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

2   domain

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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

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

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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65 ~~dolor sit amet.~~ For the first time, the studies contributing to this paper investigate

66 ~~children's understanding of xxx.~~

67 *Hypotheses.* ~~Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam~~

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74 ~~dolor sit amet.~~

Methods

76 All three studies presented here share the same methods and analyses. For

77 convenience, common aspects of the procedure, participant recruiting and stimulus design

78 are reported first before discussing the individual studies respectively.

General Methods

80 **Setup and Data Collection.** In order to trace the development of children's

81 symbolic competence continuously across the preschool years, data collection aimed at

82 testing two children per month of age between the third and the seventh birthday for a

83 total 96 participants while euqally balancing male and female participants. As children

84 participated on the basis of availability and data collection was done by several

85 experimenter teams visiting different institutions in parallel, the resulting final samples

86 slightly exceed this preregistered minimum sample size. The final sample approximate an

equal distribution of male and female participants and while aligning with conventions in the field, by providing at least 24 participants per condition and year of age.

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. Children were tested in day- and afterschoolcare for the most part, and occasionally in the lab or at home. The studies were reviewed and approved by an internal ethics committee at the **MASKED FOR REVIEW**. Data collection took place from June 2022 to February 2023.

During test sessions, one child and an experimenter sat down together to play a picture-book-style hiding game presented on a touch-screen laptop. Verbal instructions were played back by the experimental script. Experimenters supervised children during data collection an assisted with a fixed set of verbal prompts when necessary. Test sessions always took place in a quiet separate room. See figure 1 for an illustration of the setup.

Procedure. *Familiarization.* Experimenters invited children to join a hiding game and to follow the narration of the story. First, the presentation introduced a cartoon monkey. This character then placed two barriers on the bottom left and right side of the screen. After holding up a banana, one of the barriers was lifted, the banana was placed there and the barrier was lowered to conceal the banana. Children were now prompted to touch the hiding place and in doing so the barrier of their choice was lifted to reveal the banana if they chose correctly. Hence to succeed here, children solely had to remember where the item went and touch this part of the screen after a few seconds. The experimental script provided immediate feedback upon children's choice ("yes, great job!"; "No, that's not it. Let's try again!") during the familiarization. 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

but their data was not submitted to analysis. These children are reported below as failing

the familiarization phase.

Test phase. The main phase of the study commenced with announcing that the

cartoon character had an idea for a new game. The narration conveyed that children were

not allowed to see where the banana would be hidden, but that the monkey would help

them find it. Hence, the cartoon character was established as a partner in a cooperative

coordination game. The hiding sequence was identical to the familiarization phase, however

the placement of the banana was concealed by a barrier over the lower half of the screen

and the two hiding places displayed different graphical shapes in the same colour. The

monkey then held up piece of paper and a pencil. Pencil movement and a short scribble

sound indicated that the monkey was drawing something. Children were reminded that the

monkey was going to help them. Children were now prompted with the phrase "Where is

the banana?" and the monkey's drawing was placed in the center between the two barriers.

The drawing now served as a cue to guide children's choice. In the most basic experimental

condition in study one, each hiding places, for example, showed either a solid blue circle or

square and the paper displayed a simple outline drawing of either shape. Here, the drawing

was a direct representation of the target shape. Crucially, however, children received only

neutral feedback upon making a choice ("Ah, thank you") and there was no reveal

animation. The game simply continued with the next round in which two new hiding

places with different shapes were displayed, and hiding sequence was repeated as before.

Except for the geometric shapes displayed on the hiding places and the respective

drawing, the experimental representation was identical for all test trials. A single trial

lasted roughly 30 to 60 seconds, depending on how swiftly children chose. Each study

presented four different experimental conditions with four trials each in a blocked order for

a maximum of 16 test trials. Children occasionally wished to stop before completing all

trials, resulting in minor deviations of the total number of trials per condition that are submitted to analyses. Children that did not complete a minimum of eight test trials were not submitted to analysis and are reported below. The entire test session lasted about 12 minutes.

Stimuli and Experimental Manipulations. 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 choices were recorded by the experimental script and directly coded as correct or incorrect. Exclusions of data were solely made on the level of participants with regard to the exclusion criteria reported above. The analyses modeled participants' binary choices to predict the probability of children interpreting the cues correctly and to model how this probability would change as a function of their age. Logistic Bayesian generalized linear mixed models (GLMM) fitted children's responses (0/1) as a function of their age, the experimental condition and an interaction between trial and condition. Trial and sex were included as fixed effects to be controlled for. Trial number was added as a random slope within subject. To evaluate the relevance of age and condition for children's performance, a full model was compared with a reduced model lacking the interaction of age and task by using WAIC scores and weights (McElreath, 2016). Furthermore, model estimates were inspected for the different predictors (including their 95% Credible Interval (CrI)). In each study, the most simple condition was set as the reference level within conditions. All Bayesian models used default priors and were run in Stan (http://mc-stan.org/) via the function brm of the package brms (Bürkner, 2017).

To answer the main research question of when children performed above chance in any of the study's conditions, we use the models to predict the developmental trajectory

167 (with 95% CrI) for each condition (expected values of the posterior predicted dist via fct

168 fitted). The criterion for settling when children passed criterion as a group was the point at

169 which the 95% CrI for a particular trajectory did no longer overlap with a midline

170 demarcating the 50% chance level.

