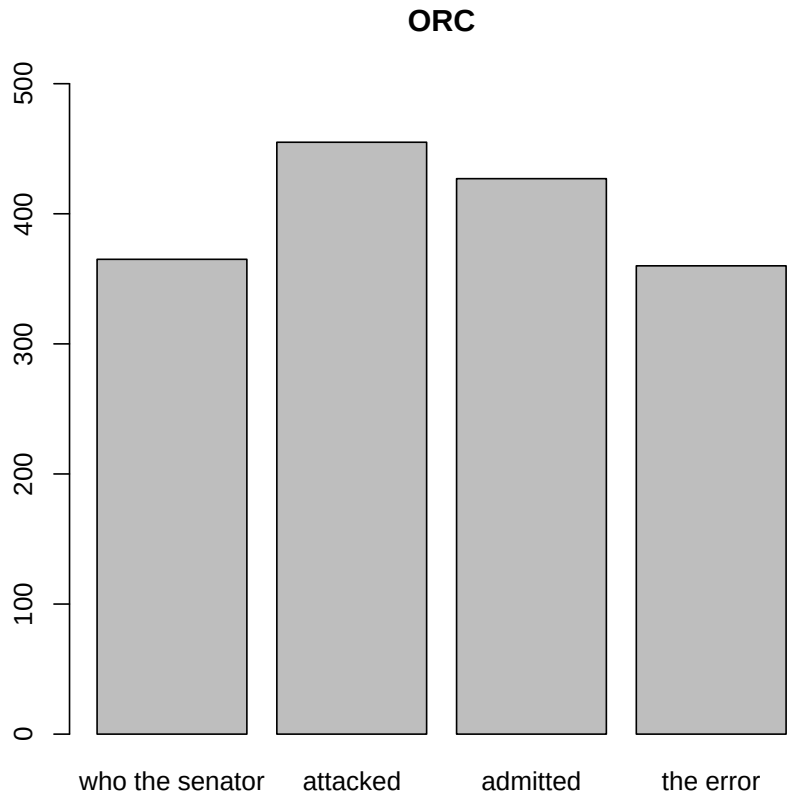


- SRC: The reporter *who attacked the senator* admitted the error.
- ORC: The reporter *who the senator attacked* admitted the error.

Processing Difficulty and Relative Clauses

We compare reading times on the main verb within the relative clause.





- SRC: The reporter *who attacked the senator* admitted the error.
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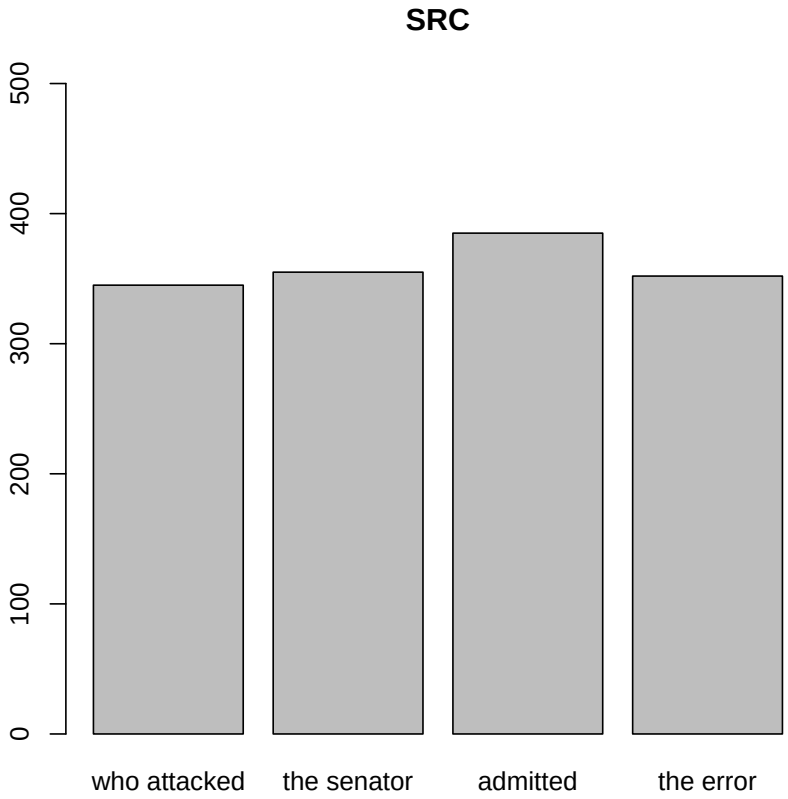
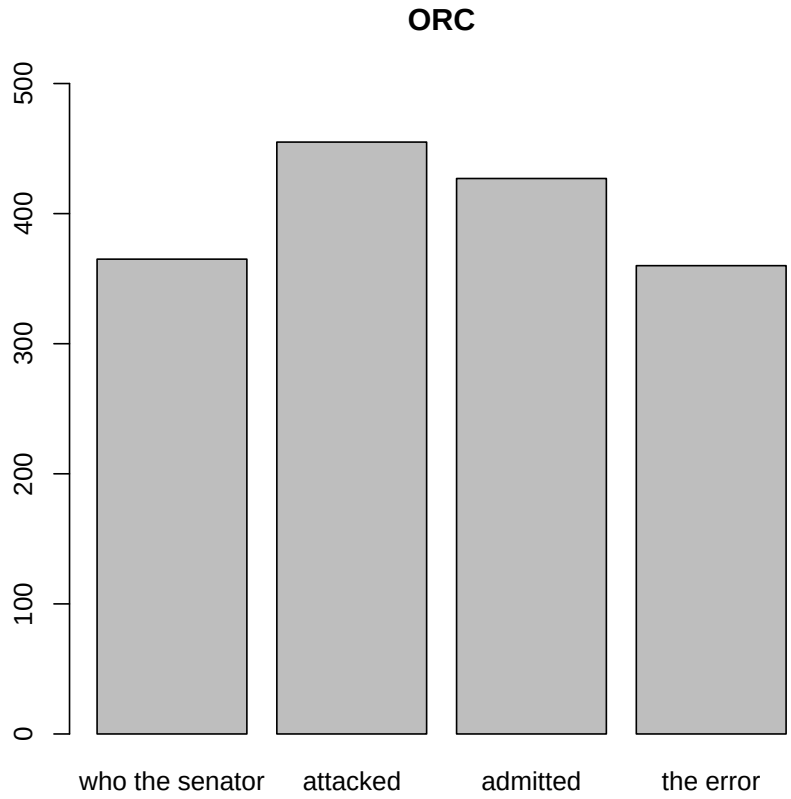
Processing Difficulty and Relative Clauses

