The sensitive period for associative learning of non-adjacent dependencies: ERP evidence from 24-month-olds

Mariella Paul^{1,2,*}, Claudia Männel¹, Jutta L. Mueller³, Anne van der Kant⁴, Isabell Wartenburger⁴, Barbara Höhle⁴ & Angela D. Friederici¹



¹Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany, ² Berlin School of Mind and Brain, ³ Osnabrück University, ⁴ University of Potsdam *paulm@cbs.mpg.de



Introduction

- Children are able to learn the grammatical rules of their native language with remarkable ease during their first years of life. Infants as young as 4 months are able to learn non-adjacent dependencies (NAD) associatively by merely listening to correct examples as evidenced by event-related potentials (ERPs) [1].
- While infants show associative learning mechanisms, adults exhibit more controlled learning

Methods

Participants

34 24-month-olds (16 female, mean age: 24.90 months, SD 0.90)
 35 24-month-olds (16 female, mean age: 24.78, SD 0.82)

Stimuli

- Italian sentences with an NAD between auxiliary and verb suffix (Figure 2A)
- Tone sequences with one tone replacing each syllable of the linguistic stimuli, preserving NADs (Figure 3A)

| | 2 | 🔍 Linguistic stimuli: Italian sentences | | | | | | | |
|--|-------------|--|--|--|--|--|--|--|--|
| | | Auxiliary Frame | Modal Frame | | | | | | |
| | (A) correct | sta x-ando | puo x-are | | | | | | |
| | | La sorella sta candando (The sister is singing) | La sorella <mark>puo</mark> cant <mark>are</mark> (The sister can sing) | | | | | | |
| | orrect | *sta x-are | *puo x-ando | | | | | | |
| | 3) incc | *La sorella <mark>sta</mark> cant <mark>are</mark> (*The sister is singing) | *La sorella puo cantando (*The sister can singing) | | | | | | |

mechanisms and are only able to learn NADs under active task conditions [1,2].

Research Questions for the ERP experiments (Figure 1)

Developmental trajectory of NAD learning

 At which developmental time point does the change from associative learning observed in infants to more controlled learning of NADS reported for adults occur?

Domain-generality/domain-specifity of NAD learning

 Does NAD learning in the non-linguistic domain have the same developmental trajectory as in the linguistic domain?

 12
 Study overview

 12
 18
 24
 36
 adult

 12
 18
 24
 36
 adult

 12
 18
 24
 36
 adult

Figure 1: Overview of experiments for the linguistic (\bigcirc) and the non-linguistc (\int) domain

Procedure

4

- *Passive-listening learning-test paradigm* (Figure 4):
- Alternating learning and test phases. Learning phases contain only correct items with NADs (Figure 2A, 3A), while test phases contain 50% correct and 50% incorrect items with NAD violations (Figure 2B, 3B).
- SETK-2 [3], eyetracking (behavioral tests of cognitive and language development)

EEG recording and analysis

- Recording: Fz, F3/4, F7/8, Cz, C3/4 CP5/6, T7/8, Pz, P3/4, P7/8, O1/2; online reference: Cz
- Preprocessing: offline reference: linked mastoids, band-pass filter: 0.3-30 Hz, trial length: -400 ms to 1500 ms relative to suffix onset, semi-automatic artifact rejection and artifact correction (ICA)
- Analysis: cluster-based permutation test [4]



Non-linguistic stimuli: Tone sequences





| Test 0 | Learning 1 | Test 1 | Learning 2 | Test 2 | Learning 3 | Test 3 | Learning 4 | Test 4 |
|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| ~1.3 min | ~ 3.3 min | ~1.3 min |
| 8 C + 8 IC | 64 C | 8 C + 8 IC | 64 C | 8 C + 8 IC | 64 C | 8 C + 8 IC | 64 C | 8 C + 8 IC |

Figure 4: Participants listened to alternating learning and test phases. C = correct, IC = incorrect.



Discussion and next steps

3

Developmental trajectory of NAD learning

- Our data suggest that 24-month-old children are unable to detect violations of NADs in our linguistic and non-linguistic stimuli under passive listening conditions.
- 24-month-old children thus show the pattern observed in adults, but not 4-month-old children [1,2].
- The developmental change from associative to more controlled learning seems to take place before 24 months of age.

Domain-generality/domain-specifity of NAD learning

- Our data show that 24-month-olds did not detect violations of NAD in either domain, revealing no domain-specific differences.
- Additional data from younger and older children will reveal whether NAD learning in the linguistic and the non-linguistic domain have the same developmental trajectory.

Next steps:

Investigating NAD learning in other age groups: Finishing data collection from 36-month-olds, data collection from 12- and 18-month-olds



→ No difference in response to correct and incorrect stimuli in the linguistic or non-linguistic domain Additional analyses (not shown) did not reveal significant differences:

- Median split based on SETK-2 scores
- Difference of first two vs. second two test phases

- Relating ERP data to measures of cognitive and language development
- Examining learning mechanisms: Analysis of the ERPs of learning phases



References

[1] Friederici, AD, Mueller, JL, and Oberecker, R (2011). Precursors to natural grammar learning: preliminary evidence from 4-month-olds infants". *PLoS One* 6.3, e17920.

- [2] Mueller, Jutta L, Oberecker, Regine, and Friederici, Angela D (2009). Syntactic learning by mere exposure An ERP study in adult learners. *BMC neuroscience* 10: 89.
- [3] Grimm, Hannelore, Aktas, Maren, and Frevert, Sabine (2000). Sprachentwicklungstest für zweijährige Kinder (SETK-2). *Göttingen: Hogrefe*.

[4] Maris, E and Oostenveld, R (2007). "Nonparametric statistical testing of EEG- and MEG-data". *Journal of neuroscience methods* 164.1, pp. 177–190.