

Polarity particles and the anatomy of n-words

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Sinn und Bedeutung, Utrecht, September 6, 2011

1 Introduction

- Two approaches to n-words

- (1) a. *No* student stepped forward.
 b. Susan *never* saw this movie.

- **Negative Indefinite (NI) approach:** n-words are indefinite expressions within the scope of a sentential negation operator ([Penka, 2007](#); [Zeijlstra, 2004](#); [Tubau, 2008](#), a.o.)

- (2) $\neg \exists x (student'(x) \wedge step-forward'(x))$

- **Negative Quantifier (NQ) approach:** in English, n-words are negative quantifiers occurring in otherwise positive sentences ([Zanuttini, 1991](#); [Haegeman, 1995](#); [De Swart and Sag, 2002](#), a.o.)

- (3) $Nx(student'(x) \wedge step-forward'(x))$

- If we had a way to **detect sentential negation**, it would be possible to tease these two approaches apart.

- Crucial observation

Sentential negation seems to affect the distribution of polarity particles (*yes*, *no*) in confirming responses to a previously made assertion:¹

- (4) A: Paul stepped forward.
 B: Yes / *No, Paul stepped forward.
- (5) A: Paul did not step forward.
 B: Yes / No, Paul did not step forward.

¹See [Kramer and Rawlins \(2009\)](#) for a closely related observation.

- Connection between n-words and polarity particles

The NI approach predicts that sentences involving n-words pattern with negative sentences like (5) rather than with positive sentences like (4):

- (6) A: No student stepped forward.
 B: Yes / No, no student stepped forward.

The NQ approach does not make this prediction

- Our goals:

1. Test whether sentential negation indeed affects the distribution of polarity particles as indicated in (4) and (5)
2. Test whether the prediction made by the NI theory is borne out

- Roadmap:

- §2 Theoretical background on polarity particles
- §3 Experiment 1: response patterns for sentences without n-words
- §4 Experiment 2: response patterns for sentences with n-words
- §5 Conclusion

2 Background on polarity particles

2.1 Introduction

- Polarity particles occur in responses to assertions and polar questions

- | | |
|--|---|
| <p>(7) Amy left.</p> <p style="margin-left: 2em;">a. Yes, she did.</p> <p style="margin-left: 2em;">b. No, she didn't.</p> | <p>(8) Did Amy leave?</p> <p style="margin-left: 2em;">a. Yes, she did.</p> <p style="margin-left: 2em;">b. No, she didn't.</p> |
|--|---|

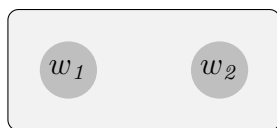
- Both assertions and polar questions express a **proposal** to update the common ground of a conversation in one or more ways²
- Polarity particles mark certain types of responses to a given proposal
- To do:
 - Specify a precise and sufficiently fine-grained formal notion of proposals
 - Specify how polarity particles are interpreted, given the proposal that they address

²See [Groenendijk and Roelofsen \(2009\)](#); [Farkas and Bruce \(2010\)](#), among others.

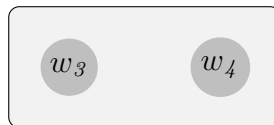
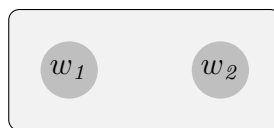
2.2 Propositions as sets of possibilities

- We will work within the framework of **inquisitive semantics**
- In inquisitive semantics, the proposition expressed by a sentence does not just capture the informative content of that sentence, but rather, more generally, the proposal that is made in uttering that sentence
- Propositions are defined as sets of **possibilities**
- Each possibility is a set of **possible worlds**, representing a potential update of the common ground
- Example:

The propositions expressed by (7) and (8) are depicted below:



(a) [Amy left]



(b) [Did Amy leave?]

w_1 and w_2 : worlds where Amy left
 w_3 and w_4 : worlds where Amy did not leave

- The proposition expressed by a sentence φ is denoted by $[\varphi]$
- In uttering a sentence φ , a speaker:
 1. **provides** the information that the actual world is contained in at least one of the possibilities in $[\varphi]$, and at the same time
 2. **requests** a response from other participants that provides enough information to establish at least one of the proposed updates

2.3 Highlighting

- For many purposes, it is sufficient to simply represent proposals as sets of possibilities
- However, to account for the distribution and interpretation of polarity particles we need a **more fine-grained** formal representation of proposals

- To see this, consider the following three questions:

(9) Is the door open?

(10) Is the door closed?

(11) Is the door open \uparrow or closed \downarrow ?

- The propositions expressed by these questions all consist of the **same two possibilities**, the possibility that the door is open, and the possibility that the door is closed
- Yet, if we consider the distribution and interpretation of polarity particles in responses to these questions, we find striking differences:

(9) Is the door open?

- a. Yes \Rightarrow open
- b. No \Rightarrow closed

(10) Is the door closed?

- a. Yes \Rightarrow closed
- b. No \Rightarrow open

(11) Is the door open \uparrow or closed \downarrow ?

- a. # Yes
- b. # No

- In order to capture these contrasts, we will make a distinction between **highlighted** and non-highlighted possibilities³
- Intuitively, highlighted possibilities are the ones that are **explicitly mentioned**
- In particular:
 - (9) highlights the possibility that the door is **open**
 - (10) highlights the possibility that the door is **closed**
 - (11) highlights **both** of these possibilities
- This is depicted in figure 1, where:
 - w_1 and w_2 are worlds where the door is **open**
 - w_3 and w_4 are worlds where the door is **closed**
 - **highlighted** possibilities are displayed with a **thick border**
- Highlighted possibilities serve as **antecedents** for subsequent **anaphoric** expressions

³See [Roelofsen and van Gool \(2010\)](#); [Pruitt and Roelofsen \(2011\)](#); [Farkas \(2011\)](#); [Farkas and Roelofsen \(2011\)](#).

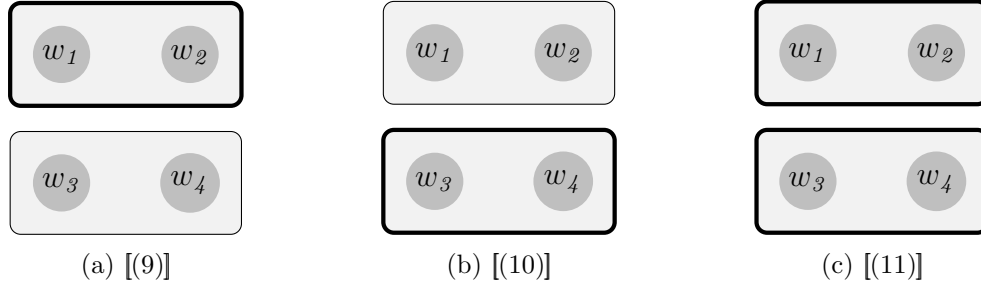


Figure 1: The possibilities proposed and highlighted by (9), (10), and (11).

