The learnability of a novel cue to prediction: An artificial language learning study of filler-gap dependencies

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Psycholinguistics in Iceland – Parsing & Prediction
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Cues to Structural Prediction

• Granularity of prediction can vary…
  • Cue can trigger a **fine-grained** structural prediction
    • e.g., *either* predicts *or* at a particular structural position (Staub & Clifton 2006; Harris & Rich yesterday)

• Cue can trigger a **course-grained** structural prediction
  • e.g., a *wh*-word predicts an upcoming gap but provides no information about its structural position
Filler-Gap Dependencies

- **Filler** – fronted element (*wh*-word)
- **Gap** – filler’s thematic position

**What** did Julie paint **the door with** __ ?

- **Active gap filling:** Adult parser makes a direct object gap prediction upon processing the filler
  - Potentially ‘reckless’ strategy – interpretation before bottom-up evidence for gap in argument structure
    - Prediction can be incorrect → leads to revision

(e.g., Stowe 1986; Frazier 1987; Traxler & Pickering 1996; Omaki 2010)
Cues to Gap Positions

• Fillers are **course-grained** cues
  • Indicate the presence of a gap later in the sentence
  • No details about the gap position

• Cue to the structural position of the gap would be **fine-grained**
  • *wh-agreement marker* → marker on the verb that indicates the gap position
Chamorro

- Austronesian language spoken in Mariana Islands
Chamorro

• Austronesian language spoken in Mariana Islands

• VSOX word order

• Optional *wh*-agreement → object gaps

Ha'fa na magågu un laksi / **linaksem-mu** gi paingi?
what? clothes AGR sew / WH[OBJ].sew-AGR LOC last.night

‘Which clothes did you sew __ last night?’

(Wagers et al. 2015)
Main Questions

1) Can English-speaking adults learn a cue that is informative about the gap position but optional (i.e., wh-agreement)?
   • What do they learn about this cue?

2) Can adults use this newly learned cue in their real time processing of sentences? If so, how do they use it?
Roadmap

• Artificial language learning paradigm
  • Description of Artificial Chamorro (AC)

• Experiment: Optional agreement marker
  • Offline tests – Acceptability judgment, production
  • Online test – Visual world eye tracking

• Briefly – Experiment 2: Obligatory agreement marker
Artificial Language Learning Paradigm

• Constructed language
  • Control over lexicon
  • Controls for participant’s prior knowledge / experience

• Pseudo-artificial language
  • English content words (nouns & verbs)

(from Clothier et al. 2017)
Artificial Language Learning Paradigm

Learning Phase

20 Learning Trials
(Declaratives; Yes-No Questions)

4 PVT Quiz Trials

30 Learning Trials
(PO Questions; Marked & Unmarked DO Questions)

8 PVT Quiz Trials

30 Learning Trials
(PO Questions; Marked & Unmarked DO Questions)

8 PVT Quiz Trials

Test Phase

Online Comprehension:
Visual World Eyetracking
(20 Trials)

Offline Comprehension:
Acceptability Judgement
(38 Trials)

Production
(20 Trials)
Artificial Chamorro

- English nouns & verbs
- VSOX word order (same as Chamorro)

- 3 novel function words / morphemes:
  - zub = question marker (equivalent to what)
  - po = preposition
  - ka- = optional direct object gap marker
Example AC Sentences

Declaratives
drawing David cat po crayon.
‘David is drawing the cat with the crayon.’

Yes-No Questions
drawing David cat po crayon?
‘Is David drawing the cat with the crayon?’

Prepositional Object Questions
zub drawing David cat po ___?
‘What is David drawing the cat with ___?’
Example AC Sentences

Direct Object Questions – Unmarked

*zub* drawing David __ *po* crayon?
‘What is David drawing with the crayon?’

Direct Object Questions – Marked

*zub ka-*drawing David __ *po* crayon?
‘What is David drawing with the crayon?’
Learning Phase

136 native English speakers

20 Learning Trials
(Declaratives; Yes-No Questions)

4 PVT Quiz Trials

30 Learning Trials
(PO Questions; Marked & Unmarked DO Questions)

8 PVT Quiz Trials

30 Learning Trials
(PO Questions; Marked & Unmarked DO Questions)

8 PVT Quiz Trials
Example Learning Trial

zub ka-drawing David po crayon?
Test Phase

Online Comprehension: Visual World Eyetracking (20 Trials)

Offline Comprehension: Acceptability Judgement (38 Trials)

Production (20 Trials)
Offline Comprehension: Acceptability Judgment

Zub ka-roasting Mary po grill?

Do you think this is a well-worded sentence in this new language?