171 To further explore the data, participants were binned according to their age in years.

172 To test whether group-level performance was above chance in all experimental groups, we

173 used two-tailed one-sample t-tests with the chance level set to .5. We provide Cohen's d as

174 a standardized effect size for significance testing (computed via the function `cohensD`).

175 - deviation from preregistration

176 - elpd_diff ist neu und zusätzlich

177 - most simple condition als reference ...warum

178 - bezeichnung output fitted function –> wie macht brms die confidence intervalle um

179 die mittelwerte –>

180 - "expected value of the posterior predicted distribution"

181 **Study 1**

182 **Participants.** A sample of 106 children (M = 59.18 months, SD = 13.58 months,

183 range 36 - 83 months; 51 female) participated in study 1. In addition, 22 children (11

184 female) were tested but excluded from analysis for not succeeding during familiarization (N

185 = 13), for not completing at least eight out of 16 test trials (N = 1), or due to being fussy

186 (N = 2). For 4 children, experimenters only learned during testing that children were not

187 fluent enough in German to participate as their families had only recently migrated.

188 Finally, 2 children had to be excluded due to technical issues. For a graphical and tabular

189 overview of participants and exclusions across all three studies presented here, please see
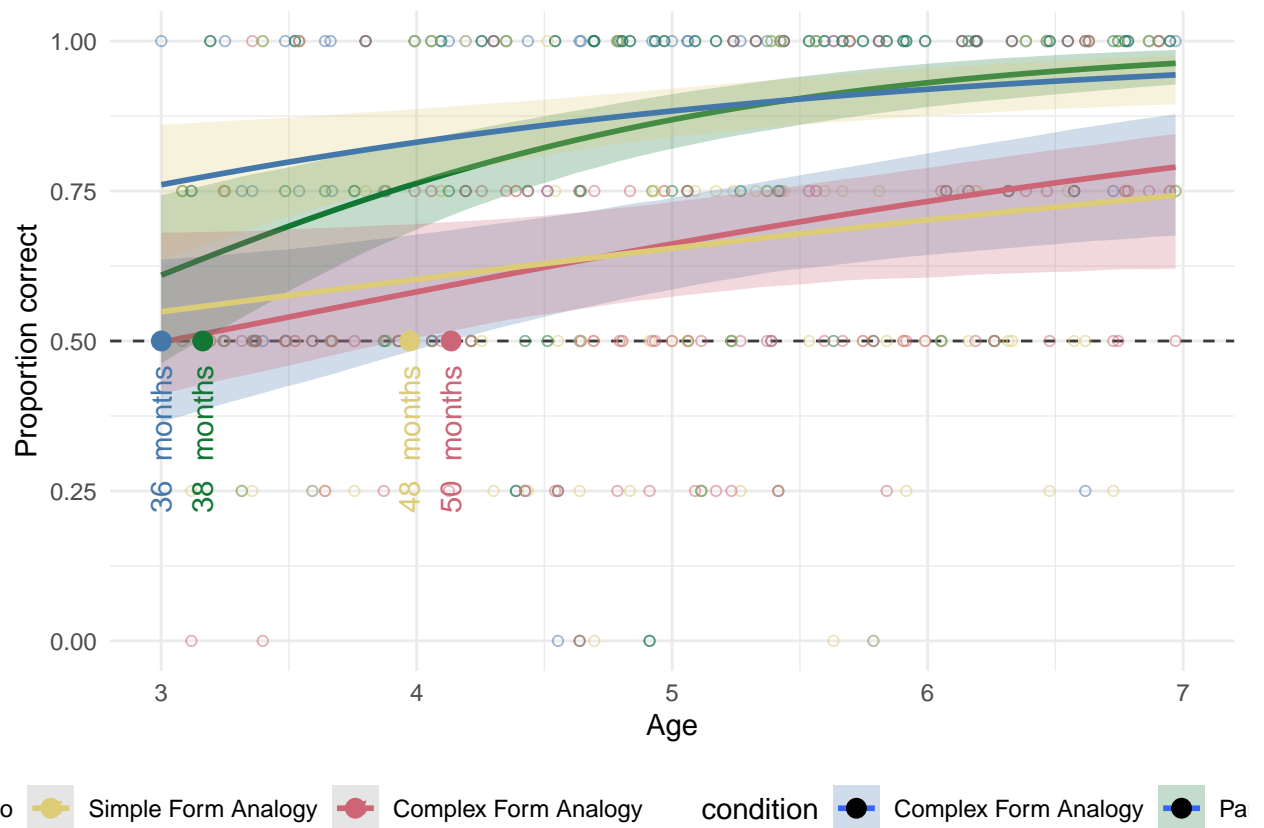
190 Appendix A.

