Incremental Interpretation of Relative Scope? Evidence from Eyetracking

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Linguistic Representations are Constructed. . .

incrementally (eg. Altmann & Mirkovich 2009, p. 604)

[The] comprehension system [...] is “maximally incremental”; it develops the fullest interpretation of a sentence fragment at each moment of the fragment’s unfolding.

globally (Frege, 1884)

Never [...] ask for the meaning of a word in isolation, but only in the context of a proposition.

Overview

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Incremental Interpretation I

- Ample of evidence for highly incremental or even anticipatory language processing (e.g. Marslen-Wilson, 1973, Kuperberg & Jaeger, 2016)
- Not only in parsing, but also in semantic and pragmatic interpretation

Incremental Interpretation II

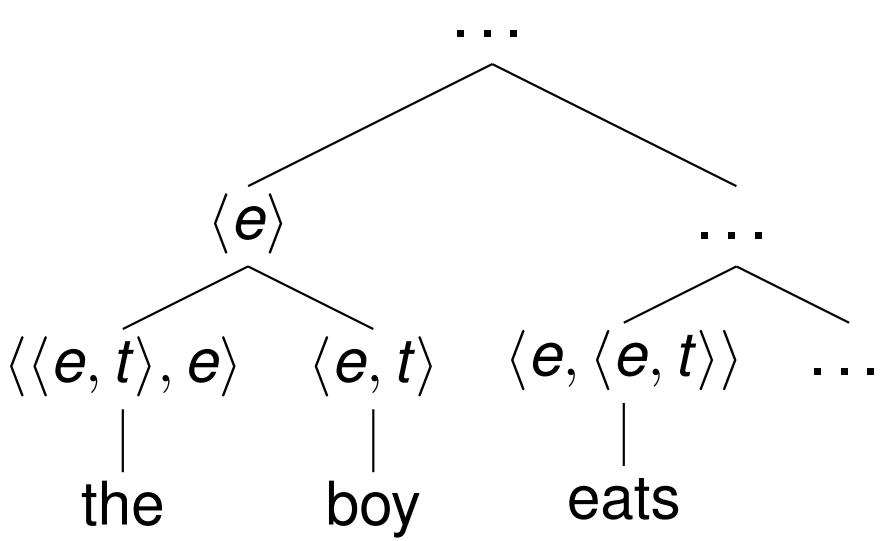
(1)
a. The boy will eat... (Altmann & Kamide 1999)
b. Put the apple on the napkin into... (Tanenhaus et al. 1995)
c. *Tomorrow had... (Baggio 2008, Bott 2010)
d. *For three hours won$_{perfective}$... (Bott & Gattnar 2015)
e. #John praised Mary because he... (Koornneef & van Berkum 2006)
f. Now click on the girl with some of... (Grodner et al. 2010)

- Thematic properties
- Referential interpretation
- Tense
- Aspect
- Discourse coherence relations and coreference
- Pragmatic enrichment

Perspective from Textbook Semantics

- No Heim & Kratzer (1998) style analysis of yet incomplete sentences beginning in *subject + verb*:

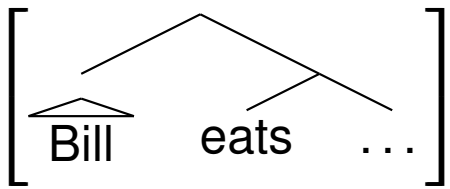
(2)



- Standard approaches not intended for incremental interpretation
- ▷ It is generally impossible to interpret non-constituents in these frameworks

(But see Beck & Tiemann 2018, for extensions)

Semantic Theories for Incremental Interpretation

- Other approaches allow us to flexibly compose incomplete sentences: Kempson et al. 2000, Steedman 2001, Barker 2002, Joshi et al. 2007
- Here: An incremental compositional semantics proposed by Bott & Sternefeld (2017) based on continuation semantics (Barker 2002)
- 

$= \lambda c_{\langle t,t \rangle} \lambda p_t [c(\exists e(\textbf{eat}(e) \wedge p \wedge \textbf{agent}(e, \textbf{bill})))]$

Is Semantic Interpretation Incremental Throughout?

- *Subject + trans. verb* is one of the simplest cases we can think of
- Does word-by-word interpretation generalize to more complex cases?

Different general cognitive constraints for syntax and semantics

- Working memory constraints enforce immediate structural integration (chunking)
- The semantic processor may suffer less pressure because the input is already integrated structurally

Avoidance of abstract meaning representations

- Incrementality calls for fairly abstract, sub-propositional meaning representations
- This may increase processing load without introducing any benefit

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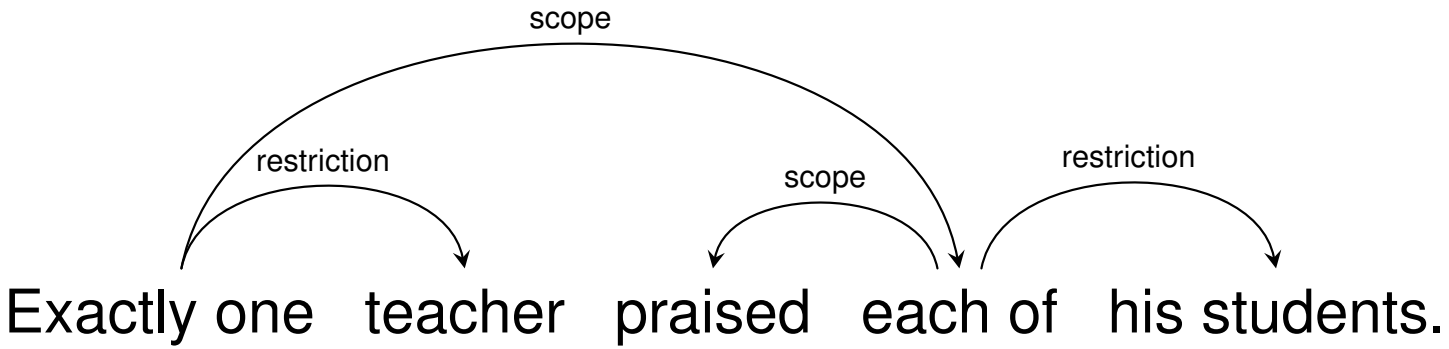
Are Quantifiers Interpreted Incrementally?



1. Restriction: First argument, reference to a contextually given set (Kaan et al. 2006)

   (3) Six flowers were put in a vase. $\left\{ \frac{\text{Eight}}{\text{Four}} \right\}$ had ...

2. Nuclear scope: Second argument (Urbach & Kutas 2010, a.o.)

   (4) $\left\{ \frac{\text{Most}}{\text{Few}} \right\}$ farmers grow $\left\{ \frac{\text{worms}}{\text{crops}} \right\}$ ...

3. Relative scope: Dependence between quantifiers (Filik et al, 2004)

   (5) Every kid climbed a tree. The $\left\{ \frac{\text{tree}}{\text{trees}} \right\}$ ...

Tests For Incremental Assignment of Relative Scope

- Scope reconstruction of fronted object quantifiers (Bott & Schlotterbeck 2015):

(6) Jeden seiner Schüler$_j$ hat genau ein Lehrer t_j ...
Each of his pupils$_j$ AUX exactly one teacher$_{subject}$ t_j ...
'Exactly one teacher AUX each of his pupils ...'

- Scope interaction in a linear scope construal:

(7) Mehr als die Hälfte der Mitarbeiter haben nicht ...
'More than half of the staff AUX not ...'

