Cross-situational learning of sign-like gestures from infancy to adulthood

An exploration of behavioral, eye-tracking, and ERP data

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Acknowledgments

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Tom Fritzsche, Lara Hamburger, Felix Dobrowohl, Jan Ries & BabyLAB team (University of Potsdam)
Fiorinda Pino (Italian Sign Language support)

OVERVIEW

Talk overview

This talk presents the adaptation of a word learning paradigm to gesture learning

a new methodological approach to studying gesture acquisition

talk structure:

3 experiments together

*background → **focus on methods** → overall results→ methodological takeaways*

Background

Theoretical premises

1. Language is multimodal
2. Gestures co-evolve and co-exist with speech in daily communication
3. Different type of gestures (deictic, symbolic, etc...)

Sign-like gestures

Context-independent (symbolic) gestures
used as referential symbols within spoken communicative interactions

Sign-like gestures

Sign-like gestures
=
resemble signs in their form but are not part of a sign language system

FORM → Resemble SL signs	USE → Not part of a sign language system
• Usually take from SL vocabulary • Can be invented (pseudosigns, following sign language-phonotactic constraints) • Arbitrary or iconic	• Produced in isolation • No morphosyntactic integration • Embedded in spoken interactions

Sign-like gestures in applied contexts

Clinical-Audiological setting
Language intervention
with bimodal method for deaf/HH children
Visual support

Parent-Child Activities
Baby signing
with hearing children
Visual salience

forms of bimodal labelling

~~bilingualism~~

Note: monolingual participants naïve to sign language

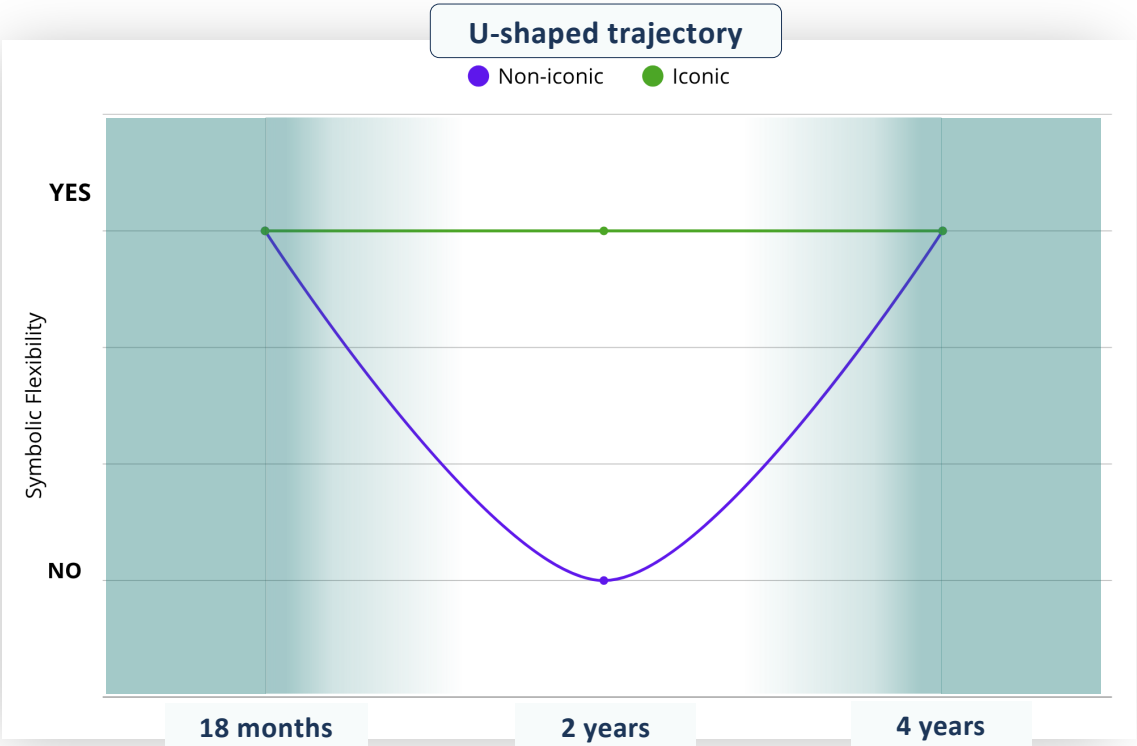
→ Do children in these contexts recognize gestures as meaningful symbols?

Symbolic flexibility

Gestures can be perceived as referential symbols

MODERATING VARIABLES

- iconic vs. non-iconic
- training type
- age (**symbolic flexibility**)
  - gestures accepted as labels until ~1.5 year after ~4 years of age

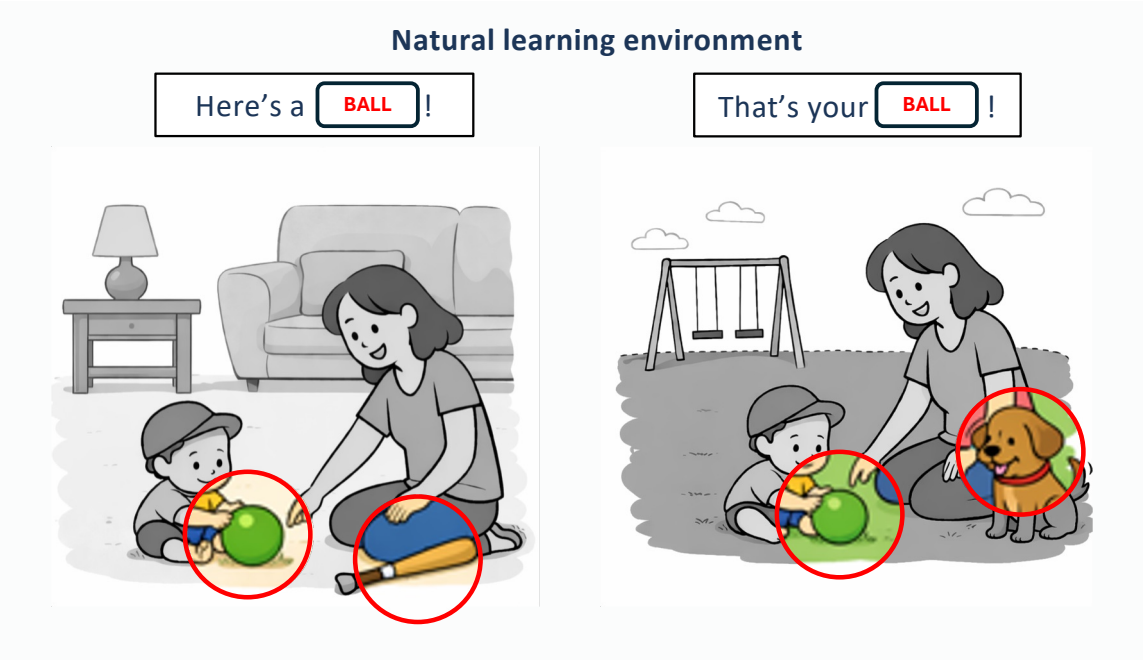


→ What mechanisms **drive the perception of gestural symbols as referential labels** across development?

Capirci & Volterra, 2008; Namy et al., 2004, Namy & Waxman, 1998; Puccini & Lizkowski, 2012

Cross-situational learning

Cross-situational learning assumes that word-meaning mappings are resolved by
tracking the co-occurrences between labels and referents across different learning instances.

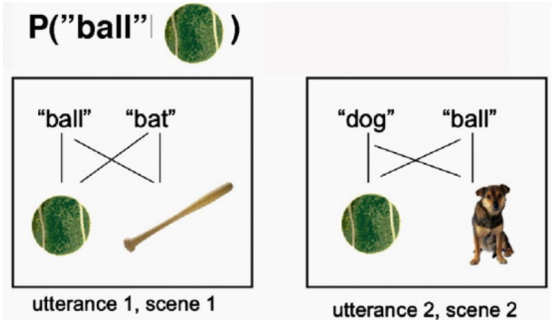


CSL in the lab

This mechanism can be simulated in the lab

Key characteristics of CSL experiments:

- Ambiguous trials
- Multiple word + multiple referents
- No indication of the correct mapping
- No instructions on the task
- No feedback during the task



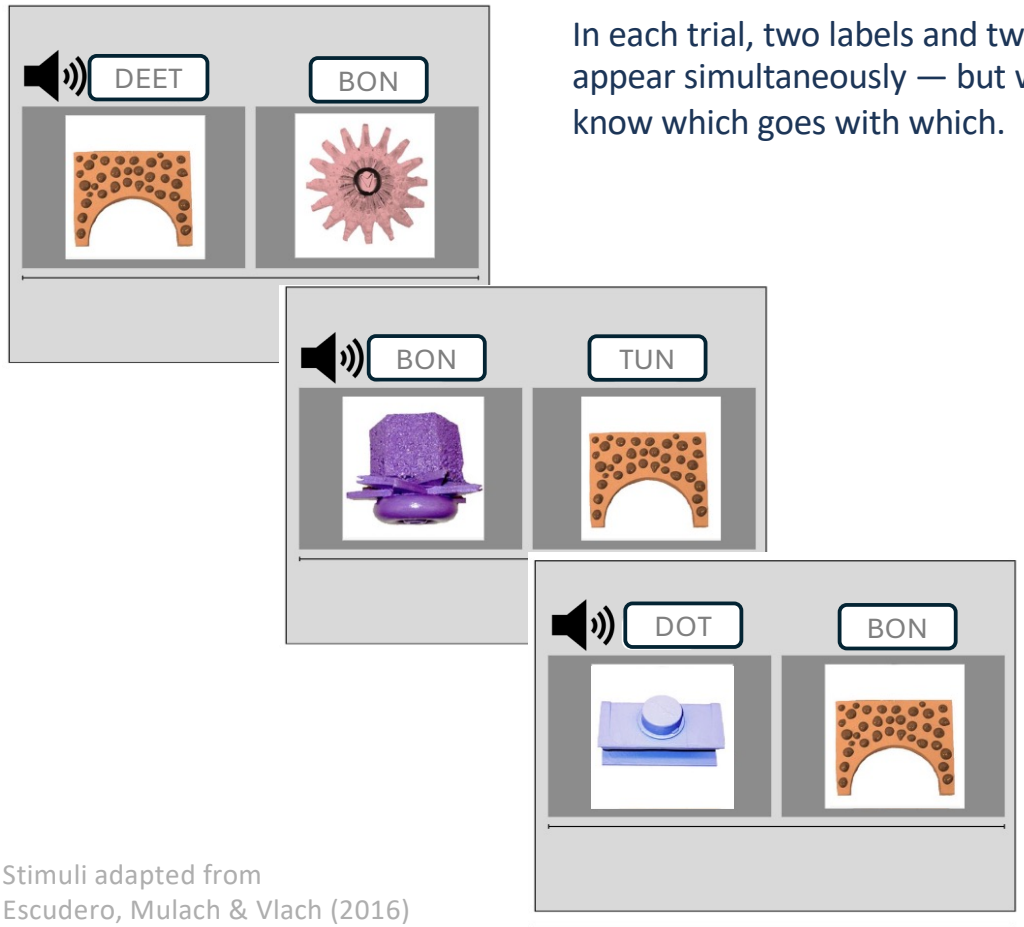
(Smith & Yu, 2008)

CSL in the lab

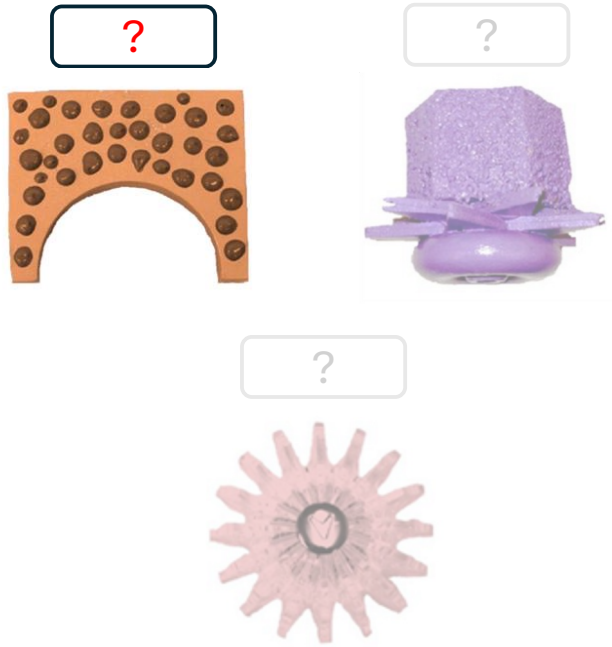
BON DEET TUN

Stimuli adapted from
Escudero, Mulach & Vlach (2016)

CSL in the lab

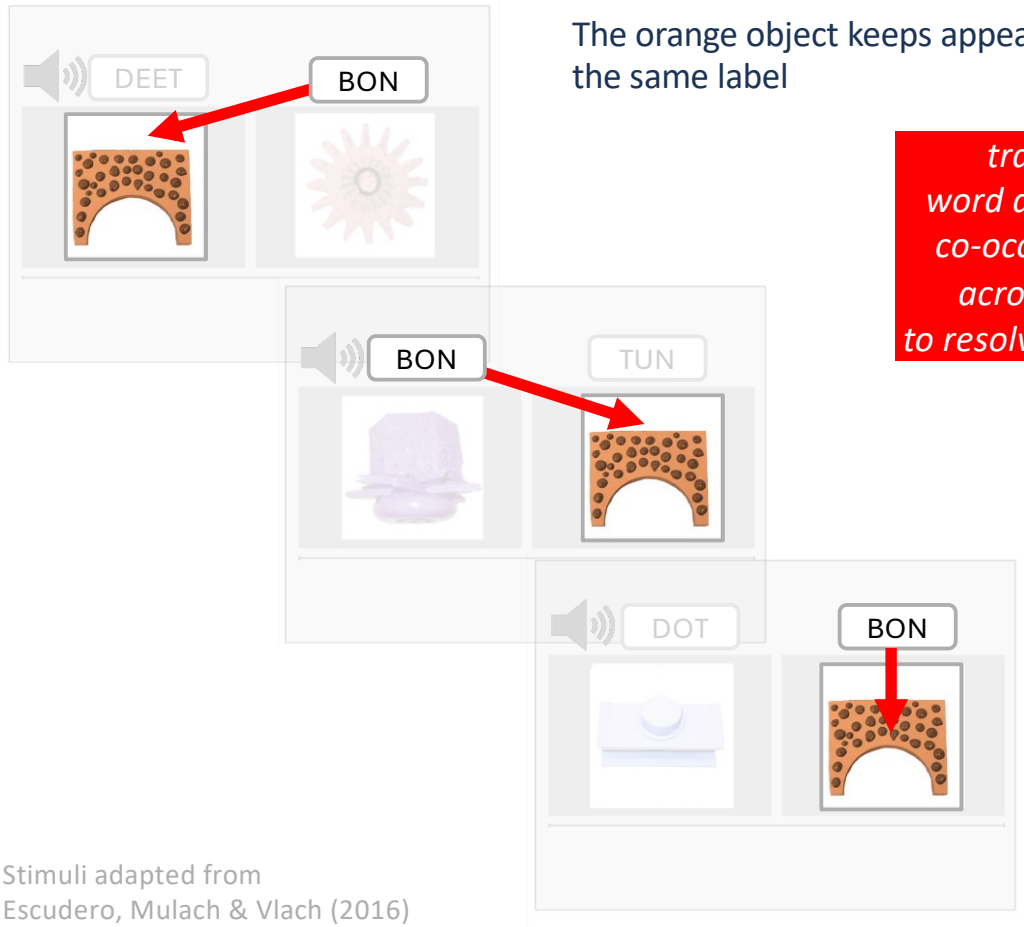


In each trial, two labels and two objects appear simultaneously — but we don't know which goes with which.



Stimuli adapted from
Escudero, Mulach & Vlach (2016)

CSL in the lab



The orange object keeps appearing with the same label

tracking word and object co-occurrences across trials to resolve mapping

Stimuli adapted from
Escudero, Mulach & Vlach (2016)

Research questions & rationale

QUESTIONS	Q1	Can gestures (bimodal labels) be learned through statistical learning across development?
	Q2	Can gestures (bimodal labels) acquire referential meaning through statistical learning?
METHODS		Cross-situational learning (CSL): theoretically grounded + pseudo-naturalistic framework
RATIONALE	1	Gestures can function as referential symbols (e.g., Capirci & Volterra, 2008)
	2	Gestures can coexist with words within the same communicative interaction (e.g., Emmorey, 2016)
	3	Cross-situational statistics support word-meaning learning (e.g., Roembke et al., 2013)
	4	**Therefore, CSL mechanisms may also inform gesture learning**
AIM		• Develop a method to study language beyond the auditory modality • Support the ecological validity of bimodal labels

Methods

METHODS

Study structure

Experiment 1

proof-of-concept

Adults + Children 8–11 y.o.