191 **Stimuli.**

192   **Analyses.**   A total of 1688 trials (mean per condition = 422, range: 420 - 424) from

193   106 participants were submitted for analysis. The full model notation was

194   $'correct\ condition * z.age + z.trial + sex + (z.trial|subid)'$. In addition, a null model

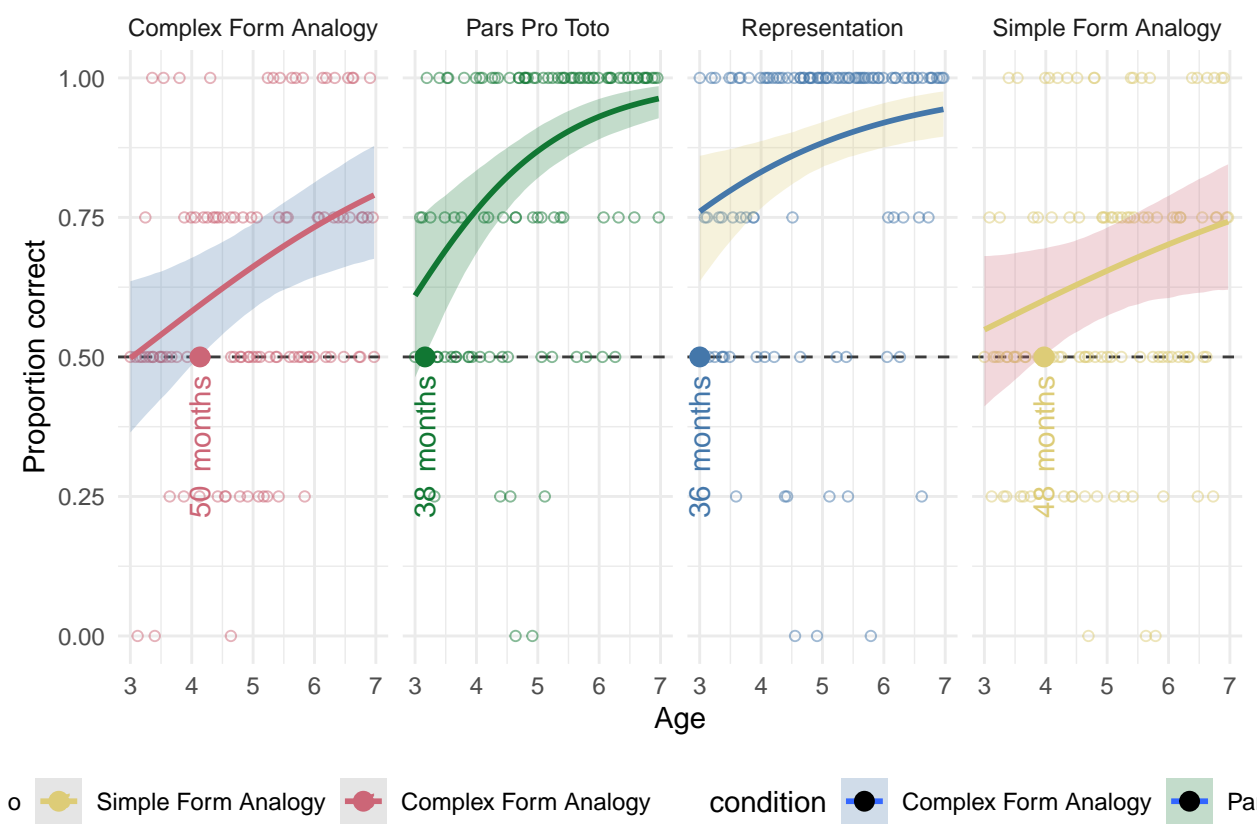195   lacking the interaction of condition and age was fitted.

196   **Results.**   Posterior predictive checks for both full and null model indicated excellent

197   fit of observed data and model predictions (see supplements for more information).

198   Comparing the models using weights based on the Widely Applicable Information Criterion

199   (WAIC) yielded 76.06% of the model weight for the full model, and 23.94% for the null

200   model. Hence, the full model generally has a higher probability of making accurate

201   predictions. Directly comparing the models' WAIC via expected log predictive density

202   (ELPD) corroborates this (ELPD WAIC; full model = -901.65; null model = -904.26). The

203   standard error of the difference in predictive accuracy (3.15), however is lower than the

204   difference itself (-2.61). While the full model slightly exceeds in predictive power, evidence

205   in favor of this model is not decisive. A similar comparison via Leave-One-Out

206   Cross-Validation (LOO) provided essentially the same results. In absence of conclusive

207   evidence for either model, we report the results for the full model below in line with the

208   preregistration.

209   Relative to the *Representation* condition, the *Simple Form Analogy* (beta = -1.39,

210   95% CI [-1.69, -1.10) and *Complex Form Analogy* (= -1.36, 95% CI [-1.67, -1.07) have a

211   considerably lower probability of correct responses. The *Pars Pro Toto* condition has no

212   clear difference from the reference condition (= -0.14, 95% CI [-0.48, 0.19). Interaction

213   terms between age and condition were not reliably different from zero. The developmental

214   curves for each condition have essentially similar trajectories.

215   Finally, by tracing when the lower bound of the 95% CrI exceeds the chance level of

216   50%, it is possible to report when children's group level performance exceeds chance level

217   and becomes robustly systematic in favor of the correct choice option. In study 1, children

218   perform above chance in the *Representation* condition as early as 36 months. Quickly after

219 at XX months, children succed in the *Pars Pro Toto* condition. In the more abstract

220 conditions *Simple Form Analogy* and Complex Form Analogy, preschoolers meet criterion

221 at 48 and 50 months respectively.

