Young children's spontaneous comprehension of symbol-object-relationships in the graphic domain

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Author Note

Ethics, consent and conflict of interest: This study confirms with recognized standards (e.g. the Declaration of Helsinki) and was approved by an internal ethics committee at the Max-Planck-Institute for Evolutionary Anthropology. Informed consent has been obtained from all participants. The authors declare no conflict of interest.

Acknowledgments: We are thankful to Susanne Mauritz for her help in the organization of the study and to Valerie Jurgenson and Cynthia Pones for help with data collection. We would like to thank Anne Deiglmayr for hosting this project in her research group and for her continuous support. Finally, we are very thankful to all parents and children participating in the study. Gregor Kachel was supported by the German Research Foundation (Deutsche Forschungsgemeinschaft) under project number 429220405.

The authors made the following contributions. Gregor Kachel: Conceptualization, Funding Acquisition, Project Administration, Investigation, Methodology, Data Curation, Formal Analysis, Visualization, Writing - Original Draft Preparation, Writing - Review & Editing; Daniel Haun: Resources, Writing - Review & Editing; Manuel Bohn: Methodology, Software, Formal Analysis, Validation, Writing - Review & Editing, Supervision.

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Abstract

One or two sentences providing a **basic introduction** to the field, comprehensible to a scientist in any discipline. Two to three sentences of **more detailed background**, comprehensible to scientists in related disciplines. One sentence clearly stating the **general problem** being addressed by this particular study. One sentence summarizing the main result (with the words "**here we show**" or their equivalent). Two or three sentences explaining what the **main result** reveals in direct comparison to what was thought to be the case previously, or how the main result adds to previous knowledge. One or two sentences to put the results into a more **general context**. Two or three sentences to provide a **broader perspective**, readily comprehensible to a scientist in any discipline. !Abstract must be less then 120words!

Keywords: graphical representation, iconicity, analogy, symbol, communication, emerging literacy

Word count: Child Development Max 40 pages // PNAS 1,500–2,000 words

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Introduction

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Preschoolers invent and comprehend iconic gestures spontaneously (Bohn, Kachel, & Tomasello, 2019).

Children's understanding of graphical representations. ~~Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diam voluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet. Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diam voluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.~~

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Hypotheses. ~~Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diam voluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet. Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diam voluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.~~

Methods

All three studies below share the same basic methods and analyses. For convenience, common aspects of the procedure, participant recruiting and stimulus design are reported first before discussing the indivual studies respectively.

General Methods

Setup and Data Collection. Children were visited in-person at their daycares. Daycares provided a separate room where experimenters (E) and children watched the presentation of a picture-book like hiding game on screen while sitting at their side. See figure 1 for an illustration of the setup.

See figure XXX for an illustration of the setup.

Procedure. *Familiarization.*

E introduced an agent, namely a cartoon monkey, and familiarized children with the framing of the task. The monkey placed two small cups at the bottom of the screen. Next, the cups were lifted and the monkey dropped a banana under one of them. The cups were lowered again to hide the banana. Hence, children saw an item being hidden in plain sight and were solely required to remember its place for a minimal amount of time before being asked "Where is the banana?". Children were required to point at the correct hiding place. In the familiarization phase, children received immediate feedback from the experimenter ("Well done!" / "hmm, lets go again!") while the hiding place of the banana was revealed.

To ensure that children were familiar with the goal of the game and the touch interface, they first had to complete a set of four to eight familiarization trials with a success rate of 75%. In case a child did not reply correctly in three out of four trials, another four familiarization trials were provided. If the child was correct in six out of eight trials, she was included in the main sample. Children that did not succeed during familiarization were allowed to participate further but their data was not submitted to analysis.

Test phase. The main phase of the study commenced with announcing that the cartoon character had an idea for a new game.

E explains that they must not see where the banana is hidden. The hiding sequence is identical to the familiarization phase, however the placement of the banana is covered by a wood fence over the lower half of the screen. Next, the monkey holds up piece of paper and a pen

The hiding place is not revealed and children do not receive feedback in test trials. E acknowledges their choices by thanking them in a neutral tone and moves on to the next trial.

Except for the geometric shapes and their placement, the presentations in both conditions were identical. A single trial lasted 20 to 30 seconds. Children were presented

with 16 test trials containing the four test conditions in a blocked order.

In order to be submitted to the analyses participants had to complete at least eight valid test trials (see coding below).The entire test sessions lasted about 12 minutes.

Stimuli. Description of cues and targets and maybe how they were created. For an illustration of the stimuli and example presentations, please see supplementary materials sections XX and XX.

Data Handling and Analyses. Participant responses were collected directly by the experimental script

Bayesian models were run in Stan (http://mc-stan.org/) and implemented via the function brm of the package brms (Bürkner, 2017). We used logistic Bayesian generalized linear mixed models (GLMM) to fit children's responses (0/1) as a function of their absolute age in days, condition (rep, pars, fsim, fcom) and an interaction between trial and task. We use default priors and include trial and sex as fixed effects to be controlled for. Trial number will be added as a random slope within subject.