Behavioral + ERPs

Colombani et al. (2025) Lang. Cog. & Neurosc.

Experiment 2

toddler adaptation

Toddlers 3–4 y.o.

Eye-tracking (preferential looking)

Colombani et al. (under review) Cog. Dev.

Experiment 3

infant adaptation

Infants 14–16 m.o.

Eye-tracking (preferential looking)

Data collection ongoing

METHODS

Stimuli rationale

- **Pseudosigns** – avoid boundaries with specific SL vocabulary
- **Follow sign language (LIS) phonotactics** – ensure linguistic salience and significance
- **No iconic relationship with their intended meaning** – avoid iconicity support (confound)

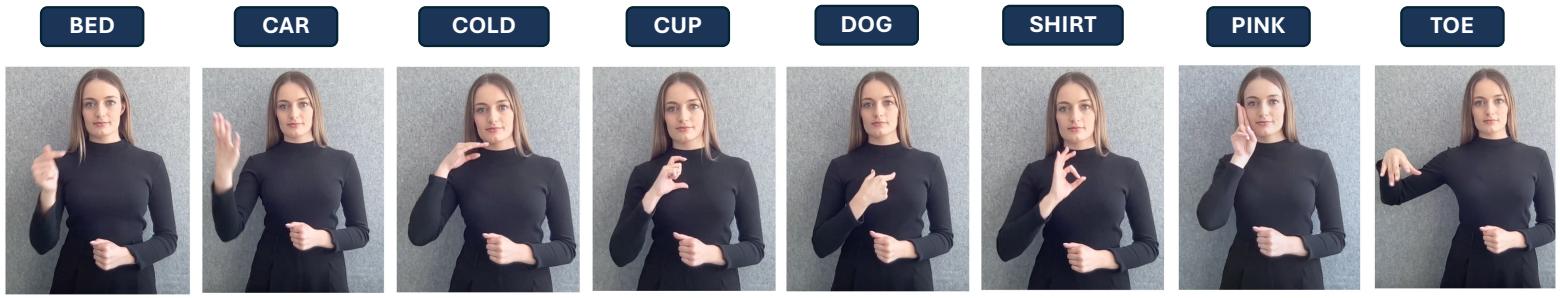
EXPERIMENT 1

Stimuli – Children (8–11 y.o.) and adults

8 items

WORD → GESTURE → MEANING

auditory label — visual label



! 8 semantic categories

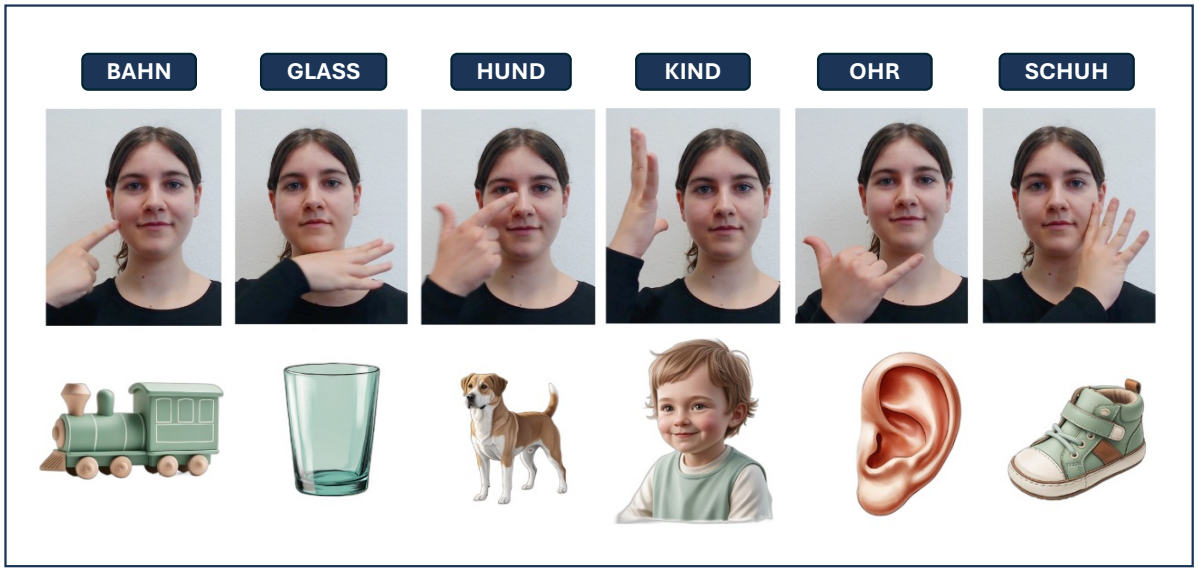
EXPERIMENT 2

Stimuli – Toddlers (3–4 y.o.)

6 items

WORD → GESTURE → OBJECT

auditory label | visual label | visual referent

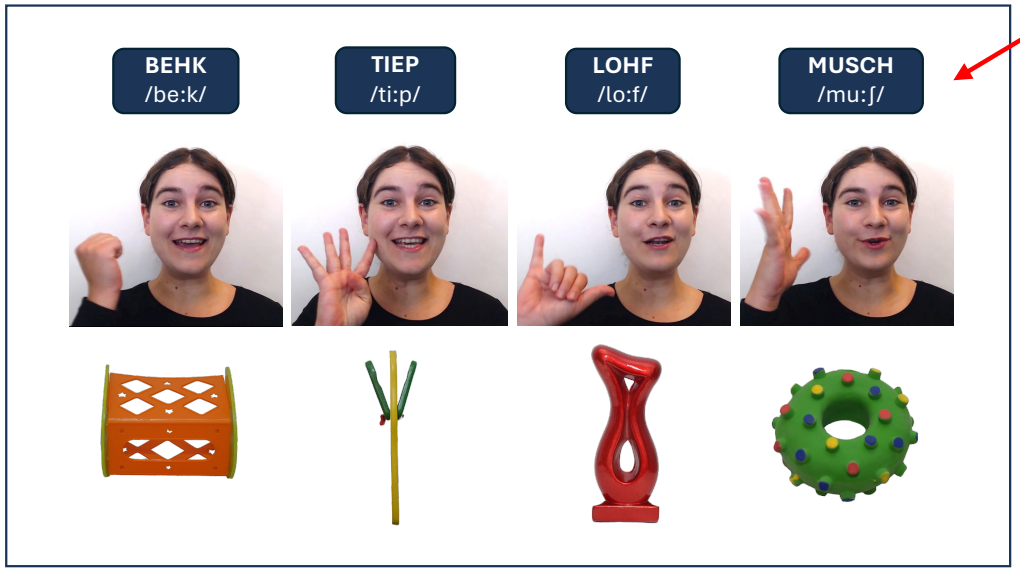


EXPERIMENT 3

Stimuli– Infants (14–16 m.o.)

4 bimodal items

pseudowords



Experimental paradigm

Experimental paradigm

Experiment 1

proof-of-concept

Adults + Children 8–11 y.o.

Behavioral + ERPs

1. Learning (CSL)
2. **Word → gesture**
3. **Gesture → meaning**

Experiment 2

toddler adaptation

Toddlers 3–4 y.o.

Eye-tracking (preferential looking)

0. Training (CSL)
1. Learning (CSL)
2. **Word → gesture**
3. **Gesture → meaning**
4. Control block

Experiment 3

infant adaptation

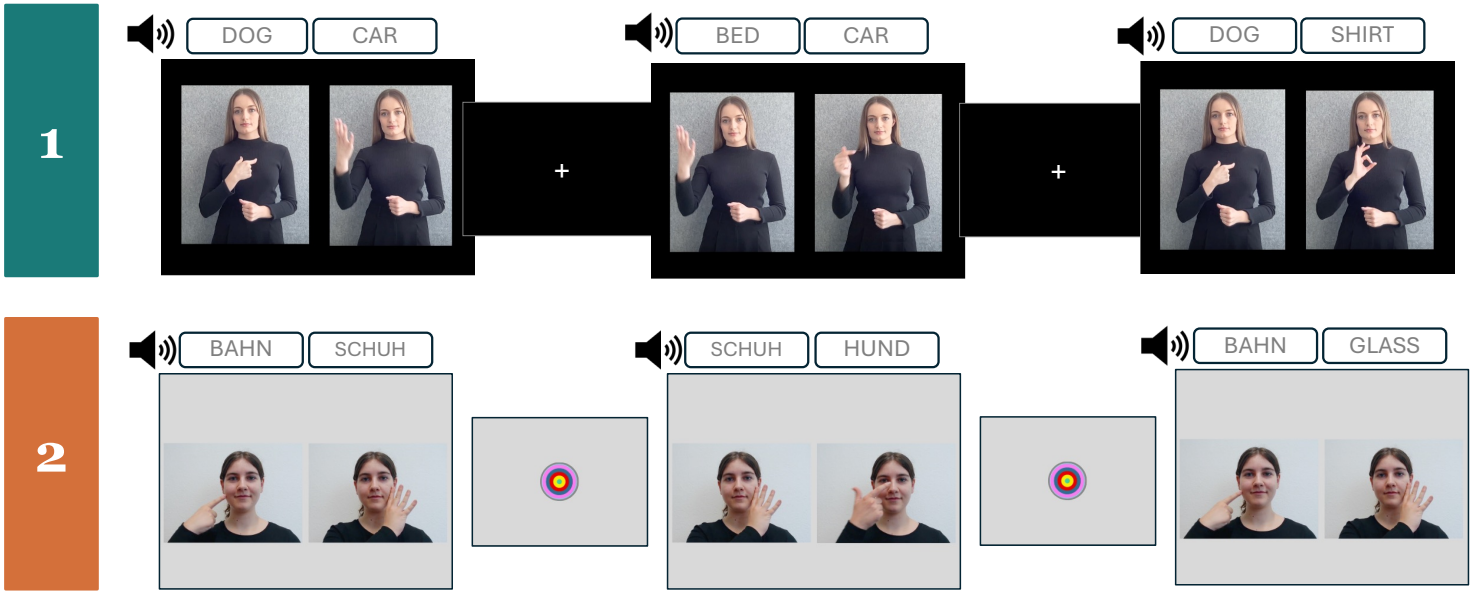
Infants 14–16 m.o.

Eye-tracking (preferential looking)

0. Control + training block
1. Learning (CSL, bimodal)
2. **Gesture → object**
3. **Word → object**

EXPERIMENTAL PARADIGM

Learning phase (CSL)

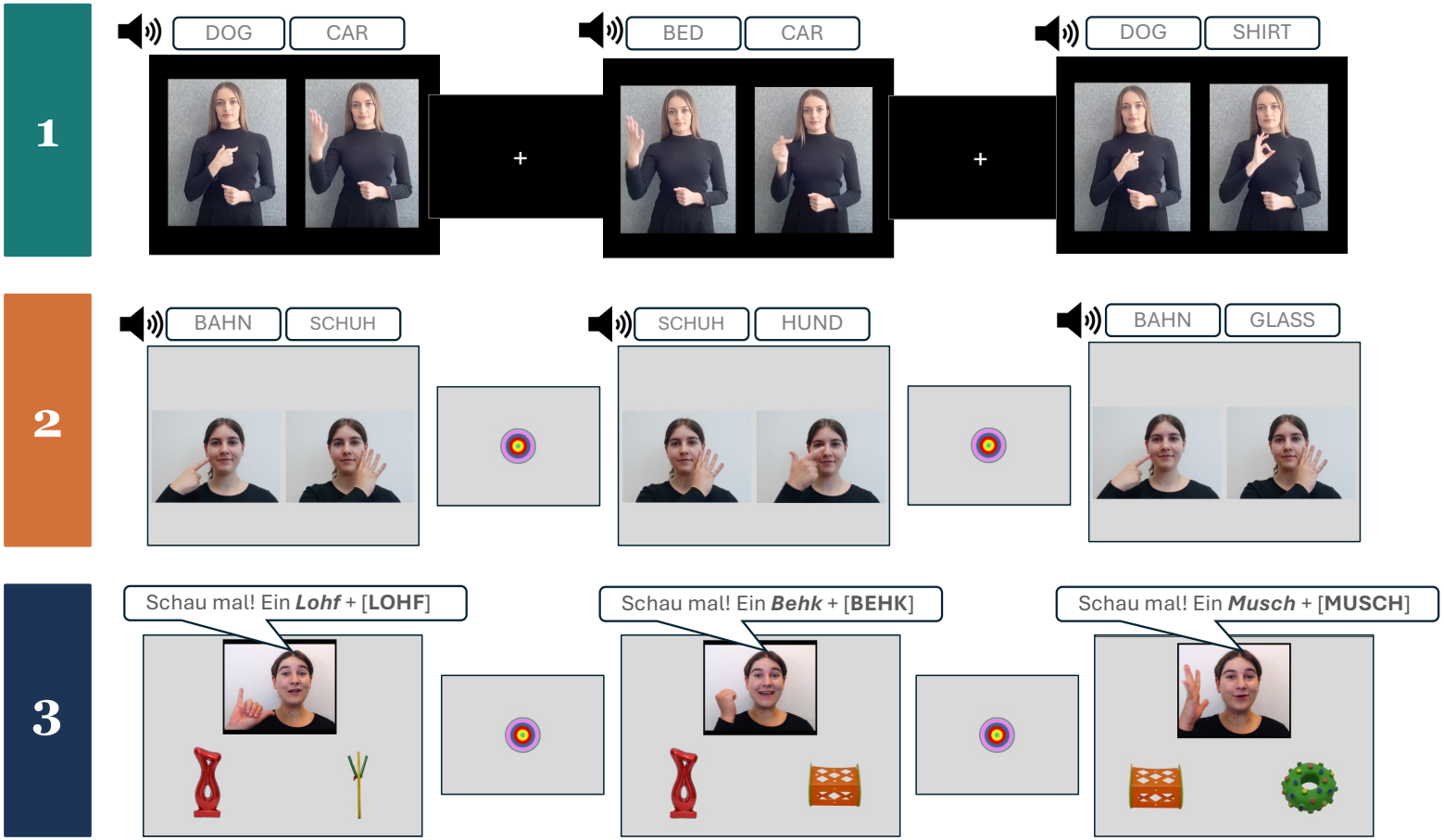


words = audio from speakers

gestures = videos playing simultaneously

EXPERIMENTAL PARADIGM

Learning phase (CSL)

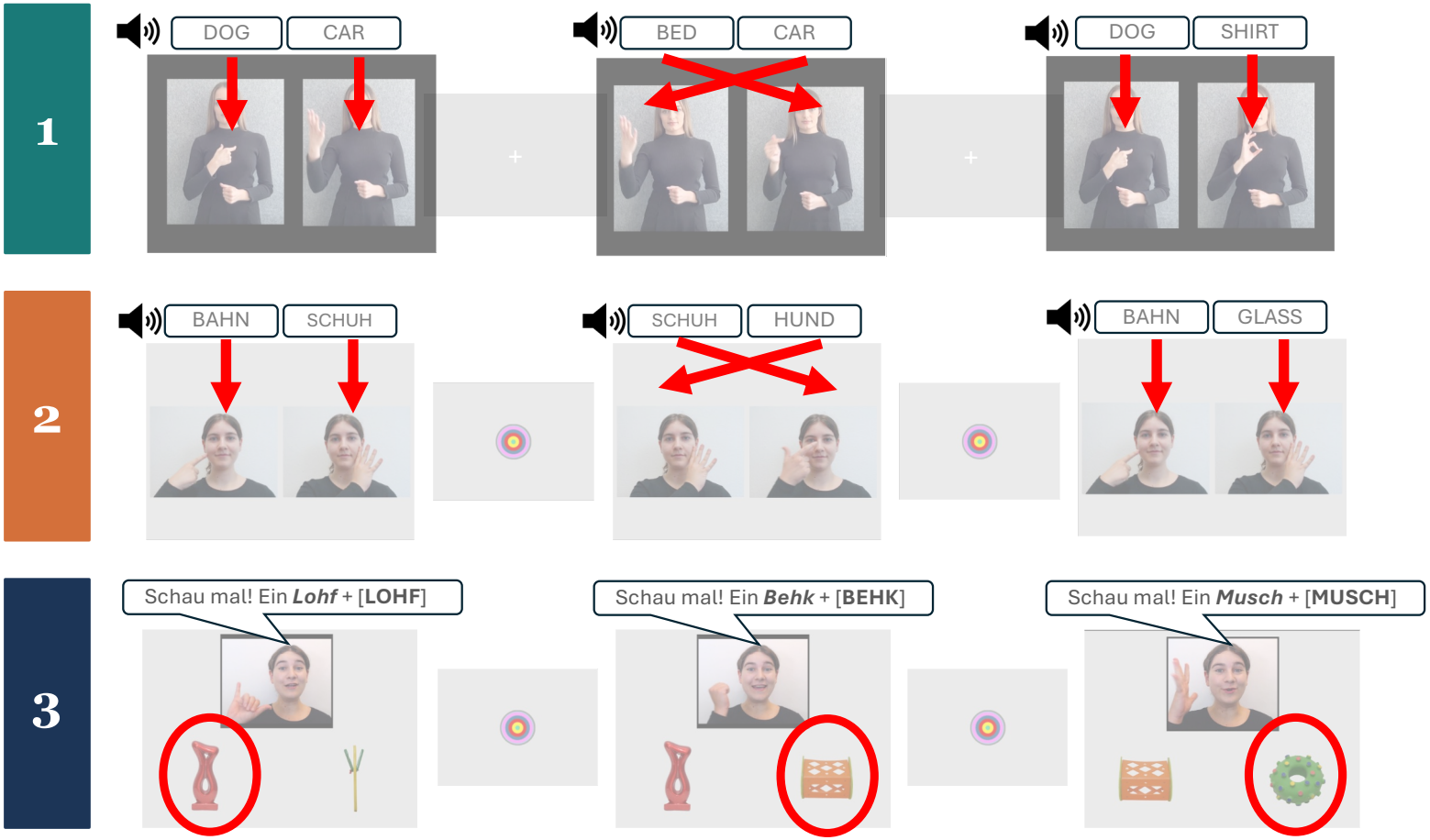


audio directly from videos

bimodal label = gesture+word

EXPERIMENTAL PARADIGM

Learning phase



correct associations by tracking co- occurrences

Experimental paradigm

Experiment 1

proof-of-concept

Adults + Children 8–11 y.o.