Bott & Sternefeld (2017) – Derivations

- Variables *c* and *p* provide slots to fill in information yet to come
- **Composition** rule (cf. categorial grammar, e.g. Steedman 2001):
  $[\![\alpha > \beta]\!] = \lambda c_{\langle t,t\rangle}[[\![\alpha]\!][[\![\beta]\!](c)]]$
  $[\![\alpha < \beta]\!] = \lambda c_{\langle t,t\rangle}[[\![\beta]\!][[\![\alpha]\!](c)]]$
- Scope preference: Try linear interpretation first (scope inversion as last resort)
- Lexical items:
  - $[\![\textit{exactly one teacher}_i]\!] =$
    $\lambda c_{\langle t,t\rangle}\lambda p_t \exists! x_i[\textbf{teacher}(x_i) \wedge c(p \wedge \textbf{agent}(e, x_i))]$
  - $[\![\textit{each of his}_i\ \textit{pupils}_j]\!] = \lambda c_{\langle t,t\rangle}\lambda p_t \forall x_j[(\textbf{pupil}(x_j) \wedge \textbf{of}(x_j, x_i)) \rightarrow$
    $c(p \wedge \textbf{patient}(x_j))]$
  - $[\![\textit{not}]\!] = \lambda c_{\langle t,t\rangle}\lambda p_t.\neg c(p)$

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  $\lambda c_{\langle t,t\rangle}\lambda p_t[\forall x_j(\mathbf{pupil}(x_j) \wedge \mathbf{of}(x_j, x_i)) \rightarrow$
  $\exists! x_i.\mathbf{teacher}(x_i) \wedge c(p \wedge \mathbf{agent}(e, x_i) \wedge \mathbf{patient}(e, x_j))]$

▷ Variable x_i unbound, scope inversion (reconstruction) is required

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- Aoshima et al. (2009): Incremental binding in a head-final language (Japanese)

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(6) Jeder / Kein Lehrer hat nicht...
Every / No teacher$_{nom.}$ has not...

- $\lambda c_{\langle t,t\rangle}[[\![\textit{every teacher}_i]\!][[\![\textit{not}]\!](c)]] = \lambda c_{\langle t,t\rangle}\lambda p_t \forall x_i[\textbf{teacher}(x_i) \rightarrow \neg c(p \wedge \textbf{agent}(e, x_i))]$
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▷ *No teacher* should be harder to process than *every teacher* due to double negation

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Overview

Scope Reconstruction

(1) Jeden seiner Schüler$_1$ lobte$_2$ genau ein Lehrer t_1 t_2.
[Each of his pupils]$_{object}$ praised [exactly one teacher]$_{subject}$
'Exactly one teacher praised each of his pupils.'

The example exhibits some interesting features:

- *OVS* order with a case disambiguated object quantifier, thematic fit (teachers should praise their students)
- Variable binding of *his* only in the inverse reading, but not in the linear reading
- Therefore, the object quantifier has to undergo scope reconstruction

Is the Verbal Predicate Required? Hendriks 1993 vs. Barker 2002

(2) Genau ein Lehrer hat jeden Schüler . . .
Exactly one teacher AUX every student . . .

Hendriks (1993)'s flexible verb types approach:

- Scope depends on interpretive schema of the verb
  $\lambda\,\mathrm{Q}_2\,.\lambda\,\mathrm{Q}_1\,.\,\mathrm{Q}_1\,(\lambda y.\,\mathrm{Q}_2\,(\lambda x.\,\mathrm{P}\,(x)\,(y)))$ (linear scope)
  $\lambda\,\mathrm{Q}_2\,.\lambda\,\mathrm{Q}_1\,.\,\mathrm{Q}_2\,(\lambda y.\,\mathrm{Q}_1\,(\lambda x.\,\mathrm{P}\,(x)\,(y)))$ (inverse scope)

As shown above, continuation semantics can handle scope indepently of the verb:

- Fully incremental scope assignment
  $\lambda\,\mathrm{p}\,.\exists!y\,[\mathrm{TEACHER}(y) \wedge \forall x\,[\mathrm{STUDENT}(x) \rightarrow \mathrm{p}]]$ (linear scope)
  $\lambda\,\mathrm{p}\,.\forall x\,[\mathrm{STUDENT}(x) \rightarrow \exists!y\,[\mathrm{TEACHER}(y) \wedge \mathrm{p}]]$ (inverse scope)

- Fairly abstract representations – plausibility or event knowledge ruled out as processing guides!

Hypotheses

Incremental scope reconstruction:

- Verb independent: quantifiers immediately undergo scope reconstruction if required, independently of the verbal predicate
- Verb dependent: quantifiers only undergo reconstruction once the verbal predicate has been encountered

Global interpretation:

Scope reconstruction is a last resort and is only considered at the end of the sentence.

Design Of Bott & Schlotterbeck 2015's Study

1) Jeden seiner Schüler$_i$ **lobte** genau ein (dieser) Lehrer t$_i$ voller Wohlwollen. [*QQ(Q-Def)-his*]

   Each of his pupils$_{DO}$ was praised by exactly one (this) teacher full of goodwill.

2) Jeden dieser Schüler$_i$ **lobte** genau ein (dieser) Lehrer t$_i$ voller Wohlwollen. [*QQ(Q-Def)-this*]

   Each of these pupils$_{DO}$ was praised by exactly one (this) teacher$_{Subj.}$ full of goodwill.

3) Jeden seiner Schüler$_i$ hat genau ein (dieser) Lehrer t$_i$ voller Wohlwollen **gelobt**. [*QQ(Q-Def)-his*]

   Each of his pupils$_{DO}$ was by exactly one (this) teacher$_{Subj.}$ full of goodwill praised.

4) Jeden dieser Schüler$_i$ hat genau ein (dieser) Lehrer t$_i$ voller Wohlwollen **gelobt**. [*QQ(Q-Def)-this*]

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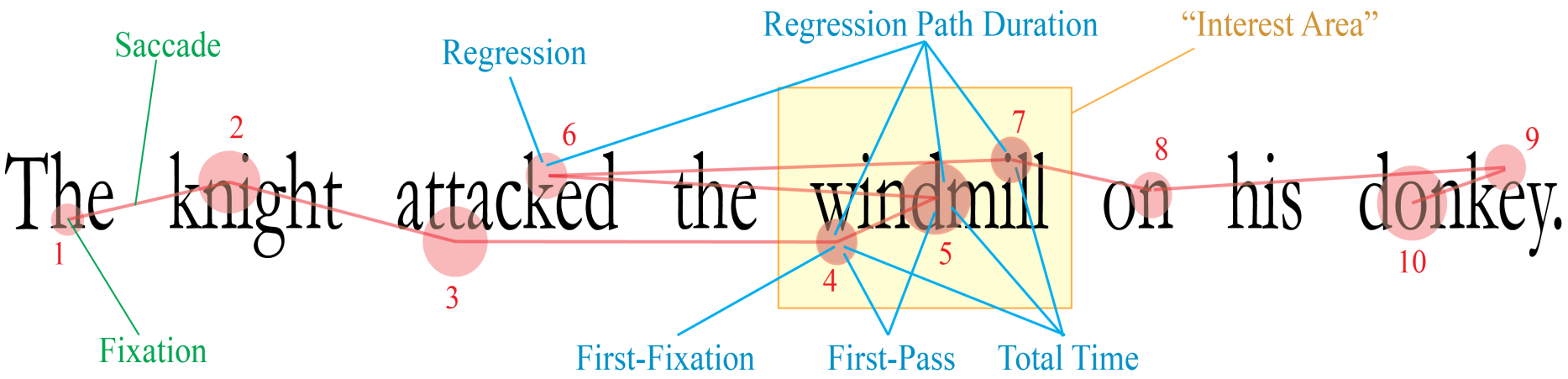
Eye-Tracking during Reading