The full model notation was:

$'correct\ condition * z.age + z.trial + z.sex + (z.trial|subid)'$ • correct: correct choice (0/1) • z.age: age in days, centered to a mean of 0 • z.trial: trial number, scaled • z.sex: participants' sex (male/female), scaled

The analysis modeled participants binary choices to predict the probability of children interpreting the cues correctly and model how this probability will change as a function of their absolute age in days. We used the model to predict the developmental trajectory (with 95% CrI) for each task type. The criterion for settling when children perform above chance with either type of stimuli is the point at which the 95% CrI for a particular trajectory does no longer overlap with a midline demarcating the 50% chance level.

For our main analyses, we used logistic Bayesian generalized linear mixed models (GLMM) to fit children's responses (0/1) as a function of their absolute age in days, task

(arrow, marker) and an interaction between trial and task. We used default priors and included trial and sex as fixed effects to be controlled for. Trial number was added as a random slope within subject. The full model notation was
$'correct\ task * z.age + z.trial + z.sex + (z.trial|id)'$.

The analysis models participants binary choices to predict the probability of children interpreting the cues correctly and model how this probability will change as a function of their absolute age in days. In order to evaluate the relevance of age and task type for children's performance, we compared a full model as specified above with a reduced model lacking the interaction of age and task by using WAIC scores and weights (McElreath, 2016). Furthermore, we inspected the model estimates for the different predictors (including their 95% Credible Interval (CrI)). To answer our main research question of when children perform above chance in a task, we use the model to predict the developmental trajectory (with 95% CrI) for each task type. The criterion for settling when children perform above chance is the point at which the 95% CrI for a particular trajectory does no longer overlap with a midline demarcating the 50% chance level.

To further explore our data, we also binned participants in age-groups (three-, and four-year-olds). To test whether group-level performance was above chance in all experimental groups, we used two-tailed one-sample t-tests with the chance level set to .5. We provide Cohen's d as a standardized effect size for significance testing (computed via the function `cohensD`). Additionally, each participant's data was also submitted to a binomial test to determine whether their performance was above chance on an individual level.

Study 1

Participants. In order to model children's development across the preschool years continuously while aligning with conventions in the field, data collection aimed at testing

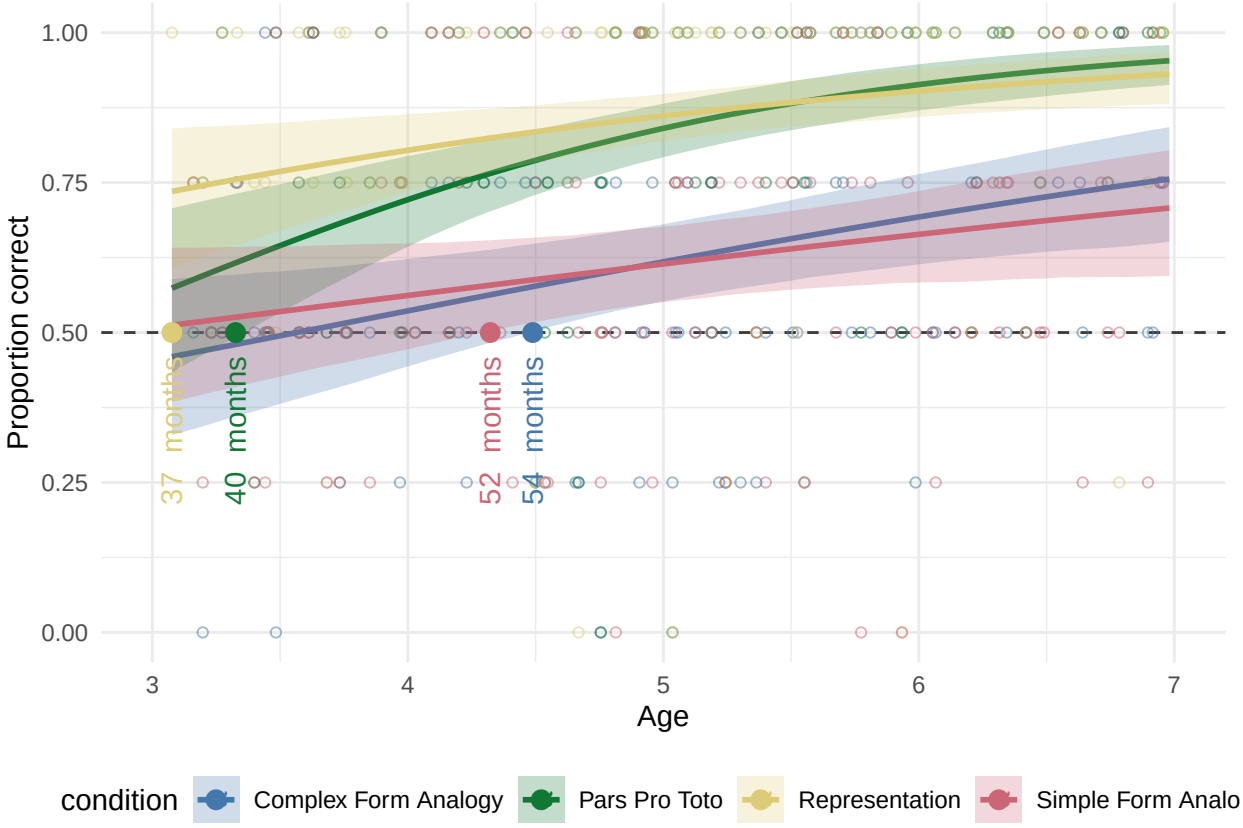
two children per month of age between the third and the seventh birthday for a minimum of 96 participants (24 per year). As children were tested on the basis of availability, the final sample exceeds this preregistered minimum by ten participants. The final sample consisted of 106 children (M = 59.18 months, SD = 13.58 months, range 36 - 83 months; 51 female). In addition, 22 children (11 female) were tested but excluded from analysis for not succeeding during familiarization (N = 13), for not completing at least eight out of 16 test trials (N = 1), or due to being fussy (N = 2). For 4 children, experimenters only learned during testing that children were not fluent enough in German to participate as their families had only recently migrated. Finally, 2 children had to be excluded due to technical issues. For a graphical and tabular overview of participants and exclusions across all three studies presented here, please see Appendix A.

