The processing cost of weak modality
and consequences for child production and typology

Paloma Jeretič

paloma@nyu.edu

Meaning and Modality Lab, Harvard
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Do these two sentences have a different processing cost?

(1) You can go to school.

(2) You must go to school.
Do these two sentences have a different processing cost?

(1) You can go to school. $\leadsto$ You don't have to go to school.

(2) You must go to school. $\leadsto$ $\emptyset$

(1) generates an implicature, (2) doesn't
Introduction

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- (1) generates an implicature, (2) doesn’t
- (1) gives the subject a choice, i.e. gives them a possible burden of decision-making, inexistent with (2)
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- (1) is associated with indeterminacy, (2) is not
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Hypothesis: Weak modal expressions are more costly than strong ones
Questions I will address today

1. Can I confirm this hypothesis?
   - I test it by measuring accuracy and reaction time in a truth-value judgment task with weak and strong modal expressions
   - Results at least partially support it: negated weak modals yield longer reaction times and lower accuracy rates

2. Can this higher processing cost affect child acquisition of modal expressions?
   - I present a child corpus study that shows results consistent with the hypothesis:
     - children begin producing strong modal expressions before weak ones
     - lower proportions of weak negated modals, compared to adults

3. Cross-linguistically, the inventory and behavior of functional modal expressions shows a sparseness of weak expressions: could processing cost provide an explanation?
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Outline

1. Weak and strong modality

2. Experimental study: Processing weak and strong modality

3. Child corpus study: acquiring weak and strong functional modals

4. A look at the typology
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Weak and strong functional root modals (in English, French, Spanish)

<table>
<thead>
<tr>
<th>Strength of modal expression</th>
<th>Possibility: Existential Quantification</th>
<th>Necessity: Universal Quantification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>can</td>
<td>not have to</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>peut</td>
<td>pas besoin, doit pas</td>
</tr>
<tr>
<td></td>
<td>puedo</td>
<td>no necesita, no tiene que</td>
</tr>
<tr>
<td>Strong</td>
<td>can’t</td>
<td>must</td>
</tr>
<tr>
<td></td>
<td>¬</td>
<td>faut</td>
</tr>
<tr>
<td></td>
<td>no puedo</td>
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</tr>
<tr>
<td></td>
<td>¬</td>
<td>can’t</td>
</tr>
<tr>
<td></td>
<td>no debe, no tiene que</td>
<td>mustn’t</td>
</tr>
</tbody>
</table>

- Weak is logically equivalent to wide scope existential quantification
- Strong is logically equivalent to wide scope universal quantification
Weak and strong functional root modals (in English, French, Spanish)

### Force of modal form

**Possibility** (existential quantification) vs. **Necessity** (universal quantification)

<table>
<thead>
<tr>
<th>Weak</th>
<th>Strong</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Can</strong></td>
<td><strong>Can’t</strong></td>
</tr>
<tr>
<td><strong>Peut</strong></td>
<td><strong>Peut pas</strong></td>
</tr>
<tr>
<td><strong>Puede</strong></td>
<td><strong>No puede</strong></td>
</tr>
<tr>
<td><strong>NA</strong></td>
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<td><strong>No debe, no tiene que</strong></td>
</tr>
</tbody>
</table>

### Strength of modal expression

**Weak**
- Logically equivalent to wide scope
- **Existential quantification**

**Strong**
- Logically equivalent to wide scope
- **Universal quantification**
Weak and strong functional root modals (in English, French, Spanish)

force of modal form

### Possibility

- **Weak**
  - Logical equivalence to wide scope: \( \exists \) quantification
  - Examples: *can*, *peut*, *puede*
- **Strong**
  - Logical equivalence to wide scope: \( \forall \) quantification
  - Examples: *must*, *faut*, *tiene que*, *can’t*, *peut pas*, *no puede*

### Necessity

- **Weak**
  - Logical equivalence to wide scope: \( \exists \) quantification
  - Examples: *not have to*, *pas besoin, doit pas*, *no necesita, no tiene que*
- **Strong**
  - Logical equivalence to wide scope: \( \forall \) quantification
  - Examples: *mustn’t*, *faut pas, doit pas*, *no debe, no tiene que*
Weak and strong functional root modals (in English, French, Spanish)

**force of modal form**

<table>
<thead>
<tr>
<th></th>
<th>possibility</th>
<th>necessity</th>
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<tr>
<td></td>
<td>existential quantification</td>
<td>universal quantification</td>
</tr>
<tr>
<td><strong>weak</strong></td>
<td>can</td>
<td>NA</td>
</tr>
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<td>+</td>
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**weak** logically equivalent to wide scope ∃ quantification

