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New indices to characterize drawing behavior in humans (Homo sapiens) and chimpanzees (Pan troglodytes)

Lison Martinet, Cedric Sueur, Satoshi Hirata, Jérôme Hosselet, Tetsuro Matsuzawa, Marie Pelé

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1 **New indices to characterize drawing behavior in humans (*Homo sapiens*)**
2 **and chimpanzees (*Pan troglodytes*)**

3
4 Short title: **An innovative analysis to understand drawing behavior**

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7 Lison Martinet^{1*}, Cédric Sueur^{1,2}, Satoshi Hirata³, Jérôme Hosselet¹, Tetsuro Matsuzawa^{4,5},
8 Marie Pelé⁶

9
10 ¹: Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France

11 ²: Institut Universitaire de France, Paris, France

12 ³: Kumamoto Sanctuary, Wildlife Research Center, Kyoto University, Kumamoto, Japan

13 ⁴: Kyoto University Institute for Advanced Study, Japan

14 ⁵: Primate Research Institute, Kyoto University, Japan

15 ⁶: ETHICS EA 7446, Lille Catholic University, Lille, Hauts-de-France, France

16
17
18 Corresponding author: Lison Martinet

19 Email: lison.martinet@iphc.cnrs.fr

20 Address: Institut Pluridisciplinaire Hubert Curien

21 Département Écologie, Physiologie et Éthologie

22 23, rue Becquerel

23 67087 Strasbourg

24 FRANCE

25 Phone number: + 33 (0)6 70 51 02 57

26
27
28 Cédric Sueur, Email : cedric.sueur@iphc.cnrs.fr Phone number : +33 3 88 10 74 53

29 Satoshi Hirata, Email : hirata.satoshi.8z@kyoto-u.ac.jp Phone number : + 81 75 771 4388

30 Jérôme Hosselet, Email : jerome.hosselet@iphc.cnrs.fr Phone number : + 33 3 88 10 62 34

31 Tetsuro Matsuzawa, Email : matsuzawa.tetsuro.8w@kyoto-u.jp Phone number : +81 75 753
32 9790

33 Marie Pelé, Email : marie.pele@univ-catholille.fr Phone number : +33 (0)3 61 76 75 63

34

35 **Abstract**

36 Techniques used in cave art suggest that drawing skills emerged long before the oldest known
37 representative human productions (44,000 years B.C.). This study seeks to improve our
38 knowledge of the evolutionary origins and the ontogenetic development of drawing behavior
39 by studying drawings of humans (N = 178, 3- to 10-year-old children and adults) and
40 chimpanzees (N = 5). Drawings were characterized with an innovative index based on spatial
41 measures which provides the degree of efficiency for the lines that are drawn. Results showed
42 that this index was lowest in chimpanzees, increased and reached its maximum between 5-year-
43 old and 10-year-old children and decreased in adults, whose drawing efficiency was reduced
44 by the addition of details. Drawings of chimpanzees are not random suggesting that their
45 movements are constrained by cognitive or locomotor aspect and we cannot conclude to the
46 absence of representativeness. We also used indices based on colors and time and asked
47 children about what they drew. These indices can be considered relevant tools to improve our
48 understanding of drawing development and evolution in hominids.

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51 **Keywords:** drawing, representativeness, efficiency, chimpanzee (*Pan troglodytes*), human
52 (*Homo sapiens*), children

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69 “My drawing was not a picture of a hat.
70 It was a picture of a boa constrictor digesting an elephant.”
71 Antoine de Saint-Exupéry, *The Little Prince*
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73 Evidence in prehistoric caves and in museums underlines that drawing is one of the most
74 characteristic behaviors of the human species, yet its definition remains vague. Indeed, drawing
75 behavior is considered by some authors as the simple will to mark, to produce visible traces but
76 it can also be etymologically understood as something more complex such as a design, or a goal
77 to reach [1]. This study considers drawing behavior in its simplest form, i.e. an active creation
78 of visible marks that may or may not be figurative [2]. Children start drawing what we call
79 scribbles around their first year of age [3]. At the age of 3-4 years, children begin to produce
80 figurative drawings, i.e. they can be recognized by external observers [3]. This progress is partly
81 linked to the improvement of motor coordination, completed by the progressive integration of
82 a visual vocabulary of patterns and graphic syntax aided by the child’s cultural and living
83 environment and of course by the maturation of their cognitive skills [4, 5]. During early
84 childhood, crucial neurological transformations occur in cerebral tissues such as important
85 increases in grey matter volumes until 4 years [6]. This organic substratum allows children for
86 example to acquire the understanding of self and others, to regulate their emotions, but also to
87 communicate and to enter a world filled with symbols [7]. Progressively the systems involved
88 in the drawing behavior develop capacities such as visual perception, graphic production
89 including action programming and planning, and visual imagery. In drawing, symbolism (i.e.
90 the use of symbols such as marks or particular shapes) helps the subject to represent their
91 thoughts by giving them symbolic meaning beyond their literal ones. Then DeLoache and
92 collaborators [8] stated “the realization of figurative drawing goes hand in hand with the
93 appropriation of symbols”. This early developmental stage of drawing is composed by traces
94 and lines which have a universal nature, belonging to a culturally inherited symbolic system
95 [9].

96 One of the first steps of children’s early symbolic drawing development is tadpole
97 figures [10]. Consisting of two lines (legs) attached to a round form (head), the tadpole figure
98 arises around 3 years of age [11] and is observed in Western as well in non-Western countries
99 [12,13]. Thus, in the same way that children reorganize their spoken language to communicate
100 efficiently, the appearance of these first recognizable drawings also allows them to be better
101 understood by others [14]. An adult can easily understand what a 4-year-old child wanted to
102 represent when they drew, because the outlined objects are recognizable. But what happens if

103 this is not the case? Does this mean that drawings of very young children do not represent
104 anything in particular?

105 For decades, researchers have suggested that the early phase of drawing - called
106 scribbling – simply reflects a simple motor activity that is visually unplanned and only
107 determined by the motor system of the arm, the wrist and the hand [15]. This would mean that
108 very young children do not take pleasure in their finished drawings, but only in the act itself.
109 Other studies acknowledge that the development of drawing follows a linear trajectory towards
110 realism and that a child’s spontaneous fortuitous realism eventually evolves into representative
111 drawings [16]. However, more recent studies tend to show evidence of pre-representative
112 activities during scribbling [17, 14].

113 Drawing is part of the larger activity of creating meaning in young children. Children
114 have multiple ways of making sense through the modes, means and materials they use to do so.
115 In their drawings, children encode a lot of information making them a way of constructing and
116 depicting their thoughts in action [18, 19]. A 2- or 3-year-old child is not capable of attributing
117 meanings to the entirety of their drawing, which is often unstructured and complex. However,
118 the child can attribute meaning to some parts of their drawing, and especially broken lines,
119 which more easily describe the contours of an object than curved ones [17]. Although caution
120 should be used here because children can change their answers when asked several times about
121 the meaning of their drawings, these kinematic aspects could be considered as precursors of a
122 graphical representation (i.e., the act of producing in visible form a figure or an idea we have
123 in mind). According to Willats [20], the developmental stages of drawing reflect attempts to
124 represent the child’s ever-increasing levels of perceptual understanding of the world in which
125 they live. In this case, lines drawn in early childhood describe entire objects and are not simply
126 random productions. These suggestions could be of use to answer the continuing debate over
127 the representativeness of drawings by young scribblers. Although the loops, lines and stipples
128 of a scribble usually have no sense for an adult, can we presume that it has no meaning for the
129 young child? Like the young Saint-Exupéry, who complained that adults did not understand his
130 drawing of an elephant eaten by a snake and that “they always need to have things explained”,
131 Longobardi [14] argues that the inability to detect representativeness in children’s scribbles
132 may be explained by the limitation of adults’ interpretations rather than the absence of this
133 intentionality. In this case, the representativeness of a drawing, namely its concrete and
134 figurative character, would result from the perspectives of two individuals: the entity who
135 produces it (here, a child) and an outside observer who evaluates it (here, an adult). These
136 individuals could be considered to represent two elements: internal representativeness (for the

137 individual who draws) and external representativeness (for the observer). All the
138 aforementioned elements underline the necessity for further studies on drawing behavior to
139 better understand the development of drawing abilities and more specifically the emergence of
140 representativeness in human beings.