- Polarity particles are such anaphoric expressions
- Assume that *yes* and *no* are interpreted as follows (to be refined)
 - A *yes* answer to an initiative ψ **presupposes** that there is **exactly one highlighted alternative** for ψ .
 - If this presupposition is met, *yes* confirms this highlighted alternative.
 - A *no* answer simply rejects all the highlighted possibilities for ψ .
- Then the contrast between (9), (10), and (11) is accounted for
- In the case of (9), there is **exactly one highlighted alternative**. So:
 - *yes* is licensed; it confirms the highlighted alt, conveying that the door is open;
 - *no* denies the highlighted alternative, conveying that the door is closed.
- In the case of (10), there is again **exactly one highlighted alternative**. So:
 - *yes* is licensed; it confirms the highlighted alt, conveying that the door is closed;
 - *no* denies the highlighted alternative, conveying that the door is open.
- In the case of (11), there are **two highlighted alternatives**. So:
 - *yes* is not licensed—its presupposition is not met;
 - *no* signals that the door is neither open nor closed, which is contradictory.
- Some additional predictions:
 - Polarity particles can only be used in responses, **not ‘out of the blue’**
 - Polarity particles can **not** be used **in response to *wh*-questions**, assuming that such questions do not highlight any possibilities

2.4 Positive and negative possibilities

- The distinction between highlighted and non-highlighted possibilities is not yet sufficient for a full account of polarity particles
- To see this, consider the following contrast:

- | | |
|---|---|
| (12) Susan failed the exam.
a. Yes, she failed.
b. *No, she failed. | (13) Susan didn't pass the exam.
a. Yes, she didn't pass.
b. No, she didn't pass. |
|---|---|

- (12) and (13) are entirely **equivalent** in the system considered so far:
 - They express exactly the same proposition
 - They highlight exactly the same possibility
- Still, they do not license the same polarity particles
- This contrast can only be accounted for semantically if we make our notion of propositions/proposals even more fine-grained
- ... fine-grained enough to reflect the relevant difference between (12) and (13)
- To this end, we will make a distinction between **positive** and **negative** possibilities⁴
- Negative possibilities are introduced by sentential negation
- [not φ] consists of a single [H,−] possibility: the complement of $\bigcup[\varphi]$
- Examples:
 - [Susan failed the exam] consists of a single [H,+] possibility
 - [Susan did not pass the exam] consists of a single [H,−] possibility
 - In both cases, the possibility involved consists of all worlds where Susan failed
 - However, in one case this possibility is positive, in the other it is negative
- Polarity phrases presuppose positive/negative antecedents, just like pronouns presuppose masculine/feminine antecedents
- Polarity particles in English do **double duty**:
 - They may signal whether the antecedent possibilities are **confirmed** or **rejected**
 - or whether the antecedent possibilities are supposed to be **positive** or **negative**
- In (12-a-b):
 - **yes** signals that the response is **confirming** or that the antecedent is **positive**
 - **no** is **not licensed** because it can only be used to signal that the response is **rejecting** or that the antecedent is **negative**

Neither is the case here: the response is confirming and the antecedent is positive
- In (13-a-b), *yes* signals confirmation, while *no* signals that the antecedent is negative

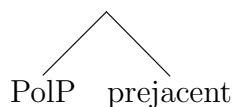
⁴See [Farkas and Roelofsen \(2011\)](#).

2.5 Absolute and relative polarity features

- To capture the idea that polarity particles do double duty, we assume that they are used to **realize** either an **absolute** or a **relative polarity feature**⁵
- An **absolute** polarity feature marks a response as being **positive** or **negative**
- A **relative** polarity feature marks a response as having the **same** absolute polarity as the antecedent, or the **reverse**
- Absolute polarity feature values: $[+]$ and $[-]$
- Relative polarity feature values: $[SAME]$ and $[REVERSE]$
- Thus, in total there are four possible feature value combinations:

	response	relation with antecedent
$[SAME, +]$	+	same
$[SAME, -]$	−	same
$[REVERSE, +]$	+	reverse
$[REVERSE, -]$	−	reverse

- Polarity features are hosted by a syntactic node called **PolP**
- Syntactically, PolP always attaches to a clausal node, which we call its **prejacent**



- The prejacent may be partially or fully elided
- To be specified:
 - The semantic contribution of the four possible feature combinations in PolP
 - Feature realization rules:
 - * which particles can be used to realize which features, and
 - * given a certain feature combination, which features are to be realized

⁵See [Pope \(1976\)](#); [Farkas and Bruce \(2010\)](#); [Farkas \(2010\)](#); [Farkas and Roelofsen \(2011\)](#).

2.6 Interpretation of feature combinations in PolP

- The semantic contribution of features in PolP is purely **presuppositional**
- If the presuppositions of PolP are met, it expresses the **identity function**, $\lambda p.p$
- [SAME, +]
 - presupposes a unique [H, +] alternative α on the Table⁶
 - presupposes that its prejacent **confirms** this alternative: $[\text{prejacent}] = \{\alpha_{[+]}\}$
- [SAME, −]
 - presupposes a unique [H, −] alternative α on the Table
 - presupposes that its prejacent **confirms** this alternative: $[\text{prejacent}] = \{\alpha_{[-]}\}$
- [REVERSE, +]
 - presupposes a non-empty set of [H, −] alternatives A on the Table
 - presupposes that its prejacent **rejects** all these alternatives: $[\text{prejacent}] = \{\overline{\bigcup A_{[-]}}\}$
- [REVERSE, −]
 - presupposes a non-empty set of [H, +] alternatives A on the Table
 - presupposes that its prejacent **rejects** all these alternatives: $[\text{prejacent}] = \{\overline{\bigcup A_{[+]}}\}$

2.7 Realization rules

- Which particles can be used to realize which features?
 In English:
 - [SAME] and [+] can be realized by *yes*
 - [REVERSE] and [−] can be realized by *no*
- Thus, polarity particles in English do **double duty**
 - they are used to realize both absolute and relative polarity features

⁶We assume a discourse model specified in [Farkas and Roelofsen \(2011\)](#), building on [Farkas and Bruce \(2010\)](#). In this model, a discourse context includes a stack of propositions, representing the proposals under consideration. This stack of propositions is called the Table. For convenience, we refer to alternatives that are contained in the *first* proposition on the Table simply as the ‘alternatives on the Table.’

- Given a certain feature combination, which features are to be realized?

