

1 **Title** Rooms Without Walls: Young Children Draw Objects But Not Layouts
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27 As specified in the text, the design, protocol, and analysis plan for this study were preregistered
28 prior to data collection on the Open Science Framework. The procedural materials, data, and
29 analysis code are publicly accessible at: osf.io/5wng2
30

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32

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34

Abstract

35 Drawing is an epitome of uniquely human expression, with few known limits beyond
36 those of our perceptual and motor systems and the cultures in and for which we draw. The
37 present study evaluates whether the drawings of young children nevertheless reveal an early
38 emerging bias in the depiction of two different foundational spatial categories: layouts and
39 objects. Across two experiments following preregistered designs and analysis plans, 4-year-old
40 children either sat in a colorful “fort” or looked at a small “toy” version of the fort and were
41 asked to draw exactly what they saw. Children’s drawings often omitted the walls composing the
42 fort’s layout but included the corresponding object-part information for the toy. Symbolic
43 representations of space in young children’s drawings thus privilege small-scale objects over
44 large and fixed layout geometry. A distinction between the intuitive geometries of layouts and
45 objects leads to their differential treatment in both humans and other animals during everyday
46 navigation. This distinction may also underlie the differential treatment of layouts and objects in
47 children’s drawings.

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48 As a form of human expression, drawing may seem limited only to that which we can
49 see, whether in the world or in the mind's eye. Sure, our limited perceptual and motor systems
50 must constrain our drawing in some ways, especially in children, and so do trends or traditions of
51 culture and history (see Nadal & Chatterjee, 2018). But under these constraints, when asked to
52 draw what we see, we should be otherwise free to do so. The present study evaluates whether the
53 drawings of young children nevertheless reveal an early emerging bias in the depiction of layouts
54 and objects.

55 Collections of children's spontaneous drawings suggest that young children tend to draw
56 mostly individual objects or collections of objects, not the extended environment that constitute a
57 scene's layout (e.g., Machón, 2013; Piaget & Inhelder, 1967). Many studies aiming to
58 understand trends in such drawing production nevertheless present children with only objects to
59 draw (e.g., Bremner & Batten, 1991). It is thus unclear whether children's object-focused
60 drawings in such experiments are a result of specific task demands. Even work aiming to
61 examine children's depiction of layouts has sometimes relied on children's depictions of objects.
62 For example, one representative study probing children's depiction of depth in the layout
63 explored where children drew objects in an otherwise empty space: When 5- to 10-year-old
64 children were asked to draw 2 apples, one behind the other, the youngest children tended to draw
65 the apples side-by-side, while children who were slightly older drew them vertically, and the
66 oldest children overlapped them (Freeman, Eiser, & Sayers, 1977). While these kinds of
67 experiments are able to chart development in children's use of spatial cues about objects in the
68 layout, they do not bear on the question of whether and how children depict the layout itself.
69 Some studies have directly probed children's drawing of layout information, for example,
70 by asking children to draw both layouts and objects: from memory (e.g., Kriendel & Intraub,

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71 2017; Lewis, 1990); from photographs (e.g. Cox & Littleton, 1995); or from scale models (e.g.,
72 Ebersbach, Stiehler, & Asmus, 2011; Lange-Küttner, 2014). In these studies, layouts and objects
73 nevertheless differed in a variety of visual features, such as shape, texture, and complexity. Of
74 such different approaches to elicit layout drawings, moreover, only the use of scale models
75 required children to perform the geometric translation of a 3D space on to a 2D piece of paper.
76 Despite being contextualized as navigable spaces, the 3D model spaces were still not themselves
77 navigable layouts. Their visual features were at least as consistent with small, manipulable
78 objects as with large, navigable layouts, and prior work has shown that young children can treat
79 such models either as objects or as layouts (e.g., DeLoache, Miller, & Rosengren, 1997).

80 The different approaches of such previous studies notwithstanding, they nevertheless
81 suggest not only that children often omit layout information from drawings but also that, when
82 drawn, layouts are much less geometrically rich than objects. For example, Ebersbach et al.
83 (2011) found that in a group of over 100 5- to 9-year-old children who were asked to draw a
84 table-top 3D model of a barn scene, more than 90% of children drew no elements composing the
85 model's layout (e.g., its ground). Lange-Küttner (2014) found that in a group of around 60 7- to
86 10-year-old children who were asked to draw several table-top 3D models of a field with 5
87 plastic figurines, a smaller but still significant percentage of children (around 22% on average)
88 drew no layout elements (whereas only one child did not include all 5 figurines), and an
89 additional 20% on average drew the field simply as a horizontal line on the paper.

90 Despite these clear and consistent trends, no studies have directly tested whether children
91 prioritize their drawing of objects over layouts. Across two experiments, the present study thus
92 evaluates whether children preferentially draw objects over layouts based on their difference in
93 spatial category alone. Different groups of 4-year-old children were presented with either a 3D

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94 navigable “fort,” with layout and object information matching in shape and complexity
95 (Experiment 1), or a 3D manipulable “toy,” a 1/20 model of the fort (Experiment 2). In both
96 experiments, children were asked to draw exactly what they saw. By measuring the number and
97 geometric richness of the walls and objects that children drew in the fort and by comparing these
98 counts and spatial dimensions to those measured on drawings of the corresponding object-part
99 configurations of the toy, this study directly tests whether children prioritize objects over layouts
100 in drawings. If children do, then such findings would raise a host of possible cognitive, cultural,
101 or developmental factors that might be driving such a bias.

102

Experiment 1

104 Methods

105 Participants.

106 Thirty-two 4-year-old children ($M_{age} = 4.50$, range = 4.03 - 4.99; 15 girls) completed 4
107 drawings of a “fort” arranged in different configurations. One additional child participated but
108 did not meet the preregistered inclusion criteria because of experimenter error during data
109 collection. The sample size was chosen in advance of data collection, was based on pilot data in
110 which patterns of responding were consistent across small numbers of children, and was
111 preregistered on the Open Science Framework (OSF). Data collection stopped when the
112 preregistered number of participants was determined to meet the inclusion criteria. Participants
113 were recruited from the New York City area, and the use of human participants for this study
114 was approved by the Institutional Review Board on the Use of Human Subjects at New York
115 University.

116 Materials and Procedures.

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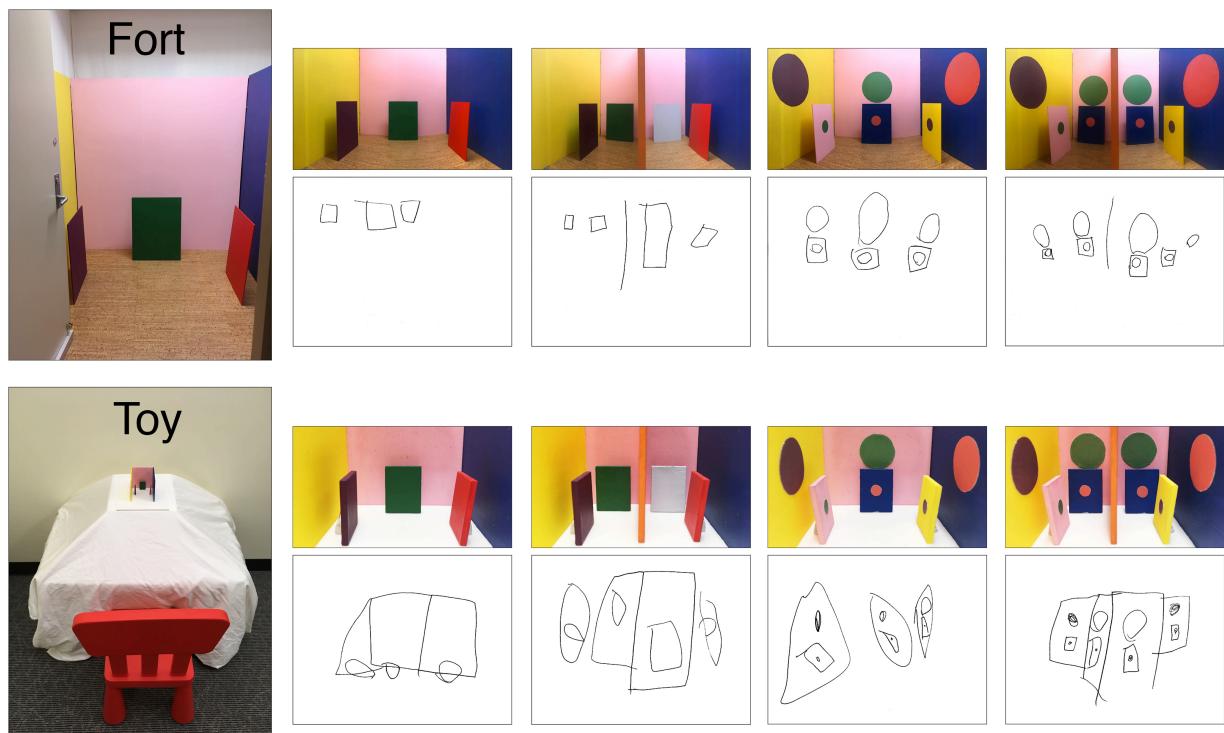
117 Children were presented with 4 configurations of a colorful “fort” (**Fig. 1**). Two
118 configurations included 2 rectangular side walls (1.68 m x 2.13 m) and one rectangular back wall
119 (1.68 m x 1.60 m), with one rectangular object (60.96 cm x 45.72 cm) in front of each wall. Two
120 configurations included an additional fourth wall (1.68 m x 1.07 m), orthogonally bisecting the
121 back wall, with one rectangular object in front of each side wall and one on either side of the
122 bisecting wall. This fourth, dividing wall was included for two main reasons. First, it allowed for
123 multiple drawings from the same individual child across multiple fort configurations, leading to
124 more statistical power for the analyses. Second, the dividing wall’s position, as the front-and-
125 center-most element, introduced configurations in which a wall was in front of all objects and
126 was in the center (in the 3-wall configurations, the objects were front-and-center). Pilot data
127 revealed no effects of this dividing wall on the relative number of wall and object elements that
128 children drew, and so the preregistered analysis treated these 3-wall and 4-wall configurations as
129 all probing children’s drawing of walls and objects in a layout more generally (see **SM** for a
130 post-hoc analysis of the dividing wall; as in the pilot data, it also yielded no effects). One 3-wall
131 and one 4-wall configuration also included flat circular “decals” placed in the center of each wall
132 (diameter = 53.34 cm) and object (diameter = 15.24 cm). Configurations with decals were also
133 included to allow for multiple drawings from the same individual child, increasing power, as
134 well as to incorporate additional types of spatial elements against which to evaluate children’s
135 drawing of layout and object information. A planned analysis of the 2 configurations that did not
136 include decals was consistent with the main analysis, which included all 4 configurations, and so
137 is reported in the **SM**.