141 An additional factor to consider when seeking to understand the development of
142 drawing behavior in humans may be its evolutionary emergence. Is drawing a typically human
143 behavior or does it originate from ancestor species? This question can be answered by studying
144 the evolution of drawing behavior in species that are genetically close to humans, such as great
145 apes. So far, no spontaneous drawing behavior has been reported in great apes in the wild. Even
146 known as the most meticulous tool makers and users [21], no chimpanzee was ever observed
147 using sticks to trace on the floor. Moreover, such marking behavior would be difficult to
148 differentiate from other actions such as digging or exploring surfaces. Nevertheless, it is more
149 and more common for captive individuals to use pencils and brushes on paper sheets or even
150 draw on tactile tablets [22]. Indeed, as Call [23] stated “testing non-human animals outside their
151 ‘natural’ box is needed to fully probe their capabilities and limitations, something that is
152 particularly desirable if our ultimate goal is to reconstruct the evolution of cognition” and in
153 our case, the evolution of drawing. Drawing by chimpanzees has been considered in human-
154 ape comparative developmental studies [24], and also in art and aesthetics research [25]. In the
155 first experimental study on drawing in chimpanzees, Schiller [26] presented geometric figures
156 to a female chimpanzee named Alpha who changed her scribbling patterns according to the
157 stimuli provided. A number of studies have shown that chimpanzees maintain their graphic
158 activity without any reinforcement, indicating a likely interest in drawing [25-27]. Beyond the
159 sensation linked to locomotor movement, visual feedback seems to play a reinforcement role:
160 drawing behavior decreases when the line drawn by the subject on the tactile screen disappears
161 [28]. Although there are many studies on mark-making in chimpanzees, none reported drawings
162 that were recognizable by observers (external representativeness), and researchers generally
163 compared the productions to the scribbles of young human children. However, some results
164 such as the trend to change scribbling patterns in presence of stimuli or patterns [5, 26] or,
165 according to Zeller [29], the manifestation of a choice for some features such as the colors used
166 or patterns drawn leads to conclude that ape drawings “are definitely not random scribbles”.

167 The most common way to establish whether a drawing is representative or not is to ask
168 the individual who produced it about its meaning, which is often done with children. A sign-
169 language trained female chimpanzee named Moja was asked this question, and she answered
170 “bird” [30]. Of course, her answer is not reliable evidence of her internal representativeness of

171 a bird; it is possible that she answered randomly, or was influenced or misinterpreted by the
172 experimenters. Thus, despite numerous studies on this topic, it is still impossible to exclude the
173 presence of goal-oriented behavior in drawing by very young children and chimpanzees. The
174 use of a symbol requires understanding it, its abstract relation to what it stands for and being
175 able to mentally represent it [8]. In humans, the basic understanding of the analogical space–
176 object–symbol relation emerges around 3 years of age [31]. At this age, a child can understand
177 for example that the illustration of a cat asleep on a couch represents the cat currently sleeping
178 on the living room couch. Besides, pretend play, a symbolic play where children express their
179 imagination by using actions or objects to represent other objects or actions begins in toddlers
180 of around 1-2 years old [32, 33]. This capacity of pretense, which is evidence of
181 representational abilities, has also been shown in chimpanzees even if it is less developed [32].
182 Other abilities, as the fact that they can track invisible displacement [34] and use a scale model
183 as a source of information for the location of a hidden item [35] prove that they are capable of
184 mental representation. Then, although their mark-making is not, a priori, driven by a desire to
185 represent an object, the absence of figurative drawings does not necessarily indicate an absence
186 of symbolism for the chimpanzee or the young child [36, 37]. Especially as in our sapiens
187 ancestors, “the elaboration of nonfigurative patterns certainly participated in the development
188 of a symbolic thought on which later prospered the invention of the figure and of a true
189 iconographic language” [38].

190 Different methods have been used to investigate drawings of young children. The most
191 well-known of these is the comparison of broken lines and curved lines to evaluate the
192 kinematic aspects of the outlines that have been drawn [17]. Although relevant, this method
193 remains subjective as researchers directly question children about what their drawings
194 represent. It cannot therefore be used with very young children (toddlers) or with great apes, as
195 neither group are able to express themselves about their drawings. It is therefore necessary to
196 find a new method of analysis for the objective study of drawing behavior in children and
197 chimpanzees.

198 To achieve this goal, we asked children aged 3 to 10 years and adults with different
199 levels of drawing skills (naive versus expert) to draw on tactile devices. Each participant was
200 given two drawing tasks, namely to draw freely (*free* drawing condition) and to draw
201 themselves (*self-portrait* condition) to assess a possible difference in results between a non-
202 specific and a specific task. Five female chimpanzees were also asked to draw freely on a
203 touchscreen tablet. We then developed an innovative and objective index based on the lines
204 drawn by both humans and chimpanzees. This was achieved through the use of spatial analysis.

205 Also called the random walk analysis [39], this approach is commonly used in ecology to study
206 the movements of animals. We considered the outline of the drawing as an animal's path
207 (meaning a set of trajectories of different lengths [40]), and characterized the efficiency of the
208 drawing, defined here as the correct reading of the drawing with a minimum of details. In other
209 words, the external representativeness of the observer matches the internal representativeness
210 of the individual who drew. The random walk analysis determines whether the distribution of
211 drawing lines follows a power law or an exponential law. If the distribution follows an
212 exponential law, we expect the drawing to be random, meaning that the individual who is
213 drawing has no intention to represent anything. Contrarily, a power distribution should reflect
214 a non-random and oriented behavior, as found for the daily paths of animals in their natural
215 environments (i.e. goal-oriented and efficient movements, 41). On one hand, we could expect
216 drawing to be random in chimpanzees (i.e. no internal representativeness) since no chimpanzee
217 has ever produced a representative drawing –with a human eye- despite a demonstrated interest
218 in the activity in several studies [25-27]. On the other hand, as chimpanzees are able to change
219 their scribbling outlines and to manifest a preference for colors used or patterns drawn, their
220 drawings might be not so random. Considering humans, we definitely expected a non-random
221 and goal-oriented behavior in children and adults, with an index that increased with age.

222 Finally, we complemented this innovative spatial index for drawing by investigating the
223 use of colors by individuals and the duration of drawing, since these indices are commonly used
224 in drawing studies. We expected a less developed use of colors in chimpanzees and
225 progressively a more important one with age in humans. Considering the duration of drawing
226 in humans, we predicted a longer one with age in parallel with the improvement of motor and
227 psychic abilities and the growing interest with age for this activity. To study and apprehend the
228 variability of these drawing indices, the variables group (age), gender, test condition, gender-
229 condition interaction and/or the group-condition interaction were used. The gender effect has
230 already been proved to influence drawing in different ways [42-44]. We tested the gender-
231 condition interaction since we thought that, especially for children, the drawing's variables
232 could be different according condition between girls and boys. Concerning the group-condition
233 interaction, we first expected that the instruction might intimidate some children, especially the
234 youngest, and potentially restrict their creative process. Then experts might react differently
235 from naive adults by being more comfortable and inspired, especially for free drawing, resulting
236 in a potentially longer drawing time and greater use of color.

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239 **Results**

240

241 1. The spatial index μ_{MLE}

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243 Chimpanzees showed a lower index μ_{MLE} than human participants (GLM Gaussian,
244 $p < .0001$, $t > 4.10$, Fig. 1, Supplementary Table S1A). The index for 3-year-old children was
245 lower than those recorded for 5- ($p < .001$, $t = 3.43$, Fig. 1, Supplementary Table S1B), 7- ($p <$
246 $.0001$, $t = 4.33$), 9- ($p < .001$, $t = 3.37$) and 10-year-old children ($p = .002$, $t = 3.05$), but was
247 similar to those of 4- and 8-year-old children and naive or expert adults. Five-year-old children
248 had a higher spatial index μ_{MLE} than the naive ($p = .032$, $t = 3.24$) and the expert ($p = .0016$,
249 $t = 4.03$) adults. Seven-year-old children showed an index higher than naive ($p = .001$, $t = 4.14$)
250 and expert ($p < .001$, $t = 4.93$) adults. Similarly, 9-year-old children presented a higher spatial
251 index than naive adults ($p = .039$, $t = 3.19$) and expert adults ($p = .0023$, $t = 3.98$). Ten-year-old
252 children also had a higher index than expert ($p = .008$, $t = 3.66$) adults, and possibly also naive
253 ($p = .097$) adults. No difference was found between the two adult groups, and no significant
254 effects of the *conditions* and *sex* factors were observed.