Features that are more **marked** have higher ‘realization needs’

- (14)
- $[-]$ is marked relative to $[+]$
 - [REVERSE] is marked relative to [SAME]
 - The absolute polarity of [REVERSE] responses is marked because it **contrasts** with the polarity of the antecedent

- Main predictions

- (15)
- [SAME,+] can only be realized by *yes*
 - [REVERSE,-] can only be realized by *no*
 - [SAME,-] can be realized by *yes* or *no*
 - [REVERSE,+] can be realized by *yes* or *no*
- (16)
- In the case of [SAME,-] we expect a **preference** for *no* over *yes* because $[-]$ is more marked than [SAME]
 - In the case of [REVERSE,+] **both features have high realization needs**; across languages we see different strategies to satisfy these needs

- In English, [REVERSE,+] polarity phrases must have an explicit prejacant with **verum focus**, reflecting the **contrastive** positive polarity of the response:

- (17)
- A: Peter didn’t call.
B: Yes, he DID. / No, he DID.

- The full paradigm:

- (18)
- A: Peter called. / Did Peter call?
B: Yes, he did. / *No, he did. [SAME,+]
- (19)
- A: Peter called. / Did Peter call?
B: *Yes, he didn’t. / No, he didn’t. [REVERSE,-]
- (20)
- A: Peter didn’t call. / Did Peter not call?
B: Yes, he didn’t. / No, he didn’t. (preference for *no*) [SAME,-]
- (21)
- A: Peter didn’t call. / Did Peter not call?
B: Yes, he DID. / No, he DID. (contrastive stress obligatory) [REVERSE,+]

2.8 Main points for our present purposes

- Particle distribution is sensitive to whether the initiative is **positive** or **negative**
- In [SAME] responses to **positive** initiatives, **only *yes*** can be used
- In [SAME] responses to **negative** initiatives, **both *yes* and *no*** can be used
- The polarity of the initiative correlates with the presence of **sentential negation** rather than with lexical negativity:

- | | |
|--|---|
| <p>(22) Susan didn't pass the exam.</p> <p>a. Yes, she didn't pass.</p> <p>b. No, she didn't pass.</p> | <p>(23) Amy doesn't like Bill.</p> <p>a. Yes, she doesn't like him.</p> <p>b. No, she doesn't like him.</p> |
| <p>(24) Susan failed the exam.</p> <p>a. Yes, she failed.</p> <p>b. *No, she failed.</p> | <p>(25) Amy dislikes Bill.</p> <p>a. Yes, she dislikes him.</p> <p>b. *No, she dislikes him.</p> |

- Thus, we can use **polarity particles as a probe to detect sentential negation**

3 Experiment 1: basic distribution of polarity particles

Experiment 1 is designed to test two basic predictions of the theory specified above:

- In [SAME] responses to **positive** assertions, **only *yes*** can be used
- In [SAME] responses to **negative** assertions, **both *yes* and *no*** can be used

3.1 Method

We used online questionnaires to test people's preferences for the particle *yes* or *no* when they agree with a previously made assertion

- Two examples of experimental items:

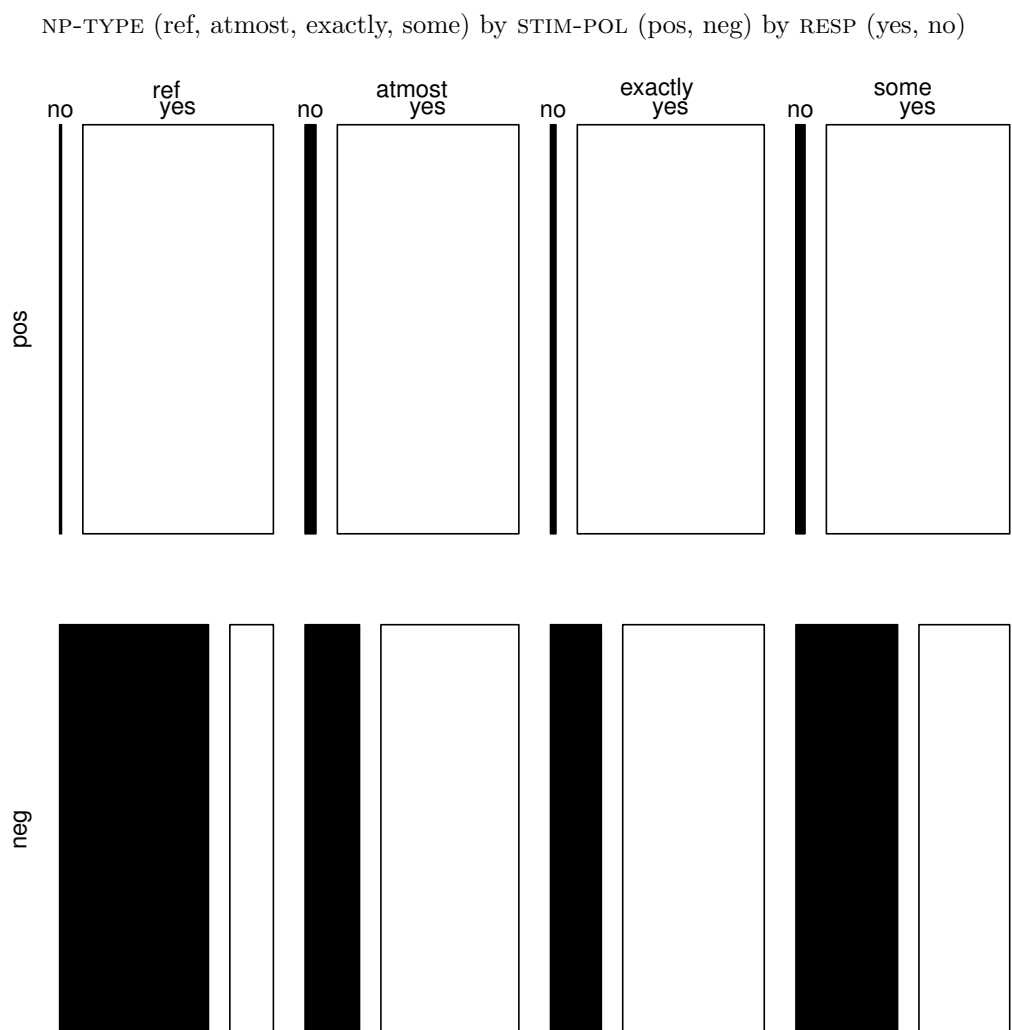
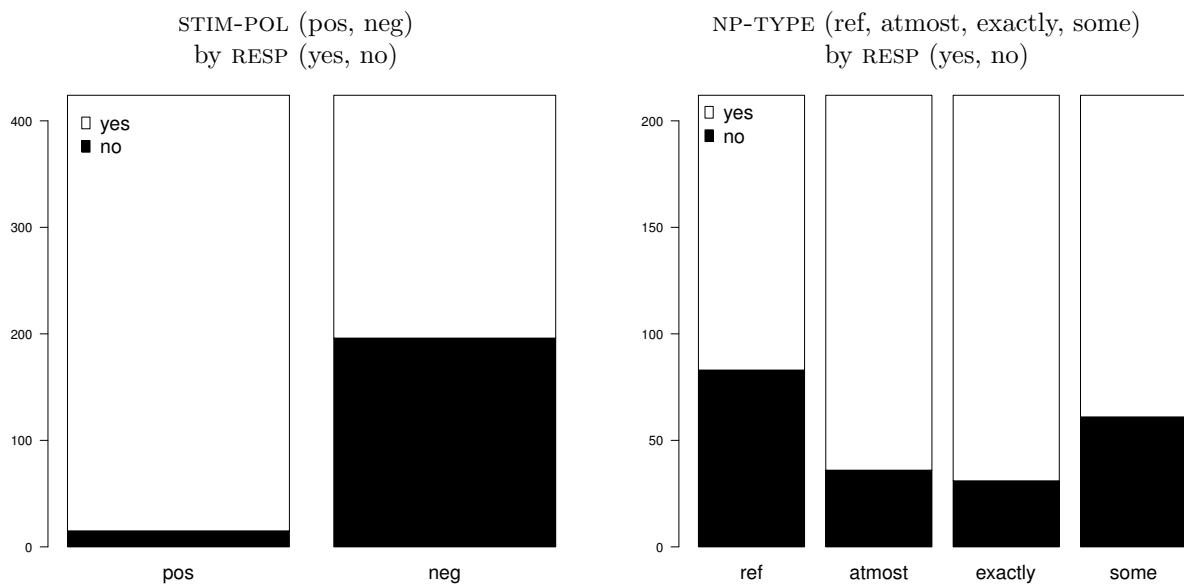
- | | |
|---|---|
| <p>(26) This substance will prevent the clay from twisting.</p> <p><input type="checkbox"/> Yes, it will.</p> <p><input type="checkbox"/> No, it will.</p> | <p>[stimulus]</p> <p>[response option 1]</p> <p>[response option 2]</p> |
| <p>(27) At most six volunteers did not sign up for free housing.</p> <p><input type="checkbox"/> Yes, at most six of them didn't.</p> <p><input type="checkbox"/> No, at most six of them didn't.</p> | <p>[stimulus]</p> <p>[response option 1]</p> <p>[response option 2]</p> |