138 Fort configurations were presented in a semi-counterbalanced order to children:
139 Configurations with or without decals were always paired, but order was otherwise fully

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140 counterbalanced. The exterior room in which the fort was set up was covered with opaque white
141 fabric to block any of its salient attributes. In addition, a white drop ceiling was installed to cover
142 all but a plain, central light fixture. Two cameras were mounted above the door.

143 Children sat on a black “X” on the floor, 15.24 cm from the fort’s opening and centered.
144 They viewed the fort from about 50 cm off the ground (the height of their eyes while sitting), and
145 the back wall of the fort subtended 44.69 degrees of visual angle in the vertical direction and
146 44.12 degrees of visual angle in the horizontal direction. These visual properties of the fort and
147 the child’s position in it, along with the fort’s size, which was large enough for the child to
148 comfortably walk around in, thus presented visual cues consistent with it being a navigable
149 space, its intended spatial category.



150
151 **Fig. 1.** Photographs of the context and configurations for the fort (Exp. 1, top row) and toy (Exp.
152 2, bottom row). A sample set of one child’s drawings from each experiment are included below
153 each set of photographs to illustrate the study’s main finding that children tend to leave out the
154 layout information in their drawings but include all shape-defining features of objects in their
155 drawings.
156

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157 Children entered the fort with two experimenters (one primary experimenter and one
158 coder) and first completed a practice trial in which they were asked to use a pencil and US-letter-
159 sized piece of white paper to draw exactly what they saw (after Lewis, Russell, & Berridge,
160 1993), but nothing more, from a laminated US-letter-sized piece of paper that depicted 16
161 colorful forms of various shapes and sizes arranged in a quasi-symmetrical layout (for practice
162 trial picture and full experimental script, see **SM**). When children indicated that they had
163 completed the practice drawing, they received instructive feedback: The experimenter went
164 through every element in the practice picture and asked children to point to that element in their
165 own drawing. If an element was missing, the experimenter asked children to add it to their
166 drawing, reiterating that children should draw exactly what they saw. If there were extra
167 elements, the experimenter reiterated to children that they should only draw what they saw and
168 nothing more.

169 The first test trial began immediately after the practice trial. The experimenter waved
170 their hand across the space and said, “See how we’re in this super cool fort? I’m going to give
171 you another piece of paper, and your job is to draw exactly what you see.” Children were given a
172 clipboard with US-letter-sized piece of white paper and a pencil to complete their drawing. As in
173 the practice trial, children were asked to indicate when they were done, and there was no time
174 limit. Unlike the practice trial, children received no informative feedback.

175 After children indicated that the drawing was complete, the coder took a photograph of
176 the drawing with an iPad and followed the preregistered coding procedure. First, the
177 experimenter asked children to point to each individual element in their drawing, and the coder
178 outlined each element on the corresponding iPad photograph with a stylus. If there were isolated
179 lines or closed shapes that children did not point out, the experimenter asked, “Is there anything

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180 else?" If children did not indicate any further elements, the experimenter pointed to the missing
181 element(s), saying, "Is this something else?" If children indicated that the missing element was
182 not an element or was a mistake, the element was not outlined or included as part of the final
183 drawing. Second, the experimenter asked children to identify each of the outlined elements by
184 touching them in the fort. To do so, the experimenter touched one element directly on the
185 drawing and asked, "Can you go touch it to show me what you drew?" The experimenter
186 repeated this procedure for each outlined element. The coder recorded the element in the fort that
187 children touched by annotating the photograph (see **SM** for the full set of coded drawings). If
188 children at that point indicated that an element they had already individuated was a mistake, that
189 element was coded as having an indeterminate referent. If children wanted to add something to
190 their drawing after the coding had begun, they were allowed to, but such elements were not
191 coded. After this procedure, children exited the testing space, and the room was re-configured for
192 the next test trial. This procedure was repeated for the next 3 test trials.

193 **Analysis.**

194 All analyses were specified prior to data collection and preregistered on OSF with one
195 change: Some analytic models had initially been specified with random-effects slopes as well as
196 random-effects intercepts (see **SM**); however, several of these models failed to converge, and so
197 random-effects slopes were dropped from all analyses. Two primary dependent variables were
198 defined. The first was the number of spatial elements that children drew according to 4
199 categories: walls; objects; wall decals; or object decals. Counts are bounded at zero, only take on
200 integer values, and are often heavily skewed. Mixed-model Poisson regressions were thus
201 planned and conducted. The findings were also robust to a mixed-model linear regression
202 framework; these regressions were conducted post-hoc and are reported in the **SM**. There were 3

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203 additional categories of elements, which were coded but not included in the analysis:
204 miscellaneous elements in the room (e.g., door handle); miscellaneous elements not in the room
205 (e.g., ice cream cone); and elements with an indeterminate referent (e.g., scribbles). The second
206 dependent variable was the dimensionality (1-, 2-, or 3-dimensional) of the spatial elements.
207 Dimensionality is on an ordinal scale and was thus analyzed with mixed-model ordinal logistic
208 regressions. The count and dimensionality variables were considered separately because they
209 focused on two different questions. The count variable focused on *whether* a child included a
210 particular element, and the dimensionality variable focused on *how* they depicted that element,
211 once included.

212 The data coding was also preregistered. The live-coding procedure, detailed above, was
213 the primary coding scheme. To determine the element count for each drawing, the coder simply
214 enumerated the total number of elements of each type per drawing. To determine the
215 dimensionality of each element, the coder judged whether each element was indicated by a single
216 line (1D), a closed frontoparallel figure (2D), or a closed figure with any judged amount of
217 perspective/recession of that figure into the picture plane, even if only the front surface of the
218 element was depicted (3D). Since both the wall and object elements of the fort appeared mostly
219 or entirely flat (see **Fig. 1**), their additional 3D surfaces were unlikely to ever be drawn. Because
220 inclusion of elements in perspective is typically not observed until children are much older (see
221 Lange-Küttner, 2014 for a review), moreover, few to no characterizations of elements being
222 drawn in 3D were expected.

223 Two additional coding schemes were implemented to evaluate the reliability and
224 robustness of the results. First, a second coder used the experimental videos to recode 25% of
225 children's drawings for their spatial element counts. The planned model for calculating coder

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226 reliability was misspecified (see **SM**), and so the reliability of these count data was calculated
227 using a measure of intraclass correlation (see Shrout & Fleiss, 1979). The coding reliability was
228 high ($ICC(1,1) = .97$, 95% CI [.96, .98]). Second, two hypothesis-naïve coders also coded the
229 drawings (coder 1 did all of the drawings; coder 2 did 25%). These naïve coders used
230 photographs of the fort from children's seated perspective to make their best guess as to the
231 identity and dimensionality of each spatial element in the original drawings. The planned
232 analyses for both element count and dimensionality were repeated on the entire set of naïve
233 coder 1's drawings, and the count reliability analysis evaluated how well naïve coder 2's coding
234 predicted naïve coder 1's. The results from this analysis are convergent with the results in the
235 main text, and so they are reported in the **SM**.