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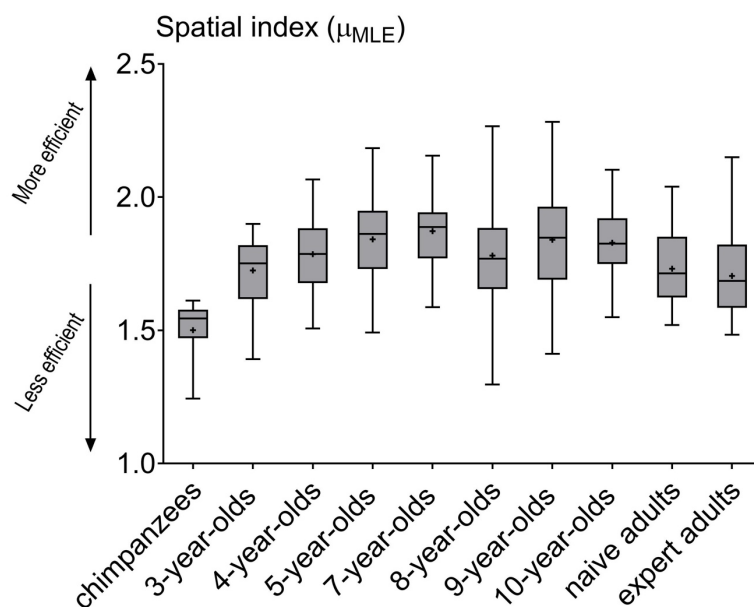
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267 **Fig 1. Boxplots of the spatial index μ_{MLE} for each group, i.e. chimpanzees and humans**
268 **(children and adults).** Since the *condition* factor is not present in the selected model, all
269 drawings were studied without distinction of conditions. Each boxplot depicts the median (bold
270 bar), 25-75% quartiles (box), mean (cross) and outliers (points).

271

272 2. Drawing duration

273

274 After model selection, we retained the most explicative model containing the *groups*
275 and *conditions* factors. In both test conditions, 3-year-old children spent less time drawing
276 (mean = 110±97 seconds) than all other participants (272±192 seconds) (GLM Gamma,
277 $p < .001$, $t > 3.32$, Fig. 2, Supplementary Table S2). Furthermore, all human participants spent
278 more time drawing in the *free* condition compared to the *self-portrait* condition ($p < .0001$, $t =$
279 4.52).

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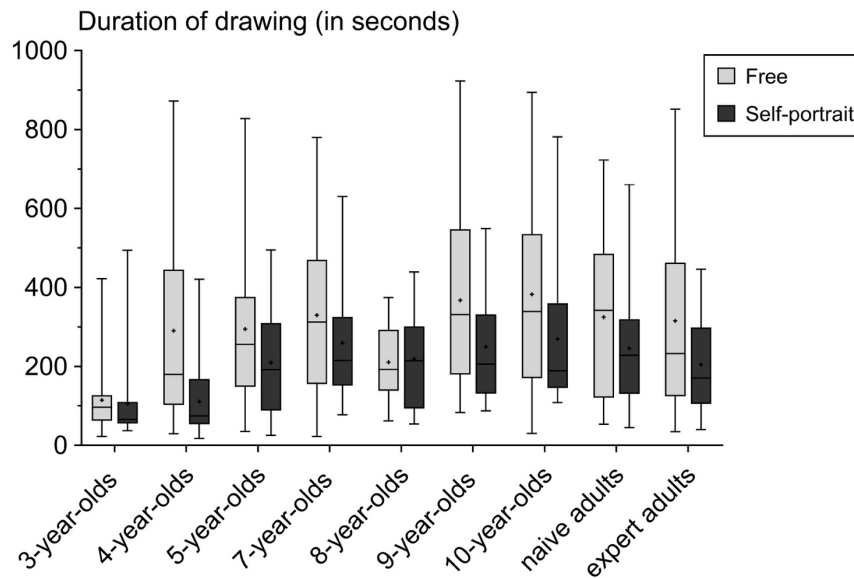
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291 **Fig 2. Boxplots of drawing duration (in seconds) for each group and for each condition.**

292 Boxplots depict the median (bold bar), 25-75% quartiles (box), mean (cross) and outliers
293 (points).

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295 3. The use of colors

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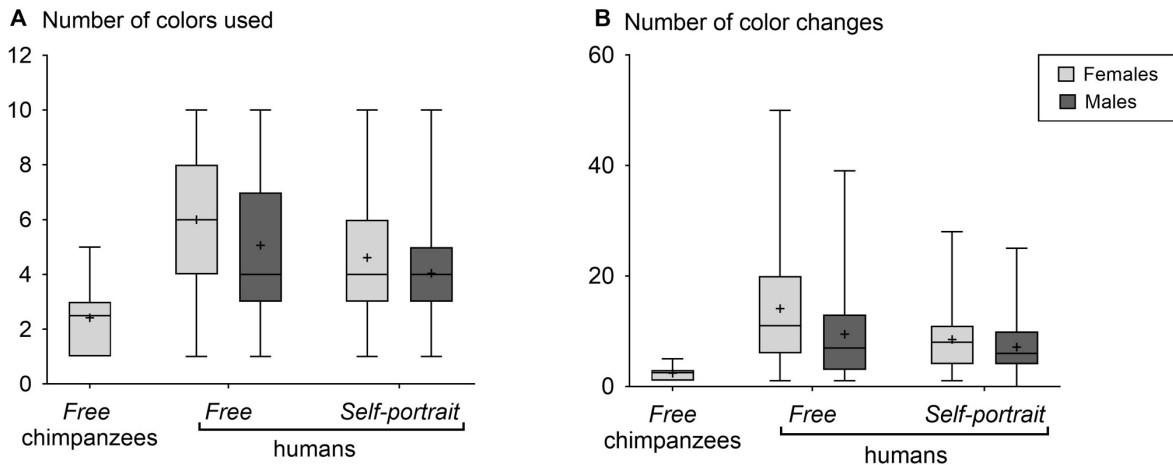
297 a. Number of colors used

298 The results of the model (Supplementary Table S3A) indicate that chimpanzees used
299 fewer colors than humans (across all groups; GLM Poisson, $p \leq .001$, $t > 3.29$, Fig. 3A). After
300 model selection, the factors *conditions* and *sex* were retained to explain the number of colors
301 used in humans. The number of colors used is higher under the *free* condition than under the
302 *self-portrait* condition ($p < .0001$, $t = 5.06$, Fig. 3A, Supplementary Table S3B). Furthermore,
303 there is a gender-related difference in the use of color. Women and girls used significantly more
304 colors than men and boys ($p < .001$, $t = 2.97$).

305

306 b. Number of color changes

307 Chimpanzees did not change the colors they used as much as the human participants did
 308 (GLM Negative binomial, $p < .008$, $t > 3.34$, Fig. 3B, Supplementary Table S4A). In humans,
 309 the number of color changes was higher in the *free* condition compared to the *self-portrait*
 310 condition (GLM Negative binomial, $p < .0001$, $t = 4.45$, Fig. 3B, Supplementary Table S4B).
 311 Furthermore, men and boys changed the colors they used significantly less often than women
 312 and girls in all groups ($p = .002$, $t = -3.11$).



313 **Fig 3. (a) Boxplots of the number of colors used by chimpanzees and humans for each**
 314 **condition and for each sex. (b) Boxplots of the number of color changes by chimpanzees**
 315 **and humans for each condition and sex.** Boxplots depict the median (bold bar), 25-75%
 316 quartiles (box), mean (cross) and outliers (points).

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318 4. The meaning of drawings in children

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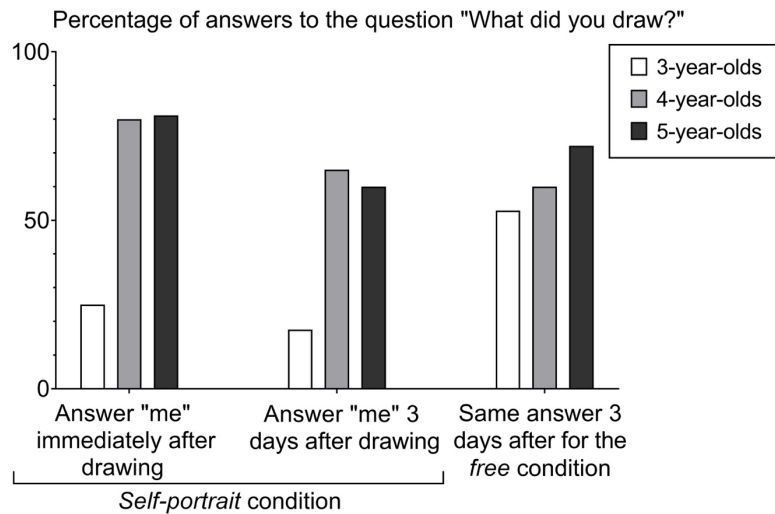
320 When asked what their drawing represented in the *self-portrait* condition, 3-, 4- and 5-year-
 321 old children were much more likely to answer “me” when questioned directly after drawing
 322 than when they were asked the same question three days later (GLM Binomial, $p < .0001$, $z =$
 323 5.16 , Fig. 4, Supplementary Table S5). However, these three age groups showed some
 324 differences in their response consistency. Four- and five-year-old children were more likely to
 325 confirm that the drawing was self-representation immediately after drawing and few days later
 326 than the youngest children ($p < .0001$, $z > 7.02$, Fig. 4, Supplementary Table S5).