- Dependent variable:
 - RESP
 - * choice of **polarity particle** in responses
 - * factor with 2 levels: yes, no; ‘success’ level: yes
- Three independent variables:
 1. STIM-POL
 - the **polarity of the stimulus**
 - if the stimulus is positive, we expect the subjects to overwhelmingly signal agreement with the particle *yes*
 - if the stimulus is negative, we expect the subjects to signal agreement with either *yes* or *no*
 - factor with 2 levels: pos, neg; reference level: pos
 2. NP-TYPE
 - the **type of subject NP** in the stimulus
 - all stimuli have the structure ‘subject + predication’
 - the subject NPs are **referential** or quantificational with 3 possible determiners: **some**, **at most n** and **exactly n**
 - we are interested in whether the referential vs. quantificational nature of the subject and their monotonicity properties affect particle choice
 - factor with 4 levels: ref, atmost, exactly, some; reference level: ref
 3. PART-POS:
 - the **position of the polarity particle** in the response
 - the particle is placed either at the **beginning** of the response or at the **end**
 - factor with 2 levels: ini, fin; reference level: ini
- (26) exemplifies the combination STIM-POL=**pos**, NP-TYPE=**ref**, PART-POS=**ini**
- (27) exemplifies the combination STIM-POL=**neg**, NP-TYPE=**atmost**, PART-POS=**ini**
- Items:
 - For each of the $16 = 2 \times 4 \times 2$ combinations, 3 stimulus sentences were generated for a total of 48.
 - The sentences were randomly selected from the Brown Corpus and the Corpus of Contemporary American English and simplified in various ways (shortened etc.)
- Subjects:
 - A total of 53 subjects in an undergraduate class completed the online experiment for extra-credit

- For each subject, we randomly selected 1 sentence for each of the 16 combinations
- Total number of observations: $53 \times 16 = 848$
- Randomization and fillers:
 - We randomized both the order of the stimuli and the order of the two possible responses for each stimulus
 - Fillers: the experiment presented in the next section together with another experiment with the same ‘stimulus + choose 1 of 2 agreeing responses’ format and 7 items in which the responses disagreed with the stimulus were used as fillers

3.2 Results

- Barplots for STIM-POL by RESP and for NP-TYPE by RESP are provided below, as well as a mosaic plot of NP-TYPE by STIM-POL by RESP
- Main observations (confirming our expectations):
 - When the stimulus is **positive**, the response particle is overwhelmingly *yes*
 - When the stimulus is **negative**, the response particle is **either *yes* or *no***
- More fine-grained observations:
 1. When the stimulus is **negative** and the subject NP is **referential**, there is a **preference for *no***
 2. When the stimulus is **negative** and the subject NP is **at most *n*** or **exactly *n***, there is a **preference for *yes***
 3. When the stimulus is **negative** and the subject NP is **some**, there is **no particular preference** for either *yes* or *no*
 4. The **position** of the particle in responses, e.g., *Yes, it will* versus *It will, yes*, was **irrelevant** for the choice of polarity particle (this is not depicted graphically)
- Observation 1 was **expected**, based on markedness considerations
- Observation 2 and 3 were **unexpected**. At this point, we do not have an explanation for these fine-grained differences between the different kinds of subject NPs. However, these differences are **not directly relevant** for the purposes of this paper
- Observation 4 was **expected**: particle choice was not predicted to depend on position
- Detailed statistical analysis is provided in appendix A



4 Experiment 2: polarity particles and n-words

Experiment 2 investigates whether sentences with n-words behave like negative sentences or like positive sentences with respect to the distribution of polarity particles in responses.

4.1 Method

We used online questionnaires to test whether people prefer to use *yes* or *no* in agreeing responses to a previously made assertion.