236

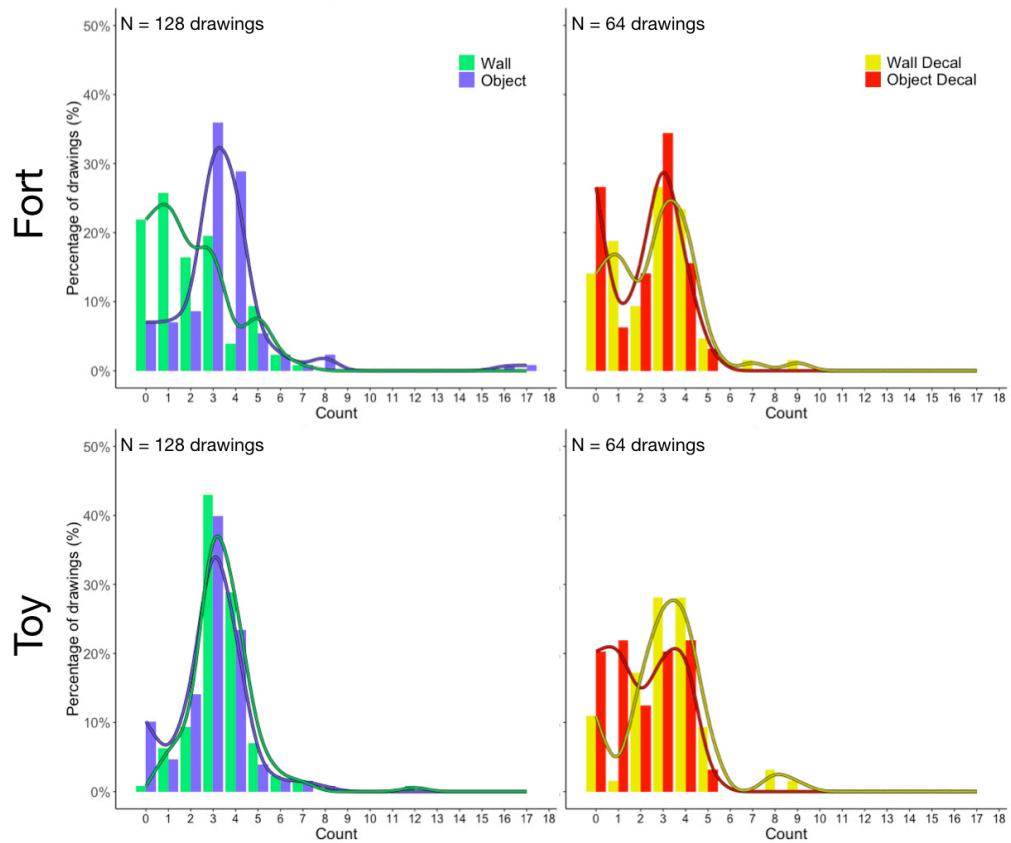
237 **Results**

238 **Element Count.**

239 The primary analysis examined the number of spatial elements that children drew. **Fig. 2**
240 presents the raw distributions of wall and object element counts across all 4 fort configurations
241 as well as the wall decal and object decal element counts across the 2 fort configurations that
242 included them. A mixed-model Poisson regression with spatial element (wall or object) and
243 configuration (each of the 4 configurations) included as predictor variables and participant
244 included as a random-effects intercept revealed main effects of both spatial element (Wald Test,
245 $\chi^2(1) = 45.90, p < .001$) and configuration (Wald Test, $\chi^2(3) = 12.76, p = .005$). As predicted,
246 children drew significantly more objects than walls (**Fig. 2**; **Fig. S1**), and children varied their
247 drawings based on the number of spatial elements present in each configuration (configurations
248 included 6, 8, 12, or 16 total elements, see **Fig. 1**). A second mixed-model Poisson regression

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249 with spatial element (wall, object, wall decal, or object decal) included as a predictor variable
 250 and participant included as a random-effects intercept, but considering only the two
 251 configurations that included decals (see **Fig. 1**), again revealed a main effect of spatial element
 252 (Wald Test, $\chi^2(3) = 25.45, p < .001$). Planned Holm-corrected pairwise contrasts also revealed
 253 that children drew significantly more objects than walls ($p < .001$; **Fig. 2**; **Fig. S1**).



254

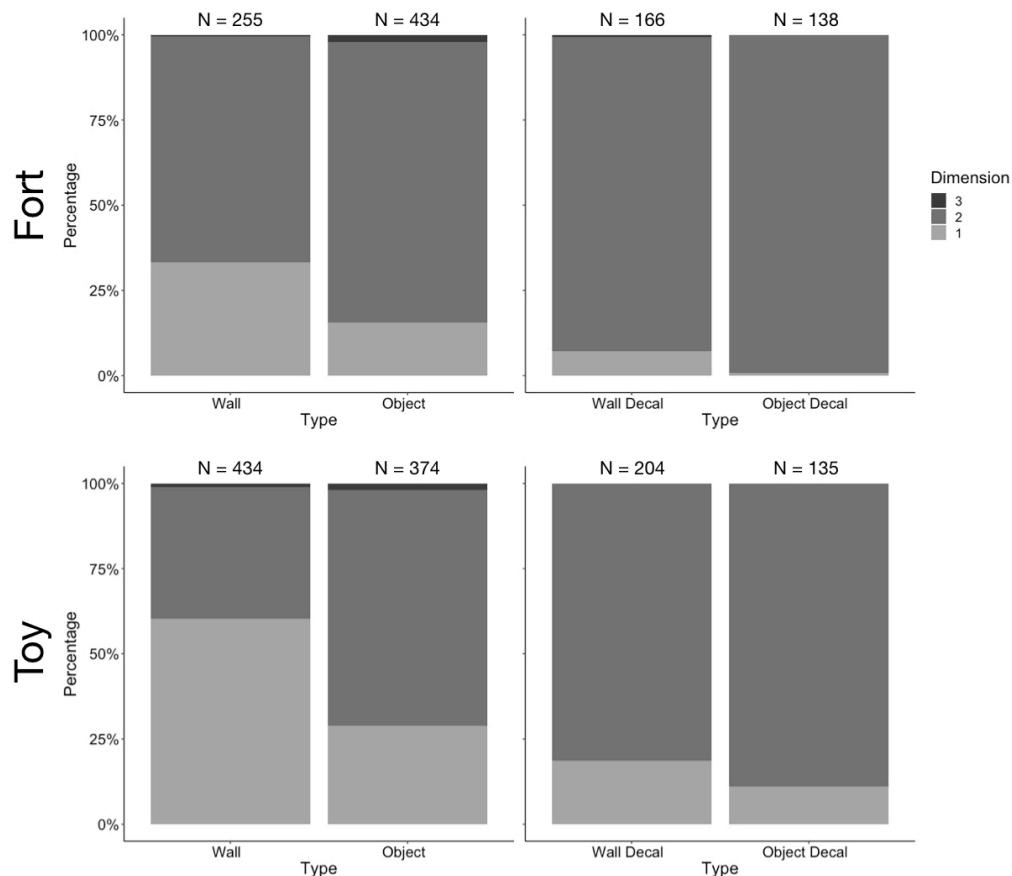
255 **Fig. 2.** The raw counts of spatial elements for the fort (Exp. 1, top) and toy (Exp. 2, bottom) for
 256 the 4 configurations in which there were walls and objects (left) and for the 2 configurations in
 257 which there were also wall decals and object decals (right). To illustrate the distribution of these
 258 counts, overlaid on each set of counts is a smooth curve, generated by a kernel regression on
 259 Count and Percentage. Across all configurations of the fort (see **Fig. 1**) the count distribution for
 260 walls is strikingly different from the count distributions for all of the other spatial elements, with
 261 wall counts peaking at 0-1 and all other element counts peaking at 3-4. In contrast, across all
 262 configurations of the toy the count distribution for walls is strikingly similar to those for all other
 263 spatial elements, with all element counts peaking at 3-4.

264

265 **Dimensionality.**

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266 The dimensionality of the spatial elements was then evaluated. A mixed-model ordinal
267 logistic regression with spatial element (wall or object) included as a predictor variable and
268 participant included as a random-effects intercept revealed that children drew objects with more
269 dimensionality than walls. The odds of children's drawing objects with greater dimensionality
270 were 270% more likely than the odds of children's drawing walls with greater dimensionality
271 (95% CI = [112, 544], $p < .001$, **Fig. 3**). For the two configurations with decals, the odds of
272 children's drawing objects with greater dimensionality were 247% more likely than the odds of
273 children's drawing walls with greater dimensionality (95% CI = [58, 661], planned Holm-
274 corrected pairwise contrast, $p = .002$, **Table S1A**).



275

276 **Fig. 3.** The percentages of spatial elements drawn at different dimensionalities for the fort (Exp.
277 1, top) and toy (Exp. 2, bottom) for the 4 configurations in which there were walls and objects
278 (left) and for the 2 configurations in which there were also wall decals and object decals (right).

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279 For both the fort and toy, children drew the walls with less dimensionality than the objects. The
280 Ns indicate the number of elements reflected in each bar.

281

282 **Discussion**

283 When told to draw exactly what they saw while sitting in a colorful fort, young children
284 primarily drew the objects in the fort, not the walls that composed its layout. This result was
285 particularly striking because the walls and objects were matched on many visual properties: all
286 elements were colorful, the same shape, the same texture, and presented in the same or similar
287 configurations. Nevertheless, children may have considered the walls to be mere background,
288 and children may, in general, prioritize figural as opposed to ground elements in their drawings,
289 regardless of whether those ground elements are or are not part of the navigable layout.

290 Experiment 2 thus evaluates whether such figure-ground relations might explain
291 children's omission of layouts in their drawings of the fort. In this experiment, children are asked
292 to draw a toy object that has the exact same figure-ground relations as the fort. If children draw
293 the toy without the object parts that correspond to the walls of fort, then selective drawing of
294 figural versus ground elements may also explain children's performance in Experiment 1. If, in
295 contrast, children draw the toy with the object parts that correspond to the walls of the fort, then
296 selective omission of layouts versus objects better explains children's performance in
297 Experiment 1.