Behavioral + ERPs

1. Learning (CSL)
2. **Word → gesture**
3. **Gesture → meaning**

Experiment 2

toddler adaptation

Toddlers 3–4 y.o.

Eye-tracking (preferential looking)

0. Training (CSL)
1. Learning (CSL)
2. **Word → gesture**
3. **Gesture → meaning**
4. Control block

Experiment 3

infant adaptation

Infants 14–16 m.o.

Eye-tracking (preferential looking)

0. Control + training block
1. Learning (CSL, bimodal)
2. **Gesture → object**
3. **Word → object**

EXPERIMENTAL PARADIGM

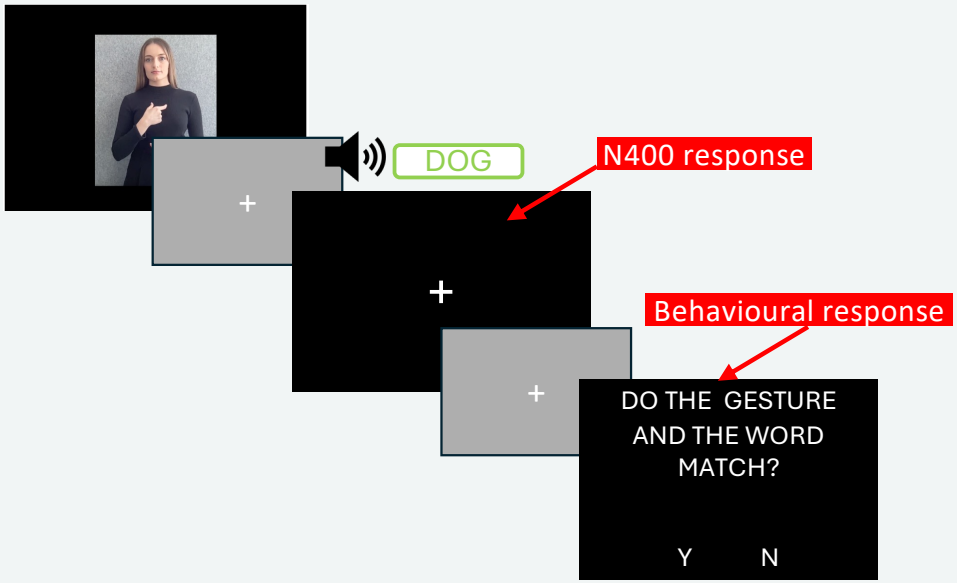
Testing blocks

Experiment 1	Experiment 2	Experiment 3
proof-of-concept	*toddler adaptation*	*infant adaptation*
Adults + Children 8–11 y.o.	Toddlers 3–4 y.o.	Infants 14–16 m.o.
Behavioral + ERPs		*preferential looking)*
1 Learning (CSL)		+ training block
2 Recognition: word →		(CSL, bimodal)
3 Categorization: gesture → meaning	2 Association: word → gesture	2 Gesture mapping
	3 Mapping: gesture → object	3 Word mapping
	4 Control block	

EXPERIMENTAL PARADIGM

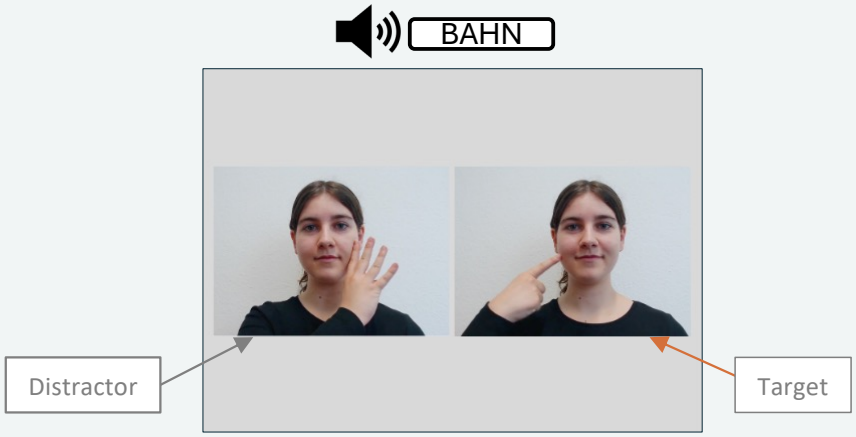
Test gesture-word association

Experiment 1



Gesture → word
(correct / incorrect match)

Experiment 2

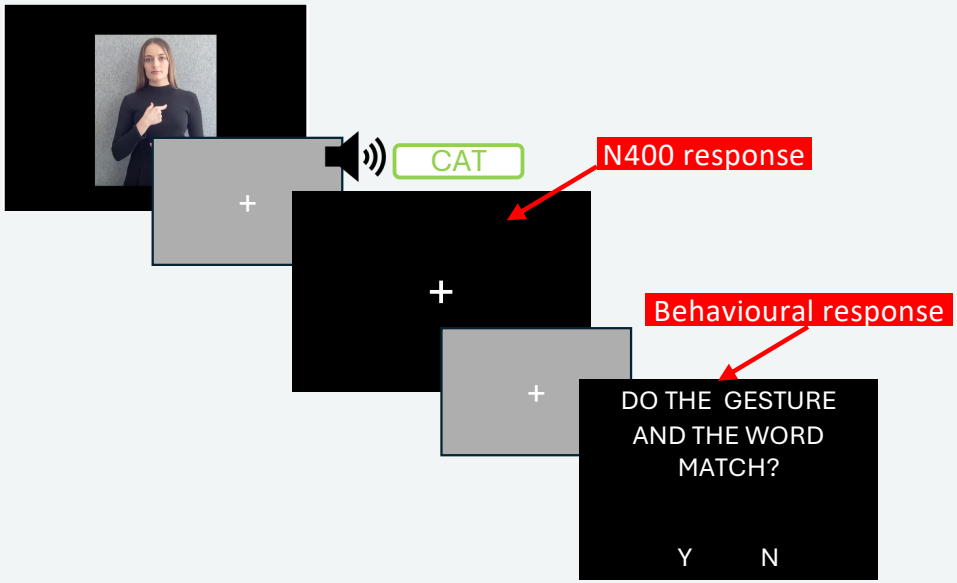


Preference for target vs. distractor (PLT)

EXPERIMENTAL PARADIGM

Test gesture-meaning association

Experiment 1



Gesture →
semantic category (same / different)

Experiment 2

Preference for target vs. distractor (PLT)

These tasks require meaning assignment, not just form recognition

EXPERIMENTAL PARADIGM

Bimodal mapping

Spoken carrier sentence

"Where is the... ?"

Test GESTURE-to-referent mapping

Test WORD-to-referent mapping

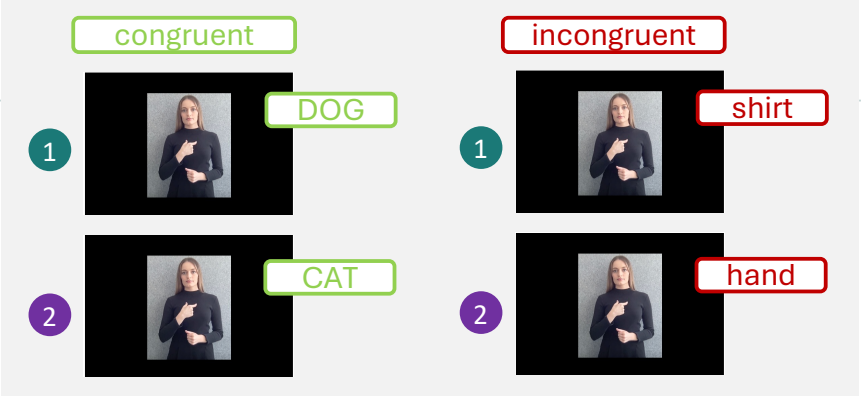
Preference for target vs. distractor (PLT)

Results

Overall results

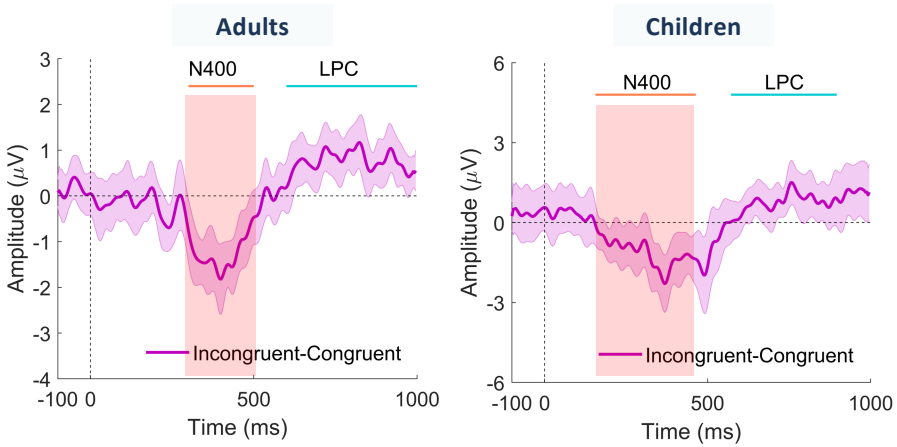
Experiment 1 (8–11 y.o. + adults)

- Behavioral performance above chance **when recognizing both a gesture form and its meaning.**
- N400 in both groups for **incongruent gesture-word and gesture-category pairs**



Behavioral performance

ERPs in gesture-word association



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Gestures can be learned via CSL
AND
learning emerges clearly with this paradigm

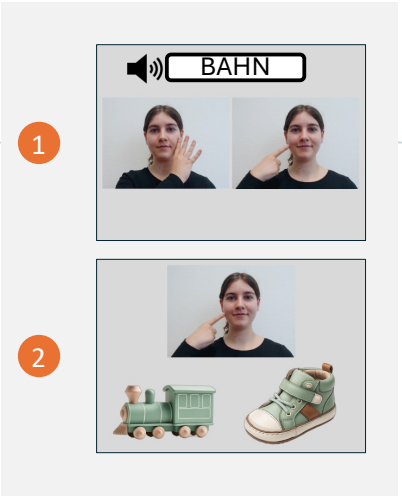
Overall results

Experiment 1 (8–11 y.o. + adults)

- Behavioral performance above chance when recognizing both a gesture form and its meaning.
- N400 in both groups for incongruent gesture-word and gesture-category pairs

Experiment 2 (36–48 m.o.)

- No learning at group level
  → expl. analyses
- **High variability**
- "Older children" (42–48 m.o.) show **familiarity to novelty shift**

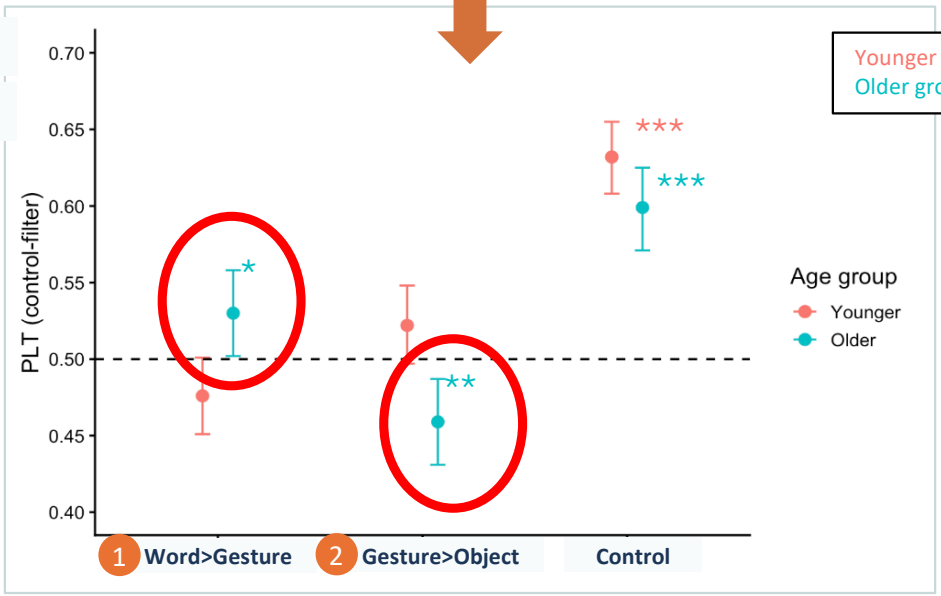


Filtered sample

Exploratory analysis

target looks
(familiarity)

distractor looks
(novelty)



RESULTS

Overall results

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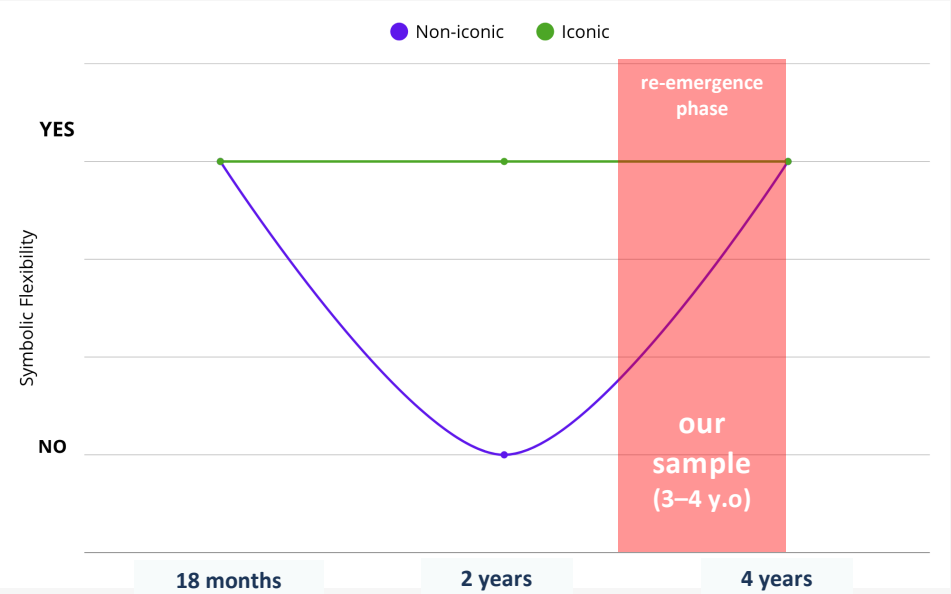
- No learning at group level
- **High variability**
- "Older children" (42–48 m.o.) show **familiarity to novelty shift**

CSL of gestures seems possible
BUT
high variability potentially due to transitional phase of symbolic flexibility.