- Three examples of experimental items:

- | | | |
|------|---|---------------------|
| (28) | None of the local bookstores are hiring full-time. | [stimulus] |
| | <input type="checkbox"/> Yes, none of them are. | [response option 1] |
| | <input type="checkbox"/> No, none of them are. | [response option 2] |
| | | |
| (29) | The Neanderthals never crossed the Mediterranean. | [stimulus] |
| | <input type="checkbox"/> Yes, they never did. | [response option 1] |
| | <input type="checkbox"/> No, they never did. | [response option 2] |
| | | |
| (30) | Infants sometimes do not learn to speak before the age of four. | [stimulus] |
| | <input type="checkbox"/> Yes, they sometimes don't. | [response option 1] |
| | <input type="checkbox"/> No, they sometimes don't. | [response option 2] |

- Dependent variable:

– RESP

- * Choice of **polarity particle** in responses
- * factor with 2 levels: yes, no; ‘success’ level: yes

- Two independent variables:

1. STIM-TYPE

– We considered three types of stimuli:

- * Sentences with n-words but without sentential negation [none]
- * Sentences with an existential and sentential negation [somenot]
- * Sentences with an existential and without sentential negation [some]

– Factor with 3 levels: some, none, somenot; reference level: somenot

– If the stimulus is positive, STIM-TYPE=**some**, we expect that agreement is generally signalled with the particle *yes*

- If the stimulus is negative, STIM-TYPE=**somenot**, we expect that agreement can be signalled with both *yes* and *no*
- Crucially, we want to see whether sentences with n-words, STIM-TYPE=**none**, license both *yes* and *no* in agreeing responses, like negative sentences, or only *yes*, like positive sentences

2. GRAM-FUN

- We consider both nominal and adverbial n-words
- Factor with 2 levels: S(ubject), A(dverb); reference level: S

• Examples:

- (28) exemplifies the combination STIM-TYPE=**none**, GRAM-FUN=**S**
- (29) exemplifies the combination STIM-TYPE=**none**, GRAM-FUN=**A**
- (30) exemplifies the combination STIM-TYPE=**somenot**, GRAM-FUN=**A**

• Items:

- For each of the resulting $6 = 3 \times 2$ combinations, 3 stimulus sentences were generated for a total of 18.
- The sentences were randomly selected from the Brown Corpus and the Corpus of Contemporary American English and simplified in various ways (shortened etc.)

• Subjects:

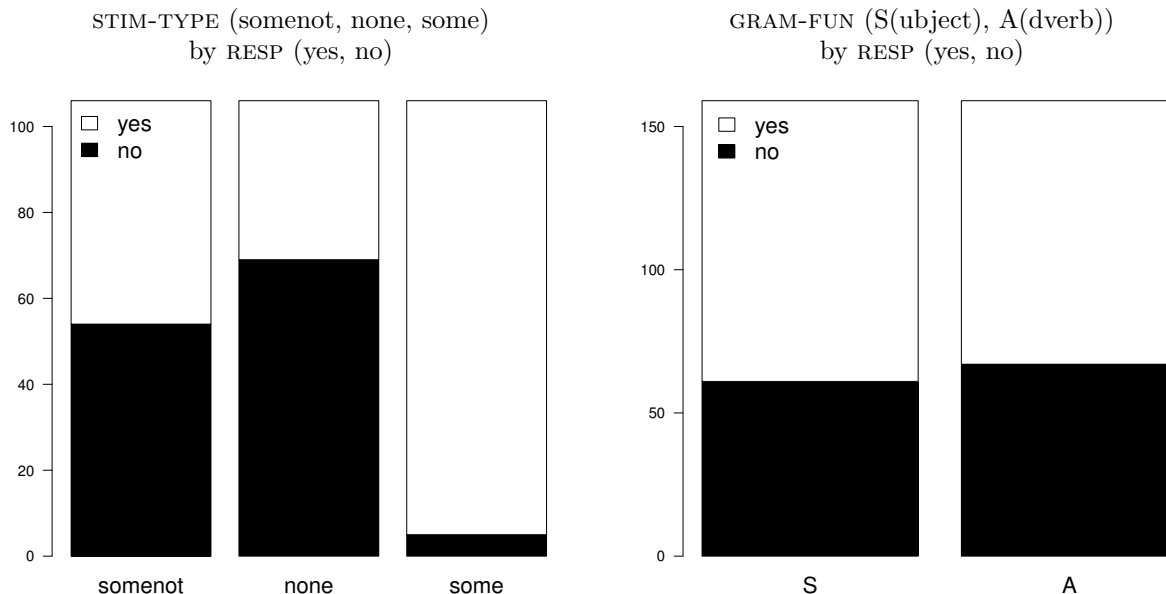
- A total of 53 subjects in an undergraduate class completed the online experiment for extra-credit
- For each subject, we randomly selected 1 sentence for each of the 6 combinations
- Total number of observations: $53 \times 6 = 318$

• Randomization and fillers:

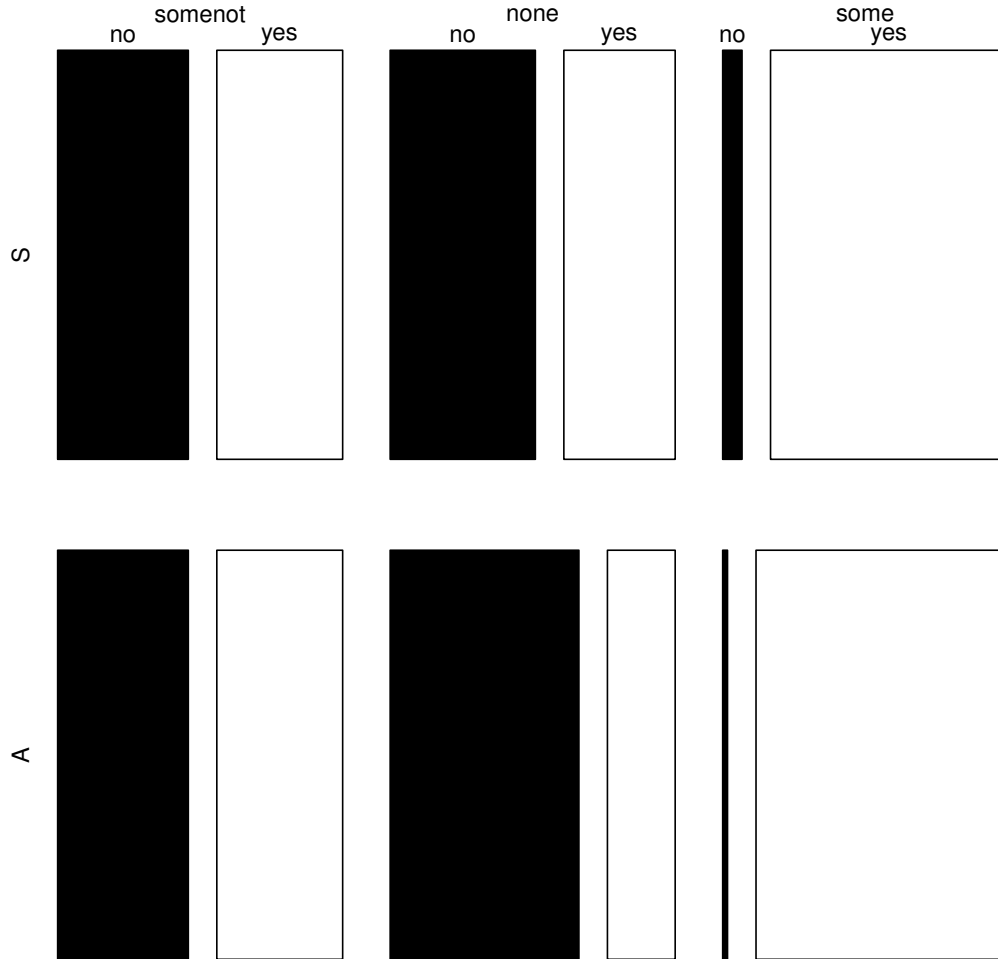
- We randomized both the order of the stimuli and the order of the two possible responses for each stimulus
- Fillers: the experiment presented in the previous section together with another experiment with the same ‘stimulus + choose 1 of 2 agreeing responses’ format and 7 items in which the responses disagreed with the stimulus were used as fillers

