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Laterality and visuospatial strategies among young children: A novel 3D-2D transcription task

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14 **Abstract**

15 Recent findings showed that children, like adults, exhibit directional biases leading to
16 asymmetrical drawings. This appears to be the result of a complex interaction between several
17 biological, motoric, and cultural factors. We created a drawing task designed to investigate the
18 influence of laterality (i.e., hemispherical functional specialization and handedness) and sex on
19 children’s graphical asymmetries. This task consists of transcribing a symmetrical three-
20 dimensional landscape model to a two-dimensional representation. Sixty-six French pre-school
21 children, aged between 5 and 6 years, were asked to undertake the 3D-2D transcription task, as
22 well as the classical Alter’s directionality task. The novel task exhibited higher sensitivity than
23 the Alter’s directionality test when examining the spatial biases resulting from handedness, and
24 sex. Specific drawing patterns related to these variables were identified. These results suggest
25 that, in addition to the influence of biomechanical factors and handedness, sex plays a role in
26 children’s early graphomotor development. They also support the influence of laterality as a key
27 factor underlying early directional biases.

28

29 **Keywords:** Lateralization, hemispherical functional specialization, handedness, sex, visuospatial
30 patterns.

31 **Introduction**

32 The human brain is asymmetrically organized showing complementary specialization of the two
33 cerebral hemispheres. This Hemispherical Functional Specialization (HFS) refers to the nature of
34 the information that each hemisphere controls as well as the way each hemisphere processes it
35 (Corballis, 2012). Thus, for most of the population, the left hemisphere is dominant for language,
36 praxis, local and sequential processing, while the right hemisphere is dominant for spatial
37 attention, face recognition, visuospatial activities, and global processing (Evans et al., 2000;
38 Tzourio-Mazoyer & Seghier, 2016; Vingerhoets, 2019).

39 The influence of HFS on individuals' drawings is well documented. Drawings are characterized
40 by directional patterns and distinct asymmetric features that are referred to as directional biases
41 (Picard, 2013). One interpretation of these directional biases is based on cognitive, attentional-
42 representational asymmetries underpinned by HFS. An attentional bias, known as
43 "pseudoneglect", is frequently reported in the literature among neurotypical individuals (Bowers
44 & Heilman, 1980) who manifest a leftward deviation when executing line bisection tasks (Jewell
45 & McCourt, 2000). This phenomenon reflects the influence of HFS on visuospatial attention and,
46 more precisely, the dominance of the right hemisphere in the treatment of spatial information and
47 in the processing of tasks with a spatial component which results in an attentional bias in favor of
48 the left visual field (Kinsbourne, 1970). This leftward attentional bias appears to be associated
49 with a general aesthetic preference for images with more elements and details on the right
50 hemispace. This aesthetic preference appears to restore the imbalance created by the leftward
51 attentional bias caused by the dominance of the right hemisphere (Levy, 1976). Interindividual
52 differences are observed concerning attentional biases in terms of importance and direction as a
53 function of biological maturity (cerebral asymmetries, corpus callosum and sensorimotor
54 development), reading experience (exposure to visuomotor explorations according to the script

55 directionality), and the nature of the visual stimuli. However, it is still unclear to what extent
56 each of these factors influence these attentional biases.

57 Handedness

58 At 3 years of age, the attentional bias in favor of the left visual field is only slight. The direction
59 of attentional bias depends on the hand used in a line bisection task: rightward when the right
60 hand is used and vice versa for the left hand (e.g., Failla et al., 2003; Girelli et al., 2017). This
61 ipsilateral bias for the used hand, called “symmetrical neglect”, reflects incomplete psychomotor
62 development and insufficient interhemispheric transfer of perceptual information, causing a
63 difficulty in crossing the midline during motor activities. From 5 years of age, increased motor
64 maturity allows for the emergence of attentional biases. However, there are variations depending
65 on the nature of the presented stimuli and implied information processing. Indeed, Girelli et al.
66 (2017) found that 5-year-old right-handed (RH) children presented a leftward attention bias for
67 the line bisection task, but rightward bias for the bisection of words and figure strings. This
68 difference suggests a differential treatment of visual stimuli according to their continuous or
69 discontinuous nature: discontinuous stimuli (e.g., series of letters) preferentially activates local
70 processing of information for which the left hemisphere is dominant, causing attentional bias to
71 the right. In line with this result, 5-year-old RH children also show attentional biases on a 3D
72 spatial line bisection task (in which they had to point to the middle of lines oriented horizontally,
73 vertically, and radially), where leftward and upward biases are more apparent for the younger
74 children (Patro et al., 2018). Picard and Zarhouch (2014) examined the influence of age,
75 handedness, and script directionality (i.e., reading and writing’s directionality) on the attentional
76 bias. With a draw-a-tree task proposed to right and left-handed French (5 to 15 years old) and
77 Moroccan (7 to 11 years old) children, the authors failed to observe any influence of age and

78 script directionality. However, they found a leftward bias concerning the location of the figure on
79 the graphical space (i.e., depiction of the figure more to the left of the graphic space), for the
80 right-handers. The absence of bias in left-handed children is commonly related to a weaker
81 lateralization generally observed in comparison with their right-handed peers (de Schotten et al.,
82 2011; Willems et al., 2014). Indeed, right-handers are strongly lateralized, while left-handers
83 present lesser hemispheric lateralization, fewer cerebral asymmetries, and a larger corpus
84 callosum (Li et al., 2014; Ocklenburg & Güntürkün, 2018a).

85 Differences according to handedness are also found in directionality preferences. Adult right-
86 handers predominately orient their drawings to the left when they are asked to draw familiar
87 objects (Alter, 1989; Karev, 1999; Shanon, 1979). However, this directionality bias is less clear
88 among the left-handers. While a weaker directionality bias is observed among the left-handers
89 (Karev, 1999; Shanon, 1979), Alter (1989) found the inverse effect where the left-handers
90 favoured right directionality. This directionality difference between right- and left-handers is
91 assumed to reflect the degree of lateralization, which is stronger in rights-handers and more
92 heterogenous among left-handers. Therefore, there is a disparity in the results concerning left-
93 handers, though this may simply be due to the relative underrepresentation of left-handed (LH)
94 participants in many handedness studies. Drawing directionality can also be influenced by the
95 hand-movement-related asymmetries arising from a biomechanical factor associated with
96 whether the right or left hand is used to draw. It is easier to perform outward-directed
97 movements than inward directed movements. Thus, the handedness of a person creates a
98 difference in the stroke's starting point and orientation (van Sommers, 1984). Right-handers
99 generally follow a left-to-right stroke direction, beginning their drawing from the left side, while
100 the opposite pattern is found among the left-handers (van Sommers, 1984, 1989). Tosun and

101 Vaid (2014) conducted two meta-analyses that revealed the importance of the hand used in
102 influencing the direction in which the object faces. They argue that figure drawing direction is
103 determined largely by biomechanical principle. They found a significant influence of handedness
104 irrespective of the script directionality. Consequently, handedness appears to determine how one
105 orients the drawing of a face. Given that the front of an object tends to be drawn first, depending
106 on whether one is using the right or the left hand to draw, the profile will end up facing leftward
107 or rightward, respectively. However, the authors emphasize that a large unexplained variance
108 remained even after correcting for uneven sample size and sampling error of left and right-
109 handers. Consequently, the authors suggest that there may be other factors, such as aesthetic
110 judgments, that may influence drawing directionality. One important factor that can affect
111 aesthetic judgments, and which the authors could not include in their study, is sex.

112 Sex

113 Different brain activity is reported between males and females during an aesthetic judgment task.
114 Cela-Conde and collaborators (2009) asked their participants to rate unfamiliar artistic and
115 natural visual stimuli as beautiful or not during magnetoencephalography. For the stimuli rated
116 as beautiful, a bilateral activity in the parietal regions was found in females, while males showed
117 lateralized activity to the right hemisphere. These findings may reflect different spatial strategies
118 in assessing aesthetic preferences. Indeed, due to their lateralized activity to the right
119 hemisphere, males are more prone to use coordinate-based strategies (i.e., relying on precise
120 metrics), whereas females, due to their bilateral activity, will tend to use categorical spatial
121 strategies (Kosslyn, 1987). An alternative interpretation was also given by the authors based on
122 spatial exploration strategies. Since the right hemisphere is associated with a global and the left

123 hemisphere with a local visual processing, males may rely more on the global features of a visual
124 stimulus to make a judgment, whereas females will rely on both global and local features.
125 This interpretation appears supported in the literature given that, at a functional level, boys are
126 more strongly lateralized than girls for language processing, facial processing and spatial
127 attention (Bourne & Maxwell, 2010; Ocklenburg & Güntürkün, 2018b). Furthermore, girls are
128 found to perform better than boys in spatial tasks requiring a categorical process such as
129 recalling spatial configuration (Silverman & Eals, 1992), and also in spatial accuracy and
130 visuomotor skills as early as five years of age (Barral & Debû, 2002; O'Gorman, 1999;
131 Karapetsas & Vlachos, 1997). These findings are associated with a more efficient
132 interhemispheric connection among girls. In agreement with this, females have a denser
133 interhemispheric connection and larger corpus callosum. The latter can be detected as soon as the
134 foetal life, where girls present a thicker corpus callosum than boys (Achiron et al., 2001;
135 Ocklenburg & Güntürkün, 2018c; for a review on sex differences, see Hirnstein et al., 2019).
136 Consistent with the previous observations, the stronger lateralization of visuospatial attention in
137 males was associated with a greater aesthetic preference for a left-to-right directionality than
138 females (Friedrich et al., 2014), and a slightly greater leftward bias in line bisection tasks (Jewell
139 & McCourt, 2000). Similarly, De Agostini et al (2011) reported a sex difference with visual
140 aesthetic preferences by comparing French children (aged from 7 to 10 years) and adults. They
141 presented static images (e.g., lamp), moving images (e.g., duck), and landscapes (e.g., an
142 umbrella in front of a beach) oriented either from left to right or from right to left. They asked
143 their participants to indicate which of the stimuli were more aesthetically pleasing. Similar
144 results were found for the static and moving objects. For left-handers, adult men preferred
145 rightward oriented images, whereas adult women did not show any directionality preference. In

146 contrast, the LH children (boys and girls) preferred leftward oriented images. All the right-
147 handers preferred a rightward directionality. These findings reflect the contribution of biological
148 factors, such as handedness and sex, in visuospatial organization. The authors suggested that the
149 shift to a rightward preference among LH males could be the consequence of the exposure to the
150 left-to-right script directionality. However, LH females appear to be less sensitive to this cultural
151 factor, explaining the absence of directional preferences. The landscape stimuli resulted in a
152 significant preference for a rightward directionality which increased with age for males,
153 compared to females who showed no significant difference. Indeed, RH or LH girls and females
154 did not have any directional preferences.

155 Overall, the results suggest that aesthetic preference for moving and static images may be more
156 sensitive to cultural factors (i.e., script directionality), whereas the aesthetic preference for
157 landscape images may be more influenced by HFS (see also Chokron & De Agostini, 2000).
158 However, Kebbe and Vinter (2013) failed to replicate the significant sex difference found by De
159 Agostini et al (2011). They asked children (aged 6 to 10 years) and adults to draw a side view of
160 different objects (e.g., vehicles, faces, animals, tools). They found a significant difference
161 according due the script directionality for the older children and adults only. The absence of a
162 sex difference can be explained by two reasons. Firstly, as the authors noted, it may be a
163 consequence of the low number of males and females per group in their study. Secondly, both
164 static and moving objects were used in this study which appear to be more influenced by the
165 script directionality, whilst the landscape objects appear to be more influenced by HFS (Chokron
166 & De Agositni, 2000; De Agostini et al., 2011).
167 Ishii et al (2011) investigated the difference between moving/statics and landscape images
168 further. They conducted a study on adults using a line bisection task and a similar aesthetic

169 preference task as the one used by De Agostini et al (2011). Interestingly, they found a
170 correlation between landscape stimuli and the line bisection task. The authors suggested that
171 landscape images and the line bisection task share common features since they require an
172 evaluation of spatial information spread across a horizontal line. Based on the pseudoneglect
173 literature, they argued that the degree of the attentional bias is stronger for stimuli with long
174 horizontal and short vertical axes, thus the correlation between the two tasks. However, this is
175 not the case for moving and static images, which due to their form, are less influenced by
176 attentional biases and more sensitive to external factors, such as script directionality (Ishii et al.,
177 2011).

178 Together, the literature suggests that visuospatial attentional bias and positioning asymmetries in
179 drawing activities mainly reflect HFS and specifically the right hemisphere dominance of visual
180 attention. These biases are more pronounced among individuals with a higher degree of
181 lateralization and can be modulated by biological factors such as handedness and sex. We should
182 note that the script directionality also plays an important role in the graphomotor asymmetries
183 (Abed, 1991; Chokron & De Agostini, 2000; Ishii et al., 2011; Kebbe & Vinter, 2013; Ossandón
184 et al., 2014; Picard & Zarhouch, 2014; Rinaldi et al., 2016; Rinaldi et al., 2020; Tversky et al.,
185 1991; for reviews see Page et al., 2017 and Vaid, 2011).

186 A complex interaction of several biological, motoric, and cultural factors leads to the directional
187 biases observed in children and adults (Rinaldi et al., 2020). Whilst these studies investigated the
188 perceptual biases, they scarcely considered the interaction between all these factors, and the
189 degree of the influence of each mechanism underlying them (Tosun & Vaid, 2014). Therefore
190 investigating these factors simultaneously is important for understanding how biological and
191 cultural factors interact at a perceptual and representational level (De Agostini et al., 2011).