All participants were recruited in **MASKED FOR REVIEW**, a medium-sized middle-European city, and came from a predominantly white population of middle to high income families. They were contacted via a database of participants for child development studies to which their parents had voluntarily signed up. Appointments were made on the basis of parents' and children's availability. The study was reviewed and approved by an internal ethics committee at the **MASKED FOR REVIEW**. Data collection took place from June 2022 to February 2023.

Stimuli.

Analyses.

Results.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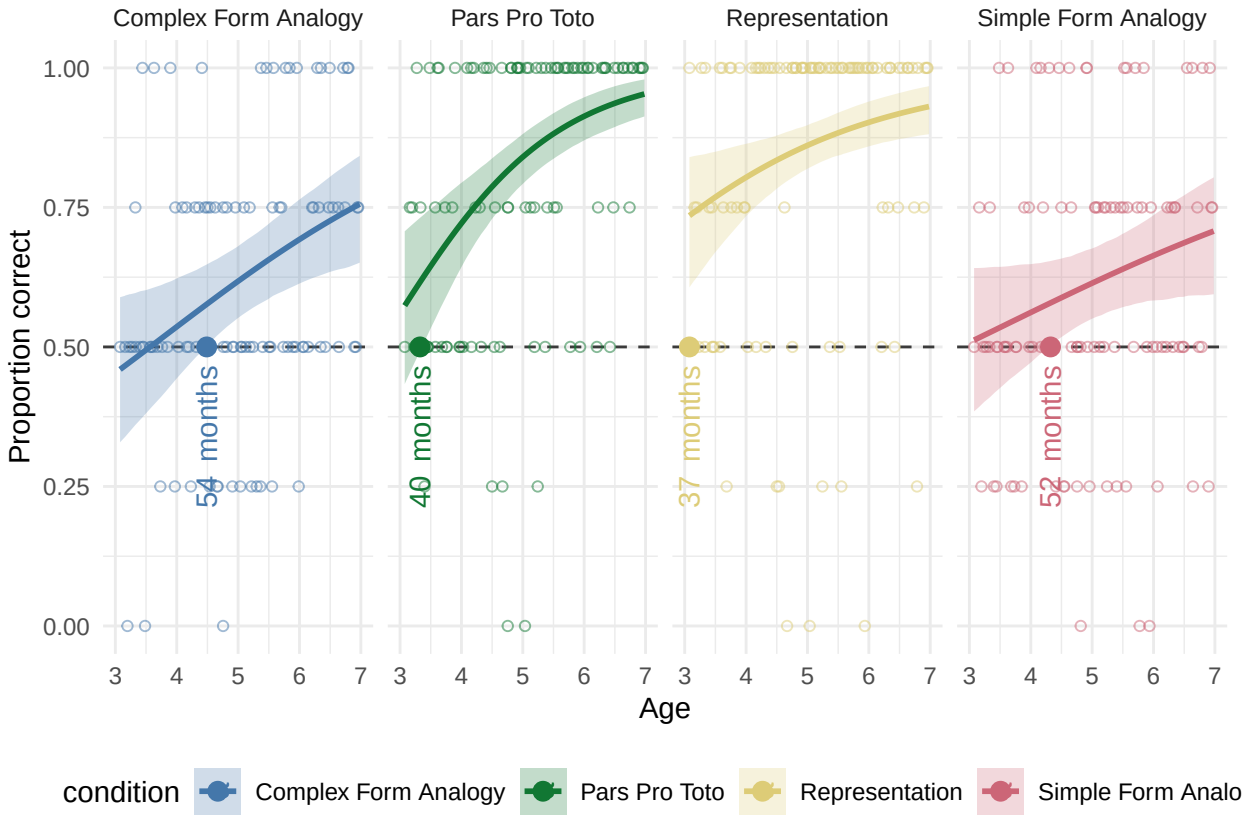