**strong** logically equivalent to wide scope ∀ quantification
Outline

1. Weak and strong modality

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4. A look at the typology
The processing of weak modality

- The literature on the processing of modal force is very sparse
- It contrasts with a huge amount of literature on force of nominal quantifiers, in particular for scalar implicature computation (e.g. *some* $\rightsquigarrow$ *not all*):
  - implicature generation in the nominal quantifier domain is associated with a processing cost (Degen & Tanenhaus, 2016; Papafragou & Musolino, 2003; Pouscoulous, Noveck, Politzer, & Bastide, 2007, a.m.o)
  - impacting L1 acquisition (Barner & Bachrach, 2010; Chierchia, Crain, Guasti, Gualmini, & Meroni, 2001; Huang & Snedeker, 2009; Noveck, 2001; Papafragou, 2006; Skordos & Papafragou, 2016, a.o.)
The processing of weak modality

- Huette, Matlock, and Spivey (2010): audio-visual two-alternative forced-choice task to examine processing differences between *should* and *must*
  - Stimuli: *You must/should brush your teeth everyday; You must/should eat from a dirty plate* – agree or disagree?
  - Results:
    - no differences in reaction times
    - divergence in fixations to the target for *should*, but not for *must*
  - “These results suggest two mental models are simultaneously activated, entailing both agreement and disagreement with the statement in question”
Online experimental studies

- 2 MTurk studies: Truth Value Judgment Tasks, recording reaction time:
  - Study 1: alethic modals, asking simple math questions
  - Study 2: deontic modals, asking questions about a short text
Methods

- 45 participants for Study 1; 54 participants for Study 2
- 6 meaning conditions:
  - $\Diamond$ (can)
  - $\neg\Diamond$ (cannot)
  - $\Diamond\neg$ (possibly not)
  - $\Box$ (must)
  - $\neg\Box$ (need not)
  - $\Box\neg$ (must not)
Methods

- 45 participants for Study 1; 54 participants for Study 2
- 6 meaning conditions:
  - ♦ (can)
  - ¬♦ (cannot)
  - ♦¬ (possibly not)
  - □ (must)
  - ¬□ (need not)
  - □¬ (must not)
- each participant saw one of the following (6 meaning conditions, varying type of context, truth value, felicity):

<table>
<thead>
<tr>
<th>det</th>
<th>T, F</th>
<th>T, F</th>
<th>T, F</th>
<th>T, F</th>
</tr>
</thead>
<tbody>
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<td>indet</td>
<td>T, F</td>
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<td>F</td>
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<td>F</td>
<td>F</td>
</tr>
</tbody>
</table>

- excluded subjects that had accuracy at or below chance
- excluded responses with reaction time below 1sec and above 19sec (for Study 1), 15sec (for Study 2)
## Methods

- **Modal lexemes used:**

<table>
<thead>
<tr>
<th>Study 1</th>
<th>Study 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>◊ <em>can, possibly</em></td>
<td><em>can, allowed</em></td>
</tr>
<tr>
<td>¬◊ <em>cannot</em></td>
<td><em>cannot, not allowed</em></td>
</tr>
<tr>
<td>◊¬ <em>possibly not</em></td>
<td><em>allowed not, permitted not</em></td>
</tr>
<tr>
<td>□ <em>must, have to, necessarily</em></td>
<td><em>must, needs, required</em></td>
</tr>
<tr>
<td>¬□ <em>not have to, not necessarily</em></td>
<td><em>need not, not required</em></td>
</tr>
<tr>
<td>□¬ <em>must not, necessarily not</em></td>
<td><em>must not, required not</em></td>
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Examples of target prompts

(1) \(x\) and \(y\) are positive integers, and \(x + y = 4\).
   Is this statement true or false:
   \(y\) is necessarily equal to 2.

(2) \(x\) and \(y\) are positive integers, and \(x + y = 3\).
   Is this statement true or false:
   \(y\) is not necessarily equal to 1.5.
Methods: Study 2

- Example of target prompt

At Institution X, students graduate only if they have passed The Secret Test.

This Test is offered once a year, and students can choose when to take the Secret Test, but there are certain requirements:
- In their first year, a student may take the Test if their GPA is above 3.0.
- In their second or third year, a student may take the Test if their GPA is above 2.0.
- Students must take the Test before the beginning of their fourth year.

This means that if by year 3, you have a GPA below 2.0, you can’t take the Secret Test so you automatically fail your degree.

These rules are strict; any attempt to cheat the system results in termination.