298

299 **Experiment 2**

300 **Methods**

301 **Participants.**

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302 A different group of thirty-two 4-year-old children ($M_{age} = 4.49$, range = 4.02 - 4.98; 21
303 girls) from those children who completed Experiment 1 completed 4 drawings of a “toy”
304 arranged in exactly the same ways as the fort from Experiment 1. No children were excluded. As
305 in Experiment 1, the sample size and stopping rule were chosen in advance and preregistered on
306 OSF. Participants were recruited from the New York City area, and the use of human
307 participants was approved by the Institutional Review Board on the Use of Human Subjects at
308 New York University.

309 **Materials and Procedures.**

310 The toy in Experiment 2 mimicked the fort in Experiment 1 in materials and procedures.
311 A 3D-printed, plastic scale model of the fort at 1/20 the size, matching the fort exactly in color
312 and configuration, was created (**Fig. 1**). While all the parts of the toy were now “objects” and the
313 toy was always described as a toy (never as, e.g., a “model fort”), for ease of comparison, the
314 parts of the toy that correspond to the walls of the fort are referred to as “walls” and the parts of
315 the toy that correspond to the objects in the fort are referred to as “objects” throughout the
316 remainder of this paper.

317 Children entered the testing room with two experimenters (one primary experimenter and
318 one coder) and sat in a child-sized chair at a small table. The experimenter sat at the table,
319 orthogonal to the children, and the coder stood behind children to one side. The toy was on top of
320 the table, positioned 30.48 cm from children and at their eye level, with the back wall of the toy
321 subtending 11.46 degrees of visual angle in the vertical direction and 10.89 degrees of visual
322 angle in the horizontal direction. These visual properties of the toy and the child’s position
323 outside of it, along with the toy’s size, which was small enough for the child to comfortably
324 grasp with their hands, thus presented visual cues consistent with it being a manipulable object

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325 with different parts, its intended spatial category. The toy was covered with opaque white fabric
326 as children entered and left the room so that they did not see the toy from an overhead
327 perspective. The table, as well as the side walls of the room, were also covered with opaque
328 white fabric to cover any of the room's salient features. One camera was placed behind children,
329 and one was placed next to the experimenter.

330 Children completed the same practice trial as in Experiment 1 and then moved on to the
331 test trials, which were presented in the same semi-counterbalanced order as in Experiment 1. For
332 the test trials, the experimenter waved their hand in front of the toy and said, "Do you see this
333 super cool toy? I'm going to give you another piece of paper, and your job is to draw exactly
334 what you see." The coder and experimenter followed the preregistered coding procedure from
335 Experiment 1. The only difference was that in Experiment 2 children used a long plastic pointer,
336 instead of their hands, to indicate the identity of each element of their drawing since the setup
337 was small.

338 **Analysis.**

339 All analyses were specified prior to data collection and preregistered on OSF. As in
340 Experiment 1, random effects slopes were dropped from all analytic models. Reliability of the
341 coding of the number of spatial elements that children drew was calculated as intraclass
342 correlation coefficient, and reliability was high ($ICC(1,1) = .89$, 95% CI [.85, .92]). As in
343 Experiment 1, the dependent variables included the number of spatial elements that children
344 drew and the dimensionality of those elements. Additional analyses directly compared the results
345 of the two experiments to evaluate whether children drew more objects versus walls for the fort
346 versus toy.

347

348 **Results**349 **Element Counts.**

350 **Fig. 2** presents the raw distributions of wall and object elements across all 4 toy
351 configurations as well as the wall decal and object decal elements across the 2 toy configurations
352 that include them. In a first mixed-model Poisson regression examining wall and object counts
353 across all 4 configurations of the toy, there were main effects of both spatial element (Wald Test,
354 $\chi^2(1) = 4.45, p = .035$) and configuration (Wald Test, $\chi^2(3) = 12.41, p = .006$). While there was a
355 prediction of no difference in the spatial element count, children showed the opposite pattern for
356 the toy in Experiment 2 compared to the fort in Experiment 1: Children drew more walls than
357 objects (**Fig. 2**; **Fig. S1**). In the regression considering the configurations with all 4 element
358 types, there was also a main effect of spatial element (Wald Test, $\chi^2(3) = 25.93, p < .001$), and
359 planned Holm-corrected pairwise contrasts also revealed that children drew more walls than
360 objects ($p = .005$; **Fig. 2**; **Fig. S1**). Indeed, while children clearly drew more objects than walls in
361 the fort condition, their drawing counts in the toy condition may have roughly reflected the
362 relative real-world sizes of each of the element types. That said, in the analysis of the
363 configurations without decals and the analysis of the data coded by the naïve coder, the greater
364 counts for walls versus objects was less consistent than in the main analysis (see **SM, Fig. S2-**
365 **S3**), so this size-based effect may be weak.

366 **Dimensionality.**

367 The next analysis measured the dimensionality of the spatial elements. Unexpectedly,
368 children drew objects with more dimensionality than walls, as in the fort condition. The odds of
369 children's drawing objects with greater dimensionality were 1824% more likely than the odds of
370 children's drawing walls with greater dimensionality (95% CI = [982, 3321], $p < .001$, **Fig. 3**).

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371 This effect persisted when just examining the two configurations with decals: The odds of
372 children's drawing objects with greater dimensionality were 897% more likely than the odds of
373 children's drawing walls with greater dimensionality (95% CI = [446, 1723], planned Holm-
374 corrected pairwise contrast, $p < .001$, **Fig. 3, Table S1B**).

375 Comparing Children's Drawings of the Fort and Toy.

376 *Element Counts.*

377 To directly examine the differences in children's drawings across the two experiments,
378 the same mixed-model regressions were conducted as above, but with experiment as an
379 additional predictor variable. First, for element count, including walls and objects across all 4
380 configurations, there were main effects both of spatial element (children drew more objects than
381 walls; Wald Test, $\chi^2(1) = 8.55, p = .003$) and of experiment (children drew more elements for the
382 toy versus the fort; Wald Test, $\chi^2(1) = 7.44, p = .006$). Critically, these results were further
383 characterized by a significant spatial element by experiment interaction (Wald Test, $\chi^2(1) =$
384 $41.44, p < .001$): Children drew significantly more walls than objects for the toy versus fort.
385 Planned Holm-corrected pairwise contrasts revealed that children did not draw significantly
386 more objects for the toy versus fort ($p = .082$), but they did draw significantly more walls for the
387 toy versus fort ($p < .001$). The second regression, examining element counts in the two
388 configurations with 4 spatial elements also revealed main effects of both spatial element (Wald
389 Test, $\chi^2(3) = 17.79, p < .001$) and experiment (Wald Test, $\chi^2(1) = 5.06, p = .024$) as well as an
390 interaction between these variables (Wald Test, $\chi^2(3) = 33.40, p < .001$). Again, planned Holm-
391 corrected pairwise contrasts revealed that children did not draw significantly more objects for the
392 toy versus fort ($p = .188$), but they did draw significantly more walls for the toy versus fort ($p <$
393 $.001$).

394 ***Dimensionality.***

395 Finally, a mixed-model ordinal logistic regression examining element dimensionality for
396 walls and objects across all 4 configurations revealed that, across experiments, children drew
397 objects with more dimensionality than walls (percent changes in odds ratio: 211%, 95% CI =
398 [106, 369], $p < .001$). Children also drew elements with greater dimensionality for the fort versus
399 toy (percent changes in odds ratio: 77%, 95% CI = [65, 84], $p < .001$), and children drew objects
400 versus walls with greater dimensionality for the toy versus fort (percent changes in odds ratio:
401 127%, 95% CI = [32, 288], $p = .003$). The model including all 4 element types across 2
402 configurations was convergent with these results. Children drew objects with greater
403 dimensionality than walls (percent changes in odds ratio: 201%, planned Holm-corrected
404 pairwise contrast, 95% CI = [60, 466], $p < .001$), and their drawings had greater dimensionality
405 for the fort versus toy (percent changes in odds ratio: 82%, 95% CI = [68, 89], $p < .001$).
406 Children also drew objects versus walls with greater dimensionality for the toy versus fort
407 (percent changes in odds ratio: 170%, planned Holm-corrected pairwise contrast comparing
408 walls and objects in the fort and toy conditions, 95% CI = [19, 512], $p = .053$).
409

410 **Discussion**

411 In this experiment, children were asked draw exactly what they saw while sitting in front
412 of a colorful toy with figure and ground elements that matched the fort from Experiment 1.
413 Young children drew the toy's parts that corresponded both to the fort's objects and to the fort's
414 walls. These results suggest that children's omission of layout information from their drawings in
415 Experiment 1 was not attributable to the more general spatial phenomenon that children include
416 figural but not ground elements in their drawings.

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417 Children's drawings in Experiment 2 did nevertheless shed light on some additional
418 spatial phenomena that might affect children's drawings, like the real-world sizes of what is
419 being drawn and the arrangements of the parts of what is being drawn (e.g., whether the
420 background elements form a concave shape). Children's inclusion of spatial elements for the toy
421 roughly corresponded to their relative real-world sizes: The toy's walls, its largest elements,
422 were drawn most frequently, while the toy's object decals, its smallest elements, were drawn
423 least frequently. This size effect was not present in Experiment 1, however, so it is not
424 generalizable across spatial contexts (otherwise children would have drawn the fort's walls most
425 frequently as well). When children did draw the walls for the fort, their depictions showed some
426 similarities to children's depictions of the walls for the toy: In both experiments, children tended
427 to draw the walls with less dimensionality than the objects. While this result was not predicted, it
428 may have been due to the more general challenge of drawing concave backgrounds, present in
429 both spatial contexts. Indeed, these results (with background information being depicted with
430 less dimensionality) are consistent with other studies using 3D toy models as tests of children's
431 layout depictions (e.g., Lange-Küller, 2014). The results of Experiment 2 thus suggest that while
432 there may have been some limited effects of more general spatial phenomena such as real-world
433 size and background concavity on children's drawing, the predominant effect is that children
434 often omitted the walls composing the fort's layout but included the corresponding object-parts
435 for the toy.