192 Proposed study

193 The aim of this study is to investigate the extent to which the HFS, modulated by the handedness
194 and sex, can influence graphical productions in children. Based on the previous findings, we
195 created a new drawing task which is both fun for the child and can probe the following
196 underlying graphic asymmetries in children: 1. attentional biases related to HFS, through graphic
197 density and drawing directionality; 2. biomechanical preferences related to handedness; 3.
198 aesthetic preferences that develops with age. From this, we will identify specific graphical
199 patterns, allowing us to investigate, in a comprehensive way, the interaction between the key
200 contributing factors.

201 In our task, pre-schoolers are asked to transcribe a symmetrical three-dimensional (3D)
202 landscape model, into a two-dimensional (2D) representation on an A4 landscape-oriented sheet.
203 These conditions were chosen for several reasons. Firstly, it is necessary to try to distinguish
204 between biological and cultural factors. For this purpose, we focused on a population of pre-
205 schoolers with a typical development (mean age 5 years and 6 months). Children at this age are
206 less exposed to literacy than the older ones, which limits the potential influence of script
207 directionality. Indeed, past studies on French children did not find any influence of script
208 directionality among children of 6 years of age (Fagard & Dahmen, 2003; Kebbe & Vinter,
209 2013; Picard & Zarhbouch, 2014). However, categorial and coordinate spatial relations are
210 present at this age, so our participants will know how to establish spatial relationships of
211 up/down and left/right (Koenig et al., 1990).

212 Secondly, at an intra-representational level, children generally depict their internal model of
213 reality around 5 years of age (Barrett & Light, 1976; Piaget & Inhelder, 1948; Luquet, 1927).
214 Hence, we suppose that our participants' drawings will be the product of their mental

215 representations and not an imitation of the outside world. Thus, their graphical transcription of a
216 realistic 3D model should be a good indicator of HFS influence on spatial attention and the
217 processing of visuo-spatial information.

218 Thirdly, we chose a landscape as our 3D model since landscape objects seems to be a better
219 reflection of HFS than other objects. Thus, we suppose that the graphical patterns, identified by
220 the 3D-2D task, will be influenced mostly by handedness and sex. Therefore, the detection of
221 specific graphical patterns is needed in order to consider this novel drawing task as a valid
222 assessment. We should observe the following patterns:

- 223 1. Biomechanically, we expect that RH children will tend to draw from left to right, whilst
224 LH children will tend to draw from right to left. Furthermore, the RH are expected to
225 begin their drawing from the left (left point of origin) and the LH from the right (right
226 point of origin).
- 227 2. According to handedness, we expect more drawings to be oriented to the left among our
228 RH participants, while an opposite pattern will be expected among the LH. Furthermore,
229 we expect that the RH children will draw a more asymmetrical 2D representation of the
230 3D symmetrical model, reflecting their stronger HFS. We expect LH children will draw
231 more balanced graphical production due to their lesser lateralization.
- 232 3. We expect that girls will produce a better quality of drawing which is more balanced and
233 symmetrical, since they present a lesser degree of HFS and greater interhemispheric
234 connection than boys.

235

236 **Participants and Methods**

237 **Participants**

238 Sixty-six children participated (mean age = 67.9 months, sd = 3.78 months). The children's
239 handedness was assessed using the Auzias laterality test (see Table 1 for descriptive statistics).
240 The participants were pre-reader children and from nursery classes located in the Paris region
241 (Aulnay-Sous-Bois), and from three kindergartens in Alsace, France. Ethical approval for the
242 study was obtained from the Research Ethics Committee of the University of Strasbourg (see
243 <https://cil.unistra.fr/registre.html#proc-374>). Preliminary academic authorization and parental
244 authorization were obtained before the beginning of the study. Only volunteer participants
245 contributed to this study. None of the children suffered from any psychomotor difficulties that
246 could hinder their writing or drawing performance.

247

248 **Materials**

249 **Auzias laterality test** (Auzias, 1975): This test measures manual preference. Ten items are
250 presented in order to calculate a Laterality Index (LI). The experimenter asks the participants to
251 manipulate different familiar objects and perform different actions (striking a match, erasing,
252 ringing a small bell, eating with a spoon, shining a shoe, combing hair, transferring water from
253 one container to another, brush teeth). Each object is placed in front of the participants in turn.
254 The experimenter observes the manipulation and notes "L" if the participants use their left hand
255 and "R" for the right one. Then, the LI is calculated by the following equation: $LI = [(nR - nL) /$
256 $(nR + nL)] \times 100$ where nR and nL correspond respectively to the number of right- and left-hand
257 uses. LI scores must be between -100 and -50 to be identified as a LH, or between +50 and +100
258 to be RH.

259 **Alter directionality test** (Alter, 1989): The children are verbally asked to draw six different
260 items: fish, airplane, spoon, boat, bus, and car. The orientation of the drawing is noted as either
261 left (L), right (R), or front (=), making it possible to calculate a Directionality Index (DI) = $(nR -$
262 $nL) / 6$ where nL is equivalent to the number of drawings oriented to the left, nR to the number
263 of drawings oriented to the right and 6 is the total number of drawings. The individual DI is
264 distributed between -1 and +1.

265 **Two-dimensional (2D) transcription of the three-dimensional (3D) model:** This task
266 consisted of the presentation of a 3D model with 3 different planes (see Figure 1a). This model
267 had to be reproduced on an A4 sheet by memory. Different coloured pencils are left at the
268 disposal of the child. At the same time as the child draws, the experimenter transcribes the child's
269 actions on an evaluation sheet (see Figure 1b).

270

271

272

Insert Figure 1 about here

273

274

275 The three planes of the model are consisted of: the foreground (plane A), representing a long
276 horizontal river surrounded by lichens; the middle ground (plane B), representing a symmetrical
277 house with three windows; the background (plane C), representing three trees on either side of
278 the house).

279 This task allows us to observe the characteristics and variations of the graphical strategies
280 employed by the children reflecting motor dominance, attentional biases, and mental
281 representations. Together these can be used as a proxy for the degree of HFS (see “Experimental

282 Design and Scoring” for a detailed explanation of all the variables). The reproduction on paper
283 encourages the child to create an orientation. For example, the top of the paper will be the distal
284 part and the bottom is the proximal part (Davis, 1985). Thus, a conversion of the vertical plane
285 into a horizontal one is needed to be able to code the elements perceived in 3D into 2D.

286 **Procedure**

287 Three trained experimenters each separately assessed a different set of children. Afterwards, the
288 lead experimenter carried out the scoring. The assessments were conducted in an isolated room
289 to avoid any alteration of the child’s concentration. Each experimenter, alone with the participant
290 in the evaluation room, is first seated on the child’s side during the handedness and directionality
291 assessments. These tests are presented in the form of small games to promote the motivation of
292 the child. After determining the manual preference and drawing directionality, the experimenter
293 shows the 3D model and retreats slightly behind the child. The table and chairs are child-sized,
294 and thus do not interfere with the motor tasks. At the end of the transcription task, the
295 experimenter accompanies the child into his class while giving some compliments on the
296 achieved work.

297 Instructions

298 The examiner stands beside the child and says (for the original instructions in French, please see
299 Appendix 1): “*Well, I see that you draw very well. I really like your drawings. Now look, I am
300 going to show you something and then I would like you to draw it for me. Be careful, look
301 carefully as you are going to make a drawing that looks as close as possible to the model you are
302 going to see*”. Showing the model: “*Do you see the house and the landscape? So, tell me what
303 you see*”. Then he follows the enumeration made by the child, repeating after him to encourage
304 him. This helps the child to pay attention on all the present elements (avoiding an exclusive

305 focus on the main and attractive element of the model, which is the house – i.e., plane B). In
306 addition, the examiner specifies the relations between the elements located on the foreground and
307 background compared to the middle: *“In the centre, we see a symmetrical house, just in front is
308 a river surrounded by bushes, and behind the house we see six trees”*. After the transcription
309 tools are placed in front of the child, the examiner states the following instruction after hiding the
310 model: *“You are now going to draw everything you saw”*. The examiner then steps back and
311 closely follows the evolution of the graphical production.

312 **Experimental design and scoring**

313 The aim of this study is to investigate the influence of handedness and sex on drawing
314 directionality (underpinned by visuo-motor coordination) and spatial strategies underlying the
315 2D reproduction of a 3D model (underpinned by visuo-spatial perception such as depth,
316 perspective, relative size). Thus, our independent variables are sex and handedness. Eight
317 dependent variables are measured in our experiment:

318 1. The dominant drawing directionality (cf. Alter’s test): A negative value on the ID was quoted
319 as left directionality preference and a positive value was considered as a right preference. A
320 score of 0 was quoted as a balanced directionality (i.e., 3 drawings oriented to the left, 3 to
321 the right).

322 The following variables are only assessed by the 3D-2D transcription task (see Figure 2 for a
323 sample of the children’s 2D transcriptions):

324 2. Origin point: This variable reflects the point at which the child begins his drawing. It can be
325 situated either to the left, the centre, or the right. Usually, the point of origin is a good
326 indicator of the progression axis.

- 327 3. Progression axis: this is the dominant line's direction - vertically or horizontally oriented. We
328 scored lines from left to right and from right to left in two separate categories, while vertical
329 strokes (down-up or up-down) are scored in a single category.
- 330 4. Density of the elements: The density is relative to the area where the different elements of the
331 drawing are located. It is evaluated from the number of occupied squares across the whole
332 surface of the page (divided into 1 cm squares of each side). Thus, the density is determined
333 relative to the middle of the vertical and horizontal axes of the graphical support. We can
334 observe a right, left or balanced density. We assume that the density of the elements reflects
335 the attentional bias underpinned by the dominance of the right hemisphere.
- 336 5. Complementarity of the main graphical elements: The level of detail represented by more
337 drawing and colouring on each side of the house is evaluated. The evaluation of the degree of
338 complexity on one side or the other of the house determines a left, right or a balanced
339 complementarity. Since the attentional bias is associated with an aesthetic preference for
340 images with more elements on one side, we believe that the complementarity of the graphical
341 elements will reflect the aesthetic preferences of the participants.
- 342 6. Correct or incorrect representation: The quality of the graphical production depends on the
343 depicted and omitted elements as well as the spatial relations between the three planes
344 characterizing the 3D model. A correct representation is identified by the offset between each
345 of the three levels along a vertical axis, which is key to the translation from the 3D spatial
346 "front-behind" relation to a 2D "bottom up relation " (Ingram & Butterworth, 1989). Thus, a
347 drawing where the river is depicted on the bottom, the house in the middle and the trees on
348 both sides of the house was considered a correct representation. Other representations were
349 therefore considered incorrect.

350 7. Placement order: The depiction order of the three planes (A, B and C) represents the
351 transcription strategy. This variable will show us the different graphic strategies adopted by
352 the children. For example, a BAC strategy will represent a drawing where the child starts to
353 draw the house (i.e., the main element), followed by the river and finishes by drawing the
354 trees (i.e., the background). However, due to the diversity of the strategies encountered
355 during the assessment, we chose to combine all the results with a low frequency into one
356 category. This category was named “other” and included the following strategies: ACB, B,
357 CAB, CBA (see Table 1 for all the indicators used in the MCA analysis with their respective
358 categories and frequencies).

359 8. Spatial arrangement: This characterizes the orientation of the drawing based on all the
360 elements. We divided this variable into three categories: A, B and C. Category A was defined
361 as when the river is depicted on the left side of the house and/or the trees are on the right side
362 (a leftward orientation). Category B was defined as a symmetrical drawing where the house
363 and river are in the middle of the picture and the trees are present on both sides of the house.
364 Category C was defined as when the river is depicted on the right side of the house and/or the
365 trees are on the left side (a rightward orientation of the drawing).

366 _____
367 *Insert Figure 2 about here*
368 _____
369

370 **Statistical analysis**

371 Our statistical analysis was divided into two parts. The first one consisted of conducting an
372 exploratory analysis allowing us to investigate the children's graphical patterns. We conducted a
373 cluster analysis to classify our participants into different groups. Each of these groups represent
374 participants with common graphical characteristics. These common characteristics allowed us to
375 uncover specific graphical patterns. However, since we have a large number of variables, it is
376 better to perform a dimensional reduction of variables before the clustering (Mitsuhiro &
377 Yadohisa, 2015). Therefore, the exploratory analysis consisted of two parts
378 The first part of the analysis was conducting a Multiple Correspondence Analysis (MCA) to
379 perform the dimensional reduction, and to examine the relationship between our several nominal
380 variables (i.e., sex, handedness, and the graphical variables). The MCA is a multivariate
381 exploratory analysis that does not need any distributional assumptions and is used to investigate
382 the relation between the variable response categories (Greenacre, 1984; Sourial et al., 2010). It
383 allows us to map our data as points in a low-dimensional space, enabling us to examine
384 underlying structures (i.e., dimensions) best suited to uncover the correlations between our
385 variables (Mitsuhiro & Yadohisa, 2015)
386 The second part of the exploratory analysis consisted of conducting a Hierarchical Clustering
387 (HC) to group our participants according to their similarities along the relevant dimensions
388 obtained by the MCA. The statistical analyses were done using R 4.0.3 (R Core Team, 2020). All
389 the study's variables are nominal. The MCA and HCPC functions of the FactoMineR package
390 were used to conduct the MCA and the clustering analyses (Lê et al., 2008). In addition, we used
391 the factoextra, FactoInvestigate, and ade4 packages to optimise our interpretations and graphical
392 representations of the MCA (Dray & Dufour, 2007; Kassambara & Mundt, 2017; Lê et al., 2008;
393 Thuleau & Husson, 2017).