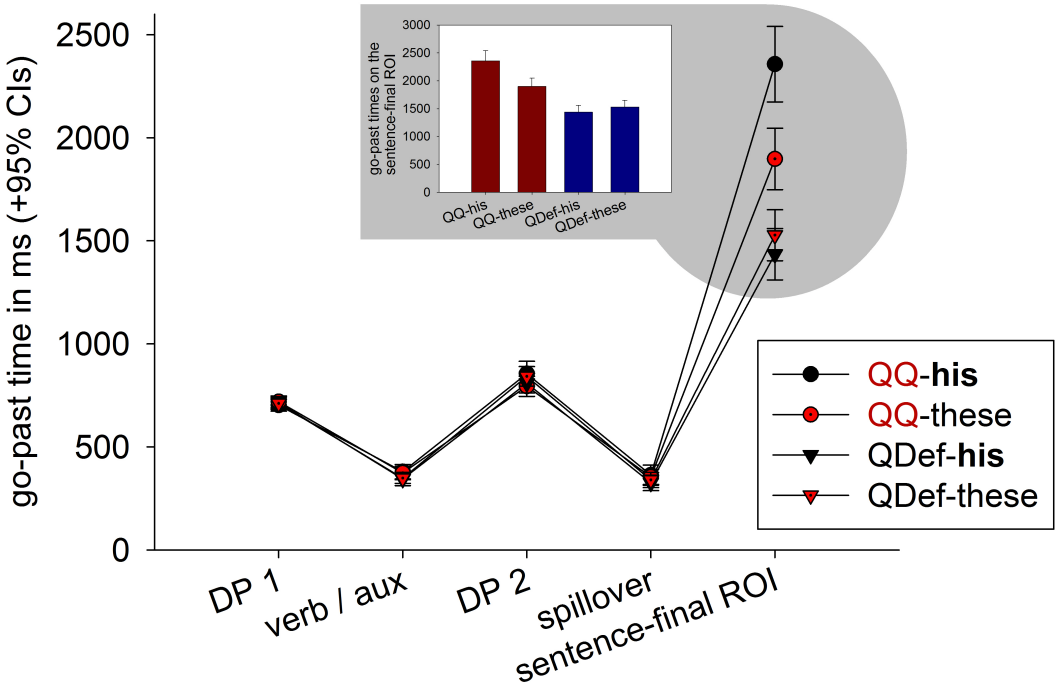


(source: www.proswrite.com)

Eyetracking measures:

- First-pass times
- First-pass regression ratios
- Regression-path durations
- Second-pass times

A Glimpse at the Results



- No effects of verb placement!
- Only at the sentence final region of interest: **1)** QQ slower than QDef, **2)** scope inversion effect

▷ Reconstruction only during rereading of QQ sentences

Our Interpretation of these Results

- Interaction of DP TYPE × PRONOUN TYPE: Scope reconstruction
- Main effect of DP TYPE: Coming up with an interpretation for a QQ sentence is overall more costly than computing an interpretation for a QDef sentence

GLOBAL INTERPRETATION:

Scope reconstruction is a last resort and is only considered at the end of the sentence.

Replication of Results

In a self-paced reading experiment using the same design and materials, we also found delayed scope reconstruction effects only at the end of the sentence.

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Overview

Do Our Findings Generalize to Surface Scope?

So far: INCREMENTAL SCOPE INTERPRETATION tested in fairly infrequent OVS constructions

- OVS needs special licensing conditions, e.g. partially ordered set relations (Weskott et al. 2011)
- Do these results carry over to other constructions?
- What about the interpretation of surface scope?

Presented data leave open two possibilities

1. GLOBAL INTERPRETATION applies to scope interpretation in general
2. INCREMENTAL SCOPE INTERPRETATION of linear scope, but scope reconstruction subject to GLOBAL INTERPRETATION

Idea to test INCREMENTAL INTERPRETATION of Surface Scope

- Manipulate semantic complexity of scope-taking operators to find out whether they are composed incrementally

combination	processing cost	
... O_1 ... O_2...	α	(baseline)
... O_1 ... O_2...	$\alpha + \beta_1$	(additional cost O_1)
... O_1 ... O_2...	$\alpha + \beta_2$	(additional cost O_2)
... O_1 ... O_2...	$\alpha + \beta_1 + \beta_2 + \gamma$	(combined cost O_1 & O_2)

▷ If combined processing cost surpasses sum of individual costs (over-additive effects), this would be a particularly clear marker for semantic composition

Entailment Relations Licensed by Quantifiers – Monotonicity

(1) At least one boy wore a red t-shirt
$\Longrightarrow$ At least one boy wore a t-shirt
$\not\Longrightarrow$ At least one boy wore a red old t-shirt

(2) At most one boy wore a red t-shirt
$\not\Longrightarrow$ At most one boy wore a t-shirt
$\Longrightarrow$ At most one boy wore a red old t-shirt

- $[\![\textit{red old t-shirt}]\!] \subseteq [\![\textit{red t-shirt}]\!] \subseteq [\![\textit{t-shirt}]\!]$
- *Monotone increasing* quantifiers (e.g. *at least one*) license inferences from subsets to supersets
- *Monotone decreasing* quantifiers (e.g. *at most one*) license inferences from supersets to subsets
- Monotone decreasing Qs are harder than increasing Qs (e.g. Urbach et al. 2010, Deschamps et al. 2015, Bott et al. 2019)

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Manipulation: *Monotonicity*

- *Monotonicity* intuitively produces over-additive effects:

(3) a. At least one boy tickled more than two girls.
b. At most one boy tickled more than two girls.
c. At least one boy tickled fewer than three girls.
d. At most one boy tickled fewer than three girls.

- However, (3-d) may be so complex that composition does not succeed (cf. Bott et al. 2013, Bott et al. 2019)

▷ Intuitively somewhat simpler combination: quantifier and negation

(4) a. More than half of the kids did not laugh.
b. Less than half of the kids did not laugh.

Pretest: Only Linear Scope Interpretations

- Rise-fall intonation might trigger scope reconstruction (e.g. Büring 1997)
- ▷ Truth-value judgment + read aloud task

(5) More/Less than half of the kids did not eat a burger.

Kid 1: ✓	Kid 5: ✓
Kid 2: ✓	Kid 6: X
Kid 3: X	Kid 7: X
Kid 4: X	Kid 8: ✓

$Q\neg$ X ¬Q ✓

- 20 participants
- Both conditions received ≈100% *no*-responses (▷ linear scope)
- Analysis of the recorded productions: not a single rise-fall (hat) contour

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Kid 2: ✓	Kid 6: ✗
Kid 3: ✗	Kid 7: ✗
Kid 4: ✗	Kid 8: ✓

$Q\neg$ ✗ $\neg Q$ ✓

- 20 participants
- Both conditions received ≈100% *no*-responses (▷ linear scope)
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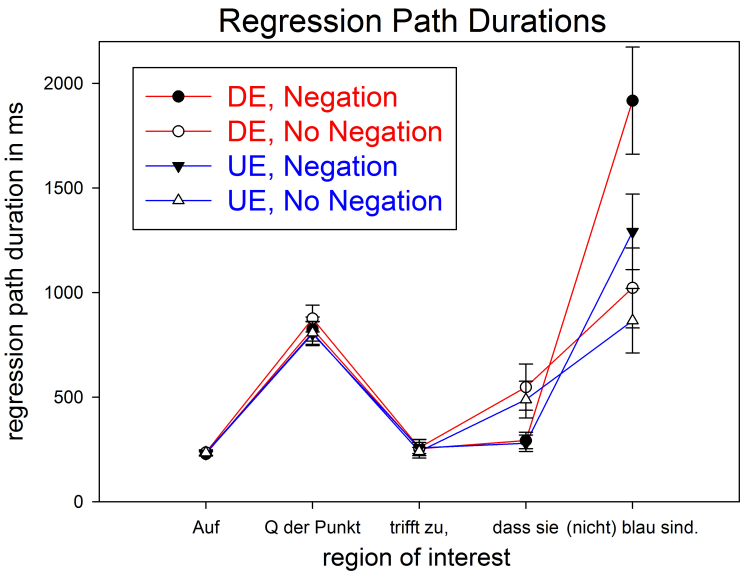
Experiment 1: Establishing Complexity Effects