327

328 The comparison of the answers given by children several days after drawing in the *two*
 329 *conditions* (free and self-portrait) showed that 4- and 5-year-olds had a better memory of what
 330 they had intended to represent a few days after drawing than the youngest children ($p \leq .021$, z
 > 2.30 , Fig. 4, Supplementary Table S6). Three days after the drawing activity, the 3-year-old

331 children seemed to find it easier to remember what they had drawn in the *free* drawing condition
 332 (52.9%) than to remember what they had intended to draw or indeed the initial instruction to
 333 draw themselves in the *self-portrait* condition (17.6%) (Fig. 4).

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345 **Fig 4. Percentages of answers given by children of 3, 4, 5 years old to the question “What**
 346 **did you draw?” for the *self-portrait* condition and for the *free* condition.**

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349 Discussion

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351 This comparative and explorative study allowed us to define new and objective indices
 352 characterizing drawing in human and non-human primates. We used common measures in
 353 drawing studies (duration and colors) combined with an innovative spatial index that is
 354 commonly used in animal trajectories studies [45]. This is the first study to use this
 355 mathematical index to understand drawings.

356 This spatial index μ_{MLE} is clearly lower for chimpanzees compared to human
 357 participants. This suggests the presence of a behavior that is less goal-oriented than that
 358 observed in humans, but which is still not random: even chimpanzees displayed a power-like
 359 distribution showing that their movements are constrained by cognitive or locomotor aspects
 360 that limit the randomness we could expect. However, these results conduct us not to conclude
 361 to the absence of internal representativeness in chimpanzees. This lack of efficiency is not
 362 surprising given their behavior when facing the touchscreen: most of them showed less interest
 363 than humans did, as proved by the fact that they were stimulated by the experimenters and their
 364 more limited use of colors. This is a surprising contrast to Zeller’s study [29] which shows that

365 chimpanzees and humans make similar use of colors in their pictures. This difference could be
366 due to the use of the touchscreen, which does not require individuals to use materials such as
367 pencils or paint. Only one chimpanzee, Hatsuka, appeared to be more attentive during test
368 sessions, looking at her fingers and at the outlines produced on the screen. This variability
369 among chimpanzees has already been described, with younger chimpanzees showing more
370 interest [28]. However, Hatsuka's drawings were not characterized by a higher spatial index
371 than those of other females. This inter-individual difference can be interpreted as a difference
372 of interest in the tool used (i.e. motivation) but did not reveal different line features (i.e. goal-
373 directedness). All chimpanzees produced more or less the same type of very angular and
374 locomotive features with no precise forms. However, these features are not random and it is
375 difficult to conclude to the absence of internal representation in chimpanzees [22]. This
376 question, which has great fundamental implications, remains to be clarified through further
377 experiments.

378 Among humans, results found were different from those expected. The spatial index
379 μ_{MLE} increased among the two youngest age groups in children and stabilized between the ages
380 of 5 and 10. The spatial index μ_{MLE} then decreased among adults to reach a similar level to that
381 of 3- and 4-year-old children. The increase of this index in young children can be easily
382 explained by the progressive development of more controlled and goal-oriented lines which
383 often underlie the production of a figurative drawing. Goal-directedness and internal
384 representation might be present in some children (at least in the four-year-olds, where external
385 representation is also present). Three-year-old children would be more motivated by motor
386 pleasure alone [46], explaining why their spatial index μ_{MLE} is the lowest observed in children.
387 The marks produced on the tablet provided a visual satisfaction which encouraged the child to
388 keep drawing on the blank parts of the screen. However, the index μ_{MLE} of 3-year-old children
389 was higher than that observed for chimpanzees, allowing us to develop a hypothesis. First, there
390 was a wide range of variability at this age because it is a period of learning how to draw, in
391 which children begin to internalize some graphic elements (vertical lines, horizontal lines,
392 crosses, dots) that they may or may not be able to reproduce efficiently in their drawings. Many
393 of the children appeared to be in the first representation phase, called action representation,
394 during which the child produces sounds that mimic the movement of the object they want to
395 represent [17, 47], while others began to draw their first recognizable figures. Also, the better
396 fine motor skills of children compared to chimpanzees can be argued. Indeed, even if 3-year-
397 old children did not intend to represent something, the shapes and outlines that they produced

398 (curved or directed to fill the entire available space) did not look like those realized by
399 chimpanzees (which were less smooth). It demonstrates better mobility and control of the hand,
400 the wrist and fingers [48] on the part of children, which could naturally lead to greater efficiency
401 (e.g. more variation in the length of the lines drawn). The spatial index μMLE increased in
402 children up to the age of five, when children are in the intellectual realism phase [16] and try to
403 draw their idea as accurately as possible. This is made possible by the enhancement of their
404 locomotor capacities. The child draws all the parts of the object they seek to depict in an
405 efficient way, e.g. without abstraction or unnecessary details. Here, the primary goal is to be
406 understood (external representativeness), with no aesthetic goal. This makes their drawings
407 more efficient. Among adults, the spatial index μMLE decreased. Even if their drawings are
408 very understandable, they appear to be more complex due to the compiling of numerous details,
409 perspectives or shadows affecting the distribution of line lengths and consequently reducing
410 their efficiency. Contrary to young children, adults may attempt to reach an ideal in their
411 representations linked to social norms that young children have not yet acquired [49]. The
412 results concerning adults allow a better understanding and definition of our spatial index μMLE .
413 The presence of goal-oriented behavior during drawing is undeniable in adults, almost all of
414 whom produced figurative drawings. They all have an internal representation of their drawings.
415 However, unlike 3-year-old children, the absence of external representation in adult drawings
416 is due to an intention to draw in an abstract way (often observed in the expert group) rather than
417 the absence of internal representativeness. Our spatial index therefore depicts the efficiency of
418 a drawing layout, whether or not it is figurative. It should be noted that the spatial index μMLE
419 is not affected by the gender of the individual or the condition in which a participant carried out
420 their drawing. Adding an instruction (free or self-portrait condition) to guide the person drawing
421 did not make the drawing layout more efficient.

422 Even if it does not affect our spatial index, condition has an effect on other measures
423 such as the duration of drawing. Among humans, all groups spent more time drawing under the
424 *free* condition than under the *self-portrait* condition. When free to draw, the participant was
425 willingly using their imagination, and spending more time on their drawing. However, we noted
426 a shorter drawing time for the youngest children, whatever the condition. Three-year-old
427 children appeared to become quickly bored; their use of the tablet was different to that of their
428 older counterparts, who clearly used it as a drawing support. The role of the tablet as medium
429 and the use of fingers as tools could influence several components of the drawing including its
430 efficiency [42]. Finger drawing seems to require less motor control than tools drawing, making
431 it easier for the youngest children to produce more codable, efficient drawings, at least when

432 they copy simple shapes [42]. However, finger drawing may be more difficult for older children
433 and adults, who are more accustomed to draw with brushes or pencils resulting in less
434 qualitative drawings. Holding and moving a tool does not require the same control (distal joints
435 and flexion/extension of the fingers) than drawing with fingers which involves movements of
436 the elbow and the shoulder [50]. It could be more difficult for older children and adults to shift
437 from distal to proximal control of their movements [50] which could then impact their
438 drawings' efficiency.