Lily is a third year.
Lily's GPA: 2.8

Is this statement true or false?
When the Secret Test is offered this year,
Lily is allowed to take it.

press C for TRUE, press M for FALSE
Results: Study 1

- No significant effect on accuracy
Results: Study 1

- No significant effect on accuracy
- No effect of context, truth value, felicity on accuracy or reaction time

Two-sample independent $t$-test: Longer reaction times for weak negated modals, compared to the rest.

Average reaction time by modal meaning: 15 / 41
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Average reaction time by modal meaning
Results: Study 1

- Controlling for lexical access and length:

<table>
<thead>
<tr>
<th></th>
<th>necessarily</th>
<th>not</th>
<th>not necessarily</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT (in sec)</td>
<td>4.320</td>
<td>4.968</td>
<td></td>
</tr>
</tbody>
</table>

\[ p = .085166 \]

Not quite significant (but: small amount of data for these two conditions)
Results: Study 2

Reaction times by condition, for correct responses
(infelicitous removed)
Study 2 results: RT for lexical modals

Reaction times by condition, for correct responses for lexical modals (infelicitous removed)

- maximally controlling for lexical access and length
Study 2 results: accuracy

Accuracy rates per condition (infelicitous removed)
Main findings

- In both studies, weak negated expressions (¬□, ◊¬) elicit slower responses than strong negated expressions (□¬, ¬◊), and apparent lower accuracy rates.
Among [+neg] conditions, strength is the only factor differentiating between negated strong ($\square \neg$, $\neg \Diamond$) and negated weak ($\neg \square$, $\Diamond \neg$) conditions: both scope and modal item are controlled for.

- For both alethic and deontic modals, the hypothesis is partly confirmed: weak modals take longer to process than strong modals. What is the significance of negation?
Possibilities for why weakness matters only with negation:
- combined cognitive load
  - while there is higher processing cost for weak (as shown by Huette et al. (2010)), non-negated are at ceiling for reaction time
  - same, negation also has a cost (Feiman, Mody, Sanborn, & Carey, 2017; Nordmeyer & Frank, 2015, a.o.), but negated sentences are also at ceiling (seen in controls)
- only the combination of both makes a difference in reaction time
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  - pragmatics:
    - as opposed to strong modals, weak negated and non-negated modals appear in the same contexts, since they are each other’s implicature. In uttering $\neg\Box p$ or $\Diamond \neg p$, there must be some expectation of $\Box p$. If it’s not there, one must accommodate.
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    - While the contexts, especially in Study 2, did allow this expectation to be there, the fact that ‘can’ was there also negated this expectation.
    - a follow-up: in the same context, compare “can leave” vs “don’t have to stay” (so expectations are constant)
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Child corpus study

- Corpus study: 11 corpora containing spontaneous speech from preschool children and their input (from the CHILDES database); 5 French, 6 Spanish
Child corpus study

- Corpus study: 11 corpora containing spontaneous speech from preschool children and their input (from the CHILDES database); 5 French, 6 Spanish
- Coded sentences containing root modals and negation, for:
  - strength (target and intended)
  - force
  - presence of negation
Results: Binomial Tests for concurrent acquisition

- Strength: 2 out of 5 French children and 2 out of 5 Spanish children acquired strong forms before weak forms; the other children showed no significant results
Results: Binomial Tests for concurrent acquisition

- **Strength**: 2 out of 5 French children and 2 out of 5 Spanish children acquired strong forms before weak forms; the other children showed no significant results.

- **Force**: 2 out of 5 French children and 4 out of 5 Spanish children acquired existentials before universals; the other children showed no significant results.
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- Force: 2 out of 5 French children and 4 out of 5 Spanish children acquired existentials before universals; the other children showed no significant results
- → several first uses were negated
### Results: counts for each modal expression

<table>
<thead>
<tr>
<th></th>
<th>□</th>
<th>□¬</th>
<th>¬□</th>
<th>♦</th>
<th>¬♦</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to age 3</td>
<td>CHI</td>
<td>252</td>
<td>32</td>
<td>2</td>
<td>244</td>
</tr>
<tr>
<td></td>
<td>ADU</td>
<td>1876</td>
<td>265</td>
<td>78</td>
<td>1326</td>
</tr>
<tr>
<td>up to age 4</td>
<td>CHI</td>
<td>425</td>
<td>56</td>
<td>9</td>
<td>461</td>
</tr>
<tr>
<td></td>
<td>ADU</td>
<td>2425</td>
<td>330</td>
<td>113</td>
<td>1787</td>
</tr>
</tbody>
</table>