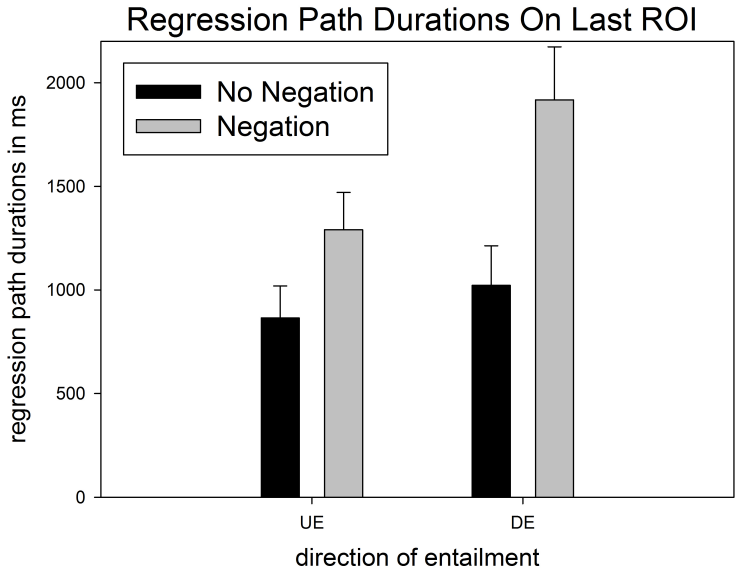
- In an eyetracking experiment, 48 participants read 32 German sentences such as

(6) Auf Q Kreuze trifft zu, dass sie (**nicht**) blau sind.
On Q crosses holds that they (**not**) blue are.
'Q crosses are such that they are (**not**) blue.'

- 2×2 within design – *montonicity* × *negation*
- Q ∈ { *mehr als die Hälfte der* ('more than half of the'), *weniger als die Hälfte der* ('less than half of the') }
- Negation in clause-bounded position to guarantee linear interpretation
- After reading, participants performed sentence-picture verification

Experiment 1: Establishing Complexity Effects (Schlotterbeck 2017)



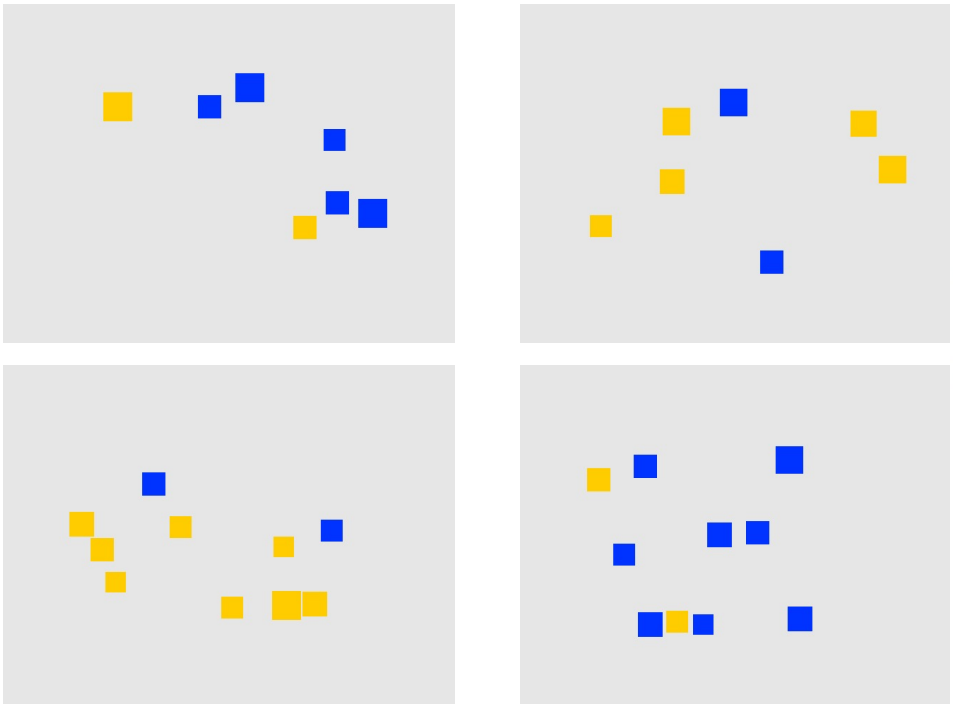


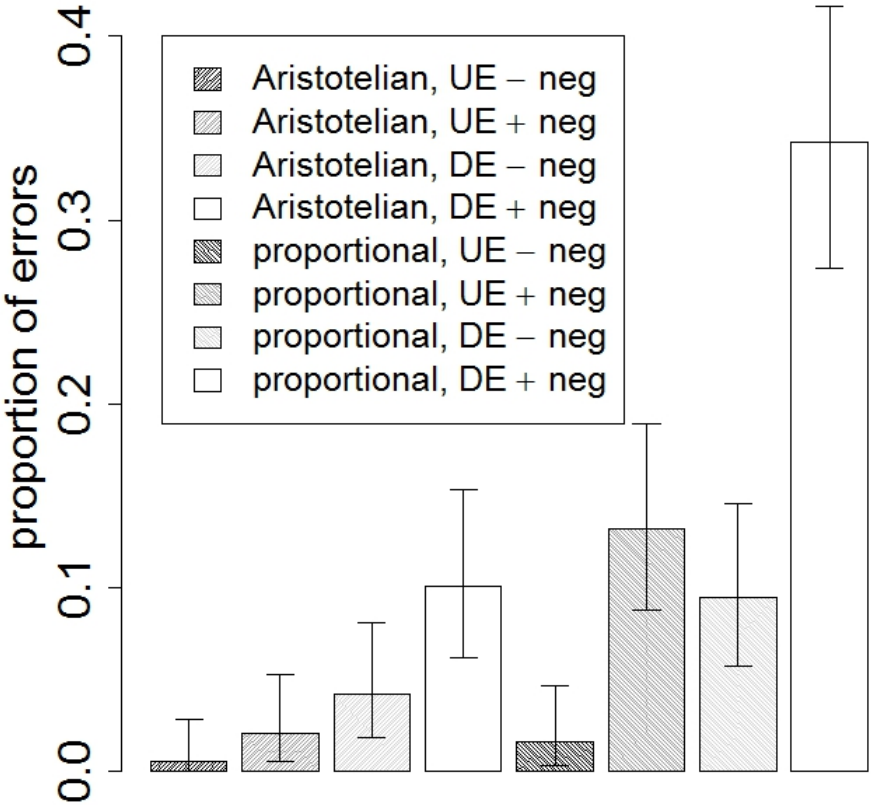
- Main result: *Direction of entailment* and *negation* affect reading times over-additively (interaction: $t = 2.78$)
- ▷ Manipulation well-suited as marker of semantic composition to test INCREMENTAL SCOPE INTERPRETATION in sentences with linear scope

Exp. 1 – Verification task (Schlotterbeck 2017)

(7) More/Less than half of the squares are (not) blue.