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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, 13 children (6 female) were tested but excluded from analysis for failing familiarization (N = 9), being fussy (N = 1), not being fluent in German (N = 1) or due to technical issues (N = 2).

236 **Materials.**

237 **Data analysis.** A total of 1561 trials (mean per condition = 390.25, range: 388 -

238 393) from 99 participants were submitted for analysis. The full model notation was

239 $'correct\ condition * z.age + z.trial + sex + (z.trial|subid)'$. In addition, a null model

240 lacking the interaction of condition and age was fitted.

241 **Results.**

242

Study 3

General note on the aim of the investigation

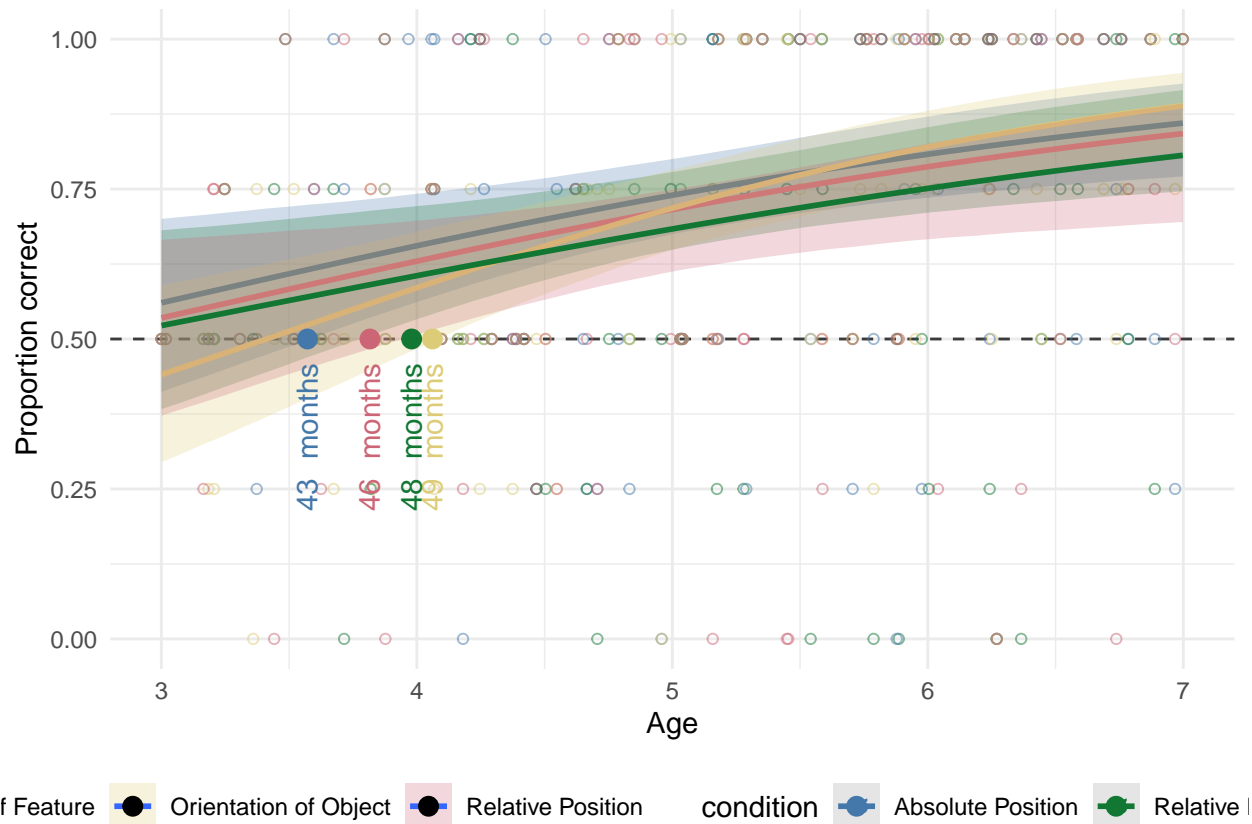**Participants.** A total of 99 three- to seven-year-old children (M = 59.88 months, SD = 13.44 months, range 36 - 83 months; 55 female) participated. In addition, 23 children (7 female) were tested but excluded for low performance during familiarization (N = 12), for not completing at least eight out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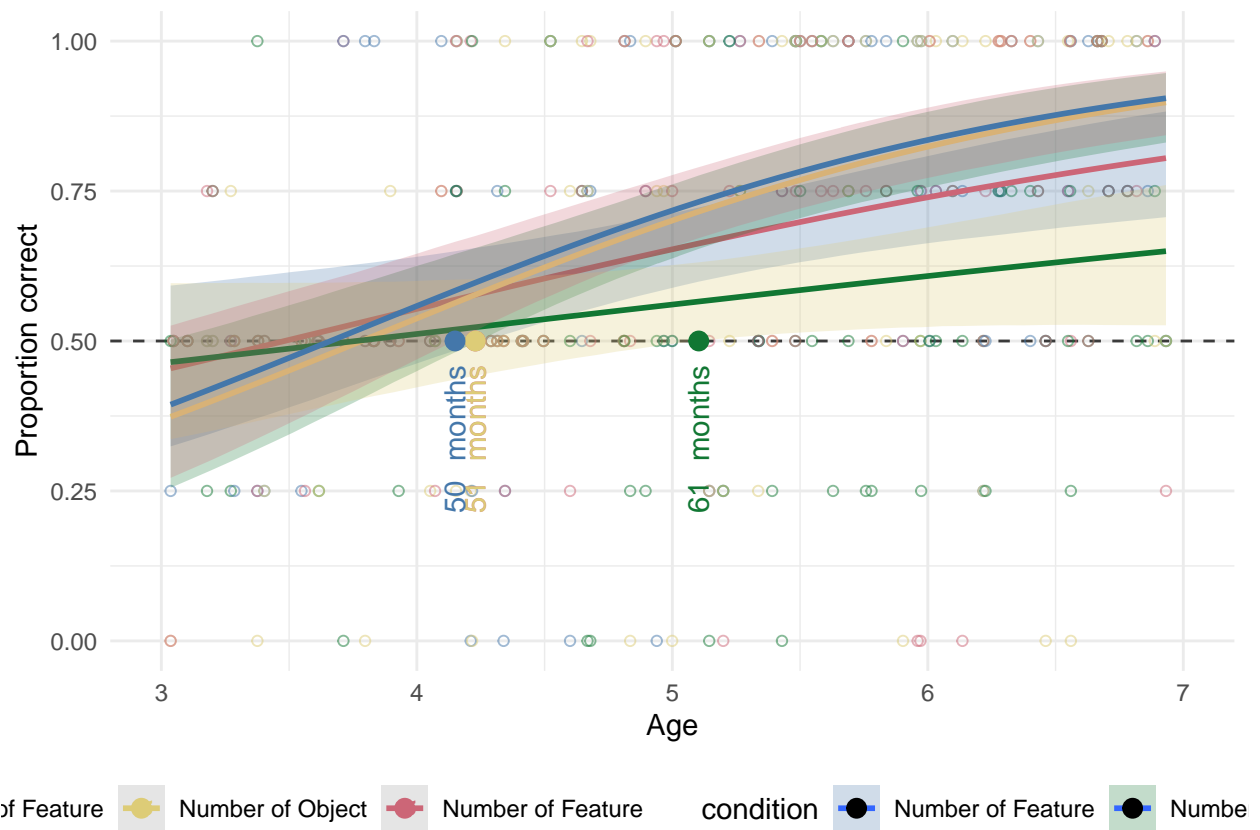
Materials.