439 While drawing is generally accepted as the expression of a mental representation, the
440 use of colors is commonly linked to personal aesthetics and is more difficult to evaluate
441 objectively [46]. Although colors alone cannot characterize a drawing, they could help to
442 understand the approach taken by the individual who is drawing. Children and adults used more
443 colors and changed them more often under the *free* condition than in the *self-portrait* condition.
444 The less limited nature of free productions increased the use of colors, while the instruction
445 “*Draw yourself*” seemed to constrain color use and led individuals to use fewer elements when
446 composing the drawing. Besides, the use of colors is consistent with the duration of drawing
447 which is higher under the *free* condition. A gender difference was found for both the number
448 of colors used and the number of colors changes. Women and girls changed the colors they
449 used more frequently and used significantly more colors than men and boys. This gender effect
450 on the number of colors used has already been found in humans, with girls showing a more
451 diverse use of color than boys [44, 51]. Gender differences in the use of colors in general have
452 also been shown in studies of drawing by non-human primates [29]. Turgeon [43] showed a
453 gender difference in color use solely in older children (7-9 years old), whereas we found a
454 difference even in younger children, a finding that is consistent with previous studies [44].
455 Turgeon [43] noted that the number of colors used can be directly linked to the subject of the
456 drawing, with some requiring more colors than others (e.g. a flower versus a car). In our case,
457 the gender effect appears in both the constrained (*self-portrait*) and the free conditions. This
458 gender difference in the use of colors has already been studied, notably from a biological
459 perspective by studying the level of prenatal androgen exposure, even if minimal support was
460 found to assess its role [43]. The importance of social influence is very often highlighted in
461 descriptions of a ‘sex role socialization’ process [44]. Our study shows that this gender
462 difference persists beyond childhood into adulthood.

463 To complement the analyses of our different indices, we asked the youngest children
464 (between 3 and 5 years of age) about the meaning of their drawings (i.e., internal
465 representativeness) in *free* and *self-portrait* conditions. We asked the children not only at the

466 end of the drawing session but also few days later. Remembering and implementing instructions
467 require the storage and the manipulation of information. For the younger ones for who this
468 exercise could be difficult, we did not hesitate to recall the drawing instruction “*do you*
469 *remember, I ask you to draw yourself*”. We naturally repeated it to children who looked at the
470 experimenter, asked her to repeat or told her they did not know what to draw. We did not, or
471 very rarely, have to repeat for the oldest children. The fact that we have to recall the instruction
472 could also be a sign of a lack of concentration on the part of the child. For the self-portrait
473 condition, approximately 80% of the 4- and 5-year-old children answered “*me*” immediately
474 after having drawn, identifying themselves in their drawing. This contrasts with the 3-year-old
475 children, who answered “*me*” significantly less frequently than the older children. Some
476 answered “*nothing*” or “*I do not know*” which may confirm, as our indices do, the absence of
477 an internal representation process for most children of this age. At this age, children are able to
478 form a mental image of themselves [15], so a misunderstanding of the instruction is not a
479 plausible explanation for our results. On this basis, several hypotheses can be considered. It is
480 possible that three-year-old children perhaps did not apply our instruction due to a lack of
481 motivation. Also, some of them could have struggled with keeping the instruction in mind
482 during the drawing session. Another hypothesis is that they were simply not capable of carrying
483 out the task since they had not yet integrated the graphical elements necessary for the production
484 of a tadpole man due to developing motor and/or cognitive abilities. We can also consider that
485 despite the habituation phase, some of them were too shy to answer when we asked them. Many
486 3-year-old children told the experimenter that they “*did not know how to do it*”. This answer
487 can be understood in two ways which are most probably linked: (1) under-developed locomotor
488 control or (2) a partial or incomplete internalization of the graphic elements necessary to draw
489 the figure of a man (round, vertical and horizontal lines). A final hypothesis is that 3-year-old
490 children realized that their drawing did not look like them and therefore could not answer “*me*”
491 when they saw it finished. Among the few 3-year-olds who managed to draw something
492 figurative (i.e., external representativeness), several responded “*a man*”, showing that they did
493 not recognize themselves, which is characteristic of the early period of figurative drawing [52].
494 It should be noted that the condition in which the drawing was made (free and self-portrait) did
495 not affect the child’s memory of its initial meaning. Like for the self-portrait condition, 3-year-
496 old children did not remember the meaning they had given to their free drawings as well as the
497 oldest children did. In addition to our indices, these results tend to show that the internal
498 representativeness may not well be elaborated in the 3-year-old children, affecting their
499 outlines’ efficiency and therefore the external representativeness of their drawings.

500 Our study uses an innovative index in this domain and reveals differences between
501 chimpanzees and human beings in their capacities to draw, and further differences between
502 humans at different ages. It is important to note that humans learn to draw –a main activity in
503 nursery school - whilst chimpanzees do not. This can explain some of the differences observed
504 between human and non-human primates. From an early age, a human child raised in an
505 industrial country lives in a graphic environment (books, television, and advertising) that might
506 contribute to the emergence of their figurative conception of drawing [46]. Following this idea,
507 it could be interesting in the future to conduct cross-cultural studies with children living in a
508 less graphic environment. However, one difficulty here would be testing children with
509 technology they are not used to. Chimpanzees can be taught to draw [53-55] and adults of this
510 species show better control of their movements than younger ones [5]. Then, like in humans,
511 the fine motor skills of chimpanzees improve with age and training, suggesting that the lack of
512 external representativeness in this species is not explained solely by a lack of adequate motor
513 skills. The meticulous examination of productions made by trained chimpanzees over several
514 years could then be an important next step for future studies. Our spatial index μ MLE already
515 reveals the high reliability of efficiency for the lines traced on screens by individuals. The
516 results presented here are preliminary but already show the relevance of pursuing research on
517 new graphical representation clues. New indices should now be developed to understand the
518 degree of representativeness in drawings by primates, and possibly in other animal taxa.

519

520

521 **Methods**

522

523 1. Ethics

524

525 Drawings by human participants were confidentially collected. Study protocol followed
526 the ethical guidelines of our research institutions and ethical approval was obtained from the
527 Strasbourg University Research Ethics Committee (Unistra/CER/2019-11). Informed consent
528 was obtained from all adult participants and from a parent or legal guardian for children.
529 Informed consent for publication of identifying images in an online open-access publication
530 has been obtained too.

531 All chimpanzees were tested in a dedicated testing room and their participation in this
532 study was voluntary [56]. Regular feeding, daily enrichment and *ad libitum* access to water,
533 leaves, and grasses of live plants were provided [57]. Animal husbandry and research methods

534 complied with international standards (Weatherall report “The use of non-human primates in
535 research”) and all our experimental protocols were approved by Kyoto University (WRC-
536 2017KS009A).

537

538 2. Subjects

539

540 a. *Human participants*

541 One hundred and thirty-eight children (63 girls and 75 boys) and forty adults (20 women
542 and 20 men) took part in this study. Children were pupils in a kindergarten and primary school
543 in Strasbourg, France. Twenty children were enrolled for each age group (3-year-old, 4-year-
544 old, 5-year-old, 7-year-old, 8-year-old, 9-year-old and 10-year-old) except for the group of 8-
545 year-olds, which was composed of 18 children (Table 1). Their participation was voluntary and
546 subject to parental consent. Drawings from kindergarten children (3-, 4-, 5-year-olds) were
547 collected in 2018 and drawings from primary school children in 2019. This means that children
548 who were 6 years old in 2019 could not be tested because they have already been involved
549 when they were 5 years old in 2018.

550 The adults tested were 21 to 60 years old (Table 1). Beyond the age effect (children
551 versus adults), experienced and naive sub-samples were tested in adults to assess the effect of
552 experience on the indices studied. Twenty adults were considered to be naive in drawing since
553 they never took drawing lessons and did not draw as a hobby. These participants were
554 researchers and students of the research institute where the authors worked (naive adults:
555 30.8 ± 10.54 years-old). Twenty experts in drawing were also enrolled, including art school
556 students and professional illustrators (expert adults: 30.4 ± 11.12 years-old). For both groups,
557 naive and expert, we accepted all ages but made sure to retain the same number of men and
558 women. Participation was voluntary.

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567 **Table 1. Groups, sex and test condition of human participants.** For each group of
 568 participants, half of the subjects began testing with the *free* condition instructions; the other
 569 half with the *self-portrait* condition. The choice was made randomly.

Participants groups		Gender	Free => Self-portrait	Self-portrait => Free
Children	3-year-olds	girls	n=2	n=3
		boys	n=8	n=7
	4-year-olds	girls	n=5	n=5
		boys	n=5	n=5
	5-year-olds	girls	n=5	n=5
		boys	n=5	n=5
	7-year-olds	girls	n=5	n=5
		boys	n=5	n=5
	8-year-olds	girls	n=5	n=4
		boys	n=4	n=5
	9-year-olds	girls	n=5	n=4
		boys	n=5	n=6
10-year-olds	girls	n=5	n=5	
	boys	n=5	n=5	
Adults	naive	women	n=5	n=5
		men	n=5	n=5
	expert	women	n=5	n=5
		men	n=5	n=5

570

571 *b. Chimpanzees*

572 Five female chimpanzees (*Pan troglodytes*) between 10 and 22 years of age were tested at
 573 the Kumamoto Sanctuary of the Wildlife Research Center of Kyoto University in Japan (Table
 574 2). Individuals belonged to the same social group of 6 individuals (5 females and 1 male) and
 575 lived in a 300m² enriched and wooded enclosure. All had experienced behavioral and cognitive
 576 tests during “participant observation” [58, 56], in which the experimenters interacted directly
 577 with the subject during test sessions and were present in the daily lives of the chimpanzees.
 578 Chimpanzees had already been familiarized with touchscreens in previous experimental
 579 procedures.