Proportional Conditions





- Combination of proportional DE quantifiers and negation strongly increased error rates

Experimental Design

(1/2) Mehr | als die Hälfte | der Gäste | tanzten **(nicht)** | zu Daddy Cool |...
More than half of the guests danced **(not)** to Daddy Cool.
'More than half of the guests did **(not)** dance to Daddy Cool...'

(3/4) Weniger | als die Hälfte | der Gäste | tanzten **(nicht)** | zu Daddy Cool |...
Less than half of the guests danced **(not)** to Daddy Cool.
'Less than half of the guests did **(not)** dance to Daddy Cool...'

(5/6) Mehr | als die Hälfte | der Gäste | haben **(nicht)** | zu Daddy Cool | getanzt...
More than half of the guests have **(not)** to Daddy Cool danced.

(7/8) Weniger | als die Hälfte | der Gäste | haben **(nicht)** | zu Daddy Cool | getanzt...
Less than half of the guests have **(not)** to Daddy Cool danced.

... nachdem | der DJ | das Stück | AUFGELEGT HATTE$_{\textit{sentence final roi}}$.
after the DJ the song started to play had.
'after the DJ had started playing the song.'

- 2×2×2 within design – VERB POSITION × MONOTONICITY × NEGATION

Hypotheses and Predictions

Strictly incremental interpretation

- Irrespective of *verb position*, composition takes place immediately
- ▷ Immediate processing cost of *monotonicity* and *negation*
- ▷ two-way but no three-way interaction.

Verb dependent incrementality

- Composition delayed until main verb is encountered
- ▷ three-way interaction: *verb position* $\times$ *monotonicity* $\times$ *negation*

Global interpretation

- Composition delayed until the end of the sentence

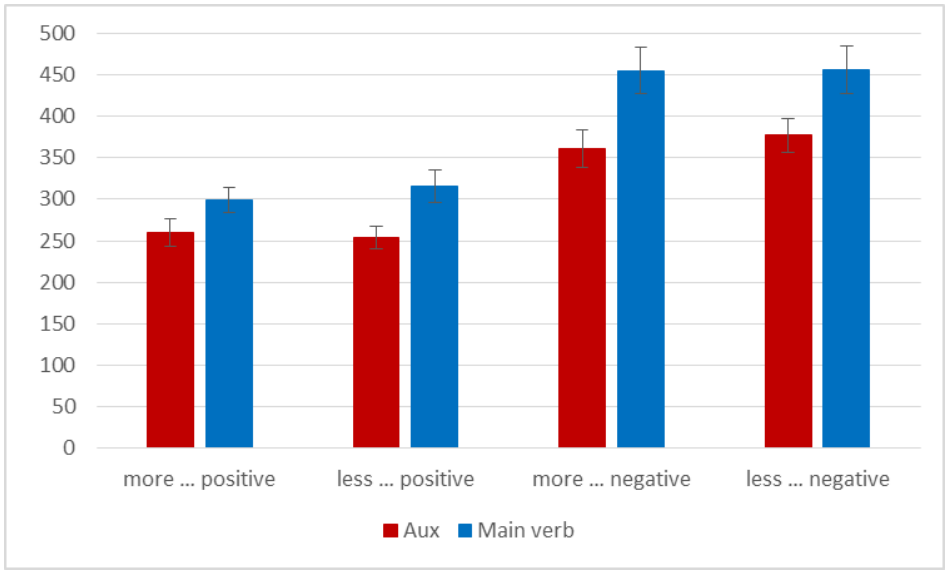
Experiment 2 – Methods

- 32 native German participants
- Eyetracking during reading
- Analysis: a) First-pass times, b) regression path durations, c) second-pass times; proportions of d) regressions out and e) regressions into a region
- 40 items + 160 fillers
- 40 trials followed by diagram judgment task, 60 trials followed by comprehension questions
- 8 lists in a latin square design

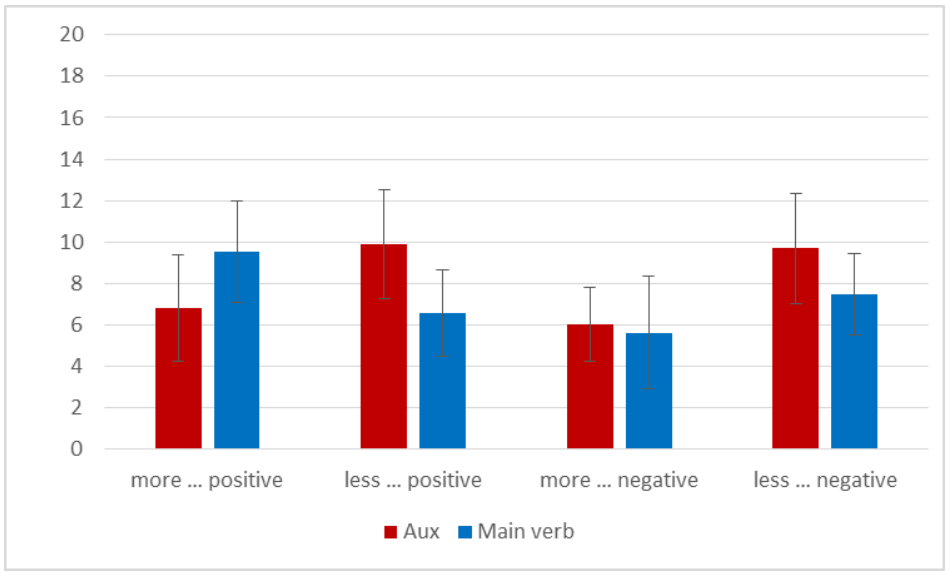
Results – No early Composition Effects

Effects at the verb+negation region (+/- 1 se):

First-pass times:



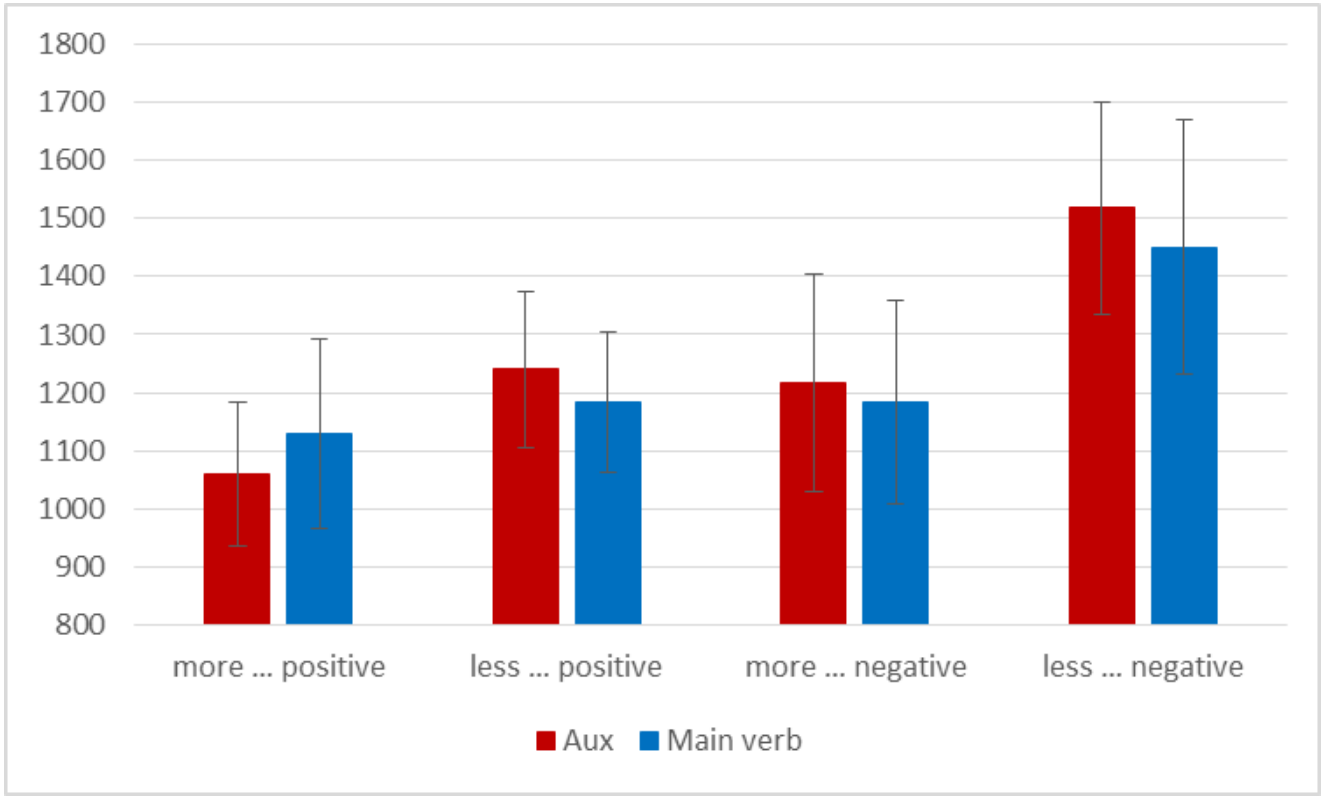
First-pass regression ratios:



- No significant effects involving MONOTONICITY (neither main effect nor interactions)
- At following regions also no MONOTONICITY effects

Composition Effect at Sentence-Final Region. . .

Regression-path durations of the sentence final region (+/- 1 se):

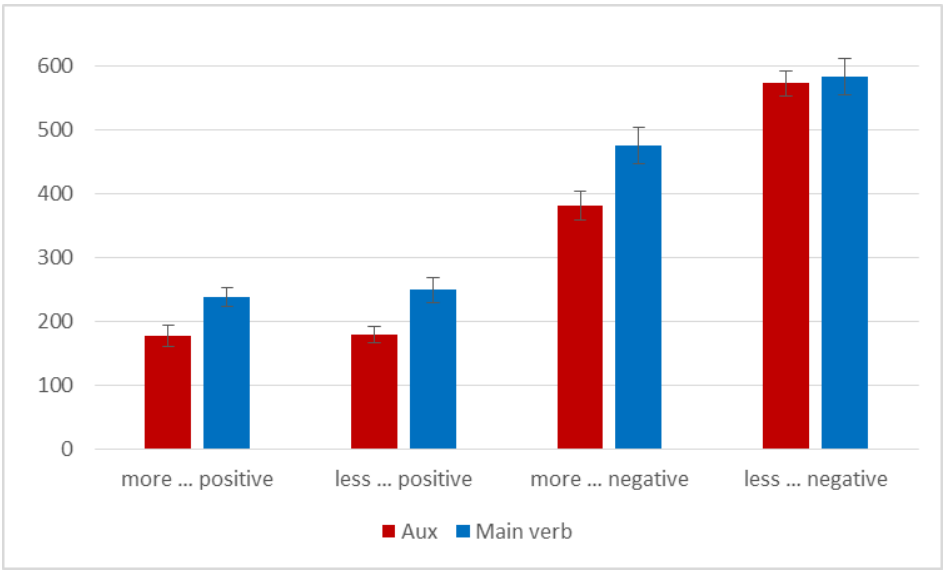


- Only after having read the entire sentence, participants show a MONOTONICITY effect (main effect (ANOVAs): $p_1 < .01$; $p_2 = .06$)

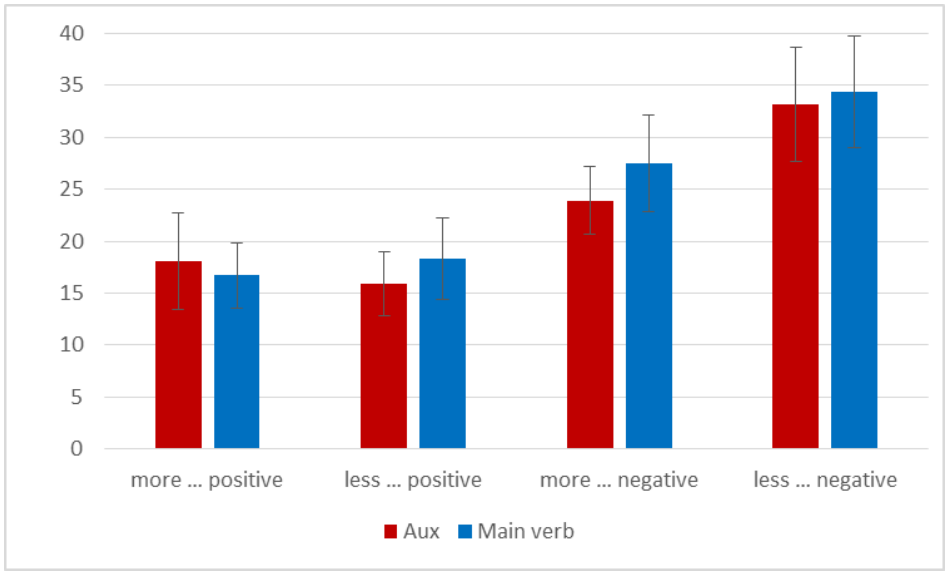
. . . due to Re-Reading of Verb+Negation ROI

Rereading effects at the verb+negation region (+/- 1 se):

Second pass times:



Proportions of *regressions in*:



- Significant 2-way interaction *monotonicity* × *negation* ($p_{1/2} < .05$):
  - Negation affected second pass times for *less than*, in particular
  - Same finding for *regressions in*

Exp. 2 – Errors in the Diagram Judgment Task

	verb 2nd	verb final
more, positive	.91	.92
fewer, positive	.84	.92
more, negative	.83	.83
fewer, negative	.67	.69

- Combination of *less than half* and negation led to errors in about a third of the trials

Experiment 2 – Discussion

Further evidence for GLOBAL INTERPRETATION

- Clear indication of enhanced processing complexity in the two *less than . . . negation* conditions
- Scope effects delayed until the end of the sentence
- Relative scope was assigned globally even though no scope inversion was required

Late Effects due to Pragmatic Constraints on Negative Statements?

(8) In front of the castle there is no ghost.

- Negative statements are often interpreted in a delayed manner (e.g. Kaup et al. 2006)
- Tian & Breheny (2010, 2016): Pragmatic effect, negative statements require special contextual licensing (▷ accommodation of question under discussion (QUD))

(9) A: Could you please tell me something about the buildings in this street?
B: This is a museum.
B: #This is not a museum.

(10) A: Is this a museum?
B: (No), this is not a museum.

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Tian et al. (2016)

Eyetracking study in the visual world paradigm:

(11)
a. Matt has shut the window.
b. Matt has not shut the window.
c. It is Matt who has shut the window.
d. It is Matt who has not shut the window.

An Alternative Explanation

(12) QUD: How many guests did (not) dance to Daddy Cool on some particular occasion?

- QUD can only be determined at the end of the sentence
- Too much indeterminacy:
  - Information structure
  - Scope
  - Event information

▷ Delayed interpretation

Semantic Complexity = Pragmatic Infelicity in Disguise?