We compare reading times in the disambiguating region, i.e. on the first word of the RC where the ambiguity between SRC vs. ORC is resolved.





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Theories for Reading Times in RCs

A number of theories have been developed that account for RC reading times:

- Gibson (1998); Lewis et al. (2006): Locality
- King & Just (1991): Storage and Role changes
- McDonald & Shillcock (2003): Transitional Probabilities
- Hale (2001); Levy (2007): Surprisal

We pick out just two theories as an example here: Integration cost from SPLT and forward transitional probabilities.

Syntactic Prediction Locality Theory

(Gibson, 1998, 20f) makes the following integration cost predictions for the relative clause regions:

SRC:	The	reporter	who	attacked	the	senator	admitted	the	error.
	–	I(0)		I(0)	I(0)+I(1)	I(0)	I(0)+I(1)	I(3)	I(0) I(0)+I(1)
ORC:	The	reporter	who	the	senator	attacked	admitted	the	error.
	–	I(0)		I(0)	I(0)	I(0)	I(1)+I(2)	I(3)	I(0) I(0)+I(1)

Integration costs occur at the heads of phrases.

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ORC:	The reporter	who	the	senator	attacked	admitted	the	error.
	–	I(0)	I(0)	I(0)	I(0)	I(1)+I(2)	I(3)	I(0) I(0)+I(1)

The main verb in the SRC should be read faster than in the ORC.

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ORC:	The reporter	who	the	senator	attacked	admitted	the	error.
	–	I(0)	I(0)	I(0)	I(0)	I(1)+I(2)	I(3)	I(0)	I(0)+I(1)

The verb (in SRCs) is more expensive to integrate than the determiner or noun (in ORCs).

Transitional Probability

Alternative account:
Shorter reading times are due to higher transitional probabilities (McDonald & Shillcock, 2003).

Claim:
$P(w_n|w_{n-1})$ is predictive of reading times.

Example:

verb region:	P(attacked | who) $>$ P(attacked | senator)
disambig. region:	P(the | who) $>$ P(attacked | who)

These probabilities can be estimated from large corpora; we used the British National Corpus (BNC, 100-million-word collection).

The Dundee Corpus

Dundee eye-tracking corpus (Kennedy et al., 2003)

- ca. 51.000 words of British newspaper articles (The Independent)
- 10 subjects
- parsed automatically with Charniak parser (Charniak, 2000)
  recall: 96%, precision: 92% for detecting RCs on WSJ

Frequency of relative clause types in Dundee eye-tracking corpus:

pronoun	SRC	ORC	proportion of ORC
that	150	18	10.7%
which	86	39	31.7%
who	137	4	2.8%
total	373	61	14%

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Some Example RCs from the Corpus

SRCs:

- ...titles that seem to stretch the definition a little...
- ...bag searches that make you wonder whether you've come to an underground military center...
- ...the bodies that deal with the human detritus...