394 The final part of our statistical analysis consisted in conducting Generalized Linear Models
395 (GLM) to examine if our independent variables (i.e., sex and handedness) can predict the
396 graphical variables. These GLM with logistic or multinomial dependent variables were computed
397 in Jamovi 1.1.9 (Gallucci, 2019; Jamovi project, 2020) and in R 4.0.3. (R Core Team, 2020)
398 using the multinom function of the nnet and ggeffect packages (Lüdecke, 2018; Venables &
399 Ripley, 2002).

400

401 **Results**

402 To investigate the relationship between our nominal variables, we conducted an MCA combined
403 with an HC. This method was designed to identify the relationship between our variables and to
404 discern any specific patterns across our participants in a multidimensional space. This allowed us
405 to create specific categories for the children’s graphical productions.

406
407 *Insert Table 1 about here*
408

409 For this analysis, we should note that participants 52 and 54 were deleted due to missing data in
410 the complementarity, representation, and spatial arrangement variables due to a poor graphical
411 production. The maximum number of dimensions are determined by subtracting total number of
412 variables (J) from total number of categories (K): $\text{Number of dimensions} = K - J$.
413 From the 18 initially obtained dimensions, dimensions 1, 2 and 3 presented a greater inertia than
414 those obtained by the 0.95-quantile of random distribution. Thus, we consider that the explained
415 variance of the first three dimensions (40.16%) is adequate to show any real correlations between
416 the variables (see Figure 3 for the Scree plot of the first 10 dimensions and Table I in Appendix 2
417 for the cumulative variance percentage).

418
419 *Insert Figure 3 about here*
420

421 To understand the characteristics of each of our three dimensions, we must identify the variables
422 that contribute the most to each of them. Therefore, we conducted correlation plots to identify
423 the contribution of the variables on the three dimensions (see Figure 4, and Figure 5 for the

424 confidence ellipses of the significant variables). Higher correlations represent higher
425 contributions of the variables on each dimension. The first dimension is strongly characterized
426 by handedness, biomechanical factors (progression axes and the origin point), and, to a lesser
427 degree, by density and placement order. The second dimension is strongly characterized by
428 complementarity and spatial arrangement variables, followed by density, representation, and sex
429 variables. Similar to dimension 2, dimension 3 is strongly influenced by complementarity and
430 spatial arrangement. However, we observe a significant influence of the origin point, the
431 directionality, and the placement order (see Table II in Appendix 3 for the effect size and p value
432 of all the variables on these three dimensions).

433 _____

434 *Insert Figure 4, Figure 5 about here*

435 _____

436

437 After identifying the main variables contributing to each of the three dimensions, we ran a
438 bidimensional plot to observe the distribution and the correlation of the categories among these
439 dimensions (see Figure 6 for the bidimensional plot).

440 _____

441 *Insert Figure 6 about here*

442 _____

443 This bidimensional plot gives us a global pattern of the relationships between our variable
444 categories. Each variable category is represented by a red triangle. The distance between the red
445 triangles gives us a measure of their similarity or their dissimilarity. Thus, correlated variable
446 categories will be close to each other, whilst negatively correlated categories will be on opposite
447 sides of a dimension. We should note also that farther the variable category is away from the

448 origin of the factor map (i.e., Figure 6), the better it is represented (see Table III in Appendix 4
449 for the estimates and p values of all the categories characterizing the three dimensions).

450 In dimension 1, the results show that right-handedness is strongly correlated to a left point of
451 origin, a left-to-right progression axis, and to a left density. We also observe that the right-
452 handers have a strong correlation with the BAC order of placement (i.e., drawing firstly the
453 house, followed by the river and lastly the trees). Conversely, left-handedness is strongly
454 correlated with a right-to-left progression axis, a right and central origin point. It is less strongly
455 but still significantly correlated with a balanced density, vertical progression axes and diverse
456 order of placement strategies (e.g., BCA, ACB).

457 In dimension 2, the results show that girls are significantly correlated with a balanced density
458 and complementarity, a B spatial arrangement (i.e., symmetrical drawing), correct representation
459 (i.e., the river is drawn at the bottom, the house in the centre and the trees in the background),
460 and with an order of placement ABC (i.e., beginning with the foreground, followed by the
461 midground, and ending with the background,). However, boys, are loosely correlated with a right
462 density, a right or left complementarity, spatial arrangements A and C (i.e., asymmetrical
463 drawings orientated to the left or right) and incorrect representations.

464 Dimension 3 shows that right and balanced directionality are associated mainly with a right
465 origin point, a right complementarity, and an A spatial arrangement (leftward orientation of the
466 3D/2D task). However, left directionality is associated with a centred point of origin, a C spatial
467 arrangement (rightward orientation of the 3D/2D task) and left complementarity.

468

469 The MCA presented a general view of the relationship between our variables and categories. The
470 second step is to perform a cluster analysis to investigate any specific patterns explained by
471 inter-individual differences between our participants.

472 Five clusters were identified using Ward's method. This distance measure, which can be applied
473 to a correspondence analysis, is an agglomerative clustering method based on the sum-of-square
474 criterion and generates clusters in a multivariate space (Husson, Lê & Pagès, 2017; Murtagh,
475 2005; Murtagh & Legendre, 2014). Each cluster includes participants with similar characteristics
476 (see Figure 7 for the visualization of the individuals' clusters).

477

478

Insert Figure 7 about here

479

480 Our classification analysis is in line with the MCA results, but allows us to make more accurate
481 observations. RH and LH children were clustered into two separate groups: clusters 1 and 2
482 represented the right-handers, whilst clusters 4 and 5 represented the left-handers (see Table 2
483 for the characteristics of the five clusters; for all the results with their coefficients values, see
484 Tables IV and V in Appendix 5).

485 The right-handers were distributed nearly equally between the two clusters regrouping
486 respectively 40.00% and 45.70% of the total number of right-handers. A left point of origin and
487 left-to-right strokes were found in common between these two clusters. However, the first group
488 were characterized by a left density and complementarity, a rightward asymmetrical drawing
489 (spatial arrangement C), a BAC order of placement, and a left directionality preference. The
490 second group was characterized by balanced transcription and the correct representation of the
491 3D model, symmetrical drawing, and Alter's test drawings that were oriented rightward (see
492 cluster 2). Conversely, LH participants were unevenly distributed between their two respective

493 clusters where cluster 4 contained 58.62% of the LH children, and cluster 5 contained 31.03%.
494 The cluster 4 was characterized by vertical and right-to-left lines, a right origin point, balanced
495 density and complementarity, symmetrical drawing and an ABC placement order. In cluster 5,
496 participants showed a right-to-left axis of progression, a left complementarity, a centre point of
497 origin, a rightward asymmetrical graphical production and a BCA order of placement. Cluster 3
498 was characterized by 7 children presenting no specific laterality or biomechanical features. These
499 children had a rightward complementarity, a leftward asymmetrical drawing, a variable order of
500 placement, and a rightward drawing on Alter's test.

501

Insert Table 2 about here

502

503

504 Overall, the five obtained clusters corresponded to five groups of participants characterized by
505 both the direction and the degree of their handedness. For the right-handers, cluster 1 represents
506 the strong right-handers and cluster 2 represents the weak right-handers. For the left-handers,
507 cluster 4 represents the weak left-handers and cluster 5 represents the strong left-handers.

508 The overall exploratory results show that the 3D/2D depiction task successfully categorised
509 participants according to handedness and sex. The second part of our statistical analysis is testing
510 these findings with GLM in which handedness and sex are the predictors. A significance
511 threshold of 0.05 was adopted for all statistical analyses. For *post-hoc* tests, the *p* values are
512 adjusted using Holm's correction. In the following section, we will present only the significant
513 models and their follow-up *post-hoc* tests (see Table 3 for the model coefficients, and Table 4 for
514 the predicted probabilities).

515

516 Complementarity

517 A significant difference is found between boys and girls in the drawings' complementarity ($\chi^2(2,$
518 $N=65) = 9.55, p=.01, R^2=.08$). Girls favoured significantly more balanced complementarity
519 compared to boys ($z = 3.11, p = .01$).

520 Density

521 The results revealed a significant difference between right- and left-handers in the drawings'
522 density ($\chi^2(2, N=66) = 9.78, p=.01, R^2=.07$). Left-handers are significantly more likely to draw a
523 balanced density compared to the right-handers ($z = 2.86, p = .02$), while the right-handers
524 favoured significant left density ($z = 3.04, p = .02$).

525 Origin point

526 The results revealed a significant interaction between sex and handedness ($\chi^2(2, N=66) = 6.78,$
527 $p=.03, R^2=.33$). The origin point of the drawing was significantly different among right- and left-
528 handers. RH boys generally began their drawing from the left compared to the LH boys and girls
529 ($z = 3.18, p=.04, z = 4.47, p<.01$ respectively), whilst LH boys often started their drawing from
530 the right more than the RH boys and girls ($z = 3.67, p=.02, z = 5.29, p<.01$, respectively).
531 Similar results are obtained for girls. Indeed, RH girls were more prone to begin their drawing
532 from the left compared to the LH boys and girls ($z = 5.29, p<.01, z = 7.42, p<.001$ respectively),
533 while LH girls preferred to start their drawing from the right significantly more than the RH girls
534 ($z = 4.23, p=.01$) and near significance compared to RH boys ($z=2.95, p=.06$).

535 However, after a *post-hoc* test (with Holm correction), neither RH boys differentiate
536 significantly from RH girls nor LH boys differentiate significantly from LH girls. The fact that
537 we do not observe any sex difference in the *post-hoc* results while the main effect of the
538 interaction is significant may be due to a lack of statistical power. However, we notice that

539 without any p correction, the results show that LH girls tend to begin their drawing from the
540 centre more often than LH boys ($z = 1.95, p=.09$). This tendency, combined with the strong
541 influence of handedness, may have contributed to the significance of the interaction's main effect
542 model.

543 Progression axis

544 A significant difference is observed between handedness and the axes of progression
545 ($\chi^2(2, N=66) = 78.68, p<.001, R^2=.62$). The right-handers typically oriented their strokes from
546 left to right ($z = 22.13, p<.001$), while the left-handers typically oriented their stroke from right
547 to left ($z = 10.31, p<.001$). Moreover, we should note too that left-handers showed a tendency to
548 draw more vertical lines than the right-handers ($z = 2.16, p=.09$).

549 _____

550 *Insert Table 3 and Table 4 about here*

551 _____

552 Neither sex nor handedness predicted the following variables: directionality, order of placement,
553 representation, and partial arrangement (see Table VI in Appendix 6 for the Goodness of fit of
554 the GLM of all the variables).

555

556 **Discussion**

557 The study's aim was to identify typical graphical characteristics according to individual
558 differences prior to the acquisition of literacy. We investigated children's depiction patterns
559 using a novel 3D/2D transcription task. We were able to report several results reflecting the
560 influence of handedness and sex on children's graphical productions. We should note that even
561 though the exploratory analysis showed strong relationship between our variables, we
562 demonstrated a statistical significance through our models only for some of them. Nonetheless,
563 we decided to interpret all our findings from the perspective of future studies to further
564 investigate these observations.

565 Sex

566 Our results showed a significant influence of sex on the graphical complementarity. A balanced
567 complementarity was presented by girls, while boys presented a lateralized one. Furthermore,
568 girls appeared to find it easier to make drawings characterized by a balanced density and a
569 symmetrical graphical production. They were also associated with the spatial arrangement B,
570 while boys showed asymmetrical and lateralized drawings (spatial arrangements A and C). This
571 is in line with previous studies where males are shown to exhibit more aesthetic preferences to
572 asymmetrical drawings (notably a rightward directional preference), contrary to females who
573 exhibit a weaker, or even an absence of aesthetic preferences for asymmetrical drawings
574 (Agostini et al., 2011; Friedrich et al., 2014). These findings may be explained by a lesser HFS in
575 girls allowing them greater gestural flexibility and weaker spatial bias. The boys drew more
576 asymmetrical drawings displaying stronger spatial bias that may be related to a stronger degree
577 of HFS (Bourne, 2008; De Agostini et al., 2011; Ocklenburg & Güntürkün, 2018c; Segond,
578 2015).

579 Furthermore, girls were more likely to create correct graphical productions than boys. Indeed,
580 their drawings tended not only to include all the perceived elements, but also to correctly
581 transcribe their respective positions into the 2D space based on their relative positions in the 3D
582 space. The boys were more prone to omit elements in addition to incorrect representation
583 characterized by a negligence of spatial relationship between the 3D model elements (e.g., the
584 river and the house were depicted on the same level). This observation may be the reflection of a
585 developmental phenomenon. Drawing requires a visual perception and visual imagery for
586 encoding spatial relations between objects (Guérin et al., 1999). Vinter and colleagues showed
587 that five-year-old children generally depict isolated and independent elements with an occasional
588 juxtaposition of these elements (Vinter et al., 2008). These findings were only spotted in the
589 graphical productions of boys. This observation may reflect the difference in maturation
590 trajectories between boys and girls. Indeed, until ~7 years of age, girls present an earlier
591 cognitive and psychomotor development (Flatters et al., 2014; Peyre et al., 2019). It is only later,
592 around the seventh and eighth year, that children will be able to integrate the totality of the
593 perceived object and take into consideration spatial characteristics, in addition to creating
594 graphical productions identical to what is perceived (Barrett & Light, 1976; Luquet, 1927; Piaget
595 & Inhelder, 1969). Thus, the sex difference found in our study may illustrate the better graphical
596 productions associated with girls' earlier maturation. Our work corresponds with studies that
597 showed that males do not outperform females on all the visuo-spatial tasks, and is in line with the
598 authors who argued that girls may be better than boys on spatial tasks requiring the recall of the
599 spatial configuration of objects (Rybash & Hoyer, 1992; see for a review Jager & Postma, 2003).