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587 **Table 2. Name and year of birth for each chimpanzee and the number of drawings**
 588 **completed for each test session.**

Name	Born in	Session 1	Number of drawings	Session 2	Number of drawings
Natsuki	2005	tested alone	1	tested alone	1
Mizuki	1996	tested with her daughter Iroha	2	tested with her daughter Iroha	1
Hatsuka	2008	tested with her mother Misaki	2	tested with her mother Misaki	2
Misaki	1999	tested with her daughter Hatsuka	1	tested with her daughter Hatsuka	1
Iroha	2008	tested with her mother Mizuki	0	tested with her mother Mizuki	1

589

590 3. Experimental design

591

592 *a. Human participants*

593 Habituation phase: each participant (children and adults) was invited to try a
 594 touchscreen tablet (iPad Pro, 13-Inch, version 11.2.2, capacitive screen reacting to the
 595 conductive touch of human fingers), then draw on it with their fingers and understand how it
 596 worked, notably to change the color used (Fig. 5A, Supplementary Video file S7). The drawing
 597 with fingers was preferred to allow the inclusion of some chimpanzees and youngest children
 598 who have not yet mastered the use of a pencil. A panel consisting of 10 different colors was
 599 displayed on the bottom of the screen, and the participant could select one color for their
 600 drawing by clicking on one of them. When they clicked on a different color in the panel, any
 601 subsequent drawing production was in that color. Children were habituated the day before the
 602 tests to avoid overstimulation. Adults were tested immediately after discovering the tablet.

603 Testing phase: each child was individually tested at school, during school time, in their
 604 classroom for 3-year-olds, and in the staff room for the older children. The experimenter (LM
 605 or MP) stayed during the test but kept their distance during drawing in order to avoid
 606 influencing the child. Adults were also tested individually in a room at the research institute for
 607 naive participants or at the art school for the experts. Contrary to children, adult participants
 608 were left alone in the room. A camera recorded the hand movements of all participants while
 609 drawing, in case we needed to control for any problem during the session (interruption of the
 610 drawing, involuntary tracings, *etc.*). No time limit was applied.

611 Each participant (child and adult) was tested in two conditions. This choice of drawing
612 tasks was made in order to assess a possible difference in results between a non-specific task
613 (*free drawing*) and a specific one (*self-portrait*).

614

615 *Free condition: "Draw what you want"*. The experimenter explained to the subject that
616 they could draw whatever they wanted, with no further instructions. The experimenter
617 systematically asked each child up to and including the age of five to say what they had drawn
618 when they had finished their drawing (in older children, it was always obvious what has been
619 drawn). The same question was asked three days later to monitor the consistency of the answer.

620 *Self-portrait condition: "Draw yourself"*. The experimenter instructed the subject to
621 draw themselves. Again, the experimenter systematically asked each child up to and including
622 the age of five what they had drawn, and repeated the question three days later to monitor the
623 consistency of the answer.

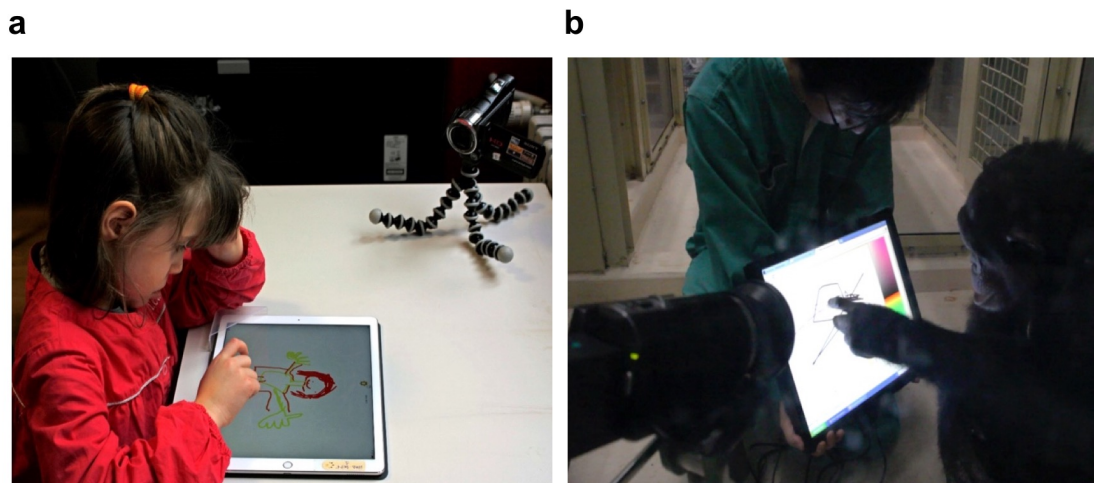
624 In each participant group, half of the subjects began the test with the *free condition*
625 instructions, the other half started with the *self-portrait condition*. The choice was made
626 randomly. To ensure adequate levels of concentration, none of the children drew under both
627 conditions the same day. A total of 356 drawings were collected in humans (Table 1,
628 Supplementary materials Figure S8).

629

630 *b. Chimpanzees*

631 Each female or mother-daughter duo was isolated during lunch time in a testing room
632 using a system of trapdoors and tunnels. Once inside the room, they were provided with fruit
633 and vegetables and asked to sit down. The experimenter (SH) presented a resistive touch screen
634 (1947L 19-Inch Rear-Mount Touch monitor) to the chimpanzee and encouraged her to draw on
635 it using her fingers (Fig. 5B, Supplementary Video file S7). Each individual was free to
636 approach and use the touchscreen. There was no time limitation. In the case of mother-daughter
637 duos, some fruit juice was given to the chimpanzee who did not draw to avoid disruptions. The
638 touch screen was connected to a computer that was controlled by a second experimenter (MP),
639 who directly recorded the data for the drawing. Since chimpanzees have a color recognition
640 quite similar to that of humans [59, 60], they also had the opportunity to use colors. A color
641 gradient was displayed on the right-hand side of the screen, and the subject could select a color
642 for her drawing by clicking on it. When she clicked a different color of the panel then any
643 subsequent drawing appeared in that color. Each test session was videotaped in order to analyze

644 the chimpanzee's behavior when drawing. Chimpanzees drew on two consecutive days in
645 October 2017, and 12 drawings were collected (Table 2, Supplementary materials Figure S9).



646 **Fig 5. Procedure set up for (a) human participants and (b) chimpanzees.** All drew
647 with their fingers and were filmed during the drawing sessions.

648

649 4. Statistical analysis

650

651 For each drawing, the software allowed us to record the spatial coordinates X and Y of
652 every point of the lines drawn as well as their time coordinates [min; s; ms].

653

654 a. *The spatial index* μ_{MLE}

655 This first index allowed us to characterize the lines of the drawing. As coordinate
656 scoring of the drawing was continuous (one point per frame), we focused on active changes
657 [61, 41]: a selection of points was carried out for each drawing via a change-point test under R
658 software (version 1.1.383; CPT; 40). This allowed us to determine points which included
659 changes of directions and to select solely the active changes of directions produced by the
660 individual who was drawing [40]. This enabled us to limit the number of points considered for
661 each drawing (Fig. 6).

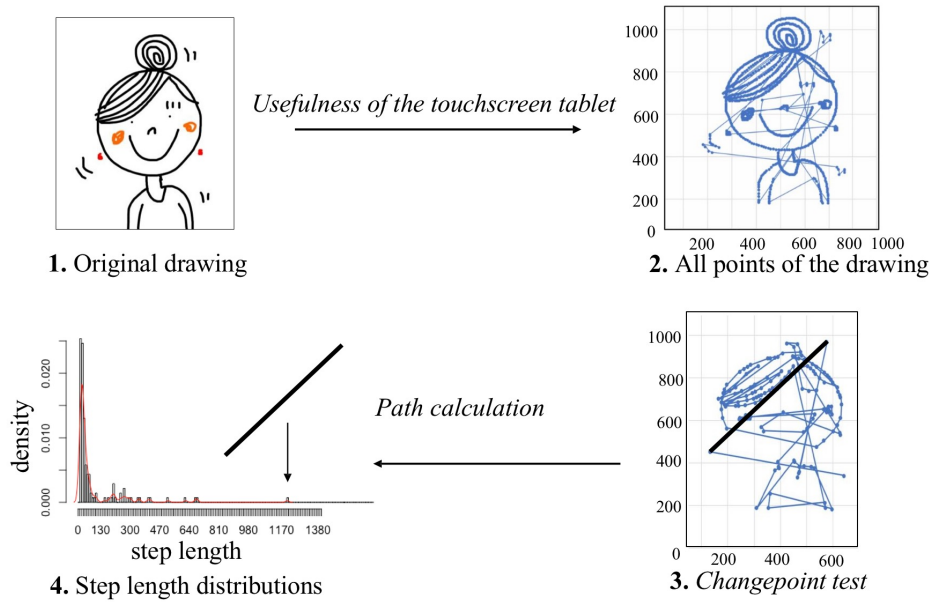
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680 **Fig 6. Schema of the different analytical stages for a drawing.** All the points of a drawing
 681 were extracted from the original one. The application of the changepoint test enabled us to use
 682 a reduced number of points; step length distribution was then analyzed. The step length (thick
 683 black line) in stage 3 is transferred onto the graph in stage 4. Isabelle Jacqué drew the original
 684 drawing.

