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.

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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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General notes Citing stuff. You have to make sure that the respective reference in included in the bib-file. I would also suggest to have two additional folders in the root, namely (1) papers to cite - where we can dumb pdfs, and (2) papers_cited. Whenever you are adding a new reference please put the citation in bibtex, name the pdf accorind to the bibtext id and add the pdf to the papers_cited folder. And this is how to cite something in markdown: 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.

Study 1

Methods

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study (Simmons, Nelson, & Simonsohn, 2012). Supplementary materials document all pilots that were run and the specific conclusions we drew from them during the development of the study. Both supplements and main article are fully reproducible manuscripts (Aust & Barth, 2022) providing all data and analyses.

Participants. We collected age as a continues predictor aiming to test two children per month of age between the third and seventh birthday.

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**.

ALL STUDIES Data collection took place from June 2022 to February 2023.

In addition, XX children were tested but not submitted to the final sample for not succeeding in familiarization trials (N = XX), for not completing at least eight out of 16 test trials (N = XX), or due to being fussy (N = XX). All excluded children were younger than 36 months of age.

Procedure and Setup. 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.

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. Children are expected to succeed in at least 4 familiarization trials in

a row in order to move to the main test. Familiarization would continue for a minimum of four and a maximum of eight trials. The familiarization ensured that all participants were familiar with the aim of the game and that E was able to read participants' responses.

*Test phase.*The main phase of the study commenced with E 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 geometric shape, namely a circle in the *marker condition* and an equilateral triangle in the *arrow condition*. E narrates "Coco is going to help you find the banana. In the arrow condition, the monkey places the triangle in a central position pointing to either the left or right target. In the marker condition, the monkey places the circle directly on the left or right target. After the placement, children are asked"where is the banana?". 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 a maximum of 16 test trials half of which in either condition. 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 15 minutes. See figure XXX for an illustration of the setup.

Materials. 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 analysis. 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.