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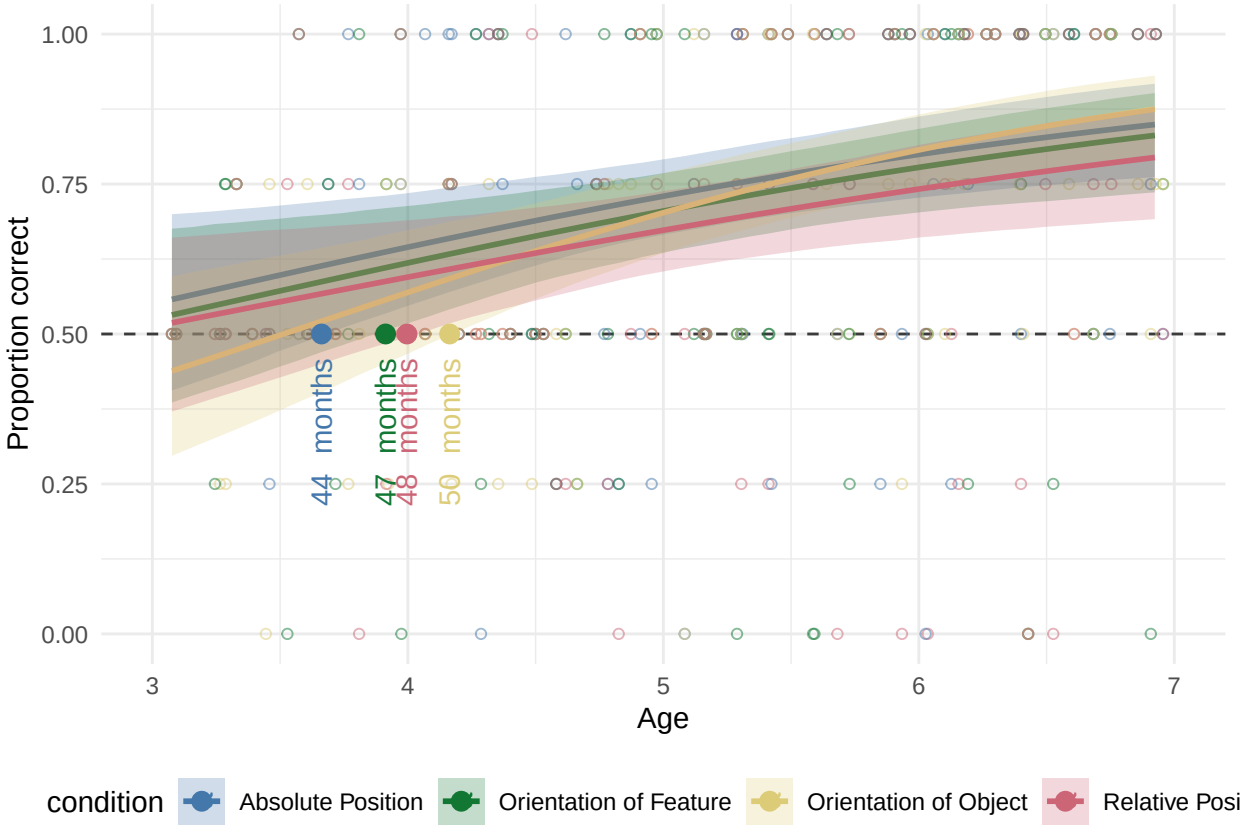
Study 2

Participants. A total of 99 three- to seven-year-old children (M = 60.04 months, SD = 13.69 months, range 36 - 83 months; 49 female) participated. In addition, 15 children (7 female) were tested but excluded from analysis for failing familiarization (N = 10), being fussy (N = 2), not being fluent in German (N = 1) or due to technical issues (N = 2).