600

601

602 Handedness

603 Handedness did significantly influence the starting point of graphical production and the strokes'
604 orientation. Most right-handers showed a strong preference for a left origin point and left-to-right
605 progression axis, whereas left-handers preferred a right origin point and right-to-left progression
606 axis. These results highlights the influence of biomechanical factors, particularly the preference
607 for performing extension movements with outward motions of the body (Picard, 2011; van
608 Sommers, 1984; Vaid, 2011). Furthermore, the LH children showed heterogeneity in their
609 results, tending to draw more vertical strokes, and beginning their depictions from the centre.
610 This finding may reflect the weaker lateralization generally associated with left-handedness
611 (Christman, 2001; Hellige, 1993; Luders et al., 2010).

612 Also, the right-handers showed a strong leftward density, while the left-handers presented a
613 balanced graphical density. It is in line with existence of a leftward attentional bias in right-
614 handers due to the right hemisphere specializing in visuospatial processing (Jewell & McCourt,
615 2000; Picard & Zarhbouch, 2014). As for the left-handers, a weaker lateralization, and a greater
616 interaction between the two hemispheres (Karev, 1999) may lead them to a more balanced
617 graphical production.

618 We did not observe a significant relationship between directionality and handedness in the
619 Alter's directionality test. This is consistent with past studies in which no difference in
620 directionality preference among five year old children was found (Kebbe & Vinter, 2013; Picard,
621 2011). Furthermore, in line with previous findings, landscape objects, represented in our study
622 by the 3D-2D task, may be more sensitive to the HFS than static/moving objects, represented
623 here by the Alter's directionality test (Chokron & De Agositni, 2000; De Agostini et al., 2011;
624 Ishii et al., 2011). However, we should note that the cluster analysis showed that the two RH

625 groups (i.e., cluster 1 and 2, see Table 2) were characterized by opposite directionality
626 preferences, whereas the LH did not have any directionality preference. This supports previous
627 results where left-handers present a greater variability in directionality compared to right-handers
628 (De Agostini & Chokron, 2002; Railo et al., 2011). This also supports Karev (1999) who argues
629 that left-handedness may reduce the emergence of a preferred directionality since a weaker
630 functional asymmetry is found among them. As for the difference between the two RH clusters, a
631 leftward directionality was observed by the children of the cluster 1. This cluster is characterized
632 also by a preference for a left origin point, density, and complementarity. Rightward
633 directionality preference characterized cluster 2, which include children who also showed
634 balanced complementarity and symmetrical drawing. Although it is not frequently observed, a
635 rightward directionality preference among the right-handers was found in a previous study on
636 children aged 7 to 10 years (De Agostini & Chokron, 2002). The HFS may have played a role in
637 the difference among our RH children. Equally, it is possible that the level of development of
638 five-year-old children may not be sufficient to consider the directionality of the drawing as a
639 relevant characteristic or be sufficiently sensitive to individual traits. With the acquisition of
640 literacy and the influence of culture, we expect that this diversity in directionality preferences
641 found in our study will decrease, while a stronger preferences, or even new preferences, will
642 emerge later for the left-handers (Alter, 1989; Faghihi et al., 2019; Kebbe & Vinter, 2013;
643 Picard, 2011; Portex et al., 2017; Vaid, 2011).

644 Regarding the graphical strategies, most of the children began by drawing the house
645 (approximately 71%, see Table 1). This corroborates the general observation that young children
646 tend to start their drawing with the main component of a figure (Vinter et al., 2008). This
647 observation shows a good ability to distinguish the essential elements from the less essential,

648 something that is not observed in younger children. The latter pay equal attention to all the
649 details of a visual scene (local processing of information) without emphasising the main theme
650 (global processing of information). The global and simultaneous processing of information
651 characterizing spontaneous visual perception develops gradually. The observer only uses more
652 local processing of visual information when required by the task for example when looking to
653 discriminate the fine details and differences (e.g., recognition of a face within a group of
654 individuals).

655 Our results showed that three graphical strategies were adopted by nearly all the children. A
656 difference was found between the RH and LH children, in contrast to Braine et al. (1993). In the
657 present study, the right-handers frequently adopted the BAC strategy to transcribe the 3D model.
658 Meanwhile, left-handers adopted two different strategies (BCA and ABC). The more lateralized
659 left-handers, who drew asymmetrical drawing (i.e., cluster 5), favoured a BCA strategy.

660 Interestingly, the less lateralized left-handers, who drew symmetrical drawings with a balanced
661 density and complementarity (i.e., cluster 4), favoured the best strategy to account for the spatial
662 relationships between the 3 planes, which is the ABC order. Indeed, the graphical representation
663 of perspective and depth requires drawing the closest elements first to account for interposition –
664 the reproduction of objects partially hidden by others in front of them. Since left-handers exhibit
665 a more diffuse inter-hemispheric connection and a lesser lateralization, they will present greater
666 global processing and spatial scanning that may lead to a balanced symmetrical drawing, and a
667 more flexible transcription strategy conform to the 3D model: The near element is drawn first,
668 followed by the farther elements (Braine et al., 1993). Thus, left-handers appear more capable,
669 depending on the task, of drawing the various elements in the appropriate order with a view to
670 their correct representation as opposed to focusing on the main theme. This leads them to start

671 their drawing with an accessory and not the main element. However, Vaid et al. (2011) found a
672 strong influence of script directionality on spatial strategies for older participants. Adults with a
673 script directionality from left-to-right represented “near objects” on the left and “far objects” on
674 the upper right hemispace, contrary to adults with a right-to-left directionality. We argue that a
675 prolonged exposure to a specific reading and writing orientation is needed to observe any effect
676 of script directionality on spatial biases in visual attention and depiction tasks (Fagard &
677 Dahmen, 2003; Faghihi et al., 2019).

678

679 Limitations and perspectives

680 The complexity and diversity of the collected results invite us to consider some future
681 improvements to our experiment. Firstly, it is necessary to confirm our results through a new
682 study with a larger sample size. Such a study would allow us to include the rare mixed-handed
683 children. Secondly, we should consider assessing handedness along a continuum based on the
684 manual performance, and not limit our assessments to manual preference as this can be a better
685 indicator for handedness (Bryden et al., 2000; Nicholls et al., 2010). This measure will allow us
686 to assess the degree of handedness as well as the direction. Thirdly, we must be cautious in our
687 interpretations since our results supporting the laterality account are based on inductive
688 inferences from a behavioural task. Brain imaging is needed to complement the laterality patterns
689 found in the present behavioural study with cerebral activity measurement. Furthermore, we did
690 not find any specific interpretation for our cluster 3. This cluster is constituted of 7 children with
691 no unique drawing pattern (see Table VII in Appendix 7). They may be an indicator that there
692 were other factors/variables that influenced the children’s graphical productions that were not
693 captured by our test. Thus, we intend to replicate this study by assessing children’s manual
694 performance and the hemispherical lateralization (i.e., language dominance, type of information

695 processing and the interhemispheric connection). We could also consider using line bisection and
696 aesthetic preference tasks alongside our graphical task. They would allow us to collect more data
697 on the children's cognitive development in parallel with data on the development of the
698 sensorimotor system. Furthermore, our assessments were conducted using a manual scoring
699 sheet. Electronic graphical tablets would enable more precise assessment. Finally, a longitudinal
700 study would allow us to follow the evolution of the graphical productions developed within each
701 specific cluster. For example, by comparing the results obtained before and after the acquisition
702 of literacy we would be investigating the social and cultural influence on our task.

703

704

705 **Conclusion**

706 This research proposed a 3D/2D task capable of distinguishing specific patterns of drawing at a
707 young age, improving our understanding of the neurotypical development of laterality. Indeed,
708 the present 3D/2D depiction task has successfully identified graphical patterns according to
709 handedness and sex and provided us with a rich dataset for examining the behavioural
710 manifestation of hemispherical lateralisation. It was more sensitive than the Alter's directionality
711 test for understanding the spatial biases resulting from handedness and HFS among young
712 children. This is in line with previous findings that landscape stimuli could be more influenced
713 by HFS than static or moving objects. Furthermore, this 3D/2D task appears promising to
714 explore specific laterality patterns identifiable in participants with atypical development,
715 particularly those with neurodevelopmental disorders. Such studies could bring up opportunities
716 for an early detection of atypical laterality patterns, underpinned by spatial difficulties. These are
717 found in many neurodevelopmental and learning disorders such as dyslexia, dyspraxia, and
718 autism spectrum disorder (Penolazzi et al., 2006; Postema et al., 2020; Querne et al., 2008; Xu et
719 al., 2015) as well as in certain psychiatric disorders such as schizophrenia (Wiberg et al., 2019).

720

721

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728

729 **Declaration of interest statement**

730 None of the authors has a financial or other conflict of interest.

731

732 **Data Availability Statement**

733 The data that support the findings of this study and the scoring walkthrough of the 3D/2D task
734 are openly available in OSF at <https://doi.org/10.17605/OSF.IO/2TQXH>.

735

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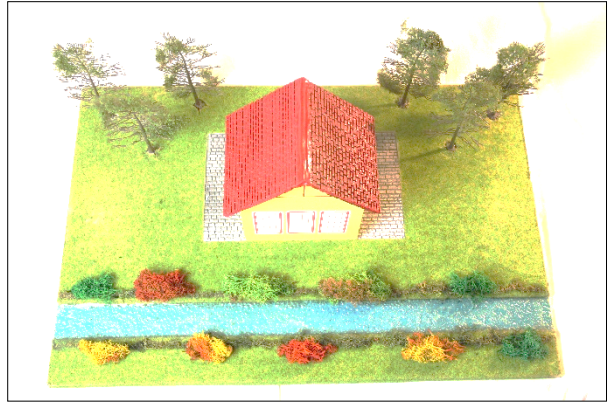
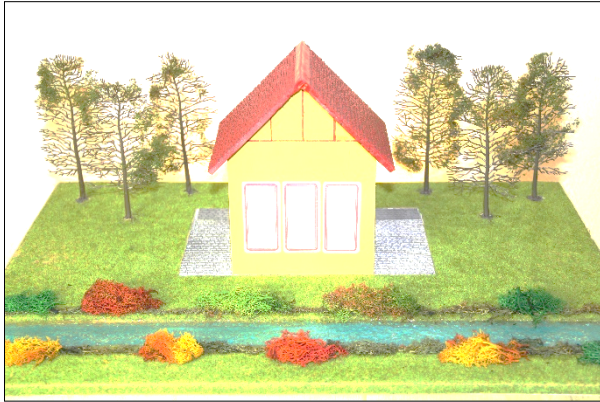
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Figure 1a. 3D model



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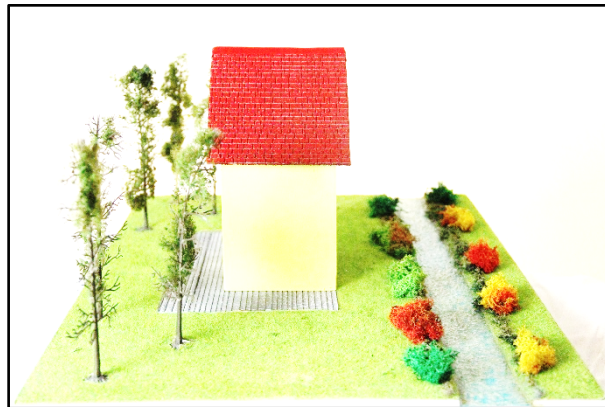
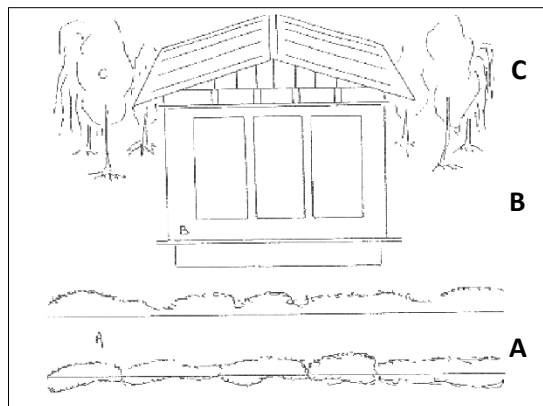


Figure 2b. Scoring sheet with the 3 planes (A, B, C)



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Figure 2. Examples of the 2D transcription

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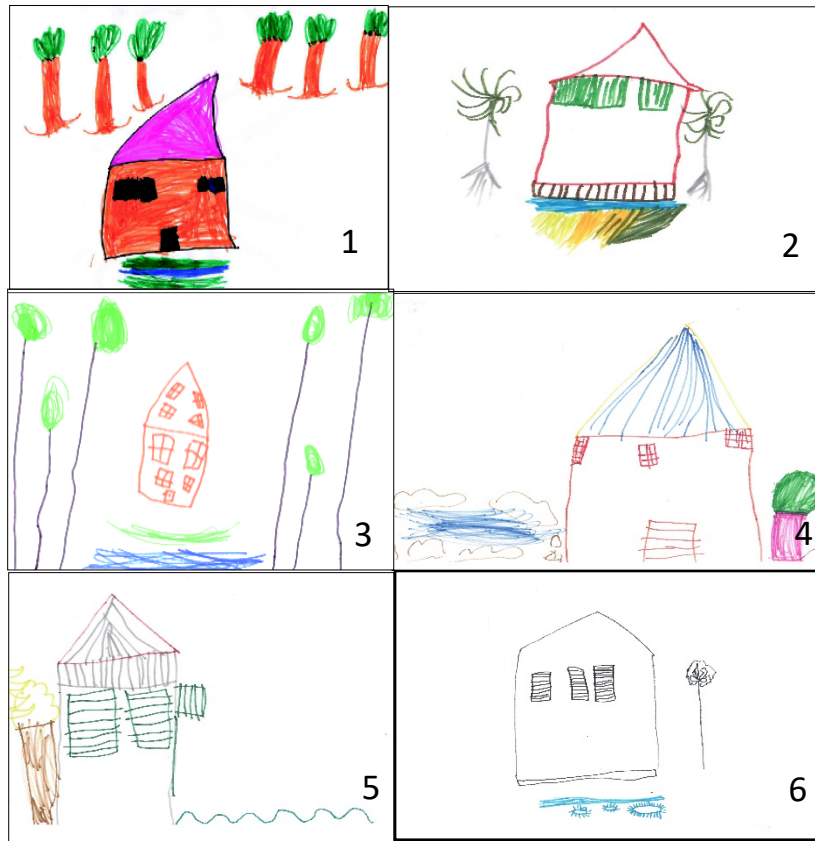
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Example 1: Correct representation and symmetrical drawing. Left density and balanced complementarity.