- **U-shaped symbolic flexibility** (Namy et al., 2004)
- **Familiarity → novelty shift** (Houston-Price & Nakai, 2004)

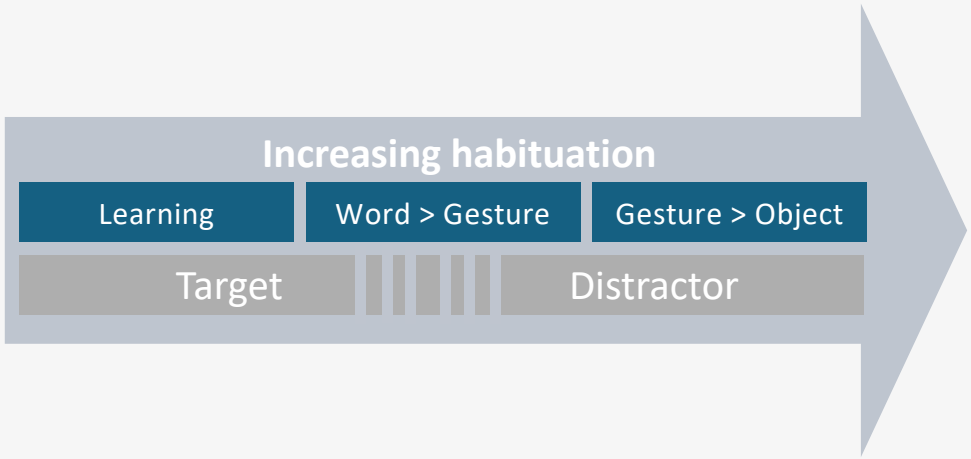
Overall results

Symbolic flexibility



(Namy et al., 2004)

Familiarity-novelty shift



(Mather, 2013; Houston-Price & Nakai, 2004)

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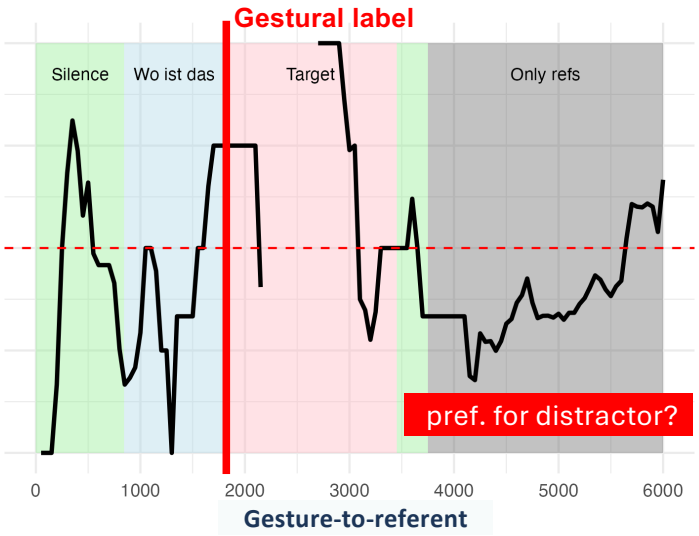
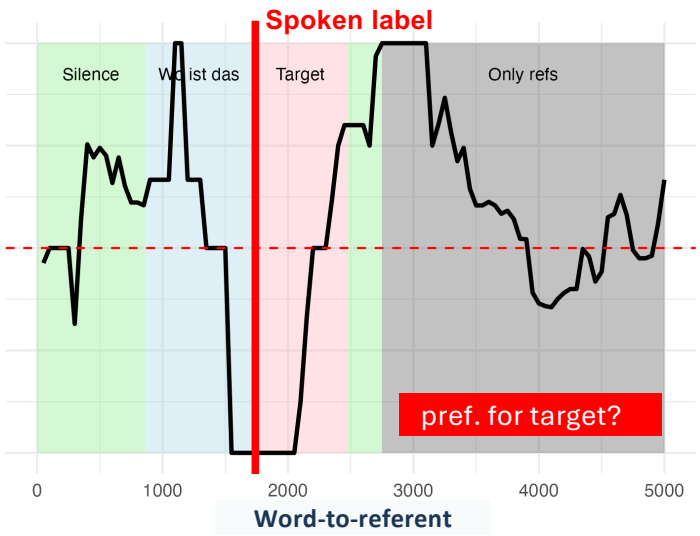
Experiment 3 (14–16 m.o.)

PRELIMINARY DATA! **(N = 5)**

- **Look to referents after both labels**
- Potential difference in post-naming gaze allocation between gesture and words

Time-course of target preference across trial





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PRELIMINARY DATA! **(N = 5)**

- **Look to referents after both labels**
- Potential difference in post-naming gaze allocation between gesture and words

Infants seem to recognize BOTH word and gestures as referential labels BUT with opposite target-distractor looking patterns.

Conclusions

Overall conclusions

Q1

Can gestures be learned via statistical learning across development?

- Yes, clearly in older populations – with behavioral and neural evidence
- Possibly in toddlers, but with high variability consistent with transitional symbolic flexibility
- Preliminary evidence in infants (N=5) — paradigm feasible at 14–16 months

Q2

Can gestures be assigned referential meaning via statistical learning?

- Yes, clearly in older populations – categorization task confirms meaning assignment beyond form recognition
- Possibly in toddlers and infants – but gesture and word labels seem to produce opposite looking patterns, consistent with a familiarity-novelty shift.

Methodological takeaways

CSL paradigm can be adapted to gesture learning across development
with age-specific adaptations in both design and measures

Methodological takeaways

CSL paradigm can be adapted to gesture learning across development

1 **Counterbalance block order**
to disentangle whether the familiarity-novelty shift reflects label modality or task order

2 **Narrow the age window**
to investigate the role of symbolic flexibility in gesture learning at each stage of development

3 **Test iconic gestures**
to test to what extent iconicity facilitates gesture learning under referential ambiguity and better reflect naturalistic bimodal input

4 **Test bilingual populations**
to examine whether naturalistic bimodal language experience modulates gesture learning

Thank you!

I would love to hear your questions and feedback!

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Acknowledgments

Varghese Peter (Univ. Sunshine Coast) · Yin Mai, Xinyu Guo, Marisa Varrica (Macquarie University)
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Fiorinda Pino (Italian Sign Language)

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Full results

EXPERIMENT 1

Results – Behavioral

```
d-prime ~ (Task * Group)
```

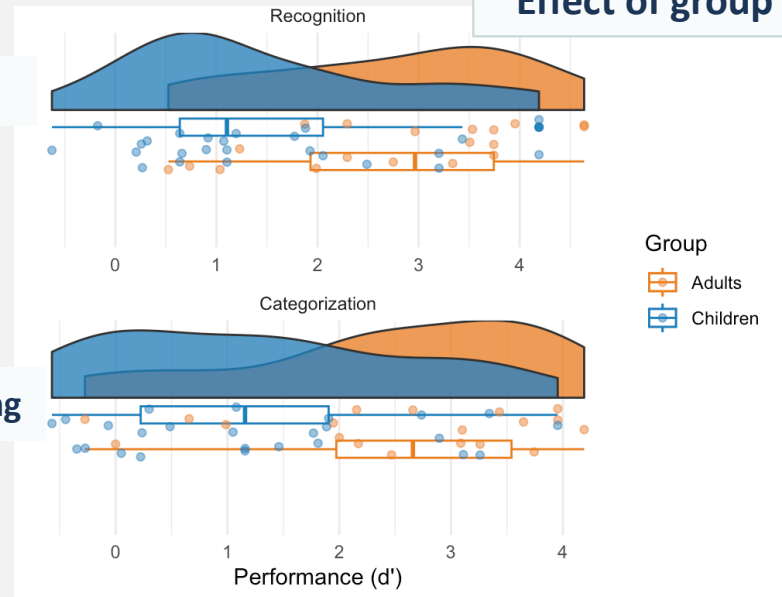
Behavioral (d')

- ✓ Both groups above chance in Gesture>Word + Gesture>Meaning
- ✓ Adults > children (expected advantage)
- No effect of task (Gesture>Word = Gesture>Meaning)

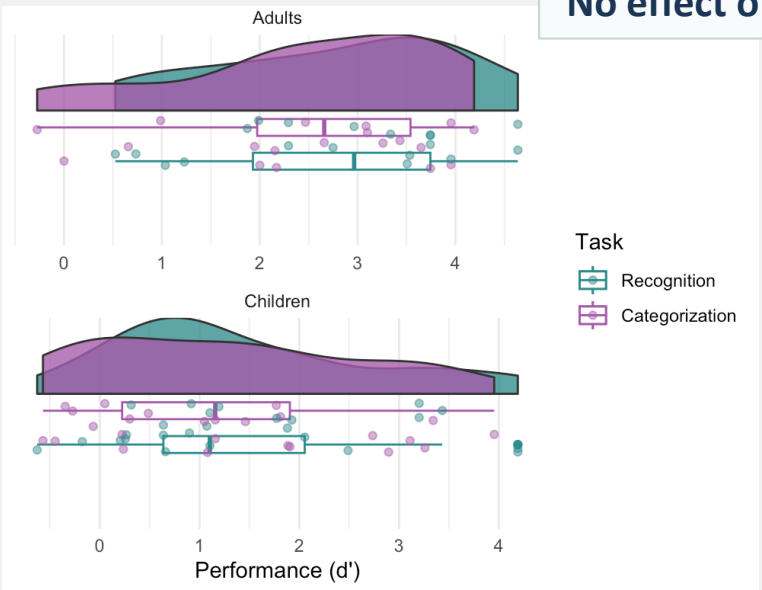
Effect of group

Gesture > Word

Gesture > Meaning



No effect of task



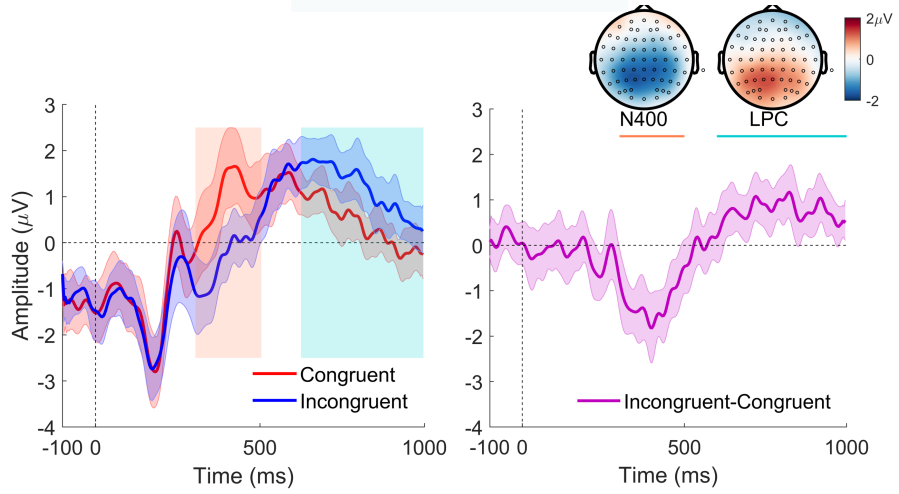
EXPERIMENT 1

Results – Gesture-to-Word ERPs

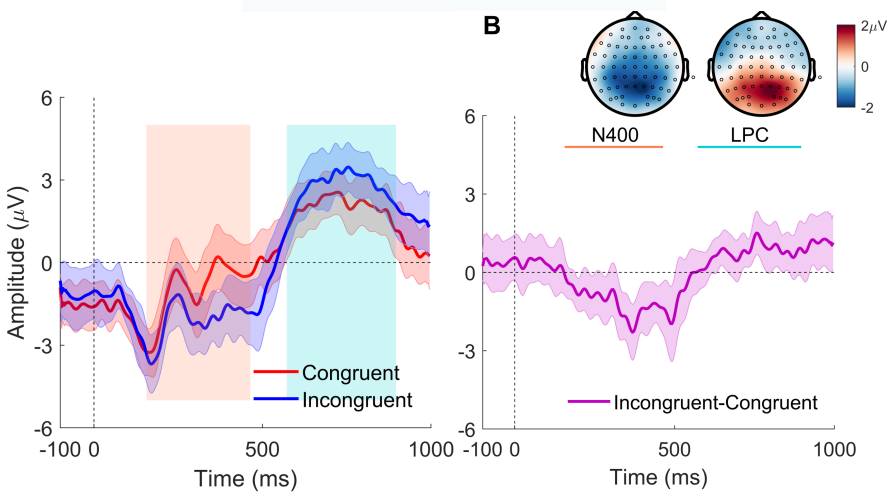
ERP

- ✓ **N400** (both groups) → semantic processing
- ✓ **LPC** (both groups) → explicit memory retrieval

Adults



Children



EXPERIMENT 1

Results – Gesture-to-meaning ERPs

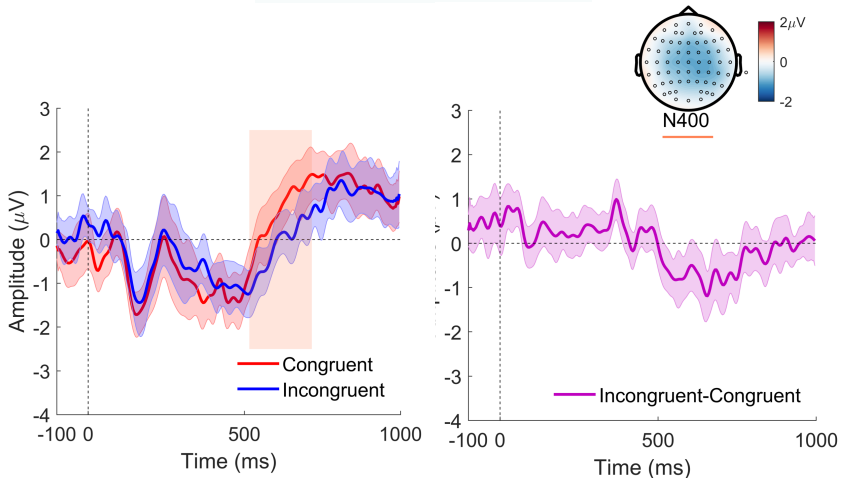
ERP

- ✓ **N400** → semantic processing
- ✓ **N400 in correctly identified trials for the Child Group**

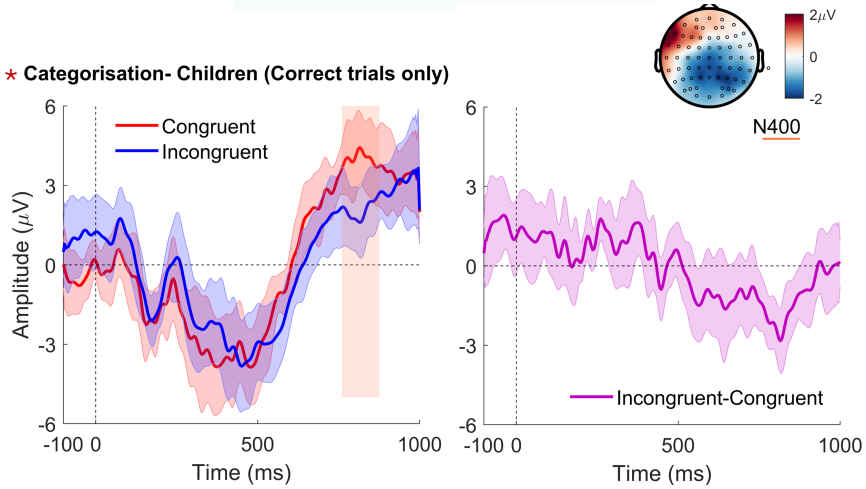
Reasons for exploratory analysis:

1. Behavioural performance above chance
2. No effect of task in behavioral perf.
3. N400 amplitude = Adult group → children's responses in line with those of adults

Adults



Children*



EXPERIMENT 1

Results – Behavioral + ERP

Behavioral (d')

- ✓ Both groups above chance in Gesture>Word & Gesture>Meaning
- ✓ Adults better than children (expected advantage)
- No effect of task (Gesture>Word ≈ Gesture>Meaning)

ERP

- ✓ **N400** (both groups) in Gesture>Word → semantic processing
- ✓ **LPC** (both groups) in Gesture>Word → explicit memory retrieval
- ✓ N400 in Gesture>Meaning : adults + children (correct trials only)

Sign-like gestures:

→ can be learned via CSL

→ can be rapidly assigned a meaning

→ elicit brain responses similar to spoken words

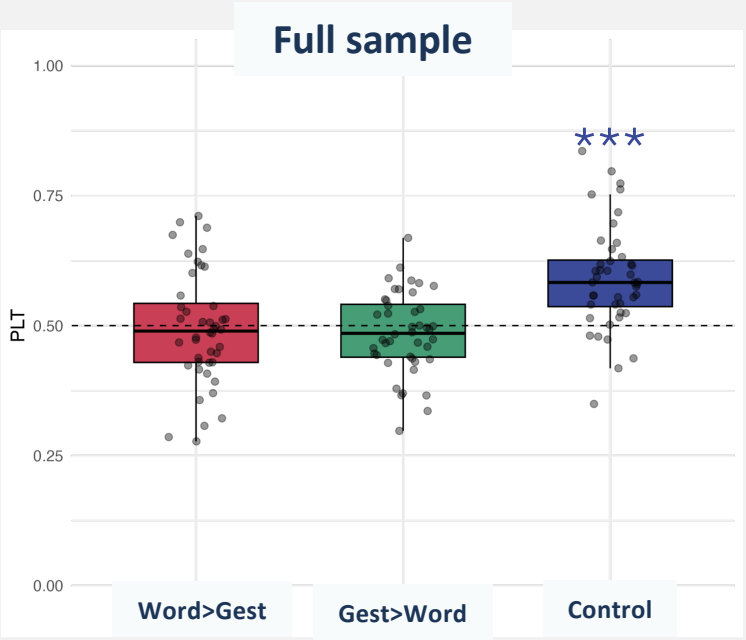
EXPERIMENT 2

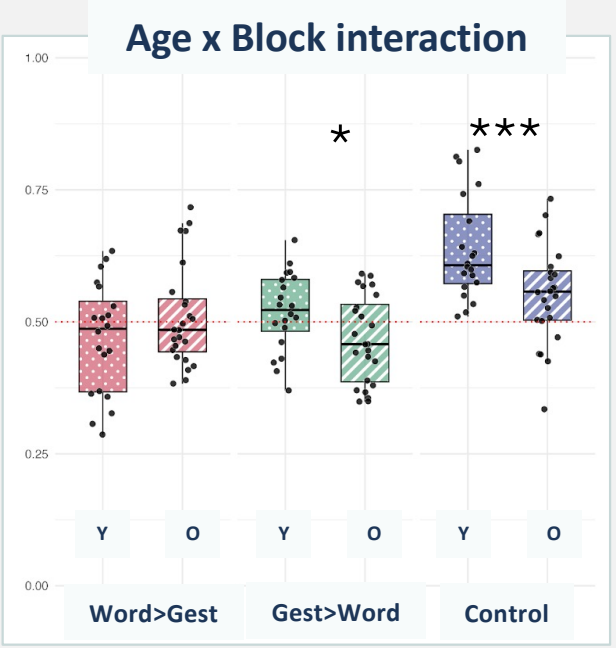
Results – PLT to target

Main analysis

- ✗ PLT at chance: **Word> Gesture (.48)** and **Gesture > Object (.49)**
- ✓ PLT above chance: **Control (.59, p < .001***)**
- **Age × Block Interaction** is significant in **Gesture > Object (*p* = .01*)** and **Control (*p* < .001***)**

high individual variability





Y Younger 36–42 m.o.