**Table:** Counts of French forms, by age and group and by meaning (cumulative)

<table>
<thead>
<tr>
<th></th>
<th>□</th>
<th>□¬</th>
<th>¬□</th>
<th>♦</th>
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</tr>
</thead>
<tbody>
<tr>
<td>up to age 3</td>
<td>CHI</td>
<td>119</td>
<td>7</td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>ADU</td>
<td>717</td>
<td>28</td>
<td>12</td>
<td>264</td>
</tr>
<tr>
<td>up to age 4</td>
<td>CHI</td>
<td>146</td>
<td>10</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>ADU</td>
<td>809</td>
<td>29</td>
<td>14</td>
<td>312</td>
</tr>
</tbody>
</table>

**Table:** Counts of Spanish forms, by age and group and by meaning (cumulative)
Results: comparing proportions

<table>
<thead>
<tr>
<th>comparing</th>
<th>French</th>
<th>Spanish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p-values</td>
<td>CHI residuals</td>
</tr>
<tr>
<td></td>
<td>p = 0.001</td>
<td>(-1.95, +2.27)</td>
</tr>
<tr>
<td>¬□ ¬◊</td>
<td>p = 0.013</td>
<td>(-1.99, +0.94)</td>
</tr>
<tr>
<td>¬□ ◊</td>
<td>p = 0.013</td>
<td>(-2.73, +0.62)</td>
</tr>
<tr>
<td>¬□ □</td>
<td>p = 0.010</td>
<td>(-2.21, +0.43)</td>
</tr>
<tr>
<td>¬□ □¬</td>
<td>p = 0.025</td>
<td>(-1.76, +0.91)</td>
</tr>
<tr>
<td>◊ ¬◊</td>
<td>p = 0.084</td>
<td></td>
</tr>
<tr>
<td>□ ¬◊</td>
<td>p &gt; 0.999</td>
<td></td>
</tr>
<tr>
<td>□ □¬</td>
<td>p = 0.590</td>
<td></td>
</tr>
<tr>
<td>□¬ ¬◊</td>
<td>p = 0.639</td>
<td></td>
</tr>
</tbody>
</table>

Aggregate results for $\chi^2$ or Fisher exact tests comparing forms across children and adults
### Results: comparing proportions

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</thead>
<tbody>
<tr>
<td>□ ◊</td>
<td>p = 0.001</td>
<td>(-1.95, +2.27)</td>
<td>p = 0.584</td>
<td></td>
</tr>
<tr>
<td>¬□ ¬◊</td>
<td>p = 0.013</td>
<td>(-1.99, +0.94)</td>
<td>p = 0.748</td>
<td></td>
</tr>
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Aggregate results for $\chi^2$ or Fisher exact tests comparing forms across children and adults

1. non-negated existentials are preferred over non-negated universals (French)
Results: comparing proportions

<table>
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<tr>
<th>comparing</th>
<th>French p-values</th>
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</thead>
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<td>□ ◊</td>
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Aggregate results for $\chi^2$ or Fisher exact tests comparing forms across children and adults

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3. negated existentials are preferred to non-negated forms (Spanish)
Results from corpus study by Dieuleveut et al.

<table>
<thead>
<tr>
<th></th>
<th>can</th>
<th>cannot</th>
<th>have to</th>
<th>not have to</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHI</td>
<td>8873</td>
<td>2617</td>
<td>350</td>
<td>7</td>
</tr>
<tr>
<td>ADU</td>
<td>1803</td>
<td>1906</td>
<td>2302</td>
<td>99</td>
</tr>
</tbody>
</table>

**Table:** Counts for English (12 child-mother pairs, age 2-3)

- Comparing child counts for pairs of forms, relative to their input:
  - *have to* vs. *not have to*: \( \chi^2 = 3.93; \ p = 0.0474; \) residuals: +0.34, -1.68 (lower child use of *not have to* relative to input)
  - *not have to* vs. *cannot*: \( \chi^2 = 53.94, \ p < 0.0001; \) residuals: -5.49, +4.6 (higher child use of *cannot*, even lower use of *not have to*, relative to input)
Discussion

- Evidence for a bias away from weak modal expressions:
  - acquisition of strong expressions before weak expressions
  - dispreference for weak negated universals (*don’t have to*) in French, relative to input
  - preference for negated over non-negated existentials in Spanish, relative to input

Table: Proportion of questions among non-negated existential utterances

- French: CHI 154/277 (55.60%), ADU 146/736 (19.84%)
- Spanish: CHI 5/51 (9.80%), ADU 83/337 (24.64%)

- These are often desire-satisfaction mechanisms, that don’t necessarily require reasoning about alternative world representations
Discussion