ORCs:

- ...services that people need or want from computers...
- ...this no-holds-barren approach to sex and its consequences that many people still associate with the original Cosmo...
- ...answer – that few of us remained with one employer for our working lives...

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- ...this no-holds-barren approach to sex and its consequences that many people still associate with the original Cosmo...
- ...answer – that few of us remained with one employer for our working lives... (parsing error)

Data Selection

434 RCs $\times$ 10 subjects $=$ 4340 data points

We excluded all data points

- where the critical region was the first or last word of a line
- where the critical region was preceded or followed by a punctuation mark
- within a region of 4 adjacent words that had not been fixated (tracking error)
- that contained contractions (e.g. that'll, who'd)

This left us with approximately 3000 data points.

Analyses were only conducted on the fixated data points:

- approx. 1900 for first fixation times
- approx. 2200 for total durations

Multiple hierarchical linear regression

Since we don't closely control the context, we need to regress out possibly confounding factors.

- Independent variables:
  - target factors:
    - RC type
    - log transitional prob.
  - confounding factors:
    - relative pronoun
    - word length
    - log word freq.
    - word's POS tag
    - fixation landing position
- Dependent variables:
  - first fixation duration
  - gaze duration
  - total reading time
- Random variable:
  - subject ID

We entered all variables and their interactions first and stepwise removed those that decreased model quality (according to AIC).

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Methods for Linear Regression

- all data points are entered directly
- averaging over items or subjects not necessary due to use of a more powerful regression method
- standard approach (Lorch & Myers, 1990):
  - separate regression for each subject
  - t-test over coefficients
- we used hierarchical linear regression (Richter, 2006):
  - account for variance that is due to subjects on a first “level”
  - the coefficients for the other independent variables are estimated in the second level
  - aka linear mixed effect models

Results – Main RC Verb

SRC: The reporter *who attacked the senator* admitted the error.
ORC: The reporter *who the senator attacked* admitted the error.

Total reading times:

Predictor	Coeff.	Sign.
(Intercept)	263.42	***
RC type(SRC)	-177.04	***
Log transitional prob	-24.73	***
Length	21.47	***
Log frequency	-11.66	**
Word landing position	6.39	
Length:landing position	-2.94	***
Log. freq:length	2.65	***
RC type(SRC):log. freq	18.65	***

$^{**}p < 0.01$, $^{***}p < 0.001$; R^2 = 15.6%

- Verbs read faster in SRC condition (as predicted by SPLT).
- Significant effect of transitional probability **in addition** to RC type effect.

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First pass times:

Predictor	Coeff.	Sign.
(Intercept)	216.1205141	***
RC type(SRC)	-42.8087717	*
Length	7.6596253	**
Log frequency	-2.7113107	
Log freq:length	-0.8476891	**
RC type(SRC):log freq	5.3769450	**

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; R^2 = 9.9.%

- RC type effect essentially identical to total reading times
- no effect of transitional probability
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Results – Disambiguating Region

SRC: The reporter *who attacked the senator* admitted the error.
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Total reading times:

Predictor	Coeff.	Sign.
(Intercept)	-205.8891	
RC type(SRC)	393.1053	**
Transitional prob	-44.7011	***
Landing pos	9.8672	*
Logarithmic frequency	22.0477	**
Length	28.4211	***
simplePOS-VP	-31.6457	*
type(SRC):Trans.prob	43.4744	**
type(SRC):Log.freq	-20.2642	*
Log.freq:Length	-1.3892	*
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- diambiguating region read faster in ORCs (consist. with SPLT)
- transitional probability also facilitates reading
- strong correlation between RC type and transitional prob (r = 0.91)

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First fixation durations:

Predictor	Coeff.	Sign.
(Intercept)	195.541736	***
RC type(SRC)	18.902473	***
Log frequency	-1.486510	**

$^{**}p < 0.01$, $^{***}p < 0.001$; $R^2 = 8.1\%$

- Only RC type and frequency were found to be significant predictors for first fixation times.
- No significant effect for transitional probabilities here.
- The first word of the SRC (first word of VP) is read more slowly than the first word of the ORC (first word of NP).

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Conclusions

- New type of evidence for locality-based theories (like SPLT).
- Transitional probability also predicts reading times, but independent of RC type effect.
- The RC type effect occurs in both the late measures and the early measures, while transitional probabilities were only predictive of the late measures.
- Regression method allows regions to be compared when they are different words, because potentially confounding variables are regressed out.
- Corpus-based methodology can easily be applied for evaluating other theories and testing them on different constructions.
- Corpus studies as complementary evidence to traditional experimental methods.

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