Results.

```
## Warning in geom_text(data = p1, aes(label = months, x = days/364.25, y = 0.24,
## : Ignoring unknown aesthetics: fill
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## Warning in geom_text(data = p1, aes(label = "months", x = days/364.25, y =
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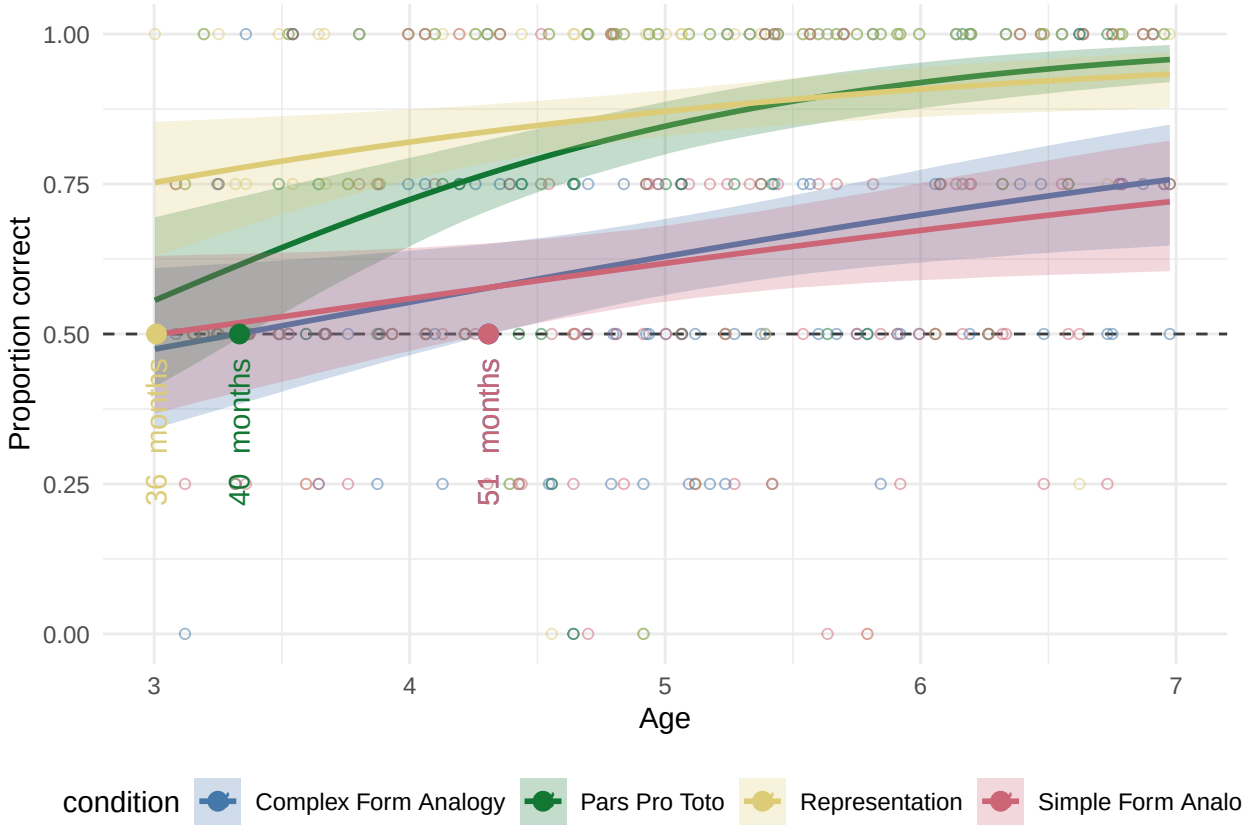


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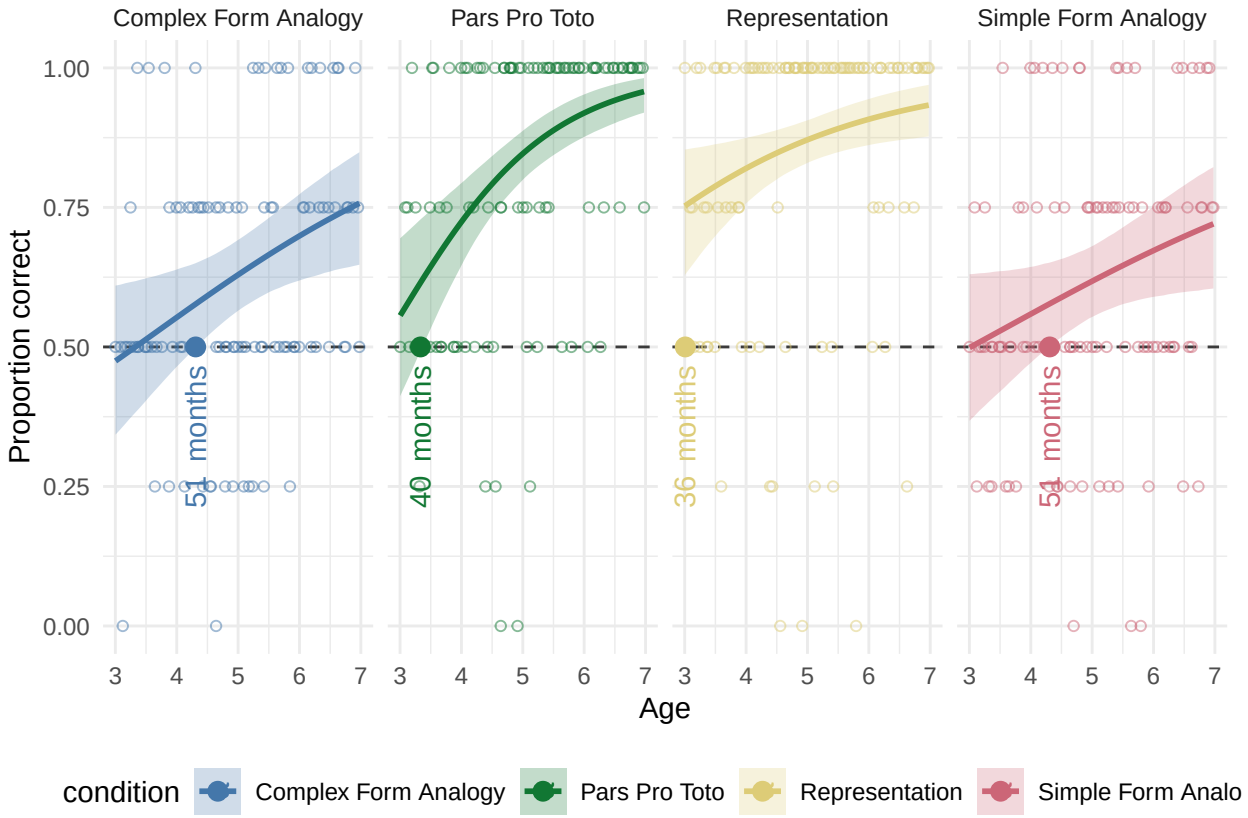

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Study 2

Methods

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study (Simmons et al., 2012). Supplementary materials document

all pilots that were run and the specific conclusions we drew from them during the development of the study. Both supplements and main article are fully reproducible manuscripts (Aust & Barth, 2022) providing all data and analyses.

Participants.

Procedure and Setup.

Materials.

Data analysis.

Results.

Study 3

Methods

Participants.

Procedure and Setup.

Materials.

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General Discussion

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Conclusion

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Figure 1. Illustration of setup.