Example 2: Incorrect representation and symmetrical drawing. Balanced density and complementarity.

Example 3: Incorrect representation and symmetrical drawing. Balanced density and complementarity.

Example 4: Incorrect representation and asymmetrical drawing, leftward orientation. Right density and balanced complementarity.

Example 5: Incorrect representation and asymmetrical drawing, rightward orientation. Left density and complementarity.

Example 6: Incorrect representation and asymmetrical drawing, leftward orientation. Left density and right complementarity.

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Figure 3. Percentage of the explained variance of the first 10 dimensions

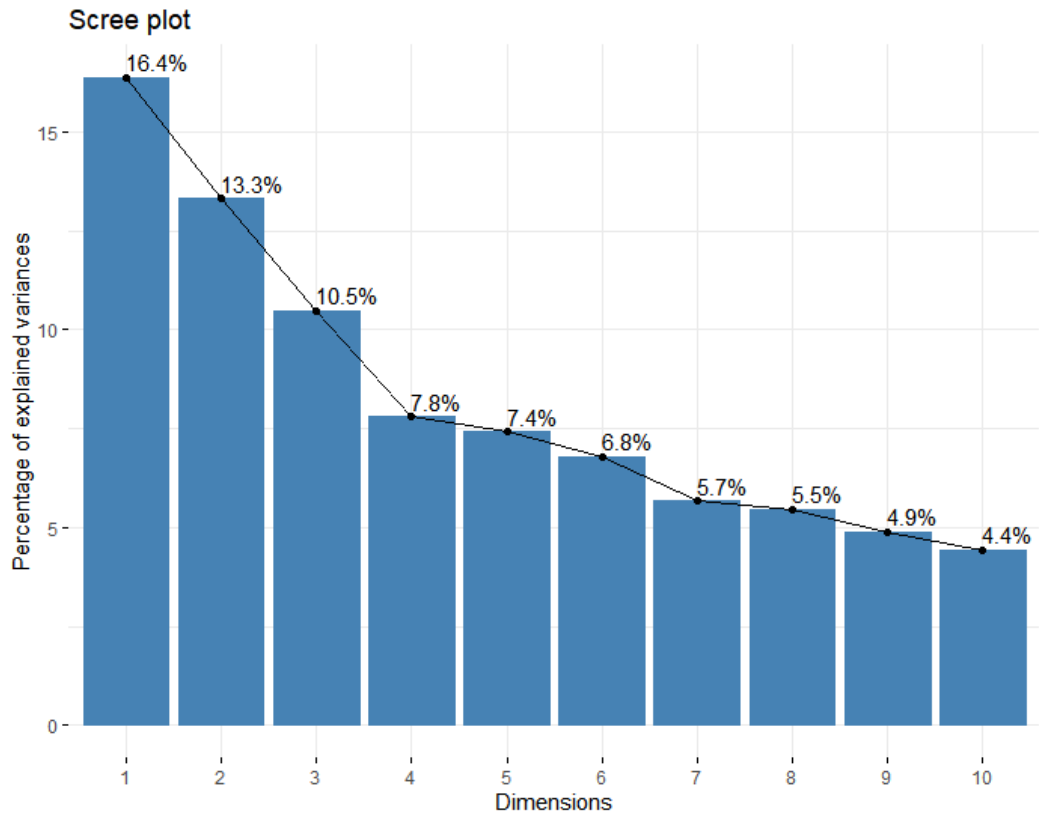
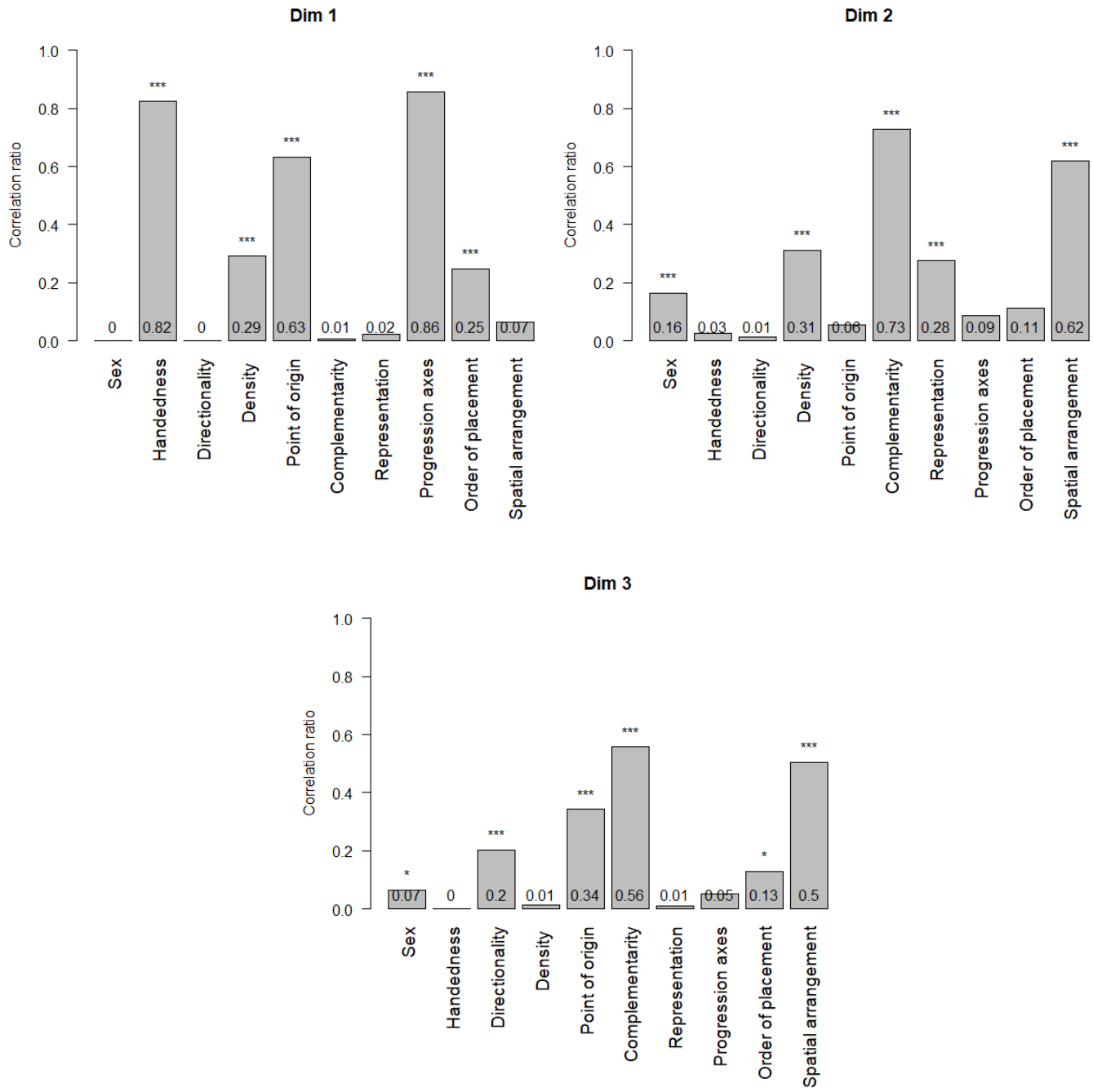


Figure 4. Bar plots presenting the association between the variables and the three dimensions

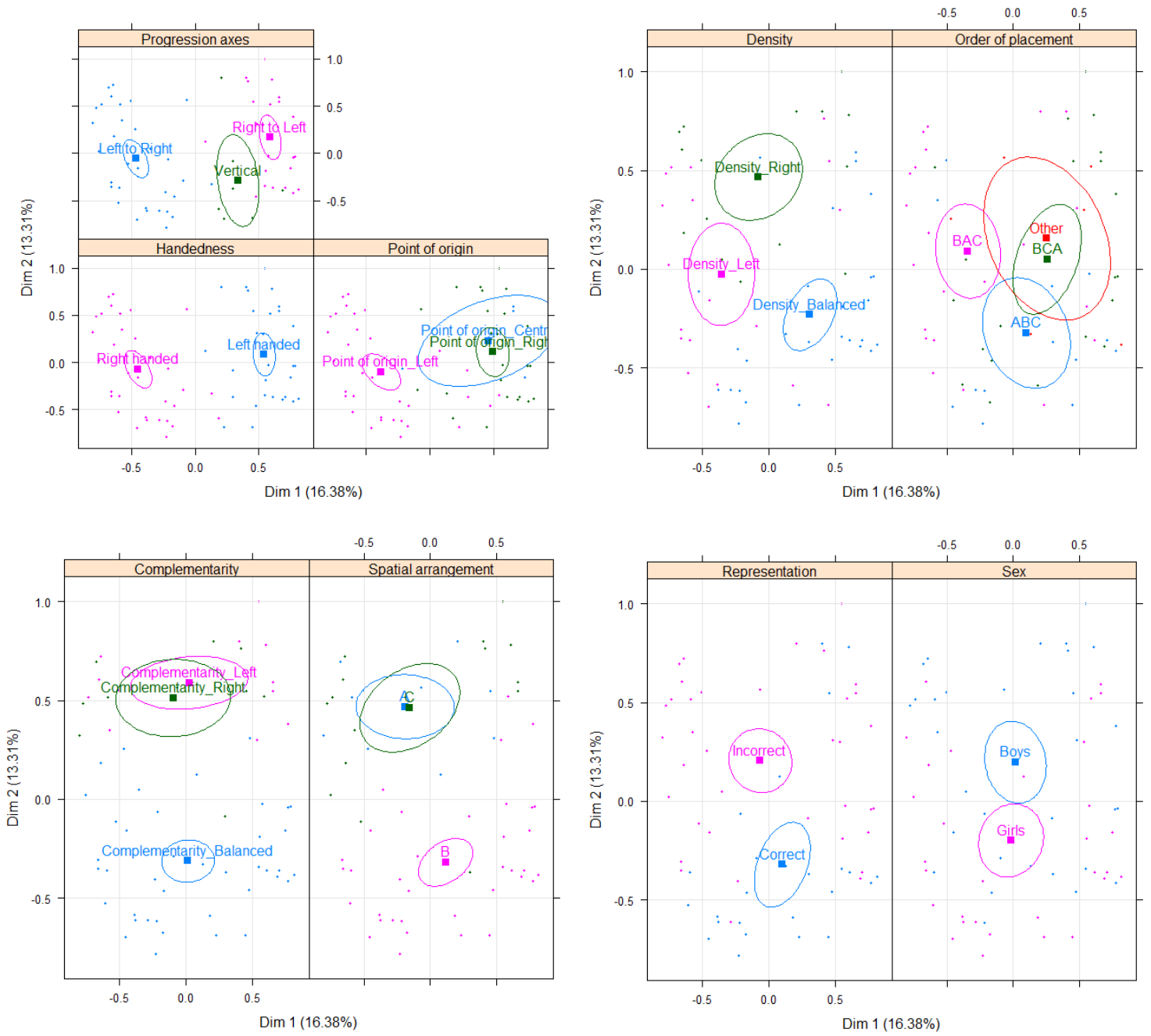


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1091 *Note.* *: p<.05; ***: p<.001

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Figure 5. Confidence ellipses for each significant categorical variable for the MCA analysis.