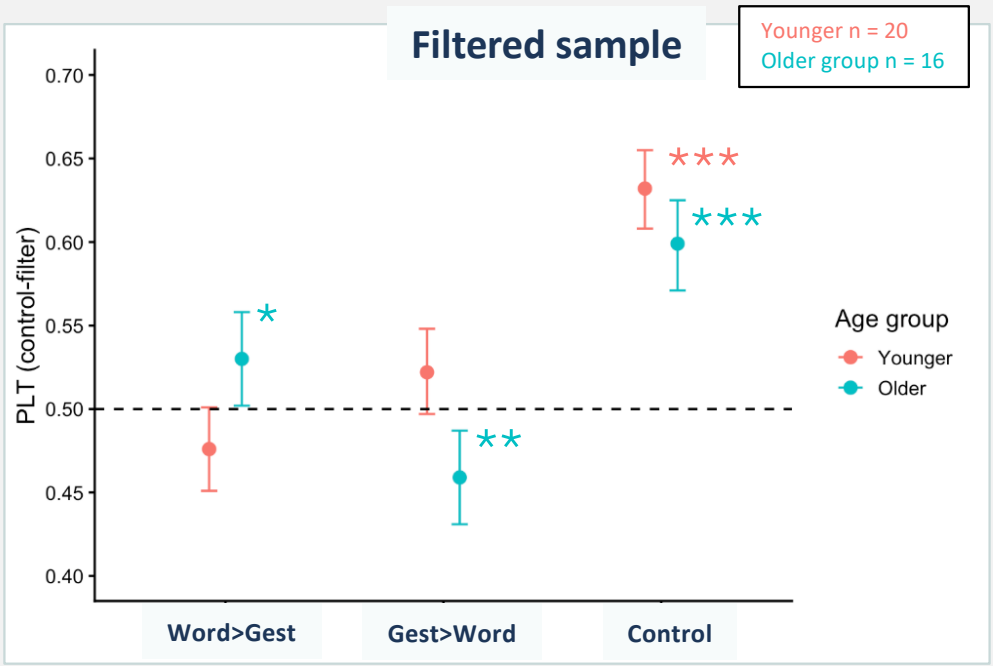
O Older 42–48 m.o.

EXPERIMENT 2

Results – PLT to target

Exploratory analysis

- Control-filtered -> **Removed participants with control PLT <.50**
- Only participant in Older group are removed (n = 8)
- ✓ Control-filtered older group: PLT **Word> Gesture .53***, PLT **Gesture > Object .46****



EXPERIMENT 2

Results – PLT to target

- **U-shaped symbolic flexibility** (Namy et al., 2004)
- **Familiarity → novelty shift** (Houston-Price & Nakai, 2004)

Main analysis

- ✗ PLT at chance: Word>Gesture (.48) and Gesture>Object (.49)
- ✓ PLT above chance: **Control (.59, p < .001)**
- Age × Block interaction significant

Exploratory analysis

- High inter-individual variability in all blocks
- ✓ Control-filtered older group: Word> Gesture **.53*,** Gesture > Object **.46****
- **Target** preference in Word>Gesture / **Distractor** preference in Gesture>Object

3–4-year-old children:

- may be in a transitional phase of symbolic flexibility
- unstable, small, heterogeneous effects

Sign-like gestures:

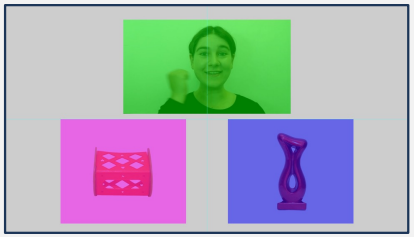
- may be learnable with CSL
- paradigm not optimal for detecting learning in this age group
- too small sample size

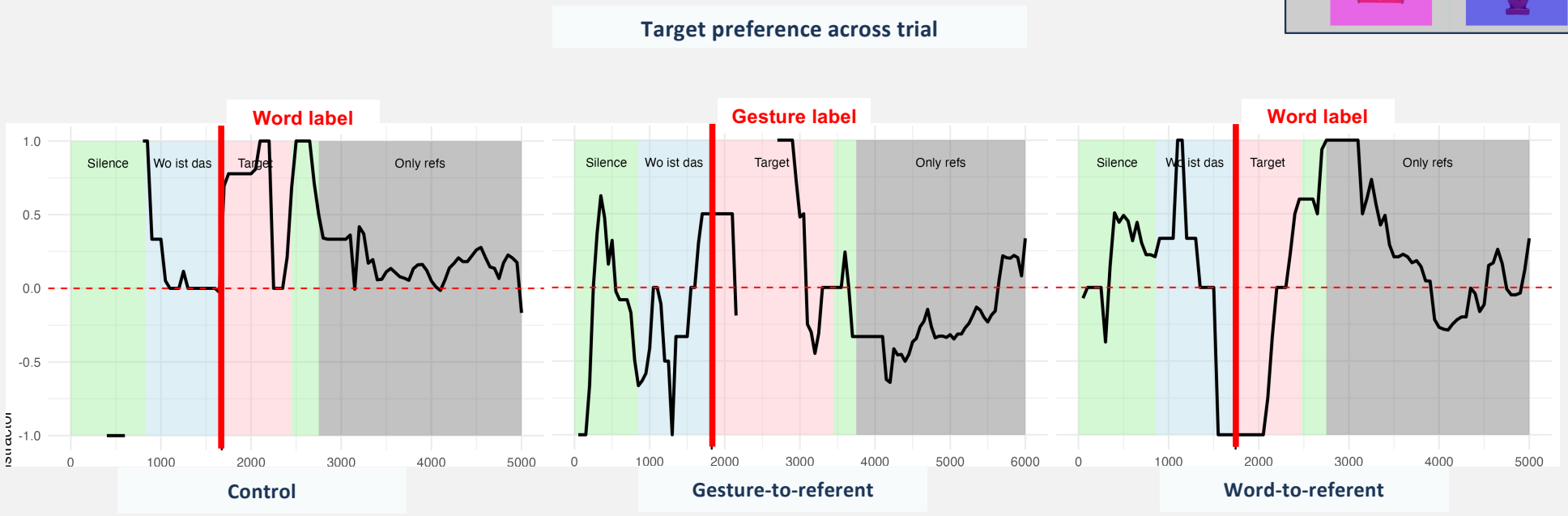
EXPERIMENT 3

Preliminary data

Participant N = 5

- Time-course as expected (looks to referent after both labels, but in opposite directions)
- Difference in post-naming gaze allocation between gesture and words
- Gaze allocation → high % of looks to video (expected but lower number of trial × participant)





EXPERIMENT 3

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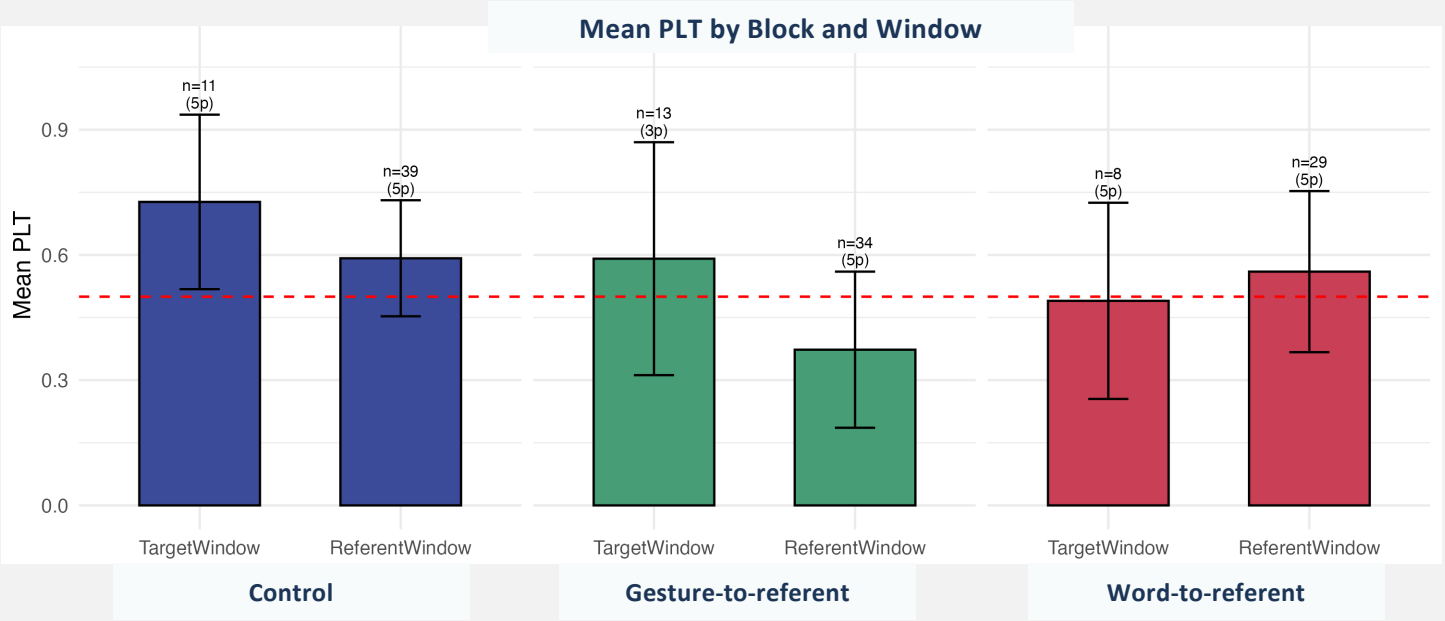

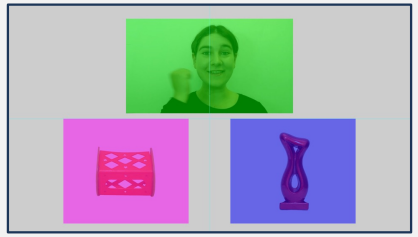

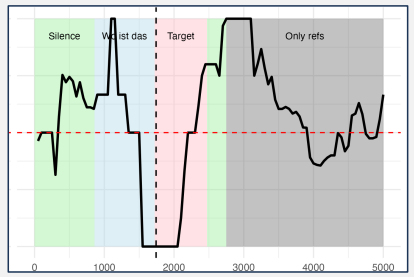

EXPERIMENT 3

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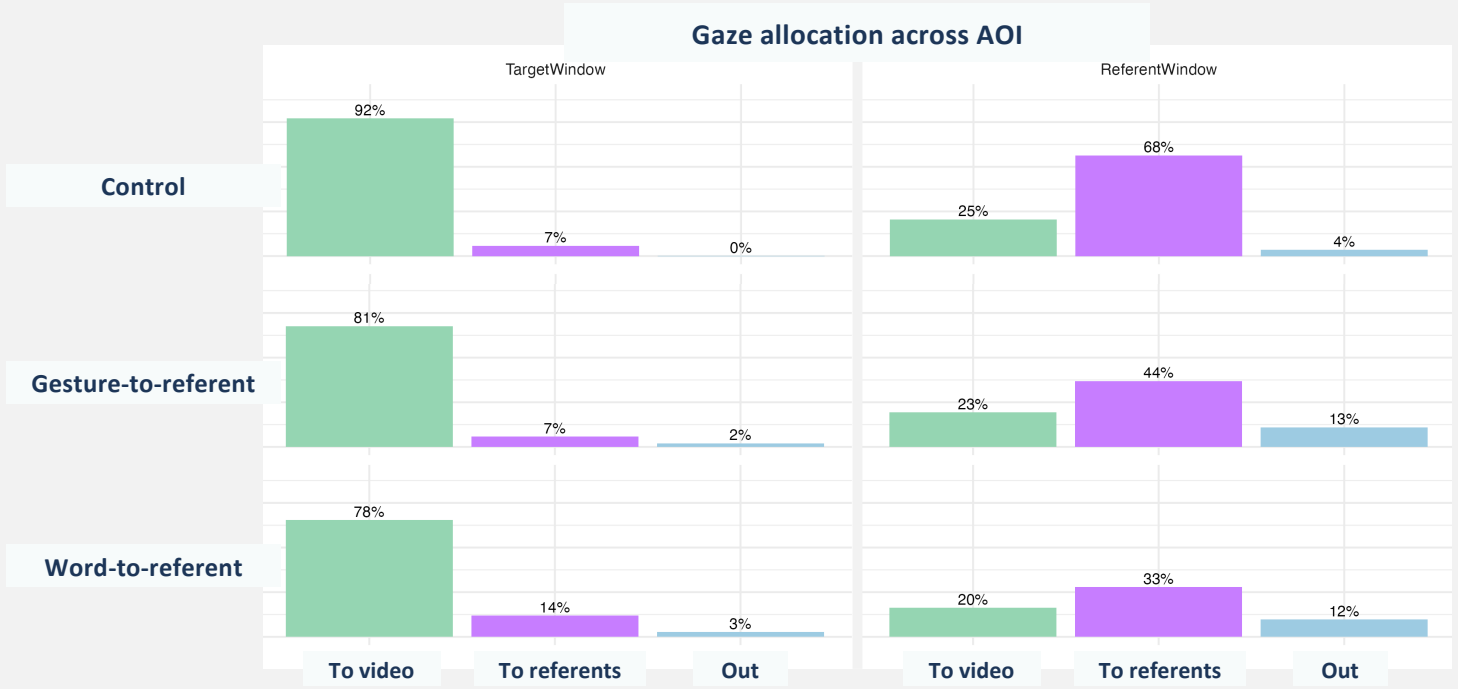
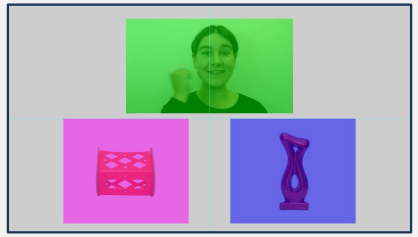


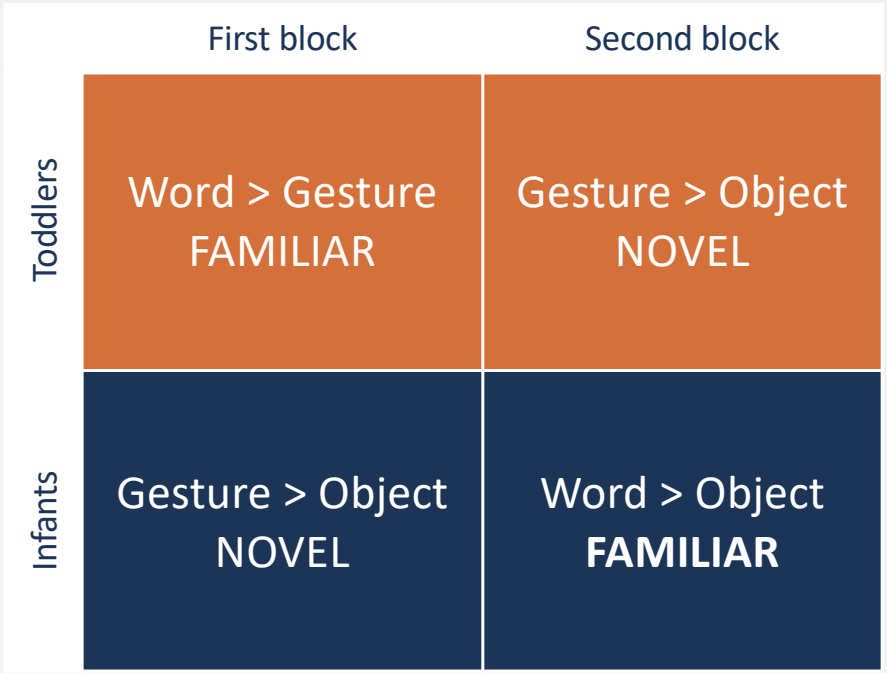


Symbolic flexibility

U-shaped symbolic flexibility (Namy et al., 2004)