685

686 Two consecutive points (i and j) in the drawing *d* determined a step or a vector of a
 687 length $L(i,j)$. We then calculated the step lengths *S* on Excel with latitude *x* and longitude *y* (in
 688 pixels).

689

$$S(i,j) = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}$$

690

691

692 Step lengths between 0 and 10 pixels were removed since they often corresponded to
 693 very short, inactive movements such as imprecise lines or finger sideslips and caused
 694 inaccuracies.

695 We then determined whether the step length frequency distribution of a drawing
 696 followed a power law ($y = a \cdot x^\mu$) or an exponential law ($y = a \cdot e^{-x \cdot \lambda}$) using the *Maximum*
 697 *Likelihood Method* [45]. To achieve this, we calculated the exponent of the distribution
 698 (Equation 1 for power law and Equation 2 for exponential law) in order to determine the

699 distribution log-likelihood (Equation 3 for power law and Equation 4 for exponential law),
 700 where n is the total number of step lengths and S_{\min} is the minimum step length.

701

702 (1) Maximum estimate of the power law exponent μ_{MLE} :

$$703 \quad \mu_{MLE} = 1 + n \left(\sum \ln \frac{S_i}{S_{\min}} \right)^{-1}$$

704

705 (2) Maximum estimate of the exponential law exponent λ_{MLE} :

$$706 \quad \lambda_{MLE} = n \left(\sum (S_i - S_{\min}) \right)^{-1}$$

707

708 (3) Log likelihood of the power law L_{pow}

$$709 \quad L_{pow} = n(\ln(\mu_{MLE} - 1) - \ln S_{\min}) - \mu_{MLE} \sum \ln S_i / S_{\min}$$

710

711 (4) Log likelihood of the exponential law L_{exp}

$$712 \quad L_{exp} = n \ln \lambda_{MLE} - \lambda_{MLE} \sum (S_i - S_{\min})$$

713

714 Log-likelihoods of the exponential and power distributions for each drawing d could
 715 then be compared using the Akaike Information Criterion (AIC) calculated with $L_{i,d}$ the log-
 716 likelihood of the exponential and of the power distribution and K_i the number of free parameters
 717 i in the model ($K=1$ as the exponent is the only one parameter for both distributions).

$$718 \quad AIC_{i,d} = -2L_{i,d} + 2K_i$$

719

720 The model retained (power or exponential) was that with the lowest AIC, considering a
 721 minimum difference of 2 between the two AICs [62].

722

723 All the drawings produced by our 10 groups of participants (chimpanzees, 7 grades of
 724 children, naive and expert adults) followed a power law (lowest AIC, see Supplementary data
 725 Table S10). The Maximum Likelihood Estimate of the power law exponent μ_{MLE} was then
 726 used to draw conclusions on the efficiency of the representation for each drawing. This index
 727 is comprised of values between 1 and 3 [39, 63]. The higher the index, the more the line was
 728 considered to be directed, well planned and efficient [63].

729

730 *b. The drawing duration*

731 In chimpanzees, drawing sessions lasted on average five minutes during which each
732 individual drew less than one minute (mean = 49 ± 17.7 seconds). However, given that
733 chimpanzees were stimulated by the experimenters and often distracted by their environment,
734 drawing duration was only analyzed in humans. The duration of each drawing was measured in
735 seconds and corresponded to the elapsed time between the first and the last point of the drawing.

736

737 *c. The use of color*

738 The color of each point has also been recorded by our drawing software. Since the
739 subjects had access to 10 different colors, we defined first a color index ranging from 1 to 10
740 and corresponding to the number of colors used. We then considered the number of times a
741 subject changed the color used. This second color index can be equal or higher to the number
742 of colors used, as the same color can be used several times.

743

744 *d. The meaning of drawings in children*

745 When asked about the meaning of their drawing, a child can say what they intended to
746 draw before drawing (internal representativeness) but also what they see once their drawing is
747 finished (fortuitous meaning; *I6*). If a child remembers the first meaning of their drawing three
748 days later, we can consider this consistency in their answer to be evidence of a real intention to
749 represent the object in question at the outset. This part of the study concerns the three youngest
750 groups of children (between 3 and 5 years old), for whom representative, decipherable and
751 readable drawing (external representativeness) was not systematic.

752 Each child was questioned immediately after drawing and three days later (LM or MP
753 showed him his drawing again) about the meaning of their drawing in the *self-portrait* and *free*
754 conditions. We chose to not question children before and after their drawing to not disturb them,
755 influence them and their choices, especially the youngest ones who, for some, were initially
756 intimidated by the exercise. Besides, drawing sessions did not last long and children could give
757 the same meaning to their drawing just to match what they had announced, even if plans
758 changed along the way (they did not have the necessary graphic skills to achieve their drawing
759 or at the end, the drawing had no real representational purpose per se). Answers were recorded
760 and coded 1 when the child gave us the same answer at the end of the test session and three
761 days later (for example, “*me*” for the self-portrait condition) and 0 when the child gave us two
762 different answers. First, we analyzed children’s answers for the self-portrait condition. This
763 allowed us to determine whether children were able to understand and follow an instruction,
764 and also indicated their ability to represent something when asked to do so, regardless of

765 whether they could produce a figurative drawing on their own under the free condition. We
766 then compared the answers given by children three days after their drawing in the self-portrait
767 condition with those given three days after drawing in the free condition. This comparison
768 allowed us to determine whether the type of test condition affected the meaning (or the memory
769 thereof) that children had given to their production.

770

771 *e. Statistics*

772 The multicollinearity of our different indices was tested using a VIF test for each model.
773 As no index had a VIF superior to 4 ($VIF_{\max}=2.71$), we concluded that there was no collinearity
774 between our variables [64]. This means that the spatial index, the color used and the time taken
775 to draw are not dependent on each other.

776 The indices were analyzed in two different ways. First, we compared human participants
777 and chimpanzees by taking only the *free* condition drawings into account. The sex factor was
778 excluded as all chimpanzees were female. In a second step, we compared *gender*, *test condition*
779 and *groups* within the groups of human participants. No influence of condition order was found
780 (Wilcoxon test, $W < 303$, $p > .05207$) meaning that data did not significantly differ whether the
781 person first drew under *free* or *self-portrait* conditions.

782 Each index was studied through Generalized Linear Models GLM (dependent variable ~
783 explanatory variables). *Individual (IDs)* was added as a random factor when considering the
784 meanings of drawings in children. We first selected the most efficient model to explain the
785 variability of the studied index, using the variables *group*, *gender*, *test condition*, *gender-*
786 *condition* interaction and/or *group-condition* interaction. The model selection was carried out
787 by a dredge (package MuMin; 65) which is a forward procedure (from the null to complete
788 model). After the dredge, we selected the one with the lowest AIC (model selection; 65). When
789 the AIC difference of the first two best models did not exceed two [62], they were compared
790 using an Anova (anova function (glm1, glm2, test: “F” or “Chisq”). When the difference was
791 not significant ($p > .05$), the simplest model was preferred to respect the parsimony principle.
792 For each selected model, the probability distribution was adapted to the dependent variable and
793 the conditions of application (normality and homoscedasticity of residuals) were graphically
794 verified. All analyses were performed in R. 3.5.0 (66) and for all tests, the significance threshold
795 was set to $\alpha = .05$.

796

797

798

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954

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965 **availability:** Information and data are available in the Supplementary Materials, and additional
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981 **Supplementary materials**

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984 **Results**

985 1. The spatial index μ_{MLE}

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987 **Table S1.** Results of the generalized linear model realized to compare the spatial fractal index
 988 μ_{MLE} . **(a)** between chimpanzees and humans (compared to chimpanzees) and **(b)** among humans
 989 (compared to 3-year-old children).