Analysis. For study three, 1559 trials (mean per condition = 389.75, range: 388 - 392) from 99 participants were submitted for analysis. Data were analyzed both with a full model ($'correct\ condition * z.age + z.trial + sex + (z.trial|subid)'$) and a null model

255 lacking the interaction of condition and age.

256   **Results.**

257
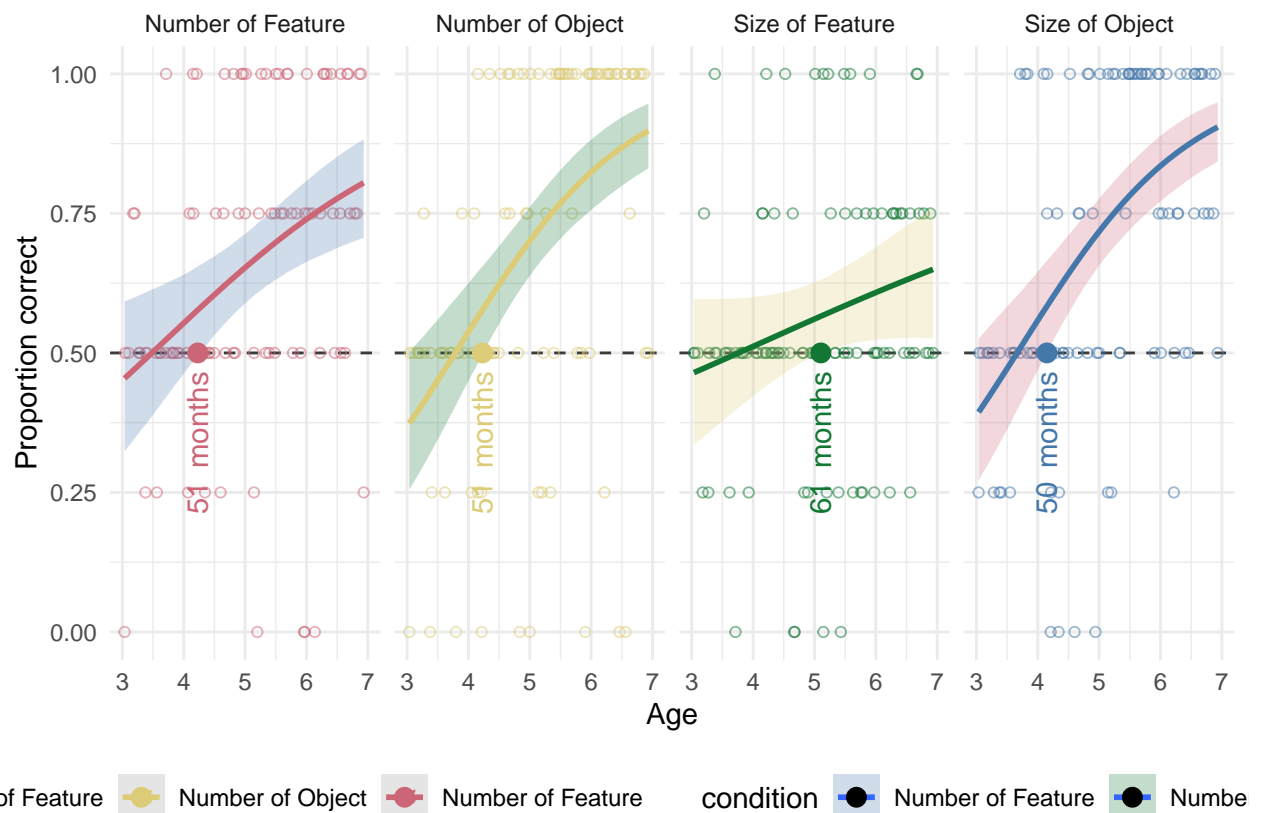
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Additional Analyses