Familiarity-novelty shift

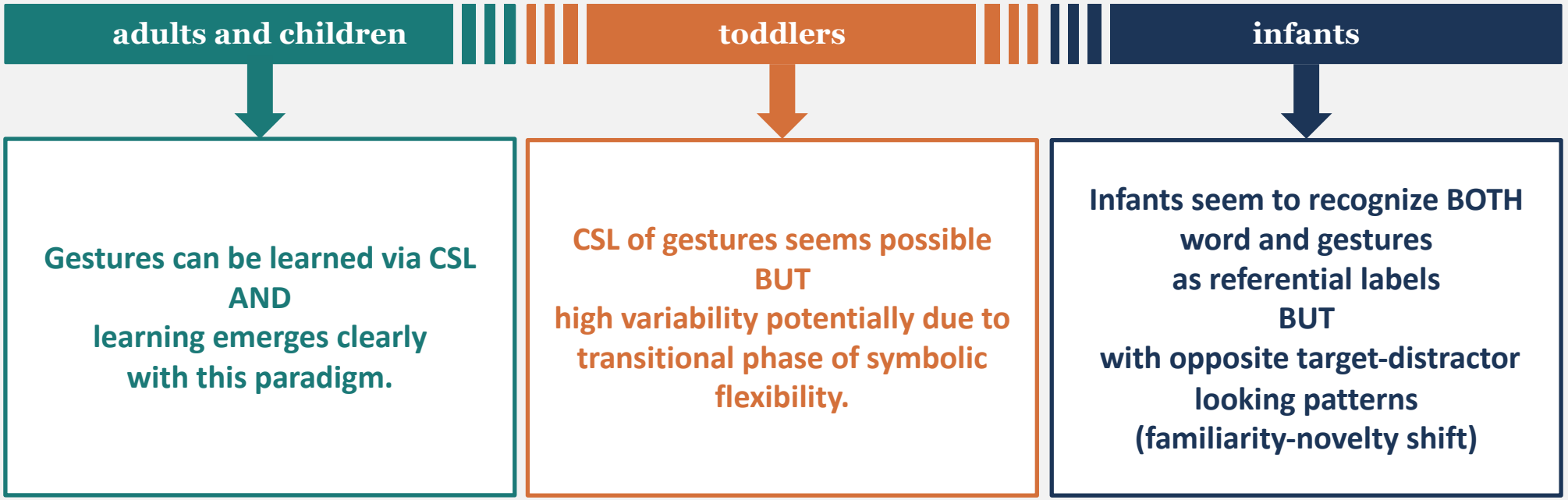
- **Familiarity-novelty shift** (Namy et al., 2004)



Effect of block?
Effect of task?
Or effect of label?

CONCLUSIONS

What did we learn about gestures?



Methodological steps

EXPERIMENT 1

From Exp. 1 to Exp.2

	Take-aways from Exp. 1		Solution in Exp. 2
1	Time-consuming method	→	Change to eye-tracking
2	Number of items	→	From 8 > to 6
3	Importance of training	→	Add Training Block (Mangardich & Sabbagh, 2022)
4	Lack of sanity check	→	Add Control Block (Ambridge & Rowland, 2017)

EXPERIMENT 2

From Exp. 2 to Exp.3

	Takeaways from Exp.2		Solution in Exp. 3
1	Insufficient exposure	→	4 items × 8 repetitions (vs. 6 × 4)
2	No carrier sentences	→	*"Where is the…?"* in all test blocks
3	Wide age range	→	Narrow age-window (14–16 months)
4	Visual-visual mapping only	→	**Bimodal input: WORD + GESTURE simultaneously**
5	Low attention across blocks	→	Control first (also serve as training phase) Mapping first test

Training & control

Experimental paradigm

Experiment 1

proof-of-concept

Adults + Children 8–11 y.o.

Behavioral + ERPs

1. Learning (CSL)
2. **Word → gesture**
3. **Gesture → meaning**

Experiment 2

toddler adaptation

Toddlers 3–4 y.o.

Eye-tracking (preferential looking)

0. Training (CSL)
1. Learning (CSL)
2. **Words → gesture**
3. **Gesture → object**
4. Control block

Experiment 3

infant adaptation

Infants 14–16 m.o.

Eye-tracking (preferential looking)

0. Control + training block
1. Learning (CSL, bimodal)
2. **Gesture → object**
3. **Word → object**

Training & control

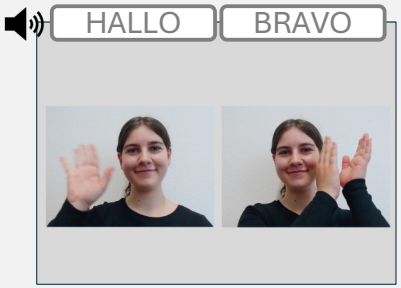
familiar items!

Training phase:
- Familiarize participant with complex structure
- No over instructions needed
- Create referential expectations

Control block:
- Check data validity
- Check paradigm
- Identify participant who don't understand / engage with the task (Ambridge & Rowlands, 2017)

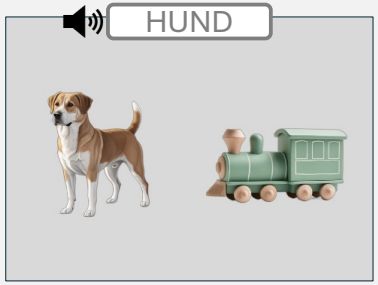
Experiment 2

0 Training phase



...

4 Control block



Experiment 3

0 Control & training together as first block

adapt to paradigm - trade off with experiment length

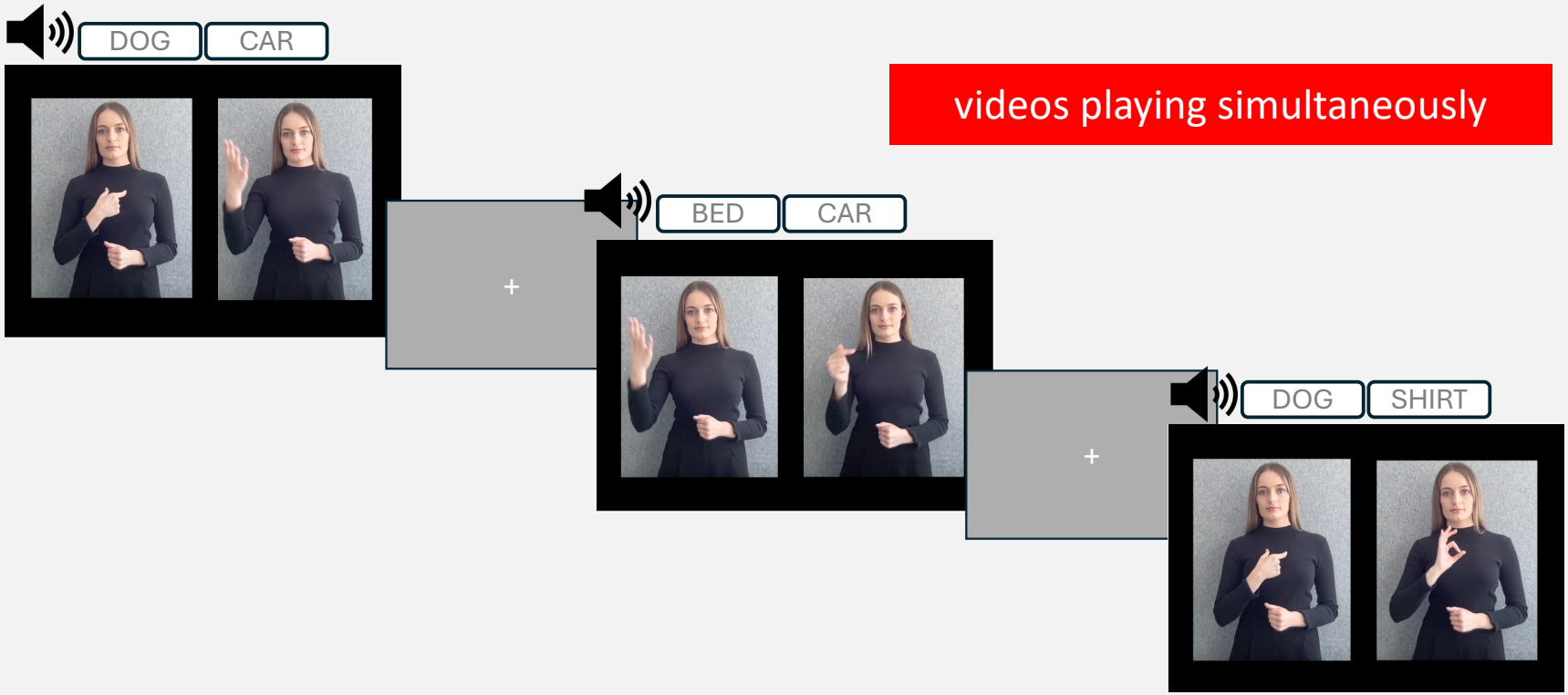
Full paradigms

Experiment 1

Procedure

8 items × 12 reps

Learning phase	Recognition task	Categorization task
8 items × 12 reps Trial N = 48	yes/no task + EEG Trial N = 96	yes/no task + EEG Trial N = 96

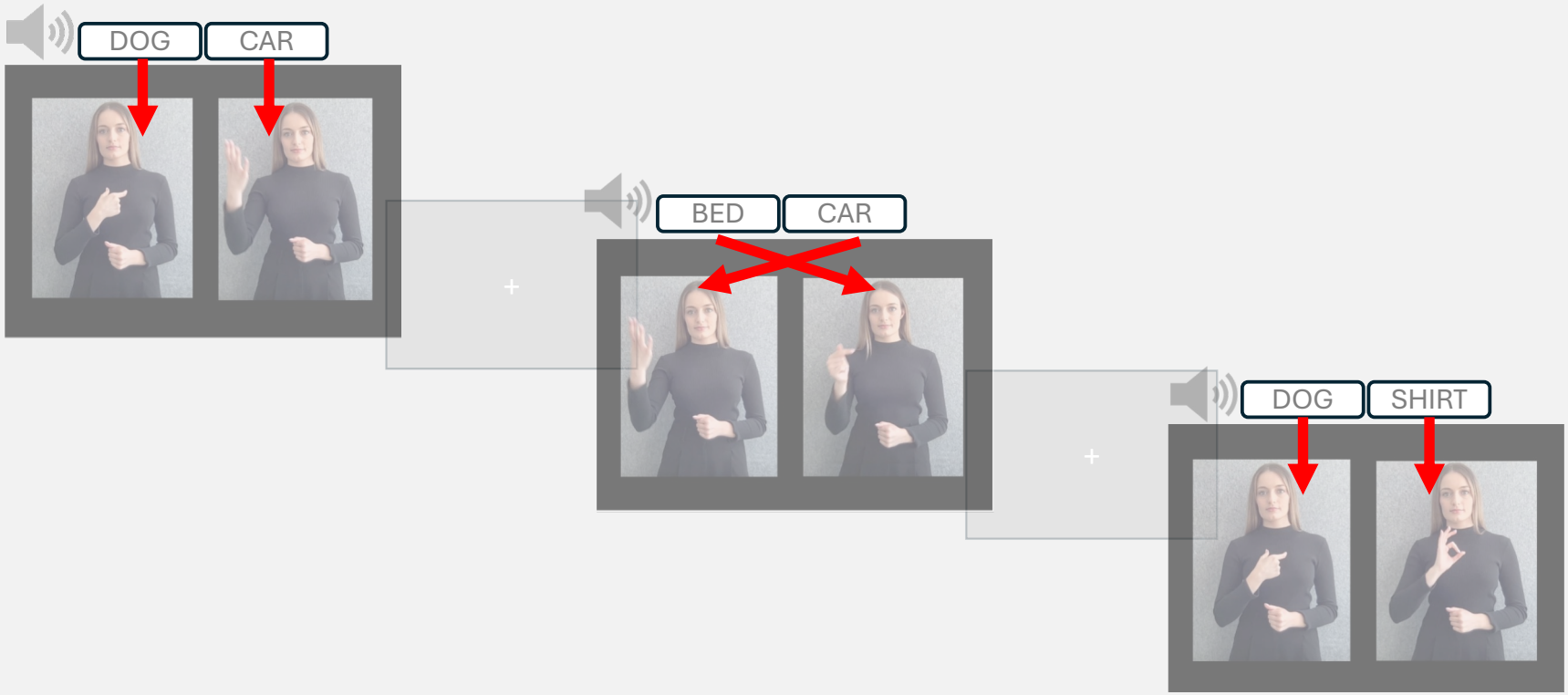


videos playing simultaneously

Procedure

8 items × 12 reps

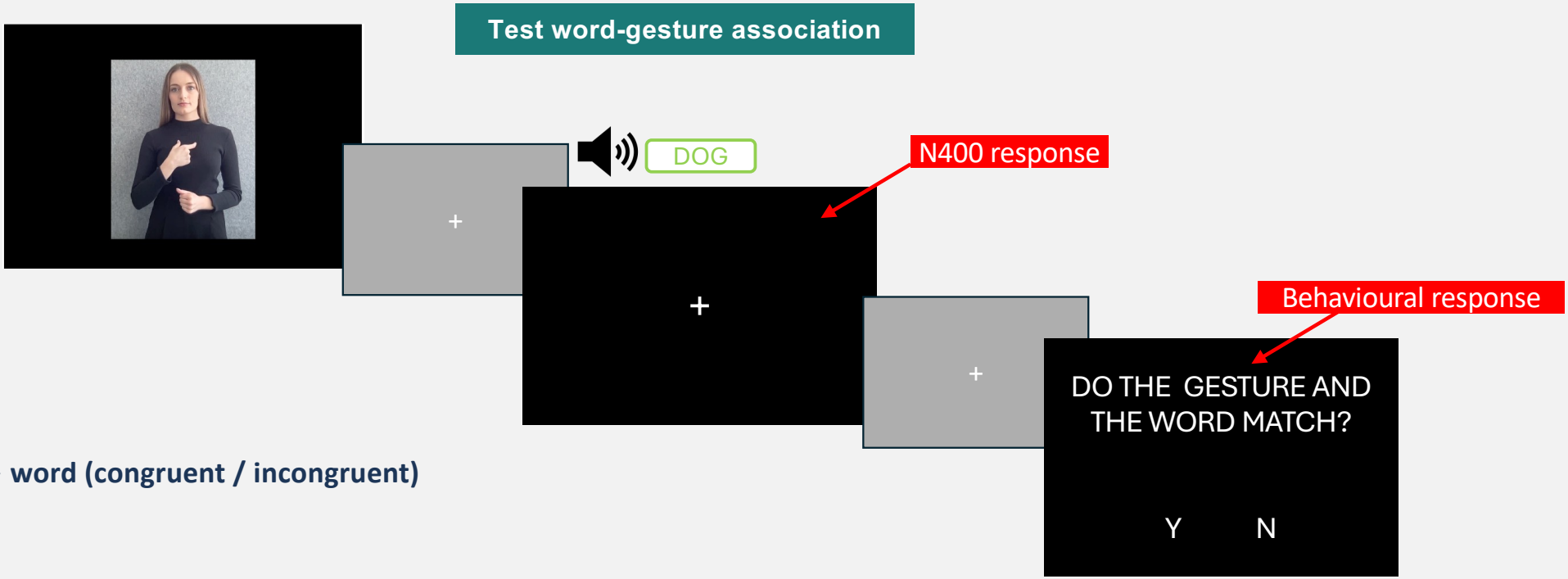
Learning phase	Recognition task	Categorization task
8 items × 12 reps Trial N = 48	yes/no task + EEG Trial N = 96	yes/no task + EEG Trial N = 96



EXPERIMENT 1

Procedure

Learning phase	**Recognition task**	Categorization task
8 items × 12 reps Trial N = 48	yes/no task + EEG Trial N = 96	yes/no task + EEG Trial N = 96