436

General Discussion

438 Decades of work exploring young children's drawings suggest a prevalence of object
439 depictions (e.g., Cox, 2005; Gardner, 1980; Machón, 2013; Piaget & Inhelder, 1967). The

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440 present study tested this suggestion across two experiments by comparing in young children's
441 drawings the frequency and richness of large, fixed layout information and small, manipulable
442 object information using stimuli matched on shape, complexity, and spatial arrangement. When
443 drawing a layout, children tended to juxtapose objects and omit extended boundaries. When
444 drawing a toy replica of the layout, in contrast, children captured all of the elements, including
445 those in the background. These findings are based on a difference in spatial category alone and
446 so are the first to show clearly that young children's drawings prioritize objects over layouts.

447 Why do children draw objects but not layouts? One possibility is that basic differences in
448 the way not only children, but also adults and non-human animals, attend to layouts and objects
449 for everyday navigation might affect what and how children draw. While humans and other
450 animals use layout information automatically to determine their position in space (e.g., Cheng &
451 Gallistel, 1984; Cheng & Newcombe, 2005; Hermer & Spelke, 1994; 1996; Spelke & Lee,
452 2012), they must attend to and learn associations between their position in space relative to
453 distinct landmark objects (e.g., Barry & Muller, 2011; Doeller & Burgess, 2008; Doeller et al.,
454 2008; Shusterman, Lee, & Spelke, 2011; Twyman, Friedman, & Spetch, 2007). This same
455 dissociation of automaticity and attention to layouts and objects is also evident in children's
456 symbol-guided navigation, like their navigation by maps and pictures (Dillon, Huang, & Spelke,
457 2013; Dillon & Spelke, 2015; 2017). Objects also elicit attention in many everyday contexts
458 (e.g., Evans, Rotello, Li, & Rayner, 2009; Scholl, 2001), and heightened attention to objects as
459 individuated entities as opposed to mere spatial extents is present from infancy (e.g., Feigenson
460 & Carey 2005; Feigenson, Carey, & Hauser, 2002). Moreover, objects serve as the referents for
461 infants' earliest symbolic learning: language. Infants first learn the names for objects (Gentner,
462 1982; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), and they use language to

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463 generalize object categories based on shape and function from as early as 6 months of age
464 (Fulkerson & Waxman, 2007; Futó, Téglás, Csibra, & Gergely, 2010). Because drawings, like
465 language, are symbolic, intentional, and communicative (see Callaghan & Corbit, 2015) they too
466 may prioritize those elements in the environment that naturally elicit our explicit attention.

467 Another, not mutually exclusive possibility, is that children prioritize objects over layouts
468 in drawings because layouts pose unique geometric challenges to drawing. In particular, the
469 geometry of a scene's large-scale layout may be more difficult to draw than the shapes of small-
470 scale objects. Layout navigation tends to rely on the distances and directions of large boundary
471 surfaces (e.g., Julian, Keinath, Marhcette, & Epstein, 2018; Lee, Sovrano, & Spelke, 2012;
472 O'Keefe & Burgess, 1996; Persichetti & Dilks, 2016), while recognition of objects tends to rely
473 on the relative lengths and angles that define small object parts (e.g., Biederman & Cooper 1991;
474 Smith, 2009). Drawing distance or depth information on a 2D surface is difficult in general (e.g.,
475 Kosslyn, Heldmeyer, & Locklear, 1977), as perhaps exemplified in the present study by
476 children's tendency to depict the concave shape formed by the walls of the fort and the
477 corresponding object-parts of the toy using only single lines. Since distance information is
478 primarily for layout navigation but not object recognition, however, the difficulty in capturing
479 large-scale layout distances as small-scale shapes on a 2D surface may be particularly
480 challenging. For objects, in contrast, the very same small-scale shape information is used both to
481 recognize objects in everyday life and to draw them on a 2D surface (Fan, Yamins, & Turk-
482 Browne, 2018; Sayim & Cavanaugh, 2011). Indeed, while by age 3 to 4 years children can
483 capture object shape information in their drawings (e.g., Cox, 2005; Drake & Winner, 2012;
484 Villarroel & Ortega, 2017), children have difficulty incorporating receding depth information
485 into their drawings through early adolescence (e.g., Freeman, 1980; Willats, 1995). To most

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486 easily convey the layout of a scene, children may thus merely juxtapose objects in drawings,
487 giving a nevertheless reasonable sense of the layout's general arrangement. Future studies might
488 explore whether there are differences in the difficulty of drawing depth information that
489 describes layouts versus objects or whether, if children are asked to construct 3D models instead
490 of making 2D drawings, they still leave out layout elements. Future studies might also explore
491 whether, when children do draw layouts, they use other spatial cues to indicate depth, like size,
492 position, or overlapping, differently for layouts versus objects (e.g., Freeman et al., 1977; Lange-
493 Küttner, 1997).

494 Differences between the fort and the toy's spatial categories in the present study were
495 also reinforced in two different ways, through both visual cues and verbal descriptions: The fort
496 was a large navigable space that children could go inside, and the experimenter always referred
497 to it that way; the toy was small and manipulable by children's hands, and the experimenter
498 always referred to it that way. It may be that either of these methods of conveying spatial
499 category – through visual cues or through language – led to the observed pattern of results.
500 Future studies might examine the individual effects of these two manipulations by using different
501 language applied to the exact same visual stimulus (i.e., referring differently to the same 3D
502 space, 3D model, or even 2D photograph).

503 While drawings reflect complex causal interactions among cognition, culture, and
504 development, the aforementioned possibilities as to why children prioritize objects over layouts
505 in drawings suggest that intuitive geometries, shared by humans with other animals, may play a
506 previously unrecognized role in what and how humans draw. Such geometries may be an
507 additional cognitive constraint that informs a cultural expression. The tools and technologies we
508 humans have developed to aid our drawing of layout geometry might thereby belie the initial

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509 cognitive challenge of intuitively drawing layouts (e.g., Gombrich, 2000). The effects observed
510 in the present study might thus be especially evident in the drawings of young children, who
511 have been exposed to less formal art instruction and fewer examples of their culture's artistic
512 traditions, such as instruction to draw horizon lines in specific ways (Nand, Masuda, Senzaki, &
513 Ishii, 2014) or technological innovations, such as visual aids like pre-drawn spatial axes that
514 highlight the geometry of layouts for drawing (Lange-Küttner, 2009; 2014). Moreover,
515 anthropologists and art historians alike have noted the puzzling absence of explicitly drawn
516 layout information in adult human drawings from around the world dating from pre-history
517 (Clottes, 2008; Fritz, 2017; White, 2003). And even today, in the wake of cultural and
518 technological innovations that have facilitated our depiction of layouts, objects may still be
519 prioritized in the drawings of skilled adults. For example, an analysis of around 500 drawings
520 from children's books recently awarded the Caldecott Medal (for their illustrations) revealed that
521 only 2.5% of drawings included just layout information, while 7.2% of drawings included just
522 object information (a statistically significant difference; Dillon & Spelke, 2017). To examine the
523 host of factors that might be driving children to prioritize objects over layouts in drawings in the
524 present study, future studies could examine how both development and culture affect human
525 drawings of layouts and objects.

526 Finally, if intuitive spatial categories for layouts and objects shared with other animal
527 species affect human drawing, then other such basic categories might as well. For example, are
528 we more likely to pay attention to potential social partners over objects, and so depict people
529 more often than objects in our drawings? Or, are objects more likely to be drawn because we use
530 drawings to communicate to people about the properties and functions of objects? Might the
531 shapes of people and other biological kinds be easier to draw than shapes of some objects

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532 because their 3D geometry is easily recoverable from a set of skeletal exes (Feldman & Singh,
533 2006)? Future studies varying the content and geometry of drawing subject matter may begin to
534 address these questions. Likewise, varying the communicative intent of drawings, including what
535 information is important to the purpose of the drawing (e.g., to show someone *where* something
536 is or *what* something does), may shed light on what attentional hierarchies are present in
537 everyday life and translate to our picture-making.

538 While drawing may seem like an epitome of relatively unconstrained human expression,
539 especially in young children, the present study has revealed a clear, early emerging bias in
540 human drawing. Drawings prioritize a layout's small-scale objects over large-scale and fixed
541 layout geometry. Among the complex interactions of cognition and culture that explain this bias
542 in children's drawings, a previously unrecognized cognitive constraint deriving from
543 phylogenetically ancient but distinct cognitive domains for navigating layouts and recognizing
544 objects may also shape our art. To better understand an individual's artistic development or even
545 the history of art, we must better understand the cognitive constraints that frame human
546 drawings.