4.2 Results

- Barplots for STIM-TYPE by RESP and for GRAM-FUN by RESP are provided below, as well as a mosaic plot of STIM-TYPE by GRAM-FUN by RESP.
- Main observations (as expected):
 - Sentences with n-words license both *yes* and *no* in agreeing responses, just like negative sentences
 - Positive sentences only license *yes* in agreeing responses
- More fine-grained observation:
 - The mosaic plot indicates that the association between stimulus type and response particle does not vary by grammatical function: the pattern observed when aggregating over both subjects and adverbs is essentially the same as the patterns we observe when we look at each of them separately
 - N-words induce a stronger preference for *no* than neg+existentials, while positive existentials have a much stronger preference for *yes* than neg+existentials
 - These preferences are more pronounced for adverbs than for subjects
- Detailed statistical analysis is provided in appendix B



STIM-TYPE (somenot, none, some) by GRAM-FUN (S, A) by RESP (yes, no)



5 Conclusion

- We have seen that:
 - Negative sentences license both *yes* and *no* in agreeing responses
 - Positive sentences only license *yes* in agreeing responses
 - **Sentences with n-words license both *yes* and *no* in agreeing responses**
 - So sentences with n-words behave like sentences with sentential negation
- This is directly predicted if n-words are analyzed as indefinites that must occur in the scope of a (possibly covert) sentential negation operator (the NI approach)
- It is not predicted, at least not without further stipulations, if n-words are simply treated as quantifiers (the NQ approach)

A Statistical modeling of the results of Experiment 1

Given that the dependent variable RESP is binary, we use logistic regression models to analyze the data.

The first model we consider:

- the full model as far as the fixed effects STIM-POL, NP-TYPE and PART-POS are concerned: main effects plus all two-way and three-way interactions
- intercept-only random effects for both subjects and items

No term involving PART-POS (main effect or interaction) is significant. Dropping PART-POS (all 8 terms: the main effect, 4 two-way interactions, 3 three-way interactions) does not significantly increase the deviance ($p=0.41$). Furthermore, the item random effects account for practically no variance, so we drop them. Therefore, we focus exclusively on the STIM-POL and NP-TYPE fixed effects and the subject random effects.

We investigate whether we need to add random effects for slopes in addition to the intercept random effects:

- adding random effects for STIM-POL in addition to intercept random effects is highly significant ($p=7.81e-08$)
- adding random effects for NP-TYPE in addition to the random effects for STIM-POL and the intercept is not significant ($p=0.86$)
- similarly, adding random effects for NP-TYPE to the model with intercept-only random effects is not significant, but adding random effects for STIM-POL in addition to random effects for NP-TYPE and the intercept is highly significant
- therefore, we will focus exclusively on the model with STIM-POL and NP-TYPE fixed effects (including interactions) and random effects for the intercept and the STIM-POL slope

We check that we need all the fixed effects:

- adding NP-TYPE to the model with STIM-POL as the only fixed effect and with random effects for both the intercept and STIM-POL is highly significant ($p=6.81e-16$)
- similarly, adding the interaction between STIM-POL and NP-TYPE to the model with STIM-POL and NP-TYPE as additive fixed effects and with random effects for both the intercept and STIM-POL is highly significant ($p=3.15e-06$)

Thus, our final mixed-effects logistic regression model is as follows:

- fixed effects: STIM-POL, NP-TYPE and their interaction
- random effects: subject random effects for the intercept and STIM-POL

- the maximum likelihood estimates (MLEs) for this logistic regression model are:

RANDOM EFFECTS		std.dev.	corr.	
	INTERCEPT	3.89		
	STIM-POL-NEG	4.2	-0.95	
FIXED EFFECTS		estimate	std.error	p-value
	INTERCEPT	8.58	1.62	1.21e-07
	STIM-POL-NEG	-10.21	1.66	7.44e-10
	NP-TYPE-ATMOST	-2.55	1.39	0.067
	NP-TYPE-EXACTLY	-1.47	1.44	0.31
	NP-TYPE-SOME	-2.25	1.4	0.11
	STIM-POL-NEG: NP-TYPE-ATMOST	5.43	1.44	1.61e-4
	STIM-POL-NEG: NP-TYPE-EXACTLY	4.47	1.49	2.74e-3
	STIM-POL-NEG: NP-TYPE-SOME	3.74	1.44	9.45e-3

We observe the following:

- the intercept (i.e., a positive polarity sentence with a referential subject) indicates a highly significant preference for the particle ‘yes’
- changing the polarity of the sentence while keeping the subject referential contributes a strong preference for the particle ‘no’, as expected; however, the particle ‘yes’ is not ruled out, it is just overall dispreferred
- for positive polarity sentences, changing the NP type of the subject does not contribute any significant preference for ‘yes’ (or ‘no’) compared to the preferences exhibited by positive sentences with referential subjects
- for negative polarity sentences however, all non-referential NP types contribute strong preferences for the ‘yes’ particle (compared to referential NPs)
- this interaction between negative polarity and non-referential NP type was already visible in the mosaic plot above – and it is rather unexpected
- discovering new fine-grained generalizations of this kind is one of the most important contributions that experimental methods and statistical modeling can make to formal semantics

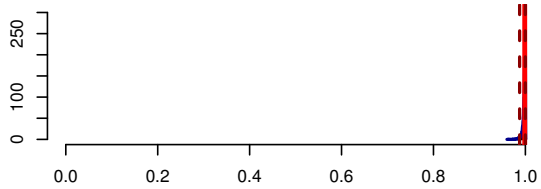
We will quantify all these ‘yes’ / ‘no’ preferences more precisely based on the Bayesian estimates of their posterior distributions.