Pragmatic account of difficulty in negation and quantifier processing:

(13) a. With the right equipment scuba diving is not dangerous (vs. dangerous). (Nieuwland & Kuperberg 2008)

b. It may be hard to build such a machine, but it is not impossible (vs. possible). (Schiller et al. 2017)

c. Alex was an unusual toddler. Few kids prefer vegetables (vs. sweets). (Urbach et al. 2015)

Incremental QUD construction seems viable for all of these examples:

- QUD(12-a): What about scuba diving with the right equipment?
- QUD(12-b): Is it possible at all to build such a machine?
- QUD(12-c): What properties do these few, exceptional kids have?

Without these QUD specifying contexts: Non-incremental effects!

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As in Tian et al. 2016 – Cleft Sentences...

Es waren	{mehr / weniger}	als	die Hälfte	der Gäste,	die	(nicht)	zu dem
It were	{more / fewer}	than	half of	the guests,	who	(not)	to the
Stück	von	Boney M	getanzt	haben,	nachdem	der DJ	es aufgelegt hatte.
piece	by	Boney M	danced	have	after	the DJ	it played had.

... enforce surface scope,

... fix QUDs,

(14) How many guests did (not) dance to *Daddy Cool*?

... and introduce presuppositions

(15) There are guests that did (not) dance to *Daddy Cool*.

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Embedded in Discourse Context

For their wedding party Peter and Mary had hired a DJ. The guests were, however, quite picky about music and danced only sporadically. So, it happened that for some songs the dance floor remained almost empty, while for others almost everybody danced. At some point, the DJ decided to play *Daddy Cool* by *Boney M*.

Es waren	$\left\{\begin{array}{c}\text{mehr}\\ \text{weniger}\end{array}\right\}$	als	die Hälfte	der Gäste,	die	(nicht)	zu dem	
It were	$\left\{\begin{array}{c}\text{more}\\ \text{fewer}\end{array}\right\}$	than	half of	the guests,	who	(not)	to the	
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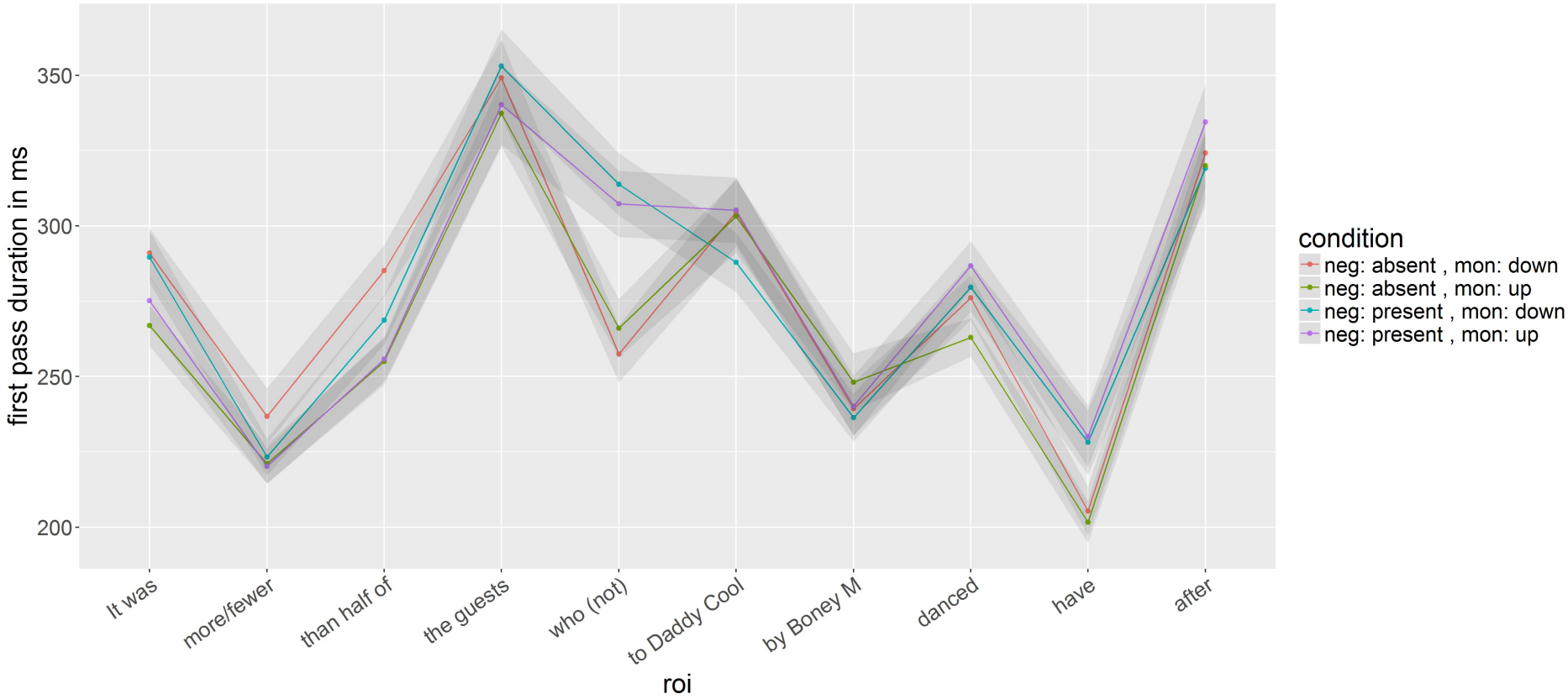
... introduce QUDs and satisfy presuppositions.

Exp. 3 – Design & Methods

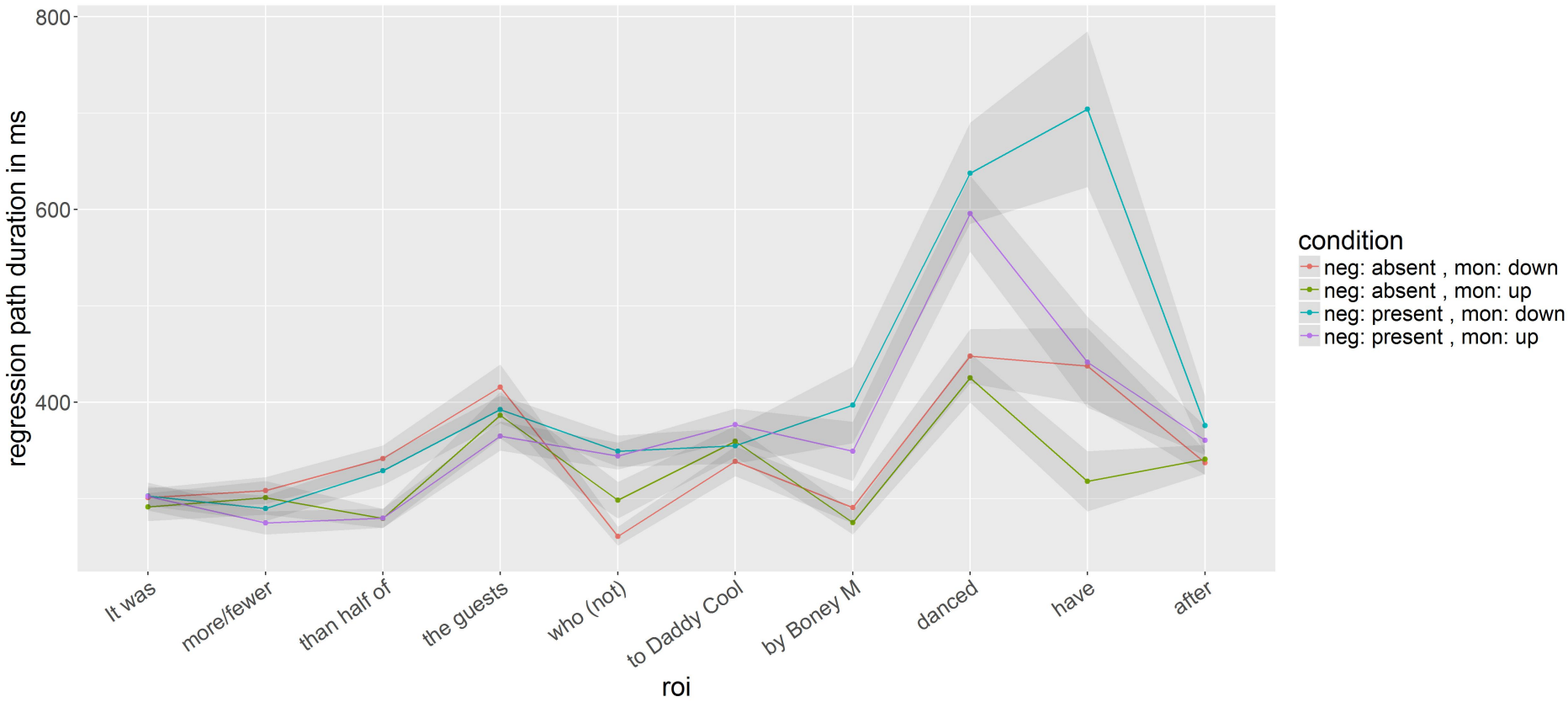
- 2×2 within design – MONOTONICITY × NEGATION
- 26 native German participants (planned 40)
- Same procedure as in the previous experiments (with two consecutive screens per trial)
- Same 40 items (+ new contexts) + 60 fillers
  - Discourses pretested in a coherence rating task
- 30 trials followed by diagram judgment task, 30 trials followed by comprehension questions
- 4 lists in a Latin-square design
- Analysis: (1) First-pass times, (2) regression-path durations, (3) first-pass regression ratios, (4) second-pass times