	Estimate	Std. Error	t value	Pr(> t)
a				
Intercept	1.50	0.04	34.91	< 0.0001
3-year-old children	0.22	0.05	4.51	< 0.0001
4-year-old children	0.28	0.05	5.73	< 0.0001
5-year-old children	0.34	0.05	6.85	< 0.0001
7-year-old children	0.37	0.05	7.47	< 0.0001
8-year-old children	0.28	0.05	5.55	< 0.0001
9-year-old children	0.34	0.05	6.82	< 0.0001
10-year-old children	0.33	0.05	6.60	< 0.0001
Naive adults	0.23	0.05	4.63	< 0.0001
Expert adults	0.20	0.05	4.10	< 0.0001
b				
Intercept	1.72	0.03	71.72	< 0.0001
4-year-old children	0.06	0.03	1.79	0.07
5-year-old children	0.12	0.03	3.43	< 0.001
7-year-old children	0.14	0.03	4.33	< 0.0001
8-year-old children	0.05	0.03	1.58	0.11
9-year-old children	0.11	0.03	3.37	< 0.001
10-year-old children	0.10	0.03	3.05	0.002
Naive adults	0.01	0.03	0.19	0.85
Expert adults	-0.02	0.03	-0.61	0.54

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993 2. The drawing duration

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997 **Table S2.** Results of the generalized linear model to study drawing duration among humans
 998 (compared to 3-year-old children, and *free* condition compared to *self-portrait* condition).

	Estimate	Std. Error	t value	Pr(> t)
Intercept	4.54	0.12	38.41	< 0.0001
4-year-old children	0.52	0.16	3.32	< 0.001
5-year-old children	0.80	0.16	5.08	< 0.0001
7-year-old children	0.96	0.16	6.11	< 0.0001
8-year-old children	0.67	0.16	4.15	< 0.0001
9-year-old children	1.06	0.16	6.33	< 0.0001
10-year-old children	1.06	0.16	6.69	< 0.0001
Naive adults	0.93	0.16	5.89	< 0.0001
Expert adults	0.83	0.16	5.23	< 0.0001
<i>Free</i> condition	0.33	0.07	4.52	< 0.0001

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1001 3. The use of colors

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1003 a. Number of colors used

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1005 **Table S3.** Results of the generalized linear model carried out to compare the number of colors
 1006 used. **(a)** between chimpanzees and humans (compared to chimpanzees) and **(b)** among humans
 1007 (*free* condition compared to *self-portrait* condition and boys/men compared to girls/women).

	Estimate	Std. Error	z value	Pr(< z)
a				
Intercept	0.88	0.18	4.75	< 0.0001
3-year-old children	0.88	0.21	4.26	< 0.0001
4-year-old children	1.06	0.20	5.21	< 0.0001
5-year-old children	0.81	0.21	3.89	< 0.0001
7-year-old children	0.77	0.21	3.65	< 0.001
8-year-old children	0.77	0.21	3.63	< 0.001
9-year-old children	0.70	0.21	3.29	< 0.001
10-year-old children	0.88	0.21	4.26	< 0.0001
Naive adults	0.71	0.21	3.34	< 0.001
Expert adults	0.74	0.21	3.60	< 0.001
b				
Intercept	1.45	0.04	35.56	< 0.0001
<i>Free</i> condition	0.24	0.05	5.06	< 0.0001
Boys/men	-0.14	0.05	-2.97	< 0.001

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1010 b. Number of color changes

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1012 **Table S4.** Results of the generalized linear model to compare the number of color changes. **(a)**
1013 between chimpanzees and humans (compared to chimpanzees) and **(b)** among humans (*free*
1014 condition compared to the *self-portrait* condition and boys/men compared to girls/women).

		Estimate	Std. Error	z value	Pr(> z)
a	Intercept	0.35	0.35	0.98	0.33
	3-year-old children	1.40	0.42	3.34	< 0.001
	4-year-old children	2.14	0.41	5.17	< 0.0001
	5-year-old children	1.99	0.41	4.81	< 0.0001
	7-year-old children	2.02	0.41	4.87	< 0.0001
	8-year-old children	1.92	0.42	4.56	< 0.0001
	9-year-old children	2.02	0.41	4.88	< 0.0001
	10-year-old children	1.95	0.41	4.70	< 0.0001
	Naive adults	2.10	0.41	5.08	< 0.0001
	Expert adults	2.34	0.41	5.71	< 0.0001
	b	Intercept	2.07	0.09	24.02
Boys/men		-0.30	0.1	-3.11	0.002
<i>Free</i> condition		0.43	0.1	4.45	<0.0001

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1017 4. The meaning of drawings in children

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1019 **Table S5.** Results of the generalized linear model carried out to study the consistency of the
1020 answer for the *self-portrait* condition among the three youngest categories of children
1021 (compared to the 3-year-old children and the response rate « me » immediately compared to
1022 « me » after three days).

	Estimate	Std. Error	z value	Pr(> z)
Intercept	-26.99	4.48	-6.03	< 0.0001
4 year-old children	39.12	5.57	7.02	< 0.0001
5 year-old children	38.76	5.51	7.04	< 0.0001
Response rate « Me » immediately after the <i>self-portrait</i> condition	14.34	2.78	5.16	< 0.0001

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1027 **Table S6.** Results of the generalized linear model carried out to study the effect of the
1028 condition on memorization (compared to the 3-year-old children).

	Estimate	Std. Error	z value	Pr(> z)
Intercept	-0.61	0.36	-1.69	0.091
4 year-old children	1.12	0.48	2.30	0.021
5 year-old children	1.26	0.49	2.54	0.011

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Data collection and analysis

1032 **Video file S7.** Short sequence of an adult's drawing session on the touchscreen tablet (iPad Pro,
1033 13-Inch, version 11.2.2) followed by a short sequence of a chimpanzee's drawing session on
1034 the resistive touchscreen (1947L 19-Inch Rear-Mount Touch monitor).

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Self-portrait condition



Self-portrait condition



Free condition



Free condition



Free condition

Figure S8. Examples of drawings by 3-year-old children, in *free* and *self-portrait* conditions.

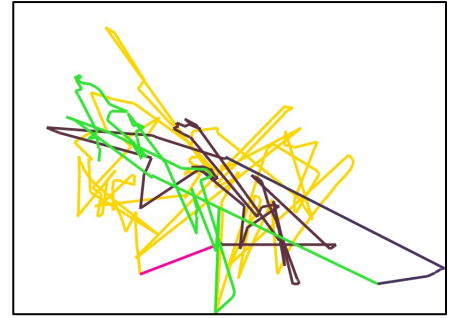
Drawings collected on 10/26/2017



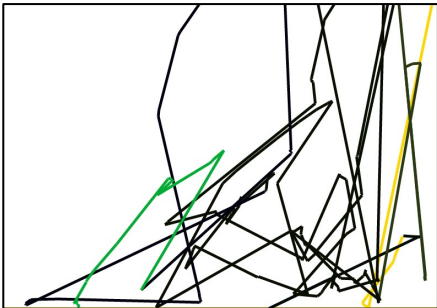
Hatsuka, first drawing



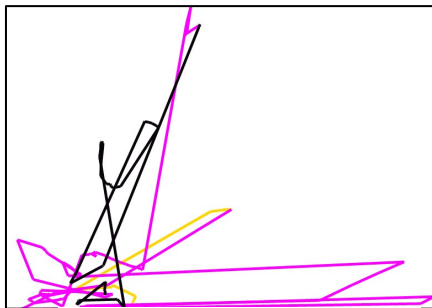
Hatsuka, second drawing



Misaki



Mizuki, first drawing

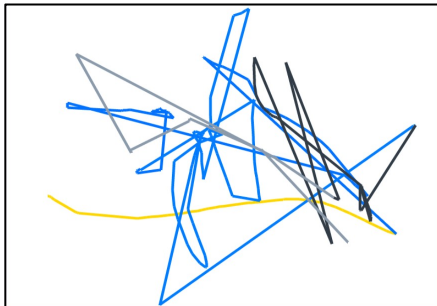


Mizuki, second drawing



Natsuki

Drawings collected on 10/27/2017



Hatsuka, first drawing



Hatsuka, second drawing



Iroha



Misaki



Natsuki

Figure S9. Chimpanzees' drawings collected on two consecutive days in October 2017.

During the second day, one of the females (Mizuki) erased her drawing but the data had been saved.

Table S10. Table with data used for the analysis, see “Data table” excel file.