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Figure 6. Two-dimensional factor maps presenting all the categories of the three dimensions

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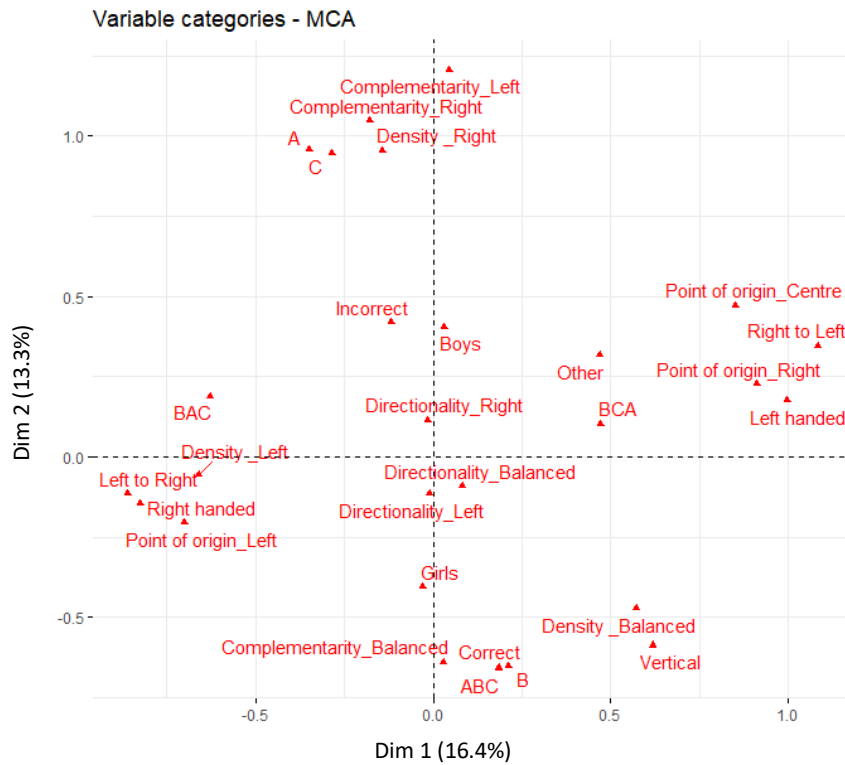
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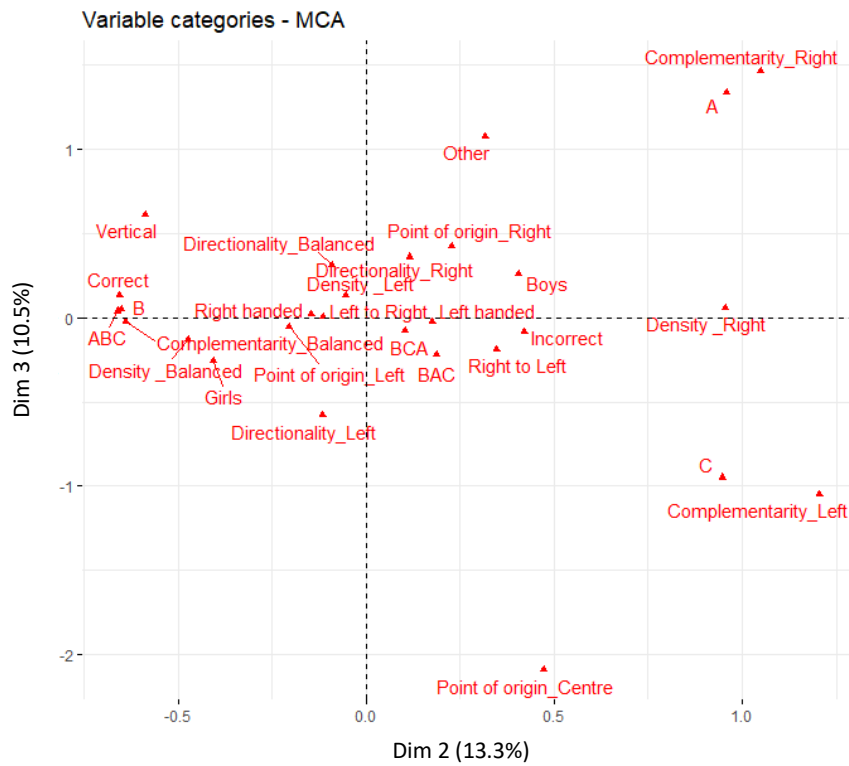
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Figure 7. Factor maps representing the different clusters among the three dimensions

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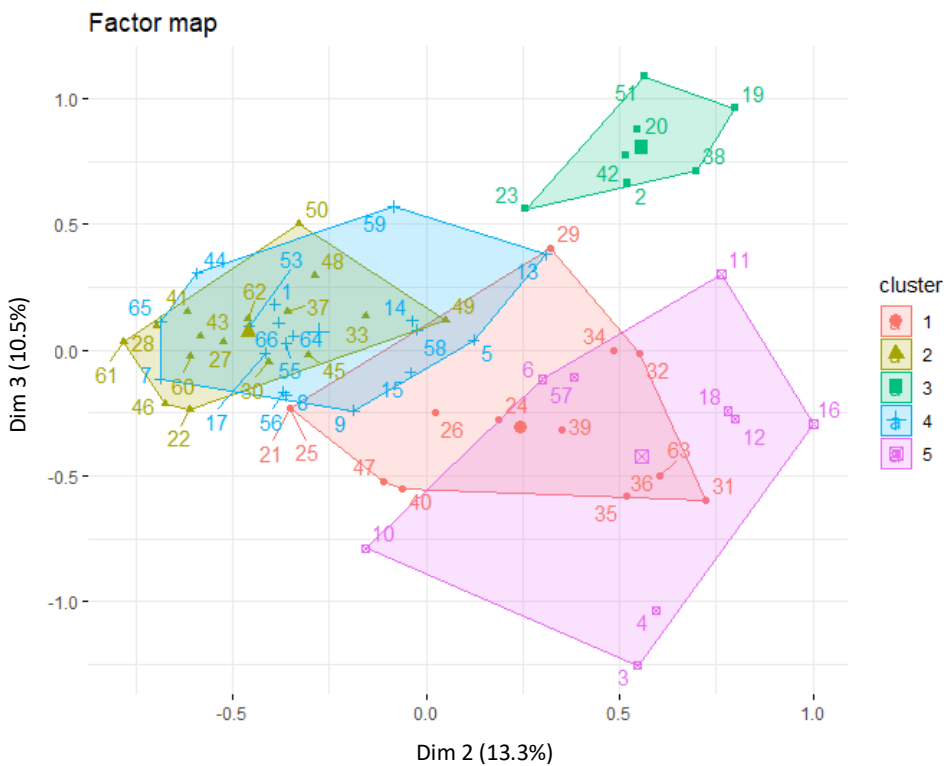
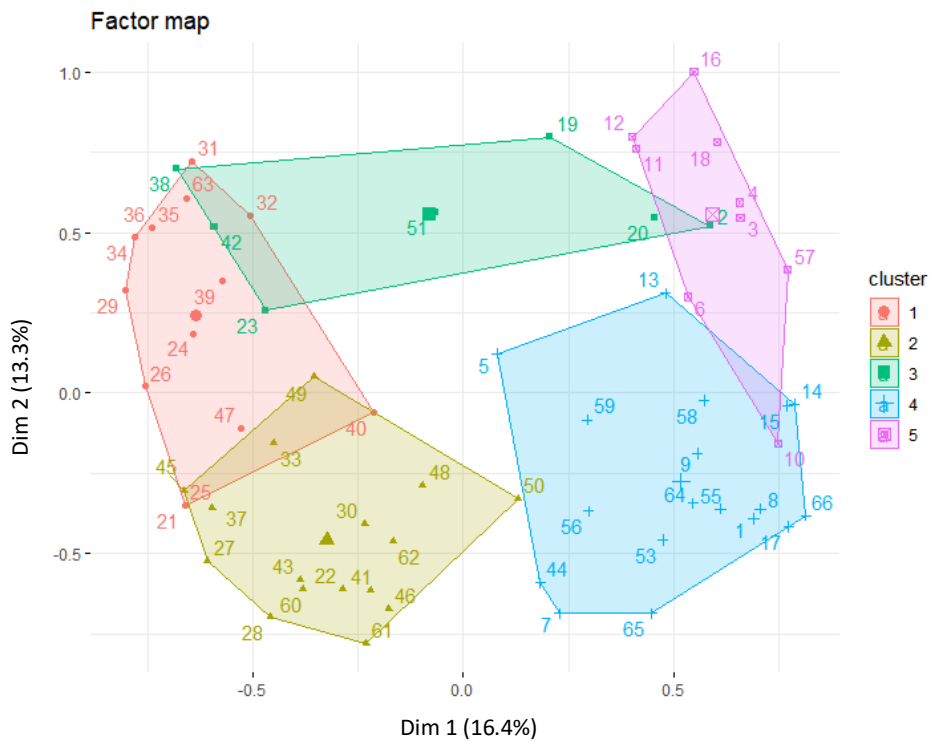
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Note. Each number represents one participant

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Table 1. Distribution of our nominal variables

Variables	Categories	n (%)	Variables	Categories	n (%)	
Sex & Handedness	Boys	Left	17 (25.8%)	Progression Axe	Left to Right	35 (53.00%)
		Right	17 (25.8%)		Right to Left	24 (36.40%)
	Girls	Left	14 (21.2%)		Vertical	7 (10.60%)
		Right	18 (27.3%)		Total	66 (100%)
Alter's directionality	Balanced	9 (13.60%)	Density		Balanced	29 (43.94%)
	Left	24 (36.40%)			Left	22 (33.33%)
	Right	33 (50.00%)			Right	15 (22.73%)
	Total	66 (100%)			Total	66 (100%)
Complementarity	Balanced	41 (62.10%)	Origin point	Centre	4 (6.06%)	
	Left	14 (21.20%)		Left	37 (56.06%)	
	Right	10 (15.20%)		Right	25 (37.88%)	
	NA	1 (1.50%)		Total	66 (100%)	
Placement order	Total	66 (100%)	Spatial arrangement	A (Left)	10 (15.20%)	
	ABC	13 (19.70%)		B (Balanced)	39 (59.10%)	
	BAC	25 (37.90%)		C (Right)	16 (24.20%)	
	BCA	22 (33.30%)		NA	1 (1.50%)	
Representation	Other	6 (9.10%)	Total	66 (100%)		
	Total	66 (100%)				
	Correct	25 (37.90%)				
	Incorrect	40 (60.60%)				
	NA	1 (1.50%)				
	Total	66 (100%)				

1197 *Note.* n(%): Sample Size.

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Table 2. Characteristics of each cluster

Clusters	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
n	14	16	7	18	9
Handedness	Right	Right	-	Left	Left
Progression axes	Left to Right	Left to Right	-	Other/ Right to Left	Right to Left
Point of origin	Left	Left	-	Right	Centre
Density	Left	-	-	Balanced	-
Spatial arrangement	C	B	A	B	C
Complementarity	Left	Balanced	Right	Balanced	Left
Order placement	BAC	-	Other	ABC	BCA
Representation	Incorrect	Correct	-	-	-
Directionality	Left	Right	Right	-	-

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Table 3. Estimates and Odds Ratio of the multinomial regressions

	<i>B (SE)</i>	95% CI for odds ratio		
		Lower	Odds Ratios	Upper
Complementarity and Sex				
Balanced vs. Left complementarity				
Intercept	0.41 (0.41)			
Girls	1.47 (0.67)*	1.15	4.33	16.26
Right vs. Left complementarity				
Intercept	-0.22 (0.47)			
Girls	-0.47 (0.99)	0.09	0.63	4.32
Density and Handedness				
Balanced vs. Right density				
Intercept	0.22 (0.47)			
Left-handedness	0.76 (0.43)	0.61	2.17	7.74
Left vs. Right density				
Intercept	0.76 (0.65)			
Left-handedness	-1.09 (0.73)	0.08	0.34	1.39
Point of origin and Handedness				
Left vs. Centre				
Intercept	3.40 (1.02)***			
Left-handedness	-2.55 (1.23)*	0.01	0.08	0.86
Right vs. Centre				
Intercept	1.39 (1.12)			
Left-handedness	0.56 (1.28)	0.14	1.75	21.38
Point of origin and Sex				
Left vs. Centre				
Intercept	2.89 (1.03)**			
Girls	-1.05 (1.20)	0.03	0.35	0.70
Right vs. Centre				
Intercept	2.71 (1.03)**			
Girls	-1.50 (1.22)	0.02	0.22	2.45
Axes of progression and Handedness				
Left to right vs. Vertical				
Intercept	3.53 (1.01)***			
Left-handedness	-5.32 (1.48)***	0.01	4.90e-03	0.09
Right to left vs. Vertical				
Intercept	-15.50 (2324.44)			
Left-handedness	16.88 (2324.44)	0.00	2.16e+07	Inf

Note. * $p < .05$; ** $p < .01$; *** $p < .001$

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Table 4. Predicted probabilities obtained by the GLM.