547

548

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Rooms Without Walls: Young Children Draw Objects But Not Layouts

Supplemental Material

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Supplemental Materials and Methods

For practice trial picture and full experimental script, see the OSF: osf.io/5wng2

Supplemental Data

For the full set of children's drawings, original and coded (by the first coder), see the OSF: osf.io/5wng2

Supplemental Analyses and ResultsReliability analysis

The preregistered analysis specified a mixed-model ordinal logistic regression, predicting coder 1's coding by coder 2's coding, for both count and dimensionality data. After data collection was complete, it became clear that this model for reliability was misspecified. Count reliabilities were thus conducted with intraclass correlation coefficients (see main text). Dimensionality reliabilities were thus evaluated only by the separate analysis of naïve coder 1's dimensionality data (see below).

Naïve coding and analyses

As planned, two hypothesis-naïve coders used photographs of the fort and toy to recode the count and dimensionality of the spatial elements that children drew in Experiments 1 and 2. The first naïve coder for each experiment recoded all of the drawings, and the analyses of the main text were repeated with the naïve-coded data. The second naïve coder recoded 25% of the drawings. The same reliability analysis was conducted between the first and second naïve coders as in the main text. The coding reliability for both experiments was moderate (fort: $ICC(1,1) = .76$, 95% CI [.67, .82]; toy: $ICC(1,1) = .73$, 95% CI [.64, .80]).

Experiment 1: Fort

A mixed-model Poisson regression with spatial element (wall or object) and configuration included as predictor variables, and participant included as a random-effects intercept, revealed main effects of both spatial element (Wald Test, $\chi^2(1) = 35.35, p < .001$) and configuration (Wald Test, $\chi^2(3) = 14.48, p = .002$). As in the main text, children drew more objects than walls (**Figures S2-S3**) and the number of elements they drew varied based on the fort configuration. When examining the configurations with decals, a second mixed-model Poisson regression with spatial element (wall, object, wall decal, or object decal) included as a predictor variable and participant included as a random-effects intercept revealed a main effect of spatial element (Wald Test, $\chi^2(3) = 15.42, p = .001$). Planned Holm-corrected pairwise contrasts also revealed that children drew significantly more objects than walls (**Figures S2-S3**).

A mixed-model ordinal logistic regression with spatial element (wall or object) included as a predictor variable and participant included as a random-effects intercept revealed that children drew objects with greater dimensionality than walls, as in the main text. The odds of children's drawing objects with greater dimensionality were 962% more likely than the odds of children's drawing walls with greater dimensionality (95% CI = [466, 1894], $p < .001$). For the two configurations with decals, the naïve coder did not rate any spatial elements as 3D. For this reason, the ordinal logistic regression model was no longer appropriate; a mixed-model binomial logistic regression with spatial element (wall, object, wall decal, object decal) as a predictor variable and participant included as a random-effects intercept revealed that children drew objects with greater dimensionality than walls (Planned Holm-corrected pairwise contrast, $P = .89$, 95% CI = [.83, .93], $p < .001$).

Experiment 2: Toy

A mixed-model Poisson regression with spatial element (wall or object) and configuration included as predictor variables and participant included as a random-effects intercept revealed a main effect of configuration (Wald Test, $\chi^2(3) = 15.37$, $p = .002$) but no main effect of spatial element (Wald Test, $\chi^2(1) = 0.16$, $p = .693$; **Figures S2-S3**). A similar analysis for the configurations with decals did reveal a main effect of spatial element (Wald Test, $\chi^2(3) = 12.29$, $p = .006$). Planned Holm-corrected pairwise contrasts did not find that children drew more walls than objects (**Figures S2-S3**). These results vary somewhat compared to the main analysis since that analysis found significantly greater counts of walls compared to objects in both regressions.

As in the main text, a mixed-model ordinal logistic regression revealed that children drew objects with greater dimensionality than walls. The odds of children's drawing objects with greater dimensionality were 1185% more likely than the odds of children's drawing walls with greater dimensionality (95% CI = [622, 2187], $p < .001$). This effect persisted when just examining the two configurations with decals: The odds of children's drawing objects with greater dimensionality were 396% more likely than the odds of children's drawing walls with greater dimensionality (Planned Holm-corrected pairwise contrast, 95% CI = [185, 763], $p < .001$).

Experiment 2: Comparing the Fort and Toy

To directly examine the differences in children's drawings across the two experiments, the same mixed-model regressions were conducted as above, but with experiment as an additional predictor variable. First, for element count, including walls and objects across all four configurations, there were main effects of both spatial element (children drawing more objects than walls; Wald Test, $\chi^2(1) = 18.40$, $p < .001$) and experiment (children drawing more elements for the toy versus fort; Wald Test, $\chi^2(1) = 5.95$, $p = .015$). Critically, and as in the main analysis, these results were further characterized by a significant spatial element by experiment interaction (Wald Test, $\chi^2(1) = 17.02$, $p < .001$): Children drew significantly more walls than objects for the toy versus fort. As in the main analysis, planned Holm-corrected pairwise contrasts revealed that children did not draw significantly more objects for the toy versus fort ($p = .774$), but they did draw significantly more walls for the toy versus fort ($p < .001$). The second regression, examining element counts in the two configurations with four spatial elements also revealed a main effect of spatial element (Wald Test, $\chi^2(3) = 8.52$, $p = .036$), but no main effect of experiment (Wald Test, $\chi^2(1) = 1.31$, $p = .253$). There was again a significant element type by experiment interaction (Wald Test, $\chi^2(3) = 19.12$, $p < .001$). Moreover, planned Holm-corrected pairwise contrasts revealed that children did not draw significantly more objects for the toy

versus fort ($p = 1.000$), but they did draw significantly more walls for the toy versus fort ($p = .014$).

Finally, a mixed-model ordinal logistic regression examining element dimensionality for walls and objects across all four configurations revealed that children drew objects with greater dimensionality than walls. The odds of children's drawing objects with greater dimensionality were 483% more likely than the odds of children's drawing walls with greater dimensionality (95% CI = [273, 813], $p < .001$). Children also drew elements with greater dimensionality for the fort versus toy: The odds of children's drawing elements with greater dimensionality for the fort were 62% more likely than the odds of children's drawing elements with greater dimensionality for the toy (95% CI = [43, 75], $p < .001$). The model did not reveal a significant dimensionality by experiment interaction (odds ratio = 0.88, 95% CI = [0.50, 1.56], $p = .662$). The model including all four element types across two configurations revealed that children drew objects with greater dimensionality than walls: The odds of children's drawing objects with greater dimensionality were 302% more likely than the odds of children's drawing walls with greater dimensionality (95% CI = [113, 654], $p < .001$). Children also drew elements with greater dimensionality for the fort versus toy: The odds of children's drawing elements with greater dimensionality for the fort were 67% more likely than the odds of children's drawing elements with greater dimensionality for the toy (95% CI = [42, 81], $p < .001$). The model did not reveal a significant element type by condition interaction (Planned Holm-corrected pairwise contrast, odds ratio = 1.17, 95% CI = [0.52, 2.64], $p = .714$).

Analysis of fort and toy configurations without decals

As part of the planned analyses, the spatial element (wall or object) counts and the dimensionality were examined in configurations without decals (**Figure 1**, first two configurations). The results are convergent with the results of the more comprehensive analysis (including all four configurations) reported in the main text.

Experiment 1: Fort

A mixed-model Poisson regression with spatial element (wall or object) included as a predictor variable and participant included as a random-effects intercept revealed a main effect of spatial element (Wald Test, $\chi^2(1) = 24.35$, $p < .001$). As in the main text, children drew significantly more objects than walls.

A mixed-model ordinal logistic regression examining element dimensionality for walls and objects in configurations without decals revealed that children drew objects with greater dimensionality than walls: The odds of children's drawing objects with greater dimensionality were 488% more likely than the odds of children's drawing walls with greater dimensionality (95% CI [139, 1343], $p < .001$).

Experiment 2: Toy

A mixed-model Poisson regression with spatial element (wall or object) included as a predictor variable and participant included as a random-effects intercept revealed that there was no significant difference between the number of walls and objects that children drew (Wald Test, $\chi^2(1) = 0.02$, $p = .885$). While the main text analysis found that children drew more walls than objects for the toy, this present result (and the results from the naïve coding, see above) falls more in line with the prediction of no difference. As suggested in the main text, while children clearly drew more objects than walls for the fort, their drawing counts for the toy may have weakly reflected the relative real-world sizes of each of the different element types.

Finally, a mixed-model ordinal logistic regression examining element dimensionality for walls and objects revealed that the odds of children's drawing objects with greater dimensionality were 3048% more likely than the odds of children drawing walls with greater dimensionality (95% CI [1124, 7992], $p < .001$).

Experiment 2: Comparing the Fort and Toy

To directly examine the differences in children's drawings across the two experiments, the same mixed-model regressions as above were conducted, but with experiment as an additional predictor variable. First, for element count, including walls and objects, there were main effects of both spatial element (children drawing more objects than walls; Wald Test, $\chi^2(1) = 11.34$, $p < .001$) and experiment (children drawing more elements for the toy versus the fort; Wald Test, $\chi^2(1) = 5.45$, $p = .019$). Critically, and as in all prior analyses, there was a significant spatial element by experiment interaction (Wald Test, $\chi^2(1) = 12.83$, $p < .001$): Children drew significantly more walls than objects for the toy versus fort. Planned Holm-corrected pairwise contrasts revealed that children did not draw significantly more objects for the toy versus fort ($p = 1.000$), but they did draw significantly more walls for the toy versus fort ($p < .001$).