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:

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

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

272 easier

273 Reaction Times just reaction times and perc correct across aged

General Discussion

275 Overview

276 Main Finding

277 Strengths and Implications

278 Limitations

Conclusion

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References

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

Figure 1. Illustration of setup. Experimenters were sitting behind the children in order to not distract them from the task and supervised data collection.

Appendix A

Participants and Exclusions

288 Data collection aimed at testing two children per month of age between the third and

289 seventh birthday for a minimum of 96 children per study. For an overview of the sample

290 distribution, please see figure A1.
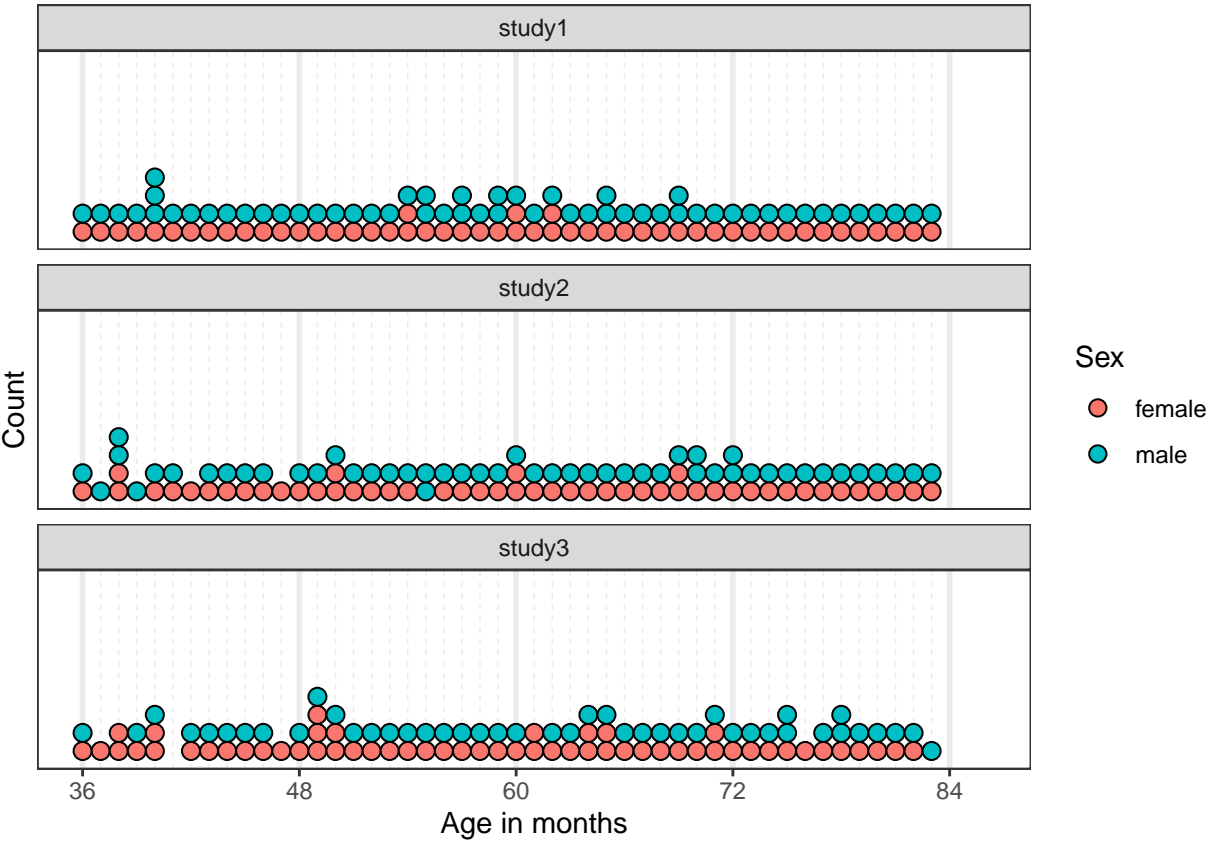
Figure A1. Illustration of participants across the age range.

291   The total number of participants in all three studies comprises XX children. In

292 addition, XX children were tested but not included in the data set due to XXXXXXXX.

293 For an overview of how the respective exclusions are distributed across the age range,

294 please see figure A2. Exclusions due to low performance during familiarization occured

295 almost exclusively between the third and fourth birthday. All other exclusion criteria

296 appear to be randomly distributed across the age range.