- Evidence for a bias away from weak modal expressions:
  - acquisition of strong expressions before weak expressions
  - dispreference for weak negated universals (*don’t have to*) in French, relative to input
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- Post-hoc results:

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<th></th>
<th>questions</th>
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<th>percentage</th>
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Table: Proportion of questions among non-negated existential utterances

- In French, kids use *pouvoir* in questions for requesting or permission-asking. Why not the same in Spanish? (maybe: imperatives are less rude and can be used for requesting)
- These are often desire-satisfaction mechanisms, that don’t necessarily require reasoning about alternative world representations
Discussion

- Possible explanations for this bias:
  - these particular children’s usage patterns (so they would express ¬□ if wanted)
Possible explanations for this bias:

- these particular children’s usage patterns (so they would express ¬□ if wanted)
- weak is more difficult to produce than strong
Discussion

Previous theoretical and experimental evidence for a cost for weak modals:

▶ Children have trouble with indeterminacy, i.e. entertaining multiple representations at once (Ackerman, 1981; Acredolo & Horobin, 1987; ¨Ozt¨ urk & Papafragou, 2015)

▶ Existential quantification involves entertaining multiple representations at once by generating alternatives (at least in the nominal domain: Kratzer & Shimoyama, 2002, a.o.)

▶ “you may do X” has the alternative “you may do not X” or “you may do Y”, for any contextually relevant Y

▶ Children are notoriously bad at generating alternatives themselves up until 5-6 years old, at least for deriving scalar implicatures (Barner & Bachrach, 2010; Chierchia et al., 2001; Huang & Snedeker, 2009; Noveck, 2001; Papafragou, 2006; Skordos & Papafragou, 2016, a.o.)
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Outline

1. Weak and strong modality

2. Experimental study: Processing weak and strong modality

3. Child corpus study: acquiring weak and strong functional modals

4. A look at the typology
The sparseness of weak functional modal forms

- The $\Diamond > \neg$ scope with functional modals and sentential negation is at most very rare
  - Iatridou and Zeijlstra (2010) make this observation
  - Among the 76 languages that De Haan (1997) describes, most have universal modals that scope above and below negation, but only one – Guyanese Creole – appears to have an existential modal scoping above sentential negation

- In Siona (M. Bruil, p.c, and from my own fieldwork), there appears to be only one functional modal, and it is a necessity modal. Its combination with negation is a prohibition
The sparseness of weak functional modal forms

- Rates of negated weak modals appear low, based on the adult data collected in the above corpus studies.
- \( \neg \) \( \bigcirc \) scope appears to be much less frequent than the other functional modal + sentential negation combinations.

<table>
<thead>
<tr>
<th>Language</th>
<th>out of all modals</th>
<th>out of negated modals</th>
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<tbody>
<tr>
<td>French</td>
<td>2.22%</td>
<td>13.08%</td>
</tr>
<tr>
<td>Spanish</td>
<td>0.88%</td>
<td>2.99%</td>
</tr>
<tr>
<td>English</td>
<td>1.62%</td>
<td>4.94%</td>
</tr>
</tbody>
</table>

**Table:** Frequency of \( \neg \) (<) \( \bigcirc \) from child directed speech.

- Note also that the rates of use of the weak \( \neg \) \( \bigcirc \) scope vary across these languages: could unnecessary modals be unnecessary?
A hypothesis for this sparseness

- Children are known to drive language change: could their bias away from weak modals affect the inventory and behavior of functional modals?
- e.g. there may be expressions with too high processing costs to be learnable
A hypothesis for the typological gap

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- **Base syntactic order of root modals and negation:**
  
  Neg > Modal
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- Base syntactic order of root modals and negation:  
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A hypothesis for the typological gap

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- Base syntactic order of root modals and negation:
  
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  - Neg $>$ must (weak) harder than must $>$ Neg (strong)
  
  → derived scopal configuration is possible
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- Hypothesis: Modal > Neg can be derived only when the resulting meaning is easier to process than that of the base order
  - Neg > must (weak) harder than must > Neg (strong) → derived scopal configuration is possible
  - Neg > can (strong) easier than can > Neg (weak) → derived scopal configuration is not possible
Conclusion

There are converging sources of evidence for a higher processing cost for weak modal expressions relative to strong ones:

- Direct measures:
  - reaction times in TVJT (for negated modals)
  - accuracy rates in TVJT (for negated modals)
  - eye movements in agreement/disagreement task (for non-negated modals) (Huette et al., 2010)

- As consequences of this processing cost:
  - later start in production (for all weak vs strong modals)
  - lower rates of negated weak modals at ages 2-4

- This high processing cost for weak modals may be a source for their typological sparseness
Thank you!