		Predicted probability (95% CI)
Complementarity and Sex		
Balanced complementarity	Girls	0.83 (0.64 – 0.93)
	Boys	0.46 (0.30 – 0.62)
Left complementarity	Girls	0.11 (0.03 – 0.29)
	Boys	0.30 (0.17 – 0.48)
Right complementarity	Girls	0.06 (0.02 – 0.22)
	Boys	0.24 (0.13 – 0.42)
Density and Handedness		
Balanced density	Left-handedness	0.61 (0.43 – 0.77)
	Right-handedness	0.29 (0.16 – 0.45)
Left density	Left-handedness	0.16 (0.07 – 0.33)
	Right-handedness	0.49 (0.33 – 0.65)
Right density	Left-handedness	0.23 (0.11 – 0.40)
	Right-handedness	0.23 (0.12 – 0.39)
Point of origin and Handedness		
Centre point of origin	Left-handedness	0 (0.00 – 1.00)
	Right-handedness	0 (0.00 – 1.00)
Left point of origin	Left-handedness	0.23 (0.11 – 0.44)
	Right-handedness	0.89 (0.69 – 0.97)
Right point of origin	Left-handedness	0.76 (0.54 – 0.90)
	Right-handedness	0.11 (0.04 – 0.28)
Point of origin and Sex		
Centre point of origin	Girls	0 (0.00 – 1.00)
	Boys	0 (0.00 – 1.00)
Left point of origin	Girls	0.69 (0.36 – 0.90)

	Boys	0.59 (0.38 – 0.77)
Right point of origin	Girls	0.31 (0.11 – 0.62)
	Boys	0.41 (0.23 – 0.61)
<hr/>		
Axes of progression and Handedness		
Left to right	Left-handedness	0.03 (0.00 – 0.20)
	Right-handedness	0.97 (0.82 – 1.00)
Right to left	Left-handedness	0.77 (0.60 – 0.89)
	Right-handedness	0.00 (0.00 – 1.00)
Vertical	Left-handedness	0.19 (0.09 – 0.37)
	Right-handedness	0.03 (0.00 – 0.18)
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1210 **Appendix**

1211 **Appendix 1**

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1213 French original instructions:

1214 *“Well, I see that you draw very well. I really like your drawings. Now look, I am going to show*
1215 *you something and then I would like you to draw it for me. Be careful, look carefully as you are*
1216 *going to make a drawing that looks as close as possible to the model you are going to see”:*

1217 **"Bien, je vois que tu dessines très bien. J'aime beaucoup tes dessins. Maintenant regarde, je**
1218 **vais te montrer quelque chose et j 'aimerais que tu me le dessines. Fait attention, regarde-là**
1219 **attentivement car après tu devras dessiner uniquement ce que tu vas voir de la maquette".**

1220 *“Do you see the house and the landscape? So, tell me what you see”:*

1221 **"Tu vois la maison et le paysage ? Alors, raconte-moi ce que tu vois".**

1222 *“In the centre, we see a symmetrical house, just in front is a river surrounded by bushes, and*
1223 *behind the house we see six trees”:*

1224 **"Au centre, nous voyons une maison symétrique, juste devant se trouve une rivière avec**
1225 **autour des buissons, et derrière la maison se trouve six arbres".**

1226 *“You are now going to draw everything you saw”.*

1227 **"Tu vas dessiner maintenant tout ce que tu vois".**

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1230 **Appendix 2**

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Table I. Eigen values and the variance percentage of the 18 dimensions

Dimensions	Eigen value	Variance %	Cumulative variance %
1	0.29	16.38	16.38
2	0.24	13.32	29.70
3	0.19	10.46	40.16
4	0.14	7.80	47.96
5	0.13	7.42	55.38
6	0.12	6.79	62.17
7	0.10	5.67	67.84
8	0.01	5.47	73.31
9	0.09	4.88	78.19
10	0.08	4.43	82.62
11	0.07	3.85	86.47
12	0.06	3.45	89.92
13	0.05	2.88	92.80
14	0.04	2.39	95.19
15	0.03	1.92	97.11
16	0.03	1.52	98.63
17	0.02	1.26	99.89
18	0.002	0.11	100.00

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1236 **Appendix 3**

1237 Table II. Significant factor sets of the three main dimensions presented in a descendent order

Dimension 1		
Variables	R ²	<i>p</i>
Progression axes	0.86	<.001
Handedness	0.82	<.001
Point of origin	0.63	<.001
Density	0.29	<.001
Order of placement	0.25	<.001
Dimension 2		
Variables	R ²	<i>p</i>
Complementarity	0.73	<.001
Spatial arrangement	0.62	<.001
Density	0.31	<.001
Representation	0.28	<.001
Sex	0.16	<.001
Dimension 3		
Variables	R ²	<i>p</i>
Complementarity	0.56	<.001
Spatial arrangement	0.50	<.001
Point of origin	0.34	<.001
Directionality	0.20	<.001
Order placement	0.13	<.05
Sex	0.07	<.05

1238 *Note.* R²: effect size of each category

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1240 **Appendix 4**

1241 Table III. Association between our variables' categories on the MCA's two dimensions

Dimension 1		
Categories	Estimate	<i>p</i>
Handedness: Left	0.50	<.001
Progression axes: Right to left	0.44	<.001
Point of origin: Right	0.30	<.001
Density: Balanced	0.35	<.001
Order of placement: BCA	0.19	<.01
Spatial arrangement: B	0.19	<.05
Density: Left	-0.32	<.001
Order of placement: BAC	-0.41	<.001
Point of origin: Left	-0.57	<.001
Handedness: Right	-0.50	<.001
Progression axes: Left to right	-0.62	<.001
Dimension 2		
Categories	Estimate	<i>p</i>
Complementarity: Left	0.33	<.001
Spatial arrangement: C	0.26	<.001
Density: Right	0.40	<.001
Representation: Incorrect	0.26	<.001
Complementarity: Right	0.25	<.001
Spatial arrangement: A	0.26	<.001
Sex: Boys	0.20	<.001
Progression axes: Right to left	0.23	<.05
Order placement: ABC	-0.32	<.01
Sex: Girls	-0.20	<.001
Density: Balanced	-0.30	<.001
Representation: Correct	-0.26	<.001
Spatial arrangement: B	-0.52	<.001
Complementarity: Balanced	-0.58	<.001

Dimension 3

Categories	Estimate	<i>p</i>
Complementarity: Right	0.60	<.001
Spatial arrangement: A	0.52	<.001
Directionality: Right	0.14	<.01
Order of placement: Other	0.38	<.01
Point of origin: Right	0.43	<.01
Sex: Boys	0.11	<.05
Sex: Girls	-0.11	<.05
Directionality: Left	-0.27	<.001
Complementarity: Left	-0.51	<.001
Point of origin: Centre	-0.66	<.001
Spatial arrangement: C	-0.47	<.001

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1244 **Appendix 5**

1245 Table IV. All the significant variables describing the five clusters

Variables	<i>df</i>	<i>p</i>
Complementarity	8	<.001
Progression axes	8	<.001
Handedness	4	<.001
Spatial arrangement	8	<.001
Point of origin	8	<.001
Order of placement	12	<.001
Directionality	8	<.001
Density	8	<.01
Representation	4	<.01

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1247 Table V. Results for all the significant categories characterizing each cluster

Cluster 1					
	Cla/Mod	Mod/Cla	Global	v.test	<i>p</i>
Progression axes: Left to right	41.18	100.00	53.13	4.18	<.001
Order of placement: BAC	50.00	85.71	37.50	4.06	<.001
Handedness: Right	40.00	100.00	54.69	4.06	<.001
Spatial arrangement: C	56.25	64.29	25.00	3.49	<.001
Point of origin: Left	36.11	92.86	56.25	3.17	<.01
Directionality: Left	41.67	71.43	37.50	2.82	<.01
Representation: Incorrect	33.33	92.86	60.94	2.82	<.01
Complementarity: Left	46.15	42.86	20.31	2.14	<.05
Density: Left	38.10	57.14	32.81	2.06	<.05
Cluster 2					
	Cla/Mod	Mod/Cla	Global	v.test	<i>p</i>
Progression axes: Left to right	47.06	100.00	53.12	4.59	<.001
Handedness: Right	45.71	100.00	54.69	4.46	<.001
Spatial arrangement: B	42.11	100.00	59.38	4.08	<.001

Complementarity: Balanced	39.02	100.00	64.06	3.71	<.001
Directionality: Right	41.94	81.25	48.44	2.98	<.01
Point of origin: Left	38.89	87.50	56.25	2.91	<.01
Representation: Correct	44.00	68.75	39.06	2.69	<.01
Cluster 3					
	Cla/Mod	Mod/Cla	Global	v.test	<i>p</i>
Spatial arrangement: A	60.00	85.71	15.63	4.28	<.001
Complementarity: Right	60.00	85.71	15.63	4.28	<.001
Order of placement: Other	50.00	42.86	9.38	2.43	<.05
Directionality: Right	19.35	85.71	48.44	1.98	<.05
Cluster 4					
	Cla/Mod	Mod/Cla	Global	v.test	<i>p</i>
Handedness: Left	58.62	94.44	45.31	5.02	<.001
Density: Balanced	50.00	77.78	43.75	3.35	<.001
Complementarity: Balanced	41.47	94.44	64.06	3.27	<.01
Progression axes: Other	85.71	33.33	10.94	3.18	<.01
Progression axes: Right to left	52.17	66.67	35.94	3.06	<.01
Point of origin: Right	50.00	66.67	37.50	2.89	<.01
Spatial arrangement: B	39.47	83.33	59.38	2.42	<.05
Order placement: ABC	53.85	38.89	20.31	2.13	<.05
Cluster 5					
	Cla/Mod	Mod/Cla	Global	v.test	<i>p</i>
Progression axes: Right to left	39.13	100	35.94	4.18	<.001
Complementarity: Left	53.85	77.78	20.31	3.93	<.001
Handedness: Left	31.03	100.00	45.31	3.57	<.001
Order of placement: BCA	33.33	77.78	32.81	2.84	<.01
Spatial arrangement: C	37.50	66.67	25.00	2.75	<.01
Point of origin: Centre	75.00	33.33	6.25	2.67	<.01

Note. Cla/Mod: % of individuals belonging to the cluster
Global: % of the individual among our sample

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Table VI. Goodness of fit of the General Linear Models

Variable	n	df	AIC	χ^2	Model R^2	p
Complementarity	65	2				
handedness			125.11	1.47	.01	.48
sex			116.73	9.55*	.08	.01
handedness*sex			122.75	1.02	.10	.60
Density	66	2				
handedness			138.90	9.78*	.07	.01
sex			147.90	0.73	.01	.70
handedness*sex			145.86	0.36	.08	.83
Directionality	66	2				
handedness			138.02	0.10	.01	.95
sex			135.11	3.60	.02	.16
handedness*sex			138.56	4.30	.06	.12
Order of placement	66	3				
handedness			176.01	3.89	.02	.27
sex			177.18	3.09	.02	.38
handedness*sex			181.07	4.43	.06	.22
Point of origin	66	2				
handedness			92.91	28.40***	.25	<.001
sex			119.77	0.23	.02	.90
handedness*sex			92.36	6.78*	.33	.03
Progression axes	66	2				
handedness			55.94	78.68***	.62	<.001
sex			132.09	2.59	.01	.27
handedness*sex			61.32	0.001	.64	.99
Representation	65	1				
handedness			90.60	0.04	.00	.83
sex			90.60	0.03	.00	.86
handedness*sex			94.31	0.23	.01	.63

Spatial arrangement 65 2

handedness	129.85	0.46	.01	.80
sex	126.23	4.14	.03	.13
handedness*sex	133.56	0.25	.04	.88

Note. * $p < .05$; ** $p < .01$; *** $p < .001$

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1256 **Appendix 7**

1257 Table VII. Description of the participants constituting cluster 3

Variables	Participants						
	2	19	20	23	38	42	51
Sex	Girl	Boy	Boy	Girl	Boy	Boy	Boy
Handedness	Left	Left	Left	Right	Right	Right	Right
Directionality	Right	Right	Right	Right	Balanced	Right	Right
Density	Right	Right	Left	Right	Right	Left	balanced
Point of origin	Right	Right	Right	Left	Left	Left	Right
Complementarity	Right	Right	Right	balanced	Right	Right	Right
Representation	Incorrect	Incorrect	Correct	Incorrect	Incorrect	Incorrect	Incorrect
Progression axes	RL	Vertical	RL	LR	LR	LR	LR
Order of placement	Other	BAC	BCA	Other	BAC	BCA	Other
Spatial arrangement	B	A	A	A	A	A	A

1258 *Note:* RL: Right to left; LR: Left to right

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1260 **Appendix 8**

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1262 Figure I. Correlations between all the categories on the three dimensions obtained by the MCA