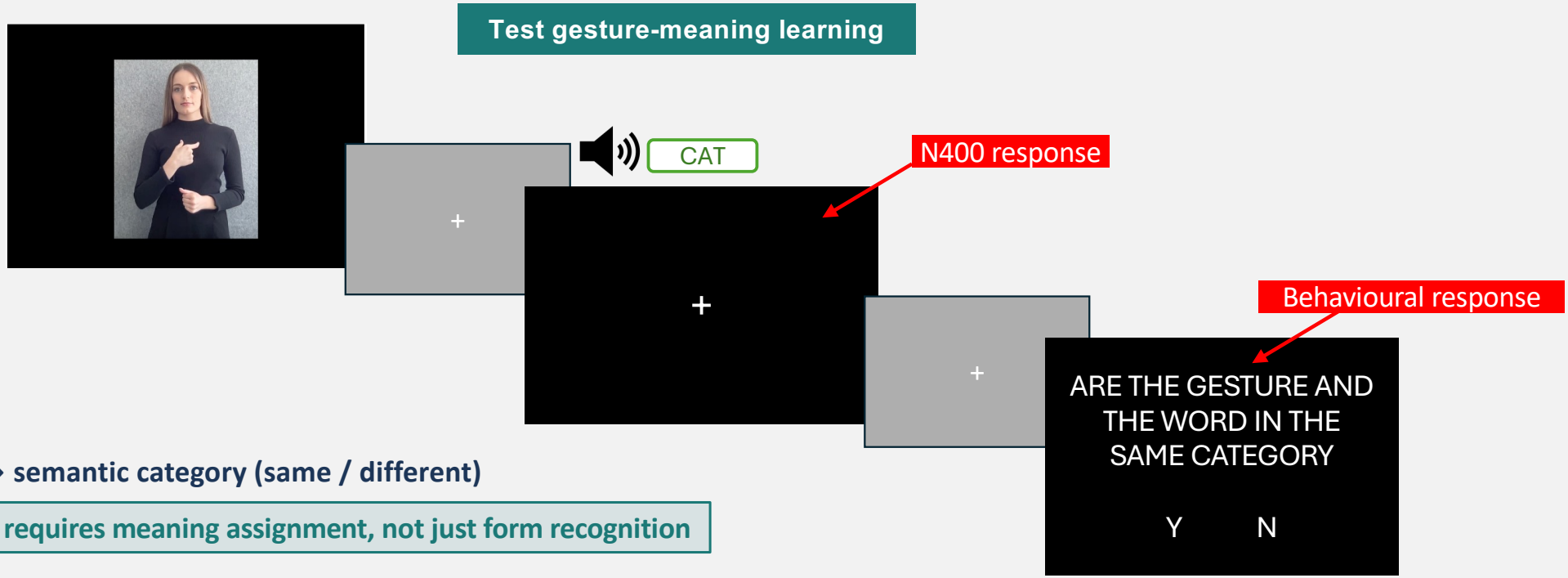


Gesture → word (congruent / incongruent)

EXPERIMENT 1

Procedure

Learning phase	Recognition task	**Categorization task**
8 items × 12 reps Trial N = 48	yes/no task + EEG Trial N = 96	yes/no task + EEG Trial N = 96



Gesture → semantic category (same / different)

This task requires meaning assignment, not just form recognition

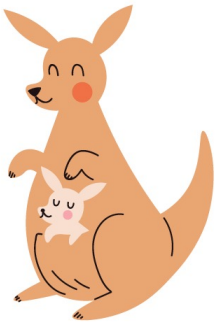
EXPERIMENT 1

Exp.1 – Practice trials (face-to-face)

Easy pairs + intentionally misleading

ANIMALS

taxi
koala



BODY PARTS

cake
leg

lemon
purple

COLOURS

chair
skirt

CLOTHES

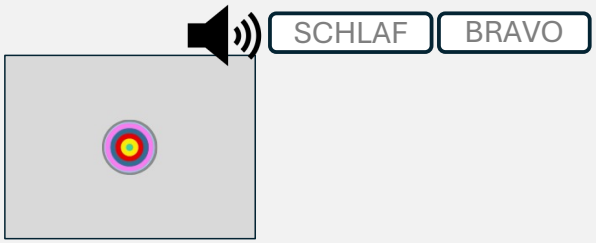
Experiment 2

EXPERIMENT 2

Procedure

6 items × 4 reps

Training phase	Learning phase	Association test	Mapping test	Control test	Tests
3 items × 2 rep. Trial N = 3	6 items × 4 rep. Trial N = 12	6 items × 2 tests Trial N = 12	6 items × 2 tests Trial N = 12	6 items × 2 tests Trial N = 12	Memory and vocabulary



EXPERIMENT 2

Procedure

6 items × 4 reps

Training phase	**Learning phase**	Association test	Mapping test	Control test	Tests
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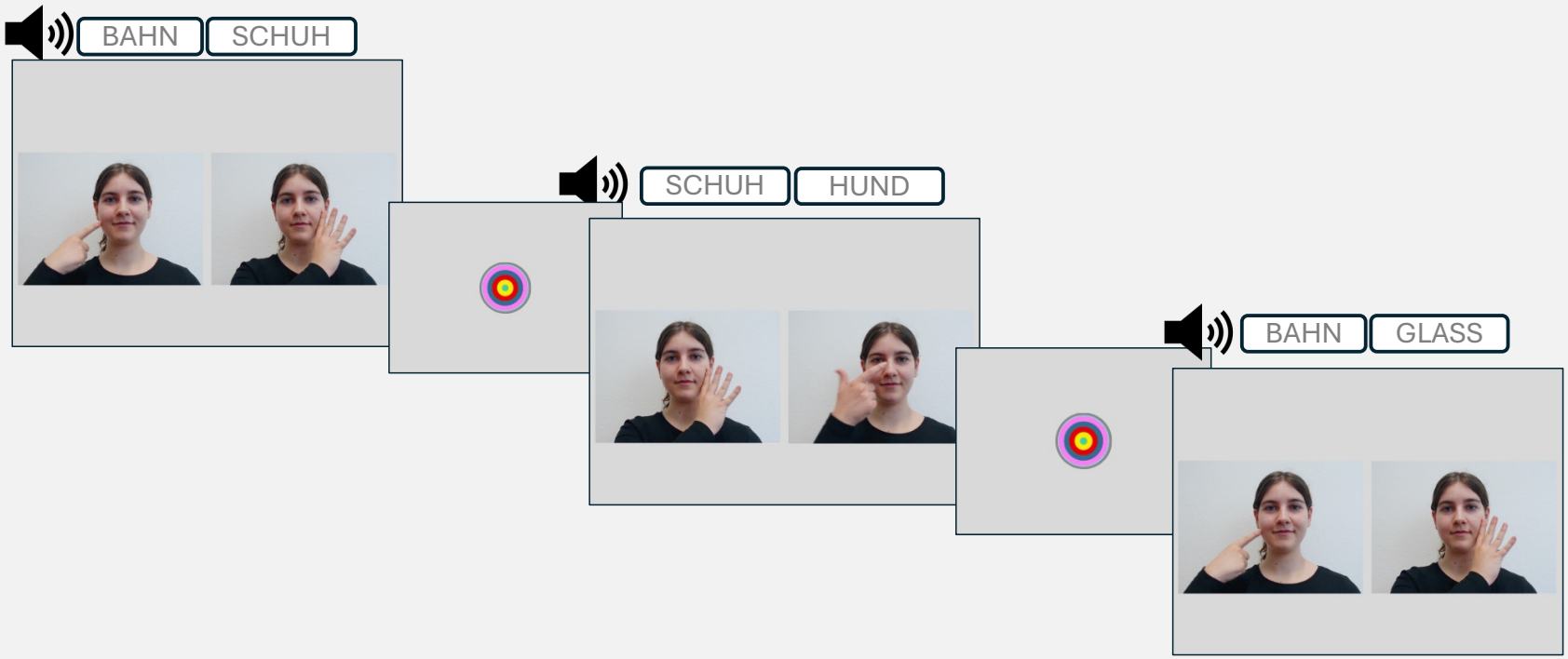

EXPERIMENT 2

Procedure

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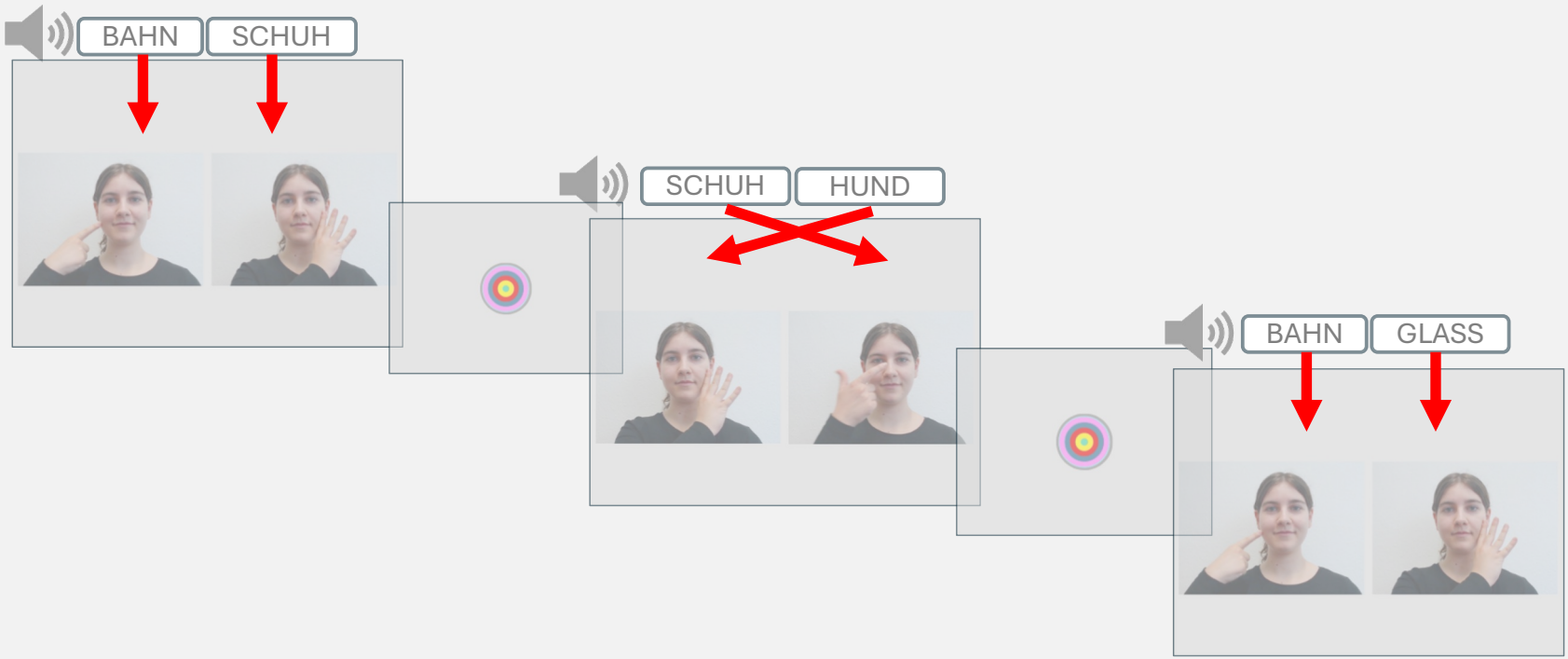
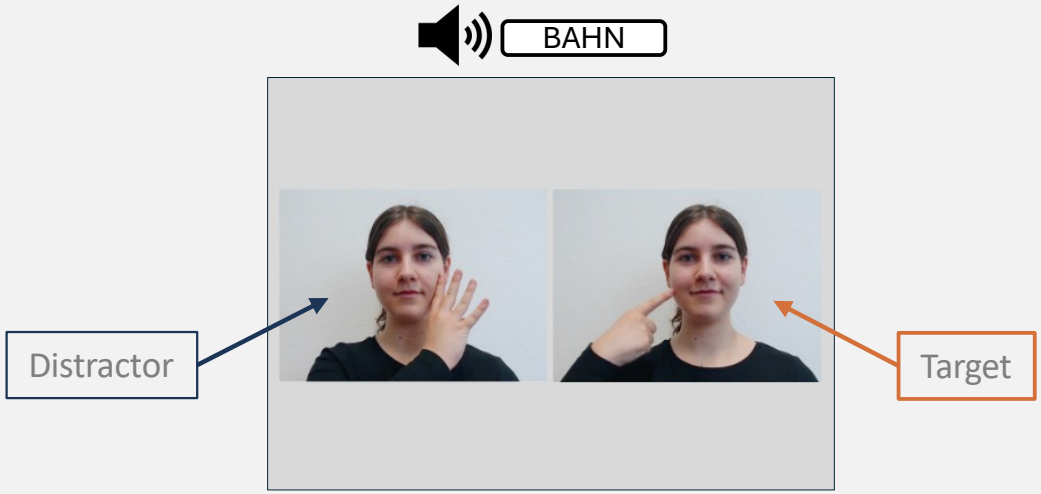


EXPERIMENT 2

Procedure

Training phase	Learning phase	**Association test**	Mapping test	Control test	Tests
3 items × 2 rep. Trial N = 3	6 items × 4 rep. Trial N = 12	6 items × 2 tests Trial N = 12	6 items × 2 tests Trial N = 12	6 items × 2 tests Trial N = 12	Memory and vocabulary

Test word-gesture association



Proportion of Looking Time (PLT) > .50 = preference for correct gesture → correct association

EXPERIMENT 2

Procedure

Training phase	Learning phase	Association test	**Mapping test**	Control test	Tests
3 items × 2 rep. Trial N = 3	6 items × 4 rep. Trial N = 12	6 items × 2 tests Trial N = 12	6 items × 2 tests Trial N = 12	6 items × 2 tests Trial N = 12	Memory and vocabulary

Test gesture-to-referent mapping

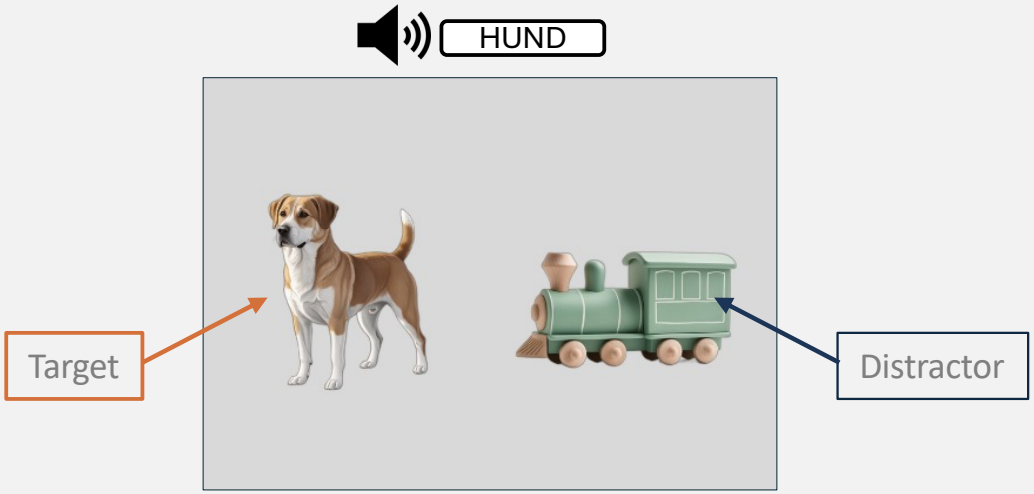
Proportion of Looking Time (PLT) > .50 = preference for correct picture

EXPERIMENT 2

Procedure

Training phase	Learning phase	Association test	Mapping test	**Control test**	Tests
3 items × 2 rep. Trial N = 3	6 items × 4 rep. Trial N = 12	6 items × 2 tests Trial N = 12	6 items × 2 tests Trial N = 12	6 items × 2 tests Trial N = 12	Memory and vocabulary

Test word-to-object mapping (sanity check)



Familiar word → familiar referent · classic preferential looking · independent of experimental learning

Experiment 3

EXPERIMENT 3

Procedure

Control block	Learning phase	Gesture Mapping	Word Mapping
4 items x 2 tests Trial N = 8	4 items x 8 repetitions Trial N = 32	4 items x 2 tests Trial N = 8	4 items x 2 tests Trial N = 8

Test word-to-object mapping (sanity check)

Familiar word → familiar referent · classic preferential looking · independent of experimental learning