297 ## Warning: The `size` argument of `element_line()` is deprecated as of ggplot2 3.4.0.

298 ## i Please use the `linewidth` argument instead.

299 ## This warning is displayed once every 8 hours.

300 ## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was

301 ## generated.
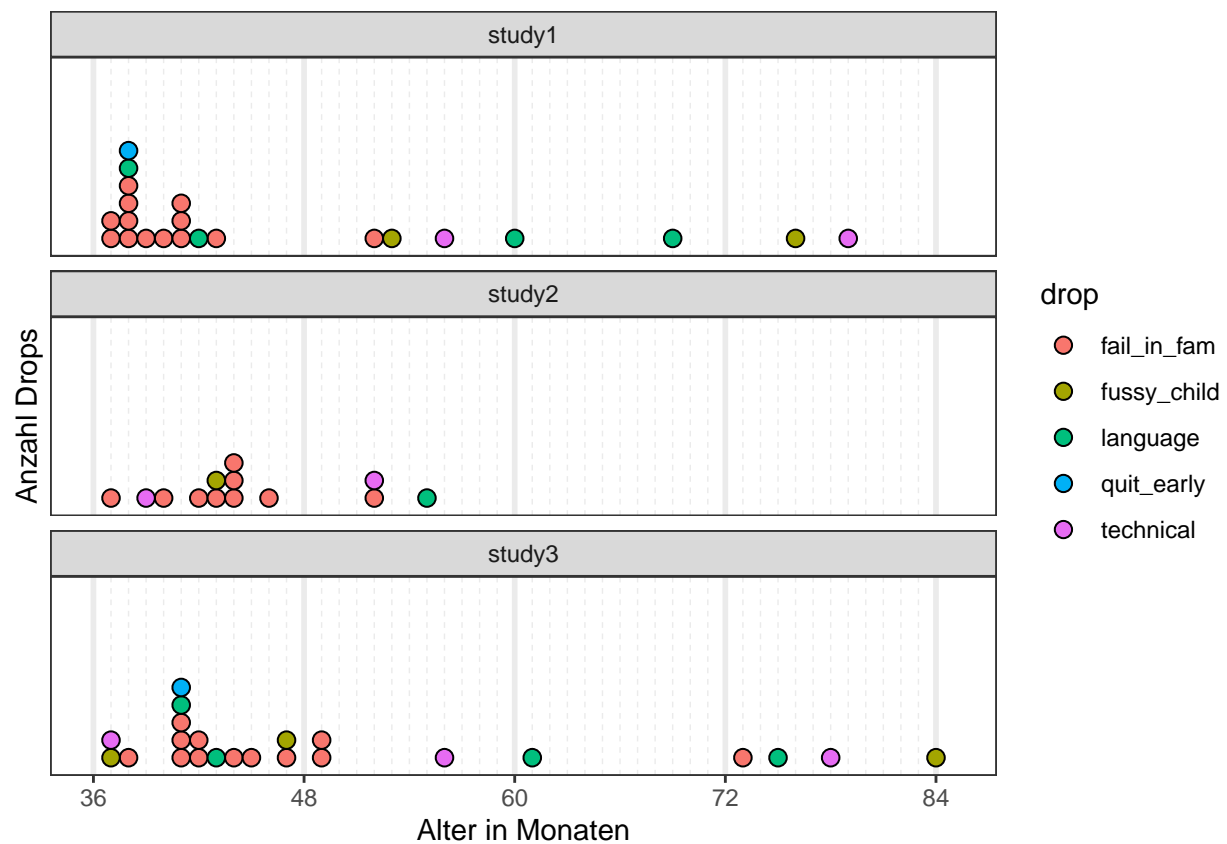
Figure A2. Illustration of exclusions across the age range.

Appendix B

Stimulus Material

302 Additional Tables and illustrations for the convenience of the reader. Add illustrations they

303 said; it will add value they said.

Study 1

305   Additional Tables and illustrations for the convenience of the reader. Add

306 illustrations they said; it will add value they said.

Some graphic

Study 2

309   Additional Tables and illustrations for the convenience of the reader. Add

310 illustrations they said; it will add value they said.

Some graphic

Study 3

313   Additional Tables and illustrations for the convenience of the reader. Add

314 illustrations they said; it will add value they said.

Some graphic

Figure B1. Check this out

Figure B2. Check this out

Figure B3. Check this out

Appendix C

Descriptive Statistics

316 Additional Tables and illustrations for the convenience of the reader. Add illustrations they

317 said; it will add value they said.

[tbp]