198 **Materials.**

199 **Data analysis.** Notation Evaluation of model Stability

200 **Results.**



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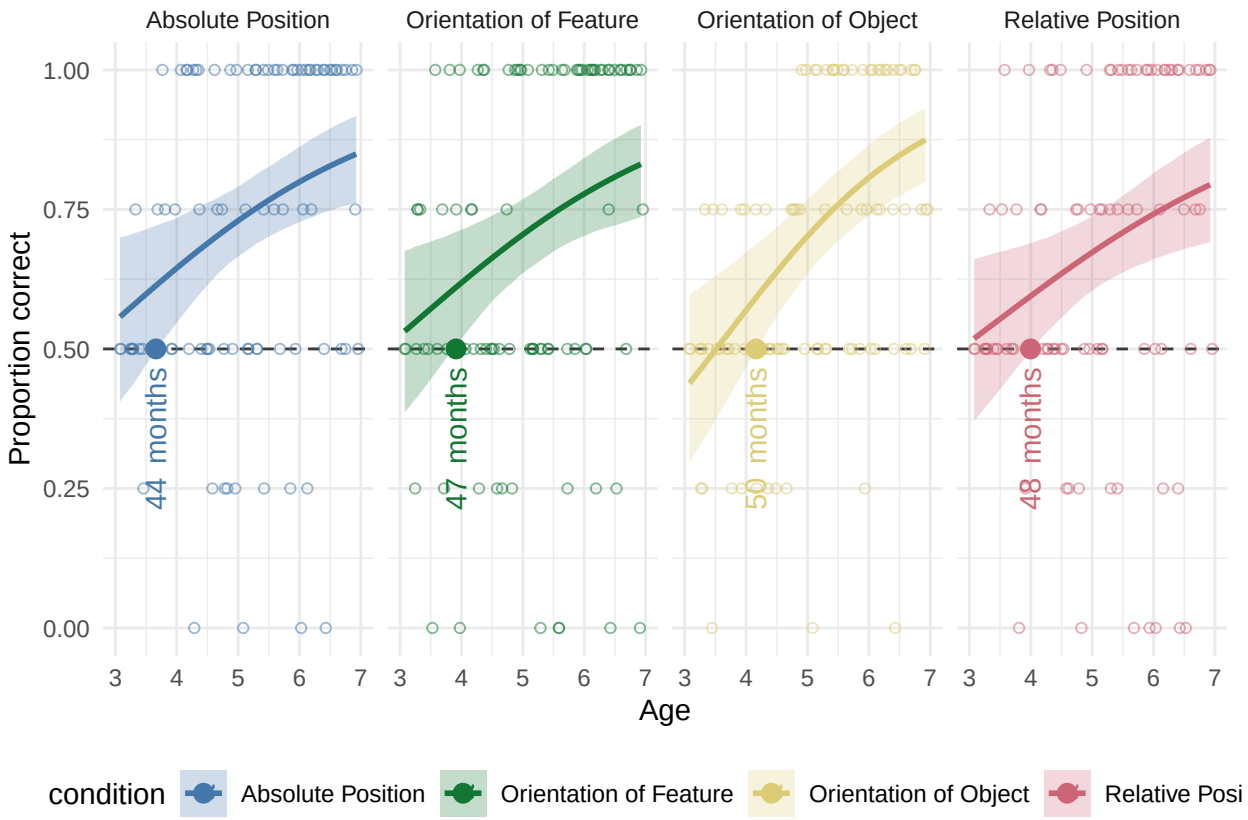


Study 3

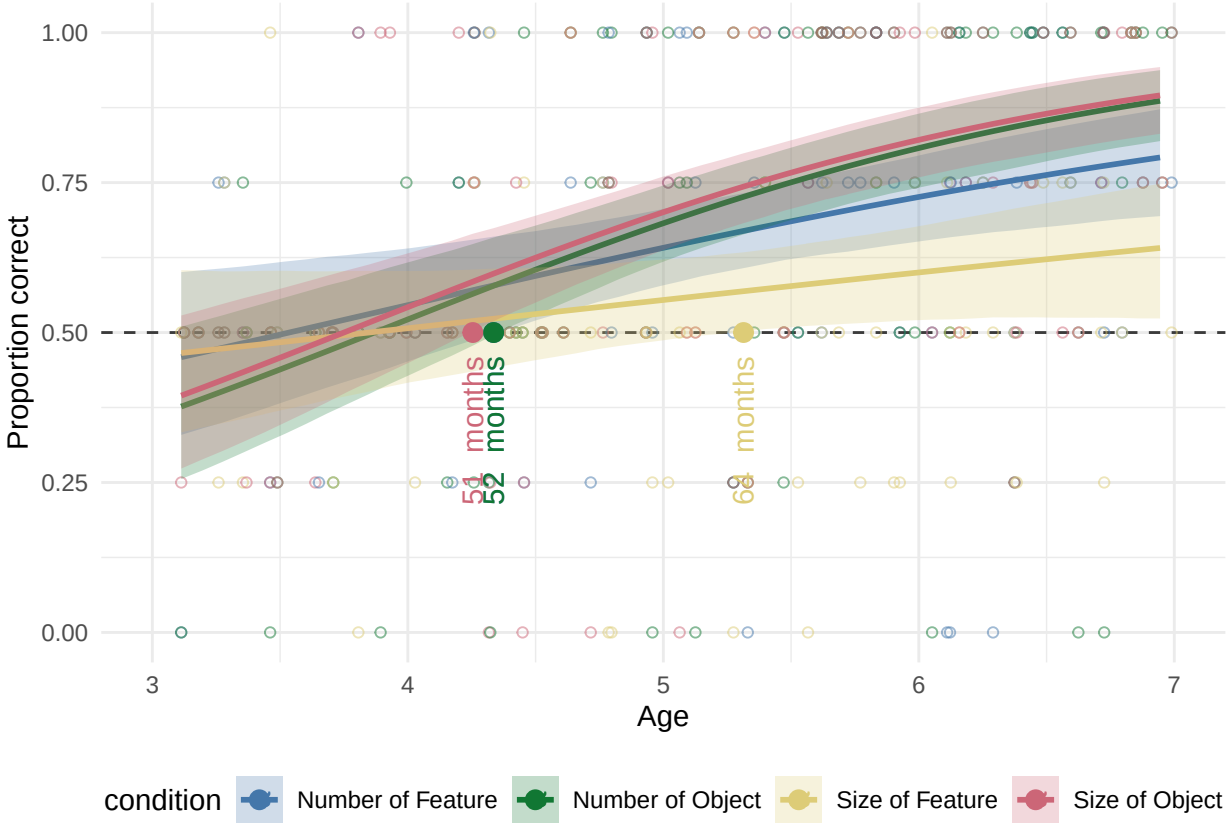
General note on the aim of the investigation