- priors for fixed effects: the priors for the intercept and the non-reference levels STIM-POL, NP-TYPE and their interaction are all independent normals $N(0, 10^2)$
- priors for random effects: we assume a bivariate normal distribution for the intercept and STIM-POL-NEG random effects with correlation ρ between the two random effects $N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma^2 & \rho\sigma\tau \\ \rho\sigma\tau & \tau^2 \end{bmatrix}\right)$; the priors for the intercept standard deviation σ and the STIM-POL-NEG standard deviation τ are independent uniforms $Unif(0, 10)$ and the prior for ρ is $Unif(-1, 1)$
- MCMC estimation: 3 chains, 300000 iterations per chain, 50000 burnin, 125 thinning
- the means and standard deviations of the posterior distributions for the random and fixed effects are close to the MLEs (with some shrinkage):

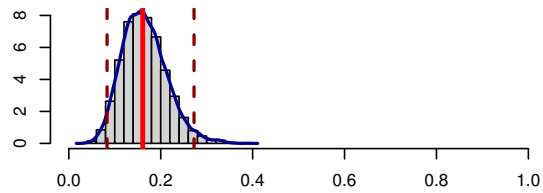
RANDOM EFFECTS		mean	std.dev.
	σ	2.22	0.75
	τ	2.84	0.74
	ρ	-0.82	0.11
FIXED EFFECTS		mean	std.dev.
	INTERCEPT	6.72	1.39
	STIM-POL-NEG	-8.39	1.43
	NP-TYPE-ATMOST	-2.18	1.13
	NP-TYPE-EXACTLY	-1.14	1.22
	NP-TYPE-SOME	-1.91	1.15
	STIM-POL-NEG: NP-TYPE-ATMOST	5.13	1.21
	STIM-POL-NEG: NP-TYPE-EXACTLY	4.22	1.29
	STIM-POL-NEG: NP-TYPE-SOME	3.45	1.21

We plot below the posterior distributions of the preference for, i.e., probability of, a ‘yes’ response together with the median probability and 95% credible interval for each of the two stimulus polarities and the four NP types.

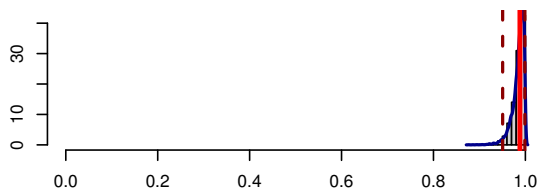
- the second plot juxtaposes the median probabilities and their 95% credible intervals for easier comparison



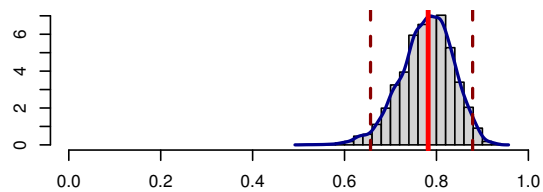
$p(\text{yes}|\text{pos},\text{ref})$, median=1



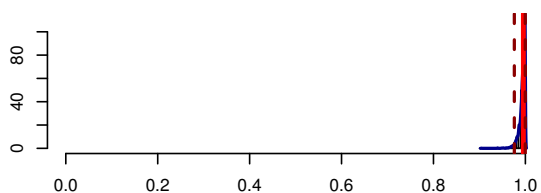
$p(\text{yes}|\text{neg},\text{ref})$, median=0.16



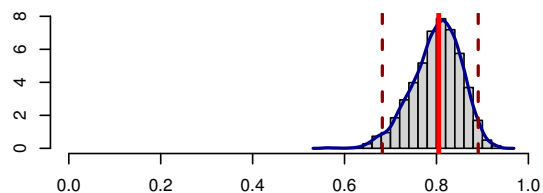
$p(\text{yes}|\text{pos},\text{atmost})$, median=0.99



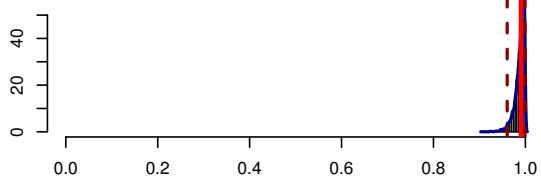
$p(\text{yes}|\text{neg},\text{atmost})$, median=0.78



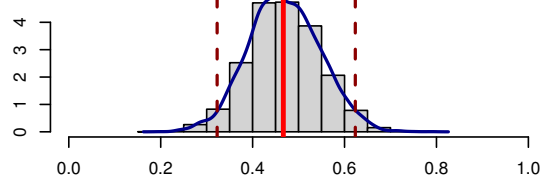
$p(\text{yes}|\text{pos},\text{exactly})$, median=1



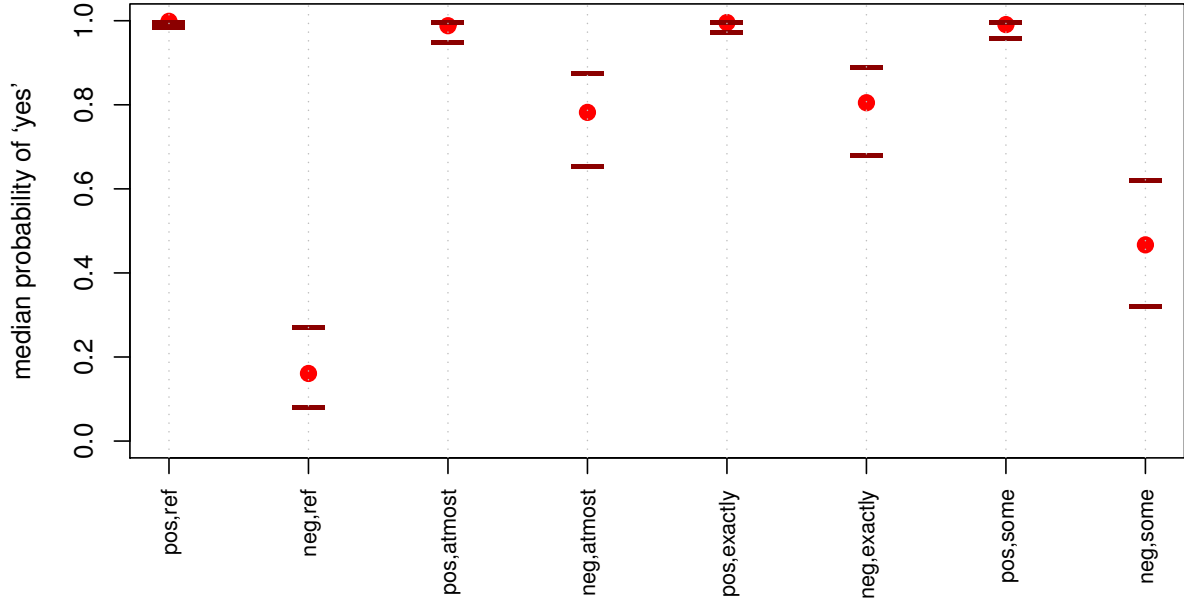
$p(\text{yes}|\text{neg},\text{exactly})$, median=0.8