Finally, a mixed-model ordinal logistic regression examining element dimensionality for walls and objects revealed that children drew objects with greater dimensionality than walls. The odds of children's drawing objects with greater dimensionality were 296% more likely than the odds of children's drawing walls with greater dimensionality (95% CI = [120, 614], $p < .001$). Children also drew elements with greater dimensionality for the fort versus toy: The odds of children's drawing elements with greater dimensionality for the fort were 71% more likely than the odds of children's drawing elements with greater dimensionality for the toy (95% CI = [48, 84], $p < .001$). The model did not reveal a significant element type by condition interaction (odds ratio = 1.70, 95% CI = [0.79, 3.66], $p = .178$).

Analysis of the dividing wall

As stated in the main text, the pilot data revealed no effects of the dividing wall on the relative number of wall and object elements that children drew, and so our preregistered analysis indeed treated these four-wall (dividing wall present) and three-wall (dividing wall absent) configurations as all probing children's drawing of walls and objects in a layout more generally. Although an analysis of the dividing wall was not planned for the test data, such an analysis further illustrates the generalizability of the findings: Just as in the pilot data, the dividing wall had no effect on the relative number of wall and object elements that children drew in either experiment, further supporting the conclusions from the main text.

In particular, for the fort in Experiment 1, a mixed-model Poisson regression with spatial element (wall or object) and dividing wall (present or absent) as predictor variables and participant included as a random-effects intercept revealed main effects of spatial element (Wald Test, $\chi^2(1) = 45.87$, $p < .001$) and dividing wall (Wald Test, $\chi^2(1) = 9.57$, $p = .002$), suggesting that children drew more objects than walls and that children drew more elements in configurations with a dividing wall (where there were, in fact, more elements to draw). Critically, there was no spatial element by dividing wall interaction (Wald Test, $\chi^2(1) = 0.16$, $p = .688$), and Holm-corrected, pairwise contrasts revealed that children drew more objects than walls in configurations *with* and in configurations *without* a dividing wall ($p < .001$). For the toy in Experiment 2, there was also no effect of the dividing wall. The regression revealed main effects of spatial element (Wald Test, $\chi^2(1) = 4.45$, $p = .035$) and dividing wall (Wald Test, $\chi^2(1)$

$= 7.89, p = .005$), but no interaction between spatial element and dividing wall (Wald Test, $\chi^2(1) = 0.01, p = .942$).

Analysis using mixed-model linear regressions on the count data

Preregistered analyses of count data included mixed-model Poisson regressions because counts are bounded at zero, only take on integer values, and are often heavily skewed. The findings were also robust to a mixed-model linear regression framework, with analyses conducted post-hoc and reported here.

Experiment 1: Fort

A mixed-model linear regression with spatial element (wall or object) and configuration included as predictor variables, and participant included as a random-effects intercept, revealed main effects of both spatial element (Wald Test, $\chi^2(1) = 39.92, p < .001$) and configuration (Wald Test, $\chi^2(3) = 10.93, p = .012$). As in the main text, children drew more objects than walls and the number of elements they drew varied based on the fort configuration. When examining the configurations with decals, a second mixed-model linear regression with spatial element (wall, object, wall decal, or object decal) included as a predictor variable and participant included as a random-effects intercept revealed a main effect of spatial element (Wald Test, $\chi^2(3) = 18.95, p < .001$). Holm-corrected pairwise contrasts also revealed that children drew significantly more objects than walls ($p < .001$).

Experiment 2: Toy

A mixed-model linear regression with spatial element (wall or object) and configuration included as predictor variables and participant included as a random-effects intercept, revealed a main effect of configuration (Wald Test, $\chi^2(3) = 20.93, p < .001$) and spatial element (Wald Test, $\chi^2(1) = 7.48, p = .006$). As in the main text, children drew more walls than objects and the number of elements they drew varied based on the fort configuration. A similar analysis for the configurations with decals also revealed a main effect of spatial element (Wald Test, $\chi^2(3) = 25.93, p < .001$). Holm-corrected pairwise contrasts also found that children drew more walls than objects ($p = .005$).

Experiment 2: Comparing the Fort and Toy

To directly examine the differences in children's drawings across the two experiments, the mixed-model linear regressions were conducted as above, but with experiment as an additional predictor variable. First, for element count, including walls and objects across all four configurations, there were main effects of both spatial element (children drawing more objects than walls; Wald Test, $\chi^2(1) = 9.57, p = .002$) and experiment (children drawing more elements for the toy versus fort; Wald Test, $\chi^2(1) = 8.30, p = .004$). Critically, and as in the main analysis, these results were further characterized by a significant spatial element by experiment interaction (Wald Test, $\chi^2(1) = 38.62, p < .001$): Children drew significantly more walls than objects for the toy versus fort. As in the main analysis, Holm-corrected pairwise contrasts revealed that children did not draw significantly more objects for the toy versus fort ($p = .065$), but they did draw significantly more walls for the toy versus fort ($p < .001$). The second regression, examining element counts in the two configurations with four spatial elements also revealed a main effect of spatial element (Wald Test, $\chi^2(3) = 13.82, p = .003$) and experiment (Wald Test, $\chi^2(1) = 4.52, p = .034$). There was again a significant element type by experiment interaction (Wald Test, $\chi^2(3) = 28.35, p < .001$). Moreover, Holm-corrected pairwise contrasts revealed that children did not draw significantly more objects for the toy versus fort ($p = .316$), but they did draw significantly more walls for the toy versus fort ($p < .001$).

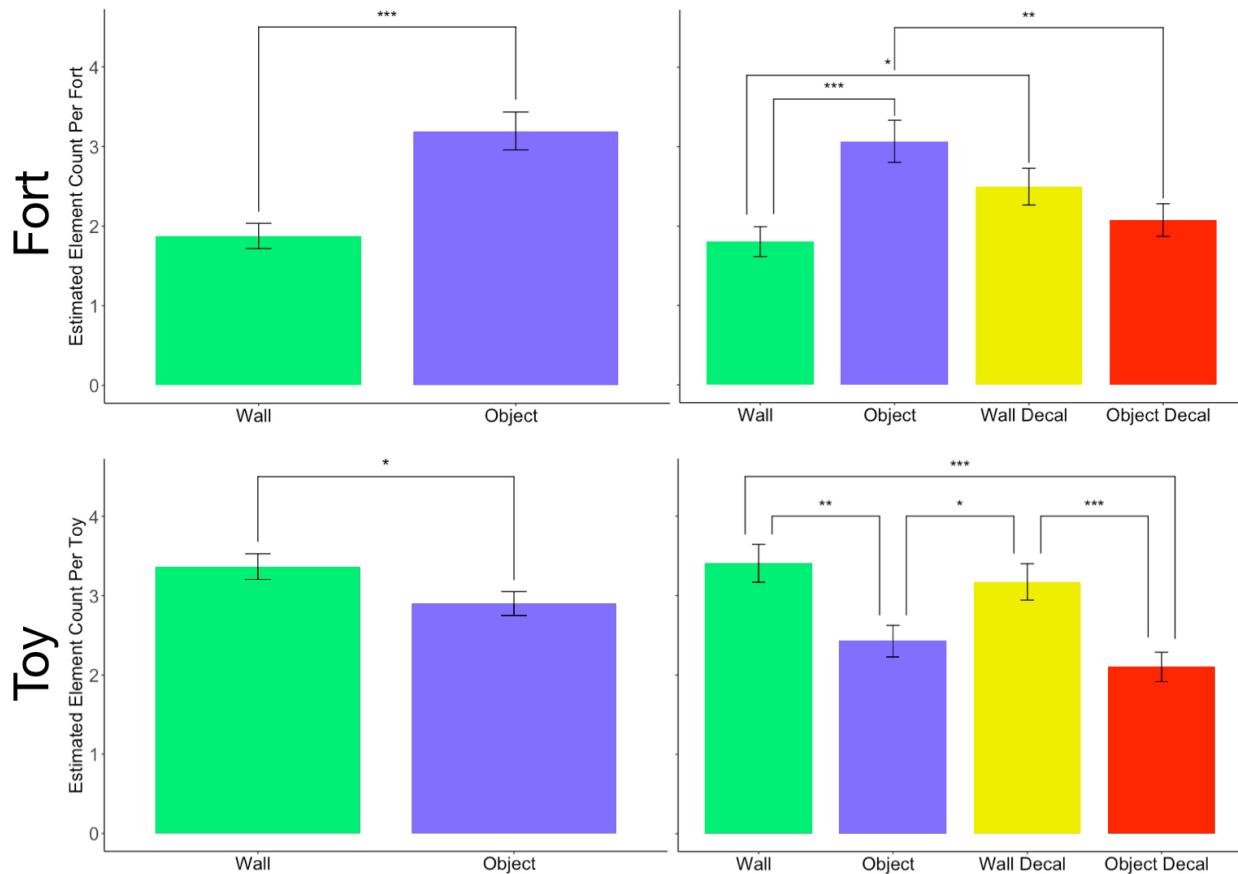


Figure S1. Spatial element counts as predicted by the model for the fort (Experiment 1, top) and toy (Experiment 2, bottom). Across all configurations, children drew more objects than walls for the fort, but not for the toy (left column). In the configurations with decals, children drew more objects than other spatial elements for the fort but appeared to draw the larger spatial elements more frequently for the toy (right column). Planned Holm-corrected pairwise contrasts, *** $p < .001$, ** $p < .01$, * $p < .05$, † $p < .1$. Contrasts not shown are not significant. Error bars display the standard error of the model fits.