Participants. A total of 99 three- to seven-year-old children (M = 59.88 months, SD = 13.44 months, range 36 - 83 months; 55 female) participated. In addition, 23 children (7 female) were tested but excluded for low performance during familiarization (N = 12), for not completing at least eight out of 16 test trials (N = 1), or being fussy (N = 3). Another 4children were excluded due to language problems or technical issues (N = 3).

Materials.

Analysis. Trails Notation Model Evaluation

Results.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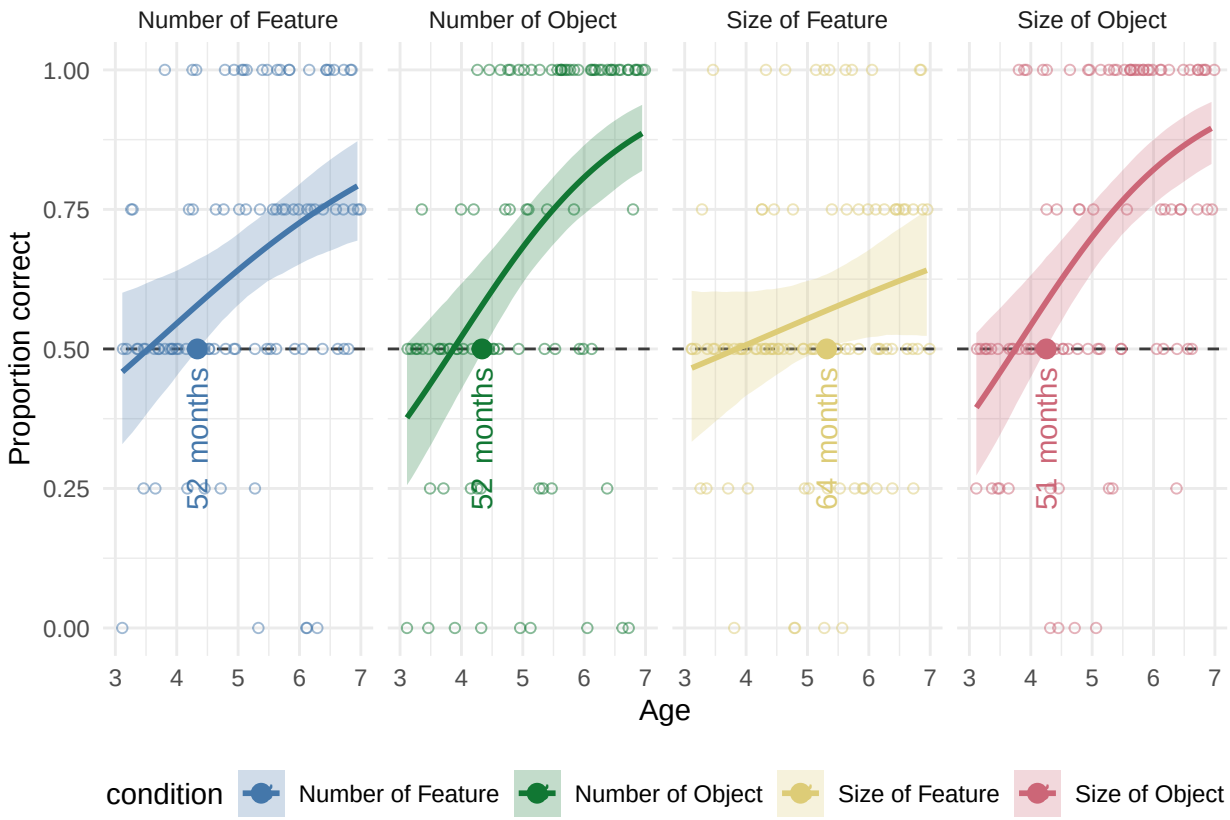