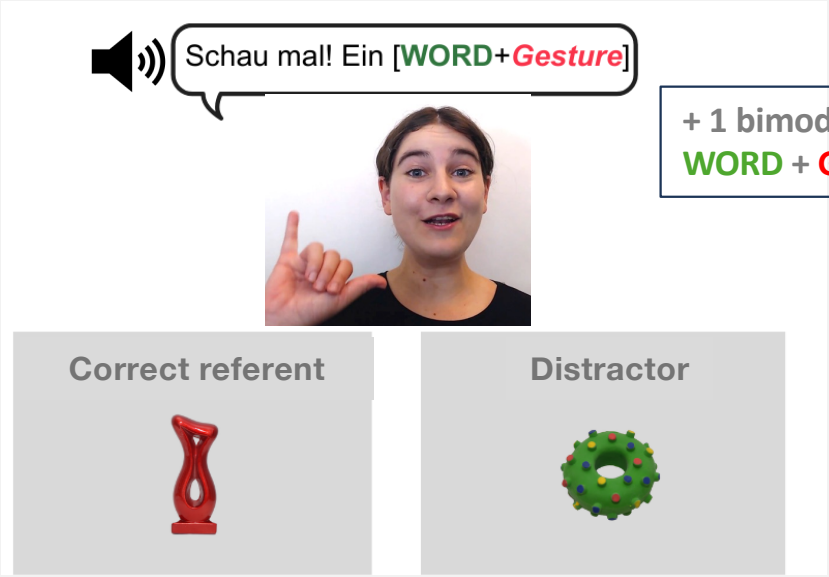
EXPERIMENT 3

Procedure

4 items × 8 reps

Control block	**Learning phase**	Gesture Mapping	Word Mapping
4 items x 2 tests Trial N = 8	4 items x 8 repetitions Trial N = 32	4 items x 2 tests Trial N = 8	4 items x 2 tests Trial N = 8

Spoken carrier sentence
"Look! A…"



Procedure

4 items × 8 reps

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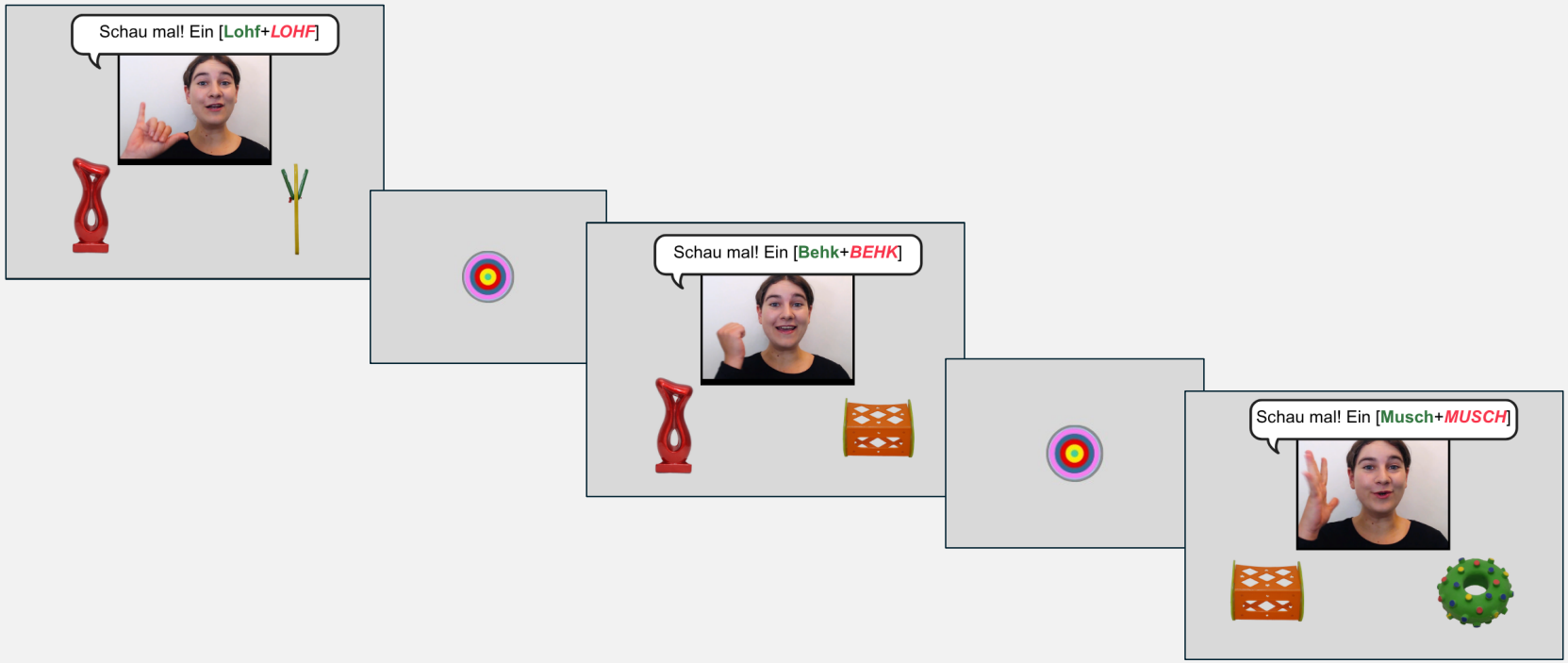

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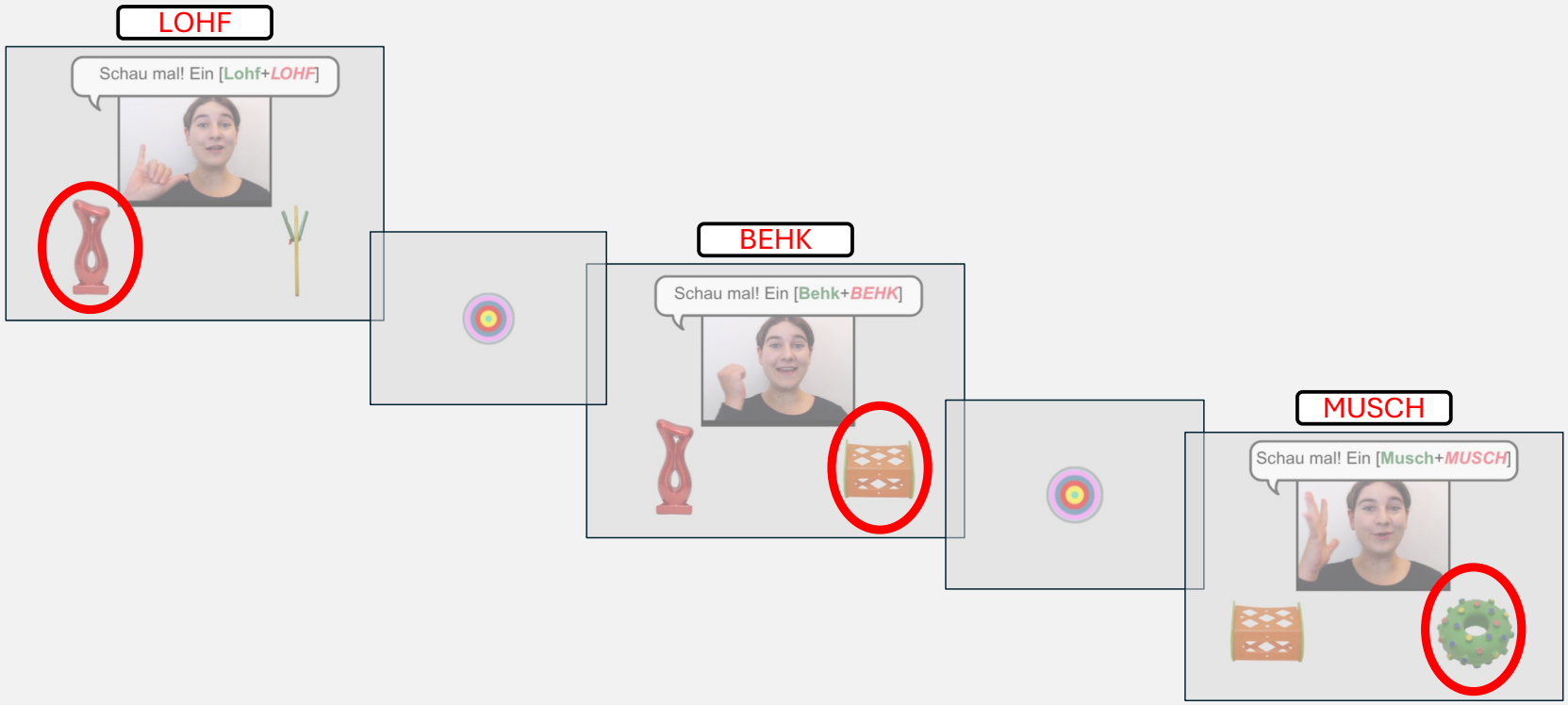


EXPERIMENT 3

Procedure

Control block	Learning phase	**Gesture Mapping**	Word Mapping
4 items x 2 tests Trial N = 8	4 items x 8 repetitions Trial N = 32	4 items x 2 tests Trial N = 8	4 items x 2 tests Trial N = 8

Spoken carrier sentence

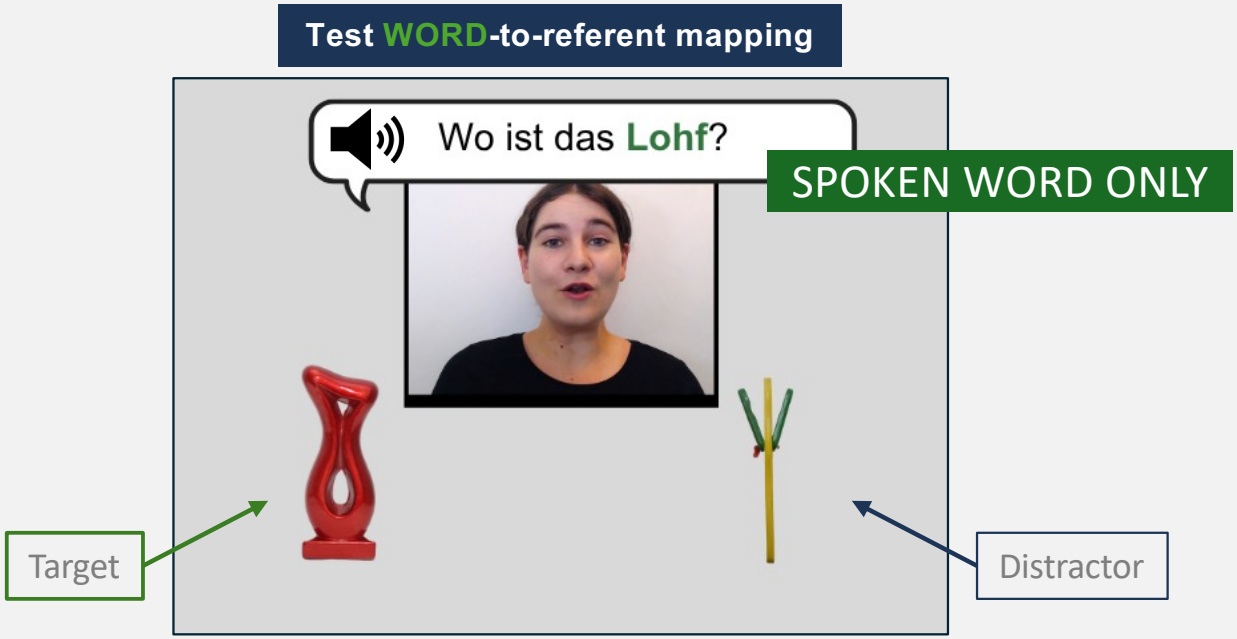
"Where is the... ?"

Procedure

Control block	Learning phase	Gesture Mapping	**Word Mapping**
4 items x 2 tests Trial N = 8	4 items x 8 repetitions Trial N = 32	4 items x 2 tests Trial N = 8	4 items x 2 tests Trial N = 8

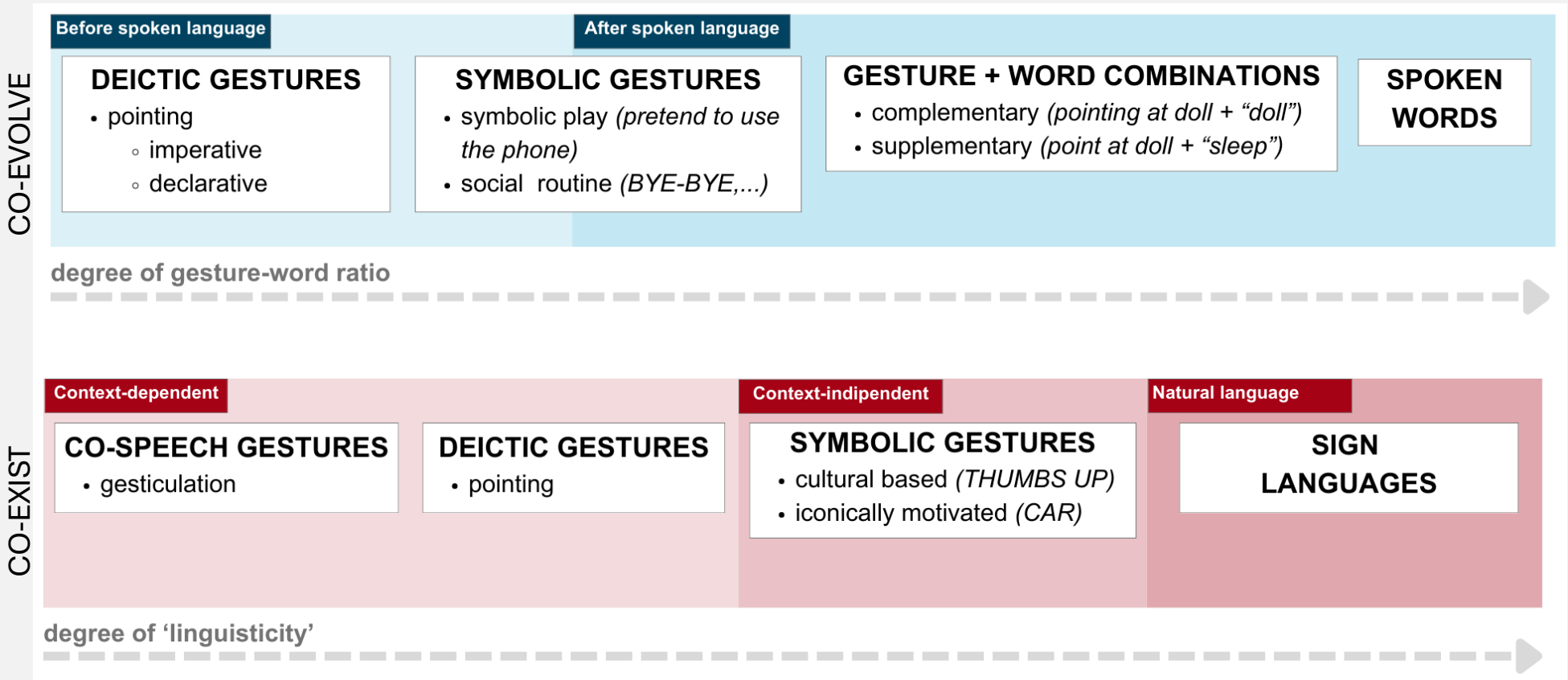
Spoken carrier sentence

"Where is the... ?"



More slides

Gesture-speech continuum



(Adapted from Kendon, 1988; Bates et al. 1979)

Adapting the CSL paradigm

Classic CSL

AUDITORY – VISUAL

WORD → OBJECT

auditory label — visual referent

Our CSL adaptation

AUDITORY – VISUAL – VISUAL

WORD → GESTURE → OBJECT

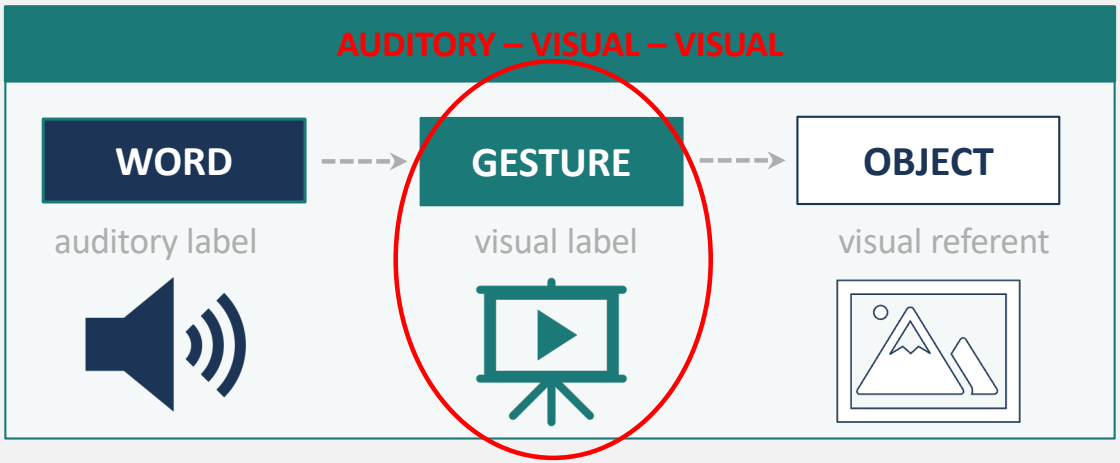
auditory label — visual label — visual referent

a word ⟶ associated to a gesture ⟶ mapped onto an object

Adapting the CSL paradigm

Classic CSL

Our CSL adaptation



a word ⟶ associated to a gesture ⟶ mapped onto an object