Exp. 3 – First-Pass Times



- No sign. effects of MONOTONICITY whatsoever

Exp. 3 – Regression-Path Durations



- Main effect of MONOTONICITY effect at the final region of the relative clause

Exp. 3 – Discussion

- Complexity effects of MONOTONICITY and NEGATION irrespective of supportive context
- Evidence for semantic complexity on top of pragmatic difficulty
- Monotonicity effect only emerged at the final region of the relative clause after having read the (entirely predictable!) verb
- Earlier than in Exp. 2 but still delayed

▷ Verb-dependent incrementality

Overview

General Discussion

- Variation in the time course of scope assignment:
  - GLOBAL INTERPRETATION: Reconstruction study & default scope study (Exp. 2)
  - PARTIAL INCREMENTALITY: Context study (Exp. 3).
- No indication of strictly incremental scope assignment
- We take this as evidence for the MINIMAL DOMAIN ACCOUNT of Radó & Bott (2012) (see also Sanford & Garrod 1998):

  *The **processing domain** of relative quantifier scope includes at least the main verb and all its arguments.*

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Open Questions

- Emerging picture:
  - Certain aspects of quantifier interpretation proceed incrementally (e.g. restriction; Augurzky et al. 2017).
  - Others, like scope assignment, are processed in a delayed or context-dependant manner (see, e.g., Urbach & Kutas 2010, Urbach et al. 2015)
- Scope is ubiquitous in semantic interpretation

$\Rightarrow$ Non-trivial challenges to a **cognitively realistic model** of semantic interpretation.

- Should be able to compute certain aspects immediately (e.g. thematic relations) while leaving relative scope underspecified
- Should also address other aspects that may involve scope (e.g. NPI licensing, c.f. Parker & Phillips, 2016)
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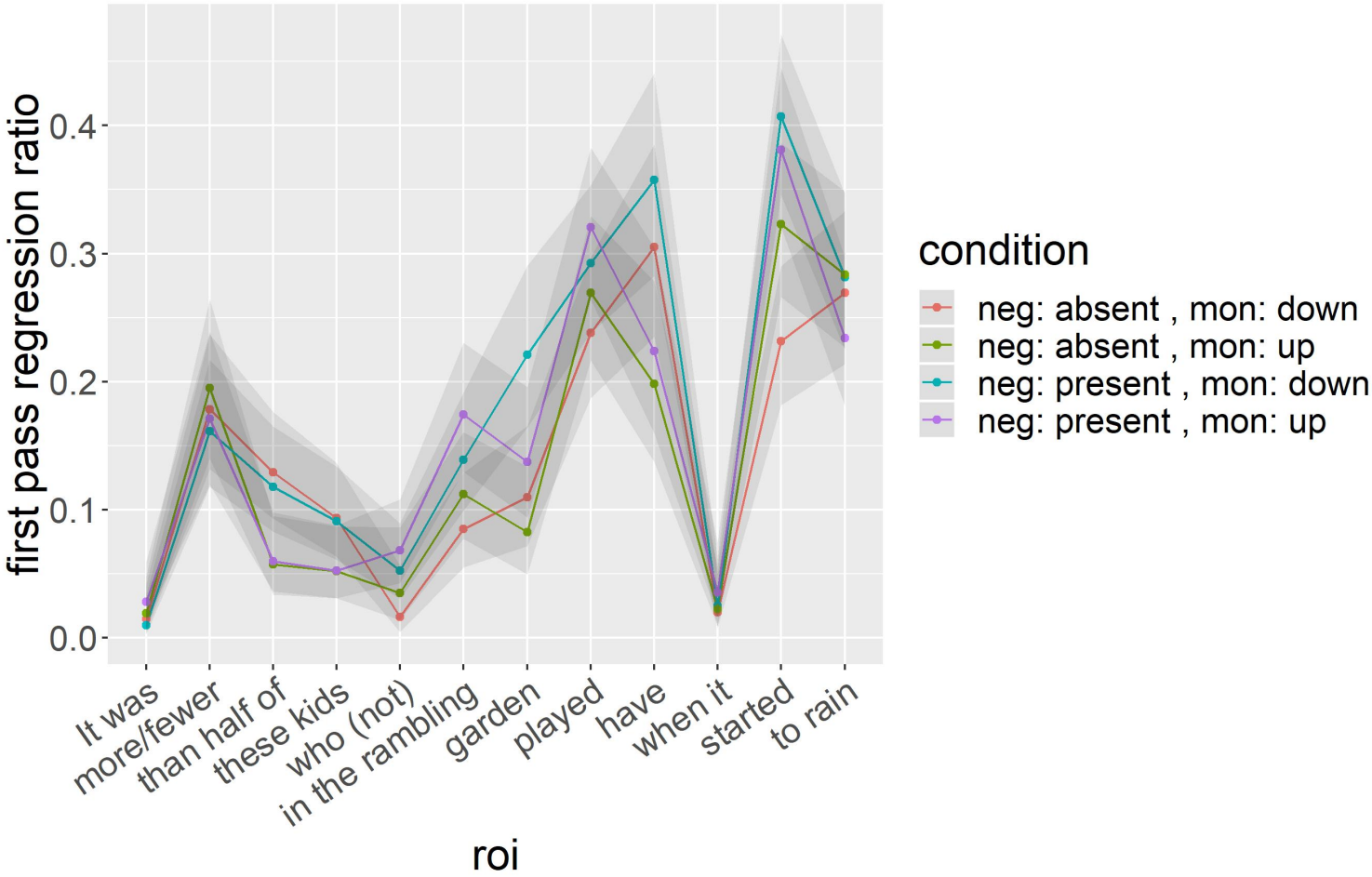
Thank you for your attention!

Exp. 3 – First-Pass Regressions



- Effect of *direction of entailment* at relative clause boundary.