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Additional Analyses

possible add-ons - a model including all conditions - comparing difficulty across items and tasks - evaluating manipulations such as complex/simple; - reaction time analyses

Additional Analyses:

object vs feature - orfe vs orob - sife vs siob - nufe vs nuob

round vs angular - Study One Study1 - cue A = rund, cue B eckig . . . if one of them is easier

Reaction Times just reaction times and perc correct across aged

General Discussion

Overview

Main Finding

Strengths and Implications

Limitations

Conclusion

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240 **References**

241 Bohn, M., Kachel, G., & Tomasello, M. (2019). Young children spontaneously recreate core
242 properties of language in a new modality. *Proceedings of the National Academy of*
243 *Sciences*, *116*(51), 26072–26077.

Figure 1. Illustration of setup.

Appendix A

Participants and Exclusions

Data collection aimed at testing two children per month of age between the third and seventh birthday for a minimum of 96 children per study. For an overview of the sample distribution, please see figure A1.

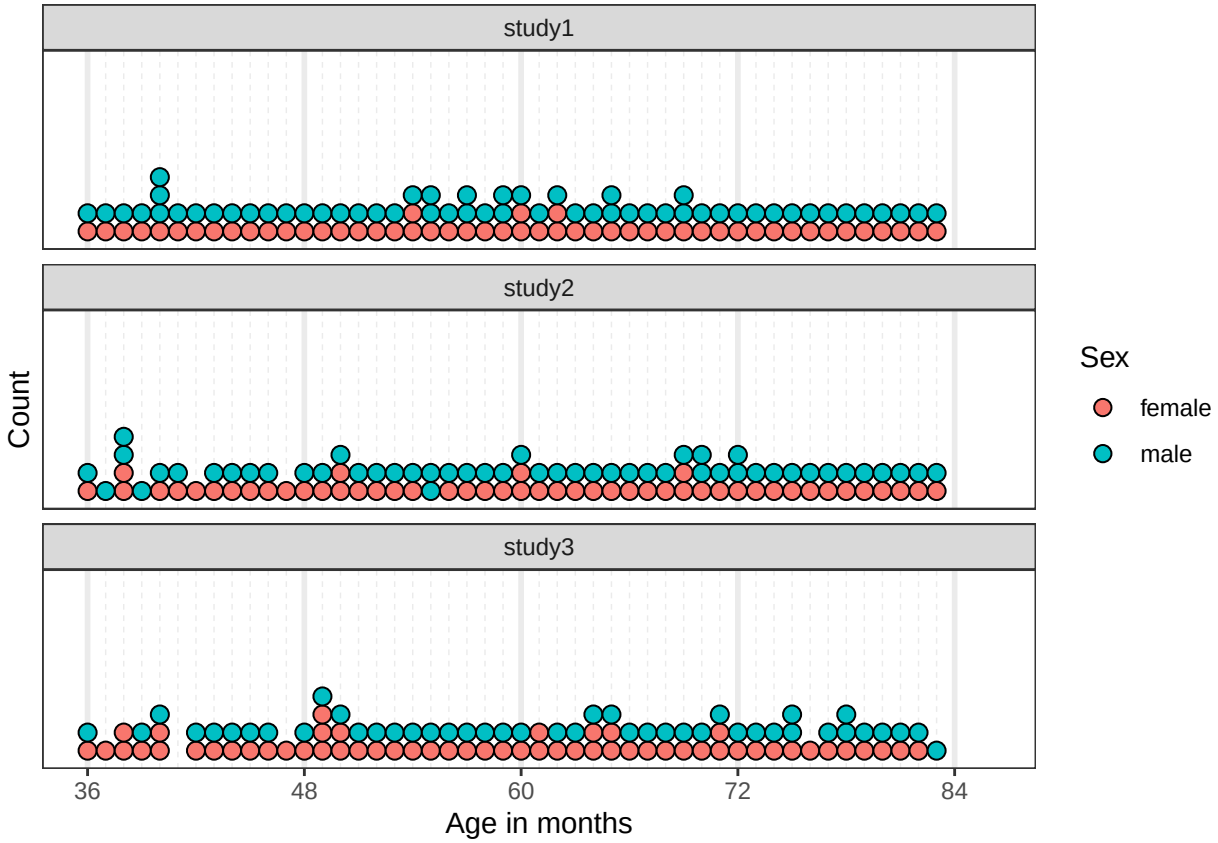

Figure A1. Illustration of participants across the age range.

The total number of participants in all three studies comprises XX children. In addition, XX children were tested but not included in the data set due to XXXXXXXX. For an overview of how the respective exclusions are distributed across the age range, please see figure A2. Exclusions due to low performance during familiarization occured almost exclusively between the third and fourth birthday. All other exclusion criteria appear to be randomly distributed across the age range.