$p(\text{yes}|\text{pos},\text{some})$, median=0.99



$p(\text{yes}|\text{neg},\text{some})$, median=0.47



B Statistical modeling of the results of Experiment 2

The first model we consider:

- the full model as far as the fixed effects STIM-TYPE and GRAM-FUN are concerned: main effects plus all two-way interactions
- intercept-only random effects for both subjects and items

We investigate whether we need to add random effects for slopes in addition to the intercept random effects:

- adding subjects and items random effects for STIM-TYPE in addition to intercept random effects is not significant ($p=0.38$)
- adding subjects and items random effects for GRAM-FUN in addition to intercept random effects is not significant ($p=0.98$)
- therefore, we will focus exclusively on the model with STIM-TYPE and GRAM-FUN fixed effects (including interactions) and intercept-only random effects for subjects and items

We check that we need all the fixed effects:

- the interaction between STIM-TYPE and GRAM-FUN does not significantly reduce deviance ($p=0.08$)

- moreover, adding GRAM-FUN to the model that has STIM-TYPE as the only fixed effect is not significant either ($p=0.47$)
- adding GRAM-FUN to the null (intercept) model is also not significant ($p=0.93$)
- in contrast, adding STIM-TYPE to the null (intercept) model is highly significant ($p=3.15e-08$) and adding STIM-TYPE to the model that has GRAM-FUN as the only fixed effect is also highly significant ($p=2.43e-08$)
- thus, we will consider models with STIM-TYPE as the only fixed effect from now on

In addition, random effects for items account for practically no variance, so we drop them. Our final mixed-effects logistic regression model is as follows:

- fixed effects: STIM-TYPE
- random effects: subject random effects for the intercept
- the MLEs for this logistic regression model are:

RANDOM EFFECTS		std.dev.		
	INTERCEPT	0.63		
FIXED EFFECTS		estimate	std.error	p-value
	INTERCEPT	-0.04	0.21	0.85
	STIM-TYPE-NONE	-0.64	0.29	0.025
	STIM-TYPE-SOME	3.22	0.52	8.76e-10

We observe the following:

- negative quantifiers have a higher preference for ‘no’ than negation + existentials that is statistically significant
- however, the intercept is not statistically significant: negation + existential sentences have no clear preference for ‘yes’ vs. ‘no’
- finally, existential sentences have a significantly higher preference for ‘yes’ than negation + existential sentences

We will quantify all these ‘yes’ / ‘no’ preferences more precisely based on the Bayesian estimates of their posterior distributions.

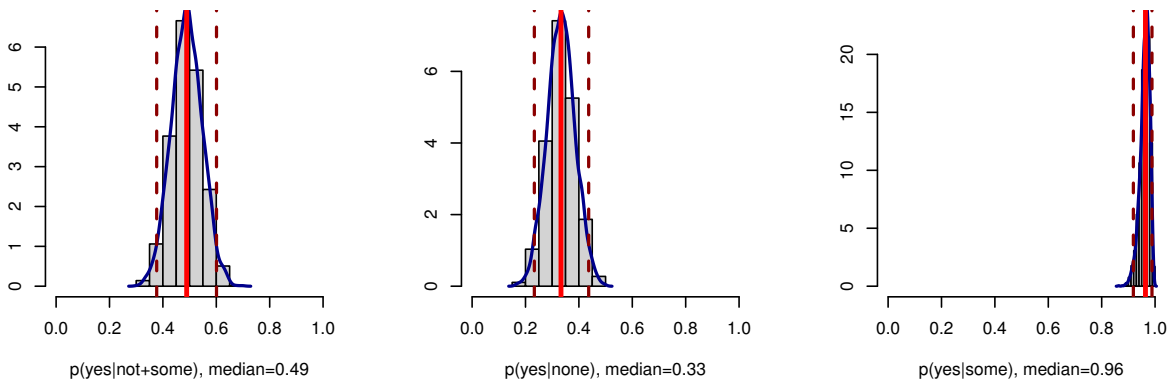
- priors for fixed effects: the priors for the intercept and the non-reference levels of STIM-TYPE are all independent normals $N(0, 100^2)$
- priors for random effects: we assume a normal distribution $N(0, \sigma^2)$ for the intercept random effects; the prior for the standard deviation σ is uniform $Unif(0, 100)$

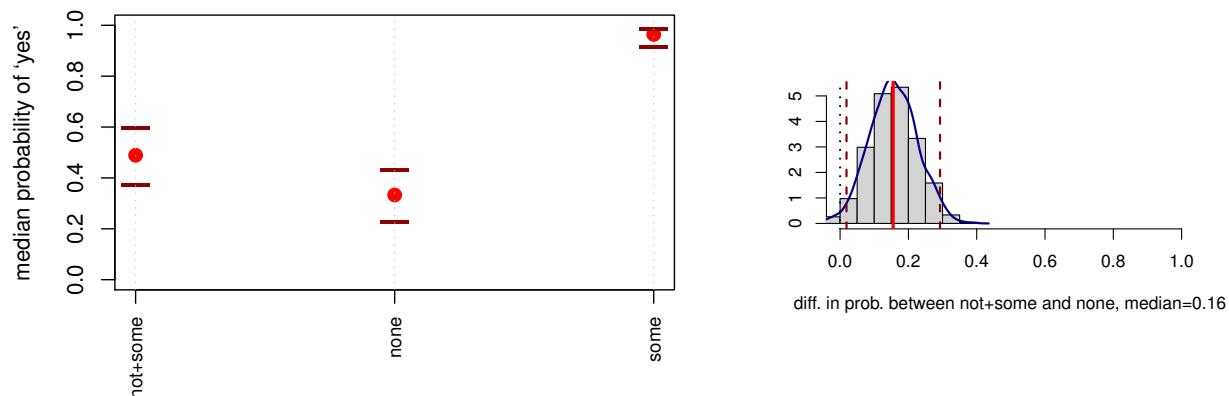
- MCMC estimation: 3 chains, 225000 iterations per chain, 25000 burnin, 200 thinning
- the means and standard deviations of the posterior distributions for the random and fixed effects are very close to the MLEs:

RANDOM EFFECTS		mean	std.dev.
	σ	0.71	0.3
FIXED EFFECTS		mean	std.dev.
	INTERCEPT	-0.04	0.23
	STIM-TYPE-NONE	-0.66	0.3
	STIM-TYPE-SOME	3.37	0.55

We plot below the posterior distributions of the preference for, i.e., probability of, a ‘yes’ response together with the median probability and 95% credible interval for the three stimulus types.

- the second plot juxtaposes the median probabilities and their 95% credible intervals for easier comparison
- the third plot shows the difference in probability of ‘yes’ between negation + existentials and negative quantifiers; since the 95% interval (0.019, 0.293) does not overlap 0, we are fairly confident that negative quantifiers have a higher preference for ‘no’





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