F = YES  J = NO
Acceptability Judgment Results

**Grammatical Sentences**

- 86.83% accurate at accepting grammatical sentences
- Presence of *wh*-agreement marker does not affect accuracy
  - i.e., no difference in accuracy on grammatical marked vs. unmarked DO questions

**Ungrammatical Sentences**
Acceptability Judgment Results

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**Ungrammatical Sentences**

![Bar chart showing % Correct Rejection for Inclusion 'ka' and Wrong Position 'ka' reasons]
Production Test

ka
po
zub
air pump
beach ball
david
inflating

Type your sentence here:
More successful at producing grammatical DO vs. PO questions
Production Results

Specificity of knowledge = \% incorrect usage in PO questions

Willingness to use marker = \% correct usage in DO questions

N = 131
Production Results

- Willingness to use marker = % correct usage in DO questions
- Specificity of knowledge = % incorrect usage in PO questions
- Generalization of *wh*-agreement marker usage despite 50:50 input
  - Usually only seen with more skewed input (e.g., 75:25)

(N = 131)

Production Results: Clustering

- Difference scores (% correct ‘ka’ - % incorrect ‘ka’)
  - Indicates preference for using wh-agreement marker in grammatical contexts

- Cluster using mclust
  - Based on Gaussian mixture model
  - Best fit = univariate, equal variance (BIC = -129.09)

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Production Results

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Production Results

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Production Rates

\% Incorrect 'ka' (PO Questions)

\% Correct 'ka' (DO Questions)

N = 131
Main Questions

1) Can adults learn a cue that is informative about the gap position but optional?
   • What do they learn about this cue?
Main Questions

1) Can adults learn a cue that is informative about the gap position but optional?

Yes!
(at least some people)

• What do they learn about this cue?
  • Knowledge somewhat unstable → poor at rejecting incorrect uses & variable production rates
  • Production rates not the result of pattern matching
Main Questions

1) Can adults learn a cue that is informative about the gap position but optional?

2) Can adults use this newly learned cue in their real time processing of sentences? If so, how do they use it?
Processing *wh*-Agreement

- Chamorro speakers treat both the presence & absence of marker as informative.

(Wagers et al. 2015)
Chamorro speakers treat both the presence & absence of marker as informative.

Active gap filling when *wh*-agreement marker present.

No active gap filling when marker is absent!

(Wagers et al. 2015)
Active Gap Filling in the Visual World

• Question-after-story design

• Question either contains a filler-gap dependency (i.e., *wh*-question) or does not (i.e., *yes-no* question)
  • Differences in eye movement patterns reflect different processing

(e.g., Atkinson et al. 2018; Sussman & Sedivy 2003; Omaki 2010)
Can you tell me…

- what Emily was **eating** the cake with __?
- if Emily was **eating** the cake with the fork?
Eye Movement Predictions

- Can you tell me…
  - what Emily was eating…
  - if Emily was eating…
Eye Movement Predictions

- Can you tell me…
  what Emily was *eating*…
  if Emily was *eating*…

![Graph showing proportion of fixations over time after verb onset. Verb (e.g., eating).](image)
Eye Movement Predictions

- Can you tell me…
  - what Emily was eating…
  - if Emily was eating…

![Graph showing proportion of fixations over time after verb onset with lines for Wh-Questions and Yes-No Questions.](image)
Verb region

- Greater increase in fixations on the target object during *wh*-questions

(Atkinson et al. 2018)
Online Comprehension: Visual World Eye Tracking

• Question-after-story design
  • Verbs displayed before animated story
  • 4 AC question types → marked & unmarked DO, PO, yes-no

• Subset of 103 participants had usable data
VWP Results

Target Patient Fixations

Proportion of Fixations vs. Time After Verb Onset (ms)

- DO Questions (Marked)
- DO Questions (Unmarked)
- PO Questions
- Yes-No Questions
### VWP Results: Know & Use Marker

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Target Patient Fixations (Class 5)
Main Questions

2) Can adults use this newly learned cue in their real time processing of sentences? If so, how do they use it?

Maybe?

• Some evidence eye tracking results vary based on knowledge & use of *wh*-agreement marker
Briefly: Obligatory Marker

- Same experiment but DO gaps obligatorily marked

- Why?
  - Participants should be more likely to learn the marker
  - More usable eye tracking data
  - Cross experiment comparison as well as comparison to Chamorro processing data
Obligatory : Acceptability Judgment

**Grammatical Sentences**

- 80.1% ($SE = 3.28\%)$ accurate at accepting grammatical sentences

**Ungrammatical Sentences**

![Bar chart showing the percentage of correct rejections for grammatical and ungrammatical sentences. The chart includes error bars and asterisk symbols indicating significance levels. The chart is divided into three categories: Inclusion 'ka', Missing 'ka', and Wrong Position 'ka'. The wrong position 'ka' category shows a significantly higher percentage of correct rejections marked with '***'.]
Obligatory: Production

- If participant produced marker in DO questions, they did so 100% of the time (22 of 32)
- 1 participant produced marker 75% of the time in PO questions
  - 3 participants produced it in 50% of their PO questions
Obligatory: VWP

**PO Questions** → transfer active gap filling

**DO Questions** → no prediction
- Recognition not English?
Obligatory: VWP

**DO Questions** → Direct object prediction

- Knowledge about function of marker becomes active?
Summary

• English-speakers can learn a novel fine-grained cue to structural prediction with limited input, even when that cue is optional
  • They do not just match the input in the use of the optional marker
  • Knowledge is not more stable when the marker is obligatory

• Immediate processing effects seen for those that learned the marker confidently enough to use it in their productions
  • Suggests that the presence of cue to a fine-grained prediction overrides predictions based on course-grained cues
Thank you!

• Thanks to…
  • Research assistants: Christiana Vargas & Subin Han
  • Akira Omaki, Tal Linzen, & Julie Boland
  • Psycholinguistics group at the University of Michigan

Contact: eeatkins@umich.edu  Slides available at http://emilyeatkinson.net