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## Warning: The ‘size‘ argument of ‘element_line()‘ is deprecated as of ggplot2 3.4.0.
## i Please use the ‘linewidth‘ argument instead.
## This warning is displayed once every 8 hours.
## Call ‘lifecycle::last_lifecycle_warnings()‘ to see where this warning was
## generated.
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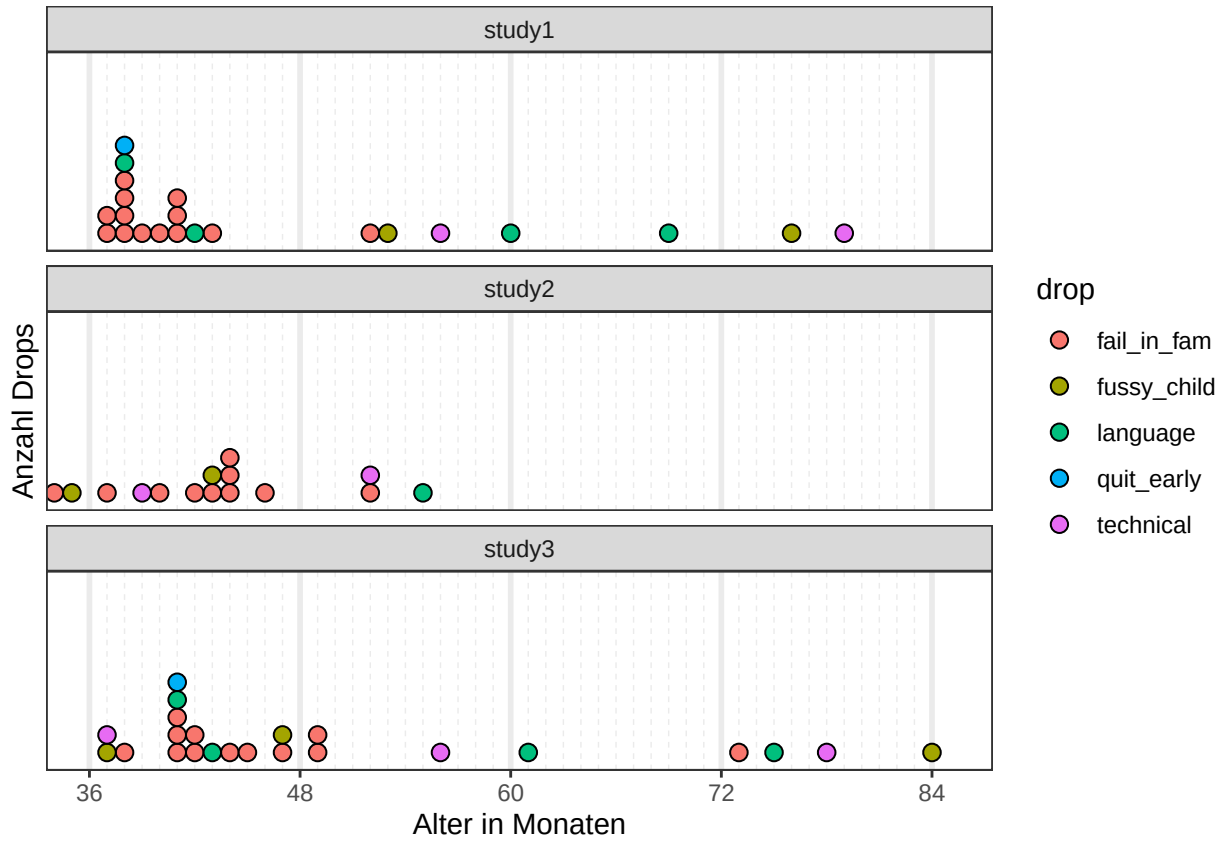

Figure A2. Illustration of exclusions across the age range.

Appendix B

Stimulus Material

Additional Tables and illustrations for the convenience of the reader. Add illustrations they said; it will add value they said.

Study 1

Additional Tables and illustrations for the convenience of the reader. Add illustrations they said; it will add value they said.

Some graphic

Figure B1. Check this out

Study 2

Additional Tables and illustrations for the convenience of the reader. Add illustrations they said; it will add value they said.

Some graphic

Figure B2. Check this out

Study 3

Additional Tables and illustrations for the convenience of the reader. Add illustrations they said; it will add value they said.

271 **Some graphic**

Figure B3. Check this out

Appendix C

Descriptive Statistics

Additional Tables and illustrations for the convenience of the reader. Add illustrations they said; it will add value they said.

Study 1

Additional Tables and illustrations for the convenience of the reader. Add illustrations they said; it will add value they said.

Study 2

Additional Tables and illustrations for the convenience of the reader. Add illustrations they said; it will add value they said.

Study 3

Additional Tables and illustrations for the convenience of the reader. Add illustrations they said; it will add value they said.