Table C1

Descriptive Statistics for Study 1

Condition	Age	N	trials	trials/N	M	SD	p	df	t(N-1)	d
Representation	3-year-olds	26	103	3.96	75.00	22.36	<0.001	25.00	5.70	1.12
	4-year-olds	28	109	3.89	81.25	33.07	<0.001	27.00	5.00	0.94
	5-year-olds	28	112	4.00	87.50	28.46	<0.001	27.00	6.97	1.32
	6-year-olds	24	96	4.00	87.50	20.85	<0.001	23.00	8.81	1.80
Pars Pro Toto	3-year-olds	26	104	4.00	66.35	22.30	<0.001	25.00	3.74	0.73
	4-year-olds	28	112	4.00	75.00	31.91	<0.001	27.00	4.15	0.78
	5-year-olds	28	112	4.00	85.71	21.97	<0.001	27.00	8.60	1.63
	6-year-olds	24	96	4.00	91.67	15.93	<0.001	23.00	12.82	2.62
Simple Form Analogy	3-year-olds	26	104	4.00	53.85	23.12	0.404	25.00	0.85	0.17
	4-year-olds	28	112	4.00	59.82	28.33	0.078	27.00	1.83	0.35
	5-year-olds	28	112	4.00	58.93	28.23	0.106	27.00	1.67	0.32
	6-year-olds	24	96	4.00	69.79	23.29	<0.001	23.00	4.16	0.85
Complex Form Analogy	3-year-olds	25	100	4.00	53.00	25.33	0.559	24.00	0.59	0.12
	4-year-olds	28	112	4.00	54.46	23.62	0.326	27.00	1.00	0.19
	5-year-olds	28	112	4.00	59.82	25.77	0.054	27.00	2.02	0.38
	6-year-olds	24	96	4.00	76.04	18.77	<0.001	23.00	6.80	1.39

Note. This table was created by Gregor.

Table C2

Descriptive Statistics for Study 2

Condition	Age	N	trials	trials/N	M	SD	p	df	t(N-1)	d
Absolute Position	3-year-olds	20	80	4.00	58.75	18.63	0.049	19.00	2.10	0.47
	4-year-olds	25	100	4.00	62.00	33.17	0.083	24.00	1.81	0.36
	5-year-olds	27	108	4.00	73.15	30.95	<0.001	26.00	3.89	0.75
	6-year-olds	25	100	4.00	81.00	29.12	<0.001	24.00	5.32	1.06
Relative Position	3-year-olds	22	88	4.00	54.55	21.32	0.329	21.00	1.00	0.21
	4-year-olds	24	96	4.00	59.38	26.39	0.095	23.00	1.74	0.36
	5-year-olds	27	108	4.00	68.52	34.39	0.010	26.00	2.80	0.54
	6-year-olds	25	100	4.00	76.00	34.97	0.001	24.00	3.72	0.74
Orientation of Object	3-year-olds	22	85	3.86	48.86	19.64	0.789	21.00	-0.27	0.06
	4-year-olds	25	100	4.00	57.00	25.54	0.183	24.00	1.37	0.27
	5-year-olds	27	108	4.00	75.93	24.50	<0.001	26.00	5.50	1.06
	6-year-olds	25	100	4.00	81.00	25.29	<0.001	24.00	6.13	1.23
Orientation of Feature	3-year-olds	21	80	3.81	55.95	28.40	0.348	20.00	0.96	0.21
	4-year-olds	25	100	4.00	67.00	28.61	0.007	24.00	2.97	0.59
	5-year-olds	27	108	4.00	65.74	34.77	0.027	26.00	2.35	0.45
	6-year-olds	25	100	4.00	79.00	33.60	<0.001	24.00	4.32	0.86

Note. This table was created by Gregor.

Table C3

Descriptive Statistics for Study 3

Condition	Age	N	trials	trials/N	M	SD	p	df	t(N-1)	d
Size of Object	3-year-olds	21	84	4.00	51.19	23.02	0.815	20.00	0.24	0.05
	4-year-olds	27	105	3.89	54.63	31.80	0.456	26.00	0.76	0.15
	5-year-olds	26	104	4.00	84.62	25.57	<0.001	25.00	6.90	1.35
	6-year-olds	24	96	4.00	78.12	22.50	<0.001	23.00	6.12	1.25
Size of Feature	3-year-olds	21	84	4.00	46.43	19.82	0.419	20.00	-0.83	0.18
	4-year-olds	26	104	4.00	51.92	23.37	0.678	25.00	0.42	0.08
	5-year-olds	26	104	4.00	56.73	32.06	0.295	25.00	1.07	0.21
	6-year-olds	24	96	4.00	62.50	19.50	0.005	23.00	3.14	0.64
Number of Object	3-year-olds	21	84	4.00	42.86	21.13	0.137	20.00	-1.55	0.34
	4-year-olds	27	108	4.00	61.11	30.49	0.069	26.00	1.89	0.36
	5-year-olds	26	104	4.00	72.12	34.88	0.003	25.00	3.23	0.63
	6-year-olds	24	96	4.00	83.33	32.69	<0.001	23.00	4.99	1.02
Number of Feature	3-year-olds	21	82	3.90	50.00	19.36	>0.999	20.00	0.00	0.00
	4-year-olds	27	108	4.00	62.96	24.39	0.010	26.00	2.76	0.53
	5-year-olds	26	104	4.00	65.38	31.68	0.020	25.00	2.48	0.49
	6-year-olds	24	96	4.00	76.04	27.07	<0.001	23.00	4.71	0.96

Note. This table was created by Gregor.

Appendix D

Model Diagnostics

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

Study 1

Model diagnostics were are provided for both full and null model in study 1. Rhat values in both models were equal to one, indicating convergence across all chains. Effective sample sizes for all fixed effects in the full model (Bulk ESS, mean = 2555, range 1760 - 3766) and the null model (Bulk ESS, mean = 2253, range 1706 - 3444) were > 1000, indicating reliable posterior estimations.

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.

Appendix E

Additional Analyses

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

Cue Level Models

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.