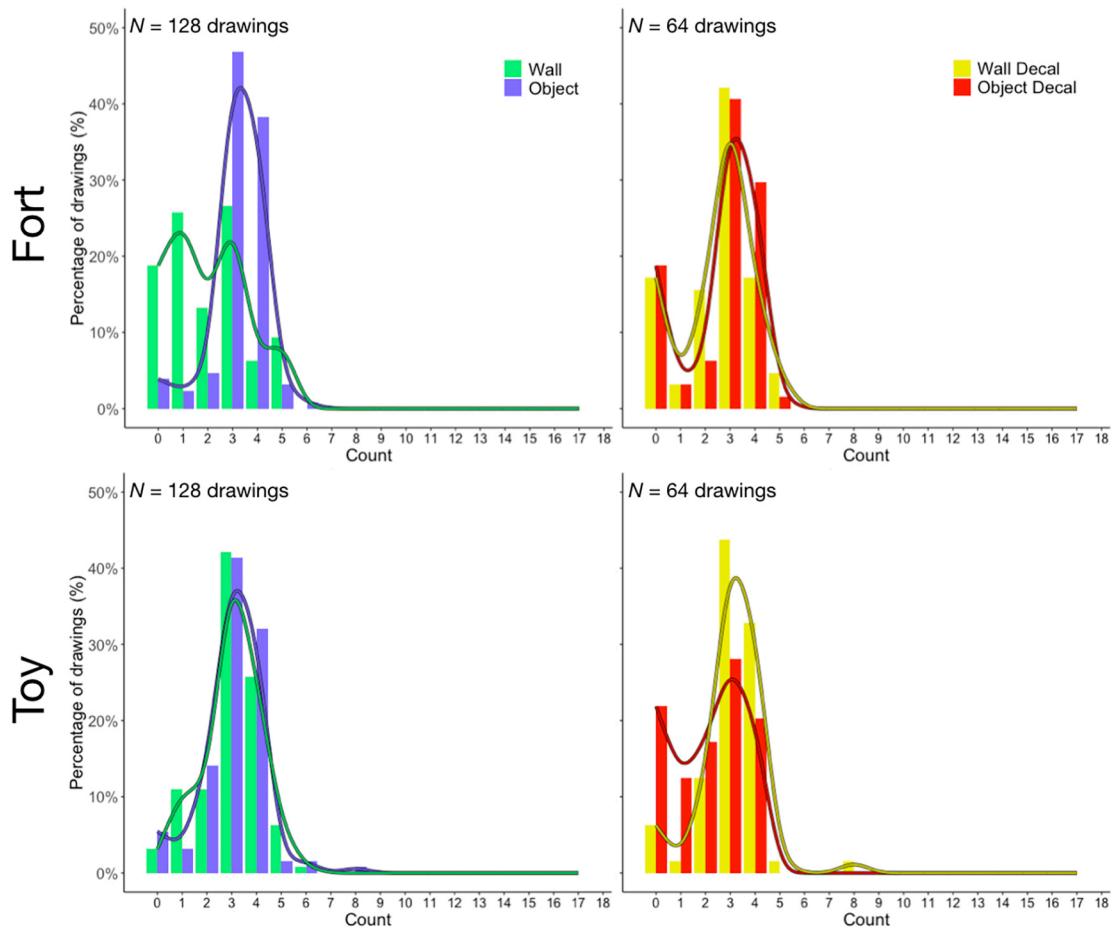


Figure S2. The raw counts of spatial elements for the fort (Experiment 1, top) and toy (Experiment 2, bottom) for the four configurations in which there were walls and objects (left) and for the two configurations in which there were also wall decals and object decals (right), as coded by the naïve coder. To illustrate the distribution of these counts, overlaid on each set of counts is a smooth curve, generated by a kernel regression on Count and Percentage. Across all configurations of the fort the count distribution for walls is strikingly different from the count distributions for all of the other spatial elements, with wall counts peaking at 0-1 and all other element counts peaking at 3-4. In contrast, across all configurations of the toy the count distribution for walls is strikingly similar to those for all other spatial elements, with all element counts peaking at 3-4.

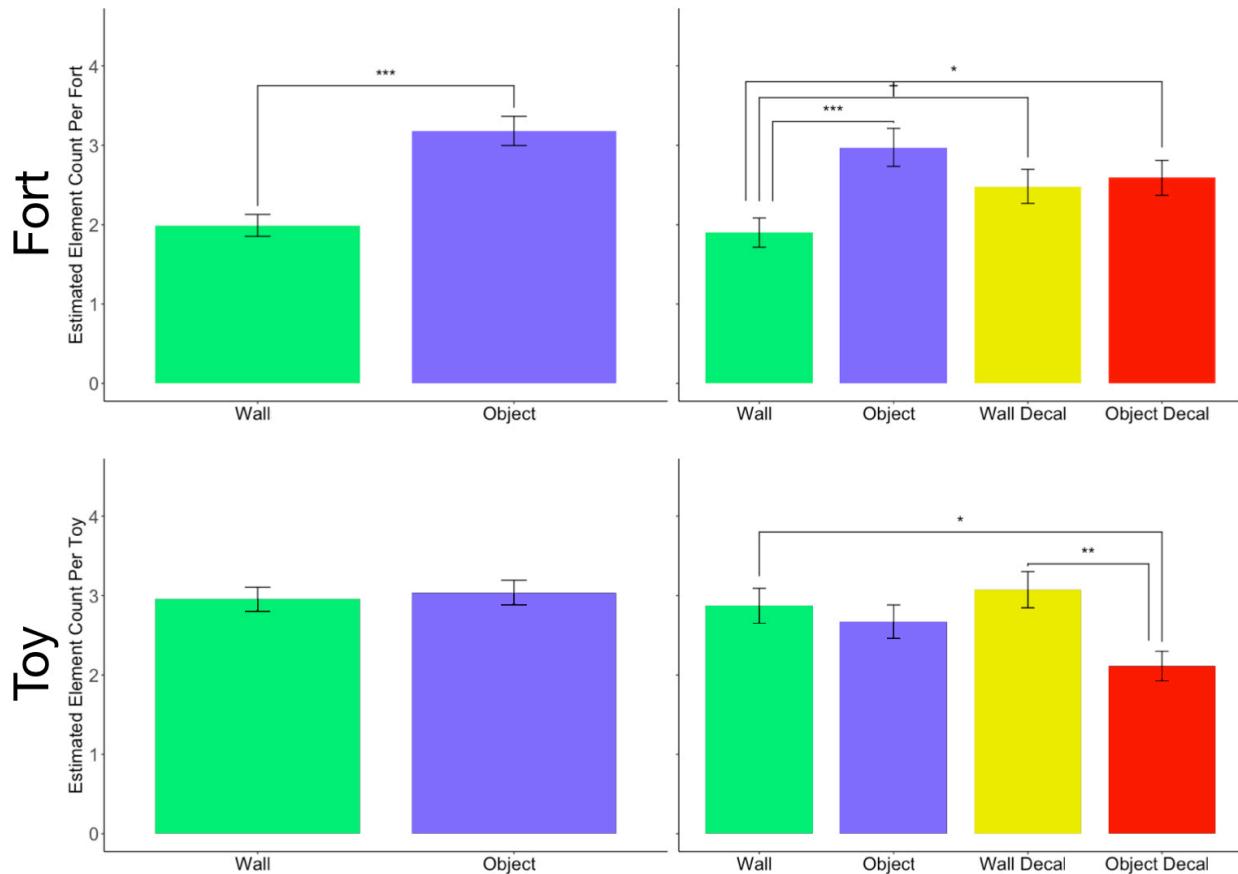


Figure S3. Spatial element counts as predicted by the model for the fort (Experiment 1, top) and toy (Experiment 2, bottom), as coded by the naïve coder. Across all configurations, children drew more objects than walls for the fort, but not for the toy (left column). In configurations with decals, children also drew more objects than walls for the fort, but not for the toy (right column). Planned Holm-corrected pairwise contrasts, *** $p < .001$, ** $p < .01$, * $p < .05$, † $p < .1$. Contrasts not shown are not significant. Error bars display the standard error of the model fits.

Table S1A. The mixed-model ordinal logistic regression from the main analysis, evaluating the dimensionality with which children drew each spatial element in configurations with decals for the fort (Experiment 1)

Reference	Comparison	p-Value ^a	% Change in odds ratio	95% CI for % change
Wall	Object	.002	248	58 - 661
Wall	Wall Decal	< .001	463	135 - 1248
Wall	Object Decal	< .001	1245	353 - 3891

Table S1B. The mixed-model ordinal logistic regression from the main analysis, evaluating the dimensionality with which children drew each spatial element in configurations with decals for the toy (Experiment 2)

Reference	Comparison	p-Value ^a	% Change in odds Ratio	95% CI for % change
Wall	Object	< .001	897	446 - 1723
Wall	Wall Decal	< .001	1147	602 - 2116
Wall	Object Decal	< .001	1602	756 - 3281

Note. Percentage changes in the proportional odds ratios produced by the ordinal logistic regression model, quantifying the degree to which the odds of producing a given element with greater dimensionality would be greater for the comparison group than the reference group. For example, in **Table S1B**, the odds of children drawing objects with greater dimensionality were 897% more likely than the odds of children drawing walls with greater dimensionality. ^aPlanned Holm-corrected pairwise contrasts.