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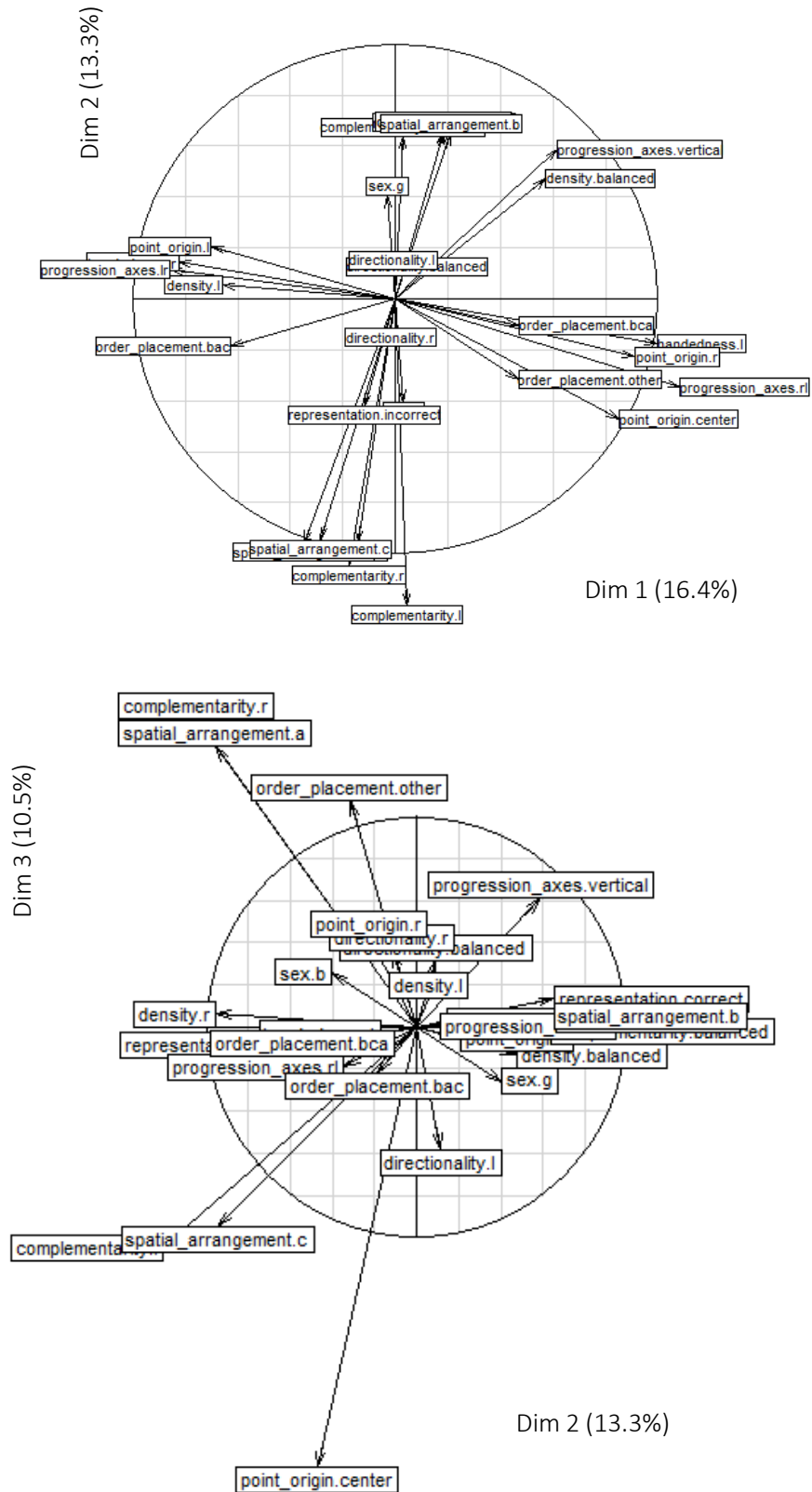
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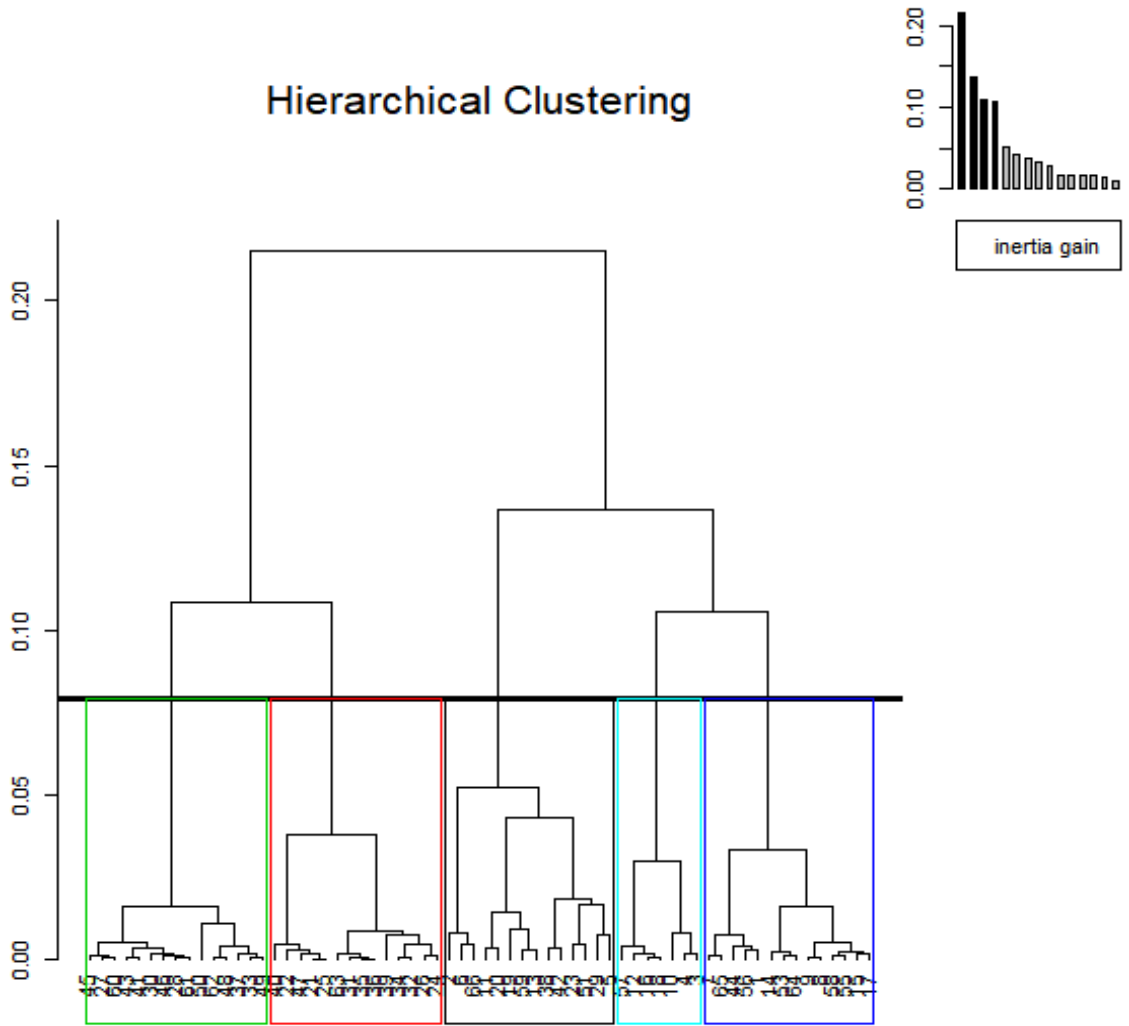
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1278 **Appendix 9**

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Figure II. Dendrogram representing the optimal number of clusters



Note. Vertical line: the tree is automatically cut at the suggested level following Ward's method

Scoring manual – 3D-2D transcription task

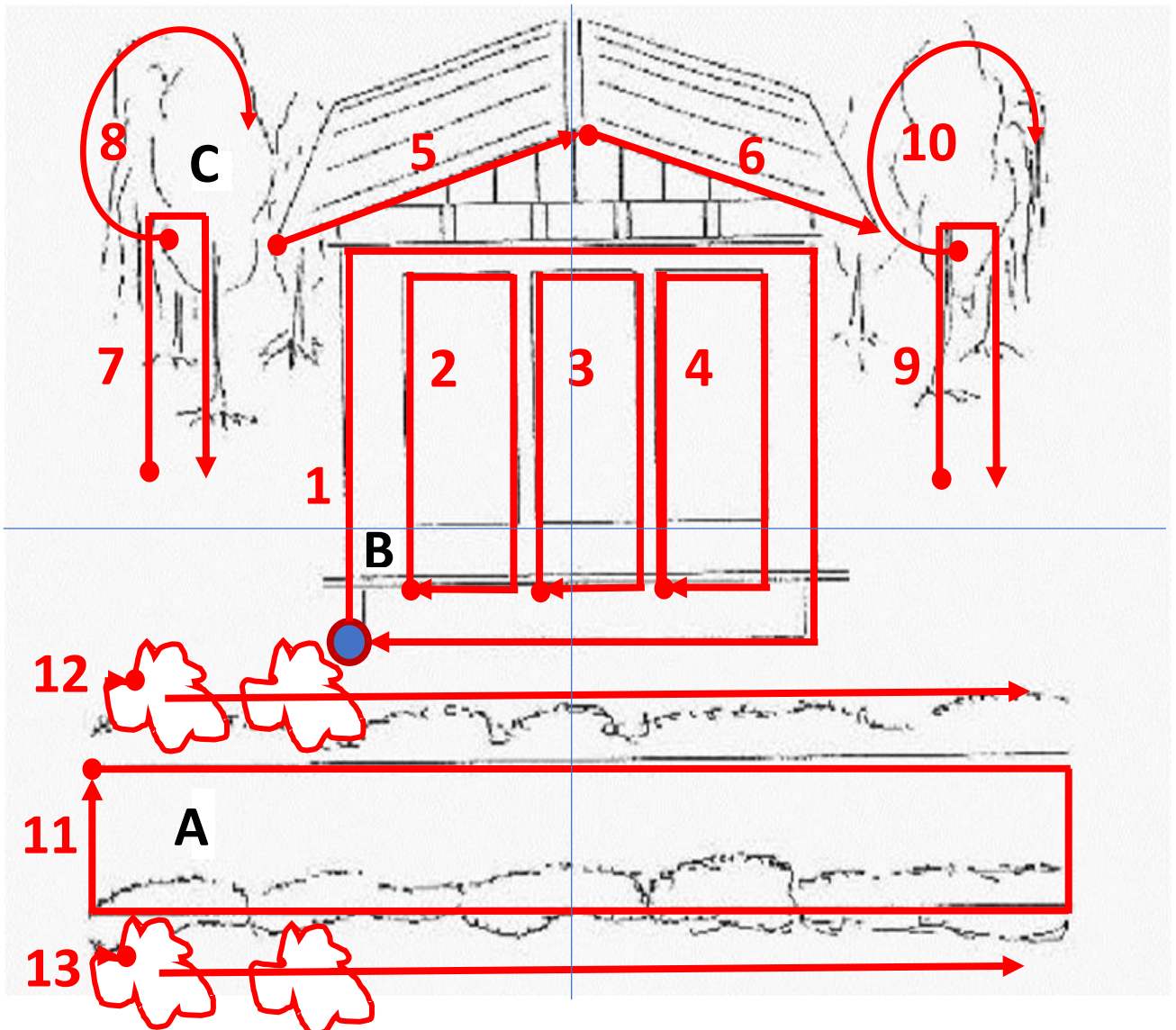
The observation grid of the test makes it possible to transcribe the progress of the child's graphics on one hand for all the 3 constitutive planes of the 3D model and then for the details of each plan (A, B, C).

On another scoring sheet, the elements present or absent in the 2D representation of the 3D model, as well as the chronology of the drawn elements, are reported for synthesis.

During the assessment, two information must be included:

1. The **initial point of origin of the drawing**: the point from which the child begins his drawing. It can be located either on the left, in the centre, or on the right. Thus, immediately after the beginning of the child's drawing, the origin point is indicated with a big dot (see the blue dot on Example 1).
2. The **progression axis**: characterized by the orientation of the stroke, the position of a structure (e.g., square) from its point of origin or the direction of drawing to represent the successive elements of series (e.g. windows, bushes, trees). **Important:** the strokes orientation must be marked by arrows in complementarity with the origin points for every structure and substructure of the drawing (e.g., respectively for the global structure of the house and its details such as windows) and their chronological order must be numbered. Thus, each structure and substructure will be referenced with a number allowing to precisely transcribe the progression of the drawing from the main origin point to the end of the task (see below the example 1 of scoring sheet).

Example 1:



The scoring sheet gives already information on the:

Point of origin, progression axis and placement order

As for the example 1:

- The point of origin is on the left (big dot on the left side of the first stroke).
- Progression axis: Dominance for the Left to Right (LR) orientation (13 LR)
- The depiction order of the three planes (A, B and C) can be scored following the numbering of drawn elements according to each plane. We observe in example 1 that the child began to draw the house (plane B). After finishing the sixth stroke (stroke

number 6), the trees were drawn (strokes number 7 to 10 on the plane C). And at the end, the child drawn the river (plane A). Therefore, the placement order was BCA.

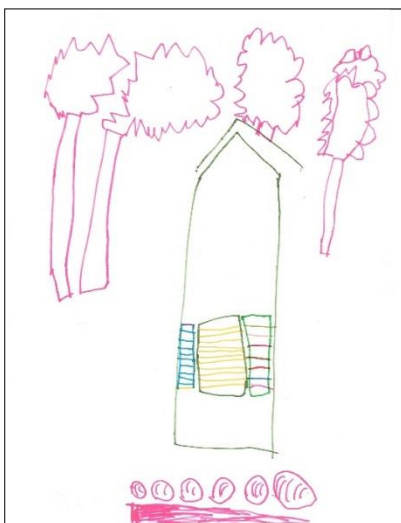
After this step, the scoring sheet should be put aside. To continue the scoring procedure, we analyse the children's drawing to determine after completion the quality of the 2D

representation (correct or not), the **density** of graphic content, the graphic complement or **complementarity** and the **spatial arrangement** (or directionality).

Representation:

A correct representation is identified by the offset between each of the 3 levels along a vertical axis characterizing a good 2D transcription of front-behind type of relationship between each of the three 3D planes: foreground (A), main plan (B) and background (C). A so-called "correct" representation will show a base shift of each of the 3 planes following a vertical axis, reflecting this way the 3D relation "front-behind" by a 2D relation "below-above" (see example 2). Thus, a drawing where the river is depicted on the bottom, the house in the middle and the trees on both upper sides of the house was considered as a correct representation. Other representations were therefore considered incorrect (see example 3).

Example 2: Correct representations.



Example 3:

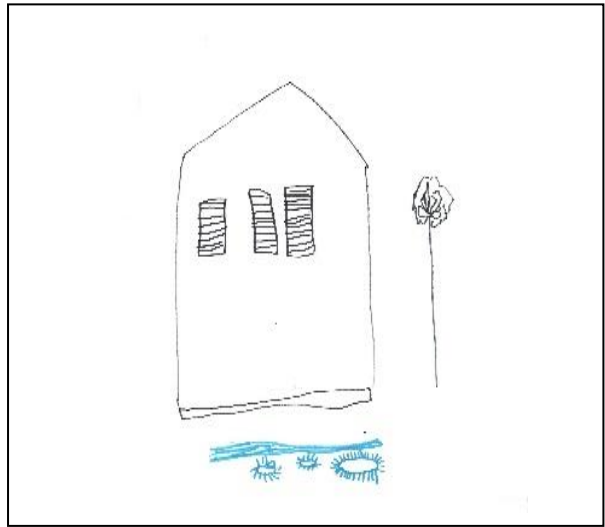


Incorrect representation (due to either a profile type representation or a poor representation of the 3 planes - foreground A, main plane B, background C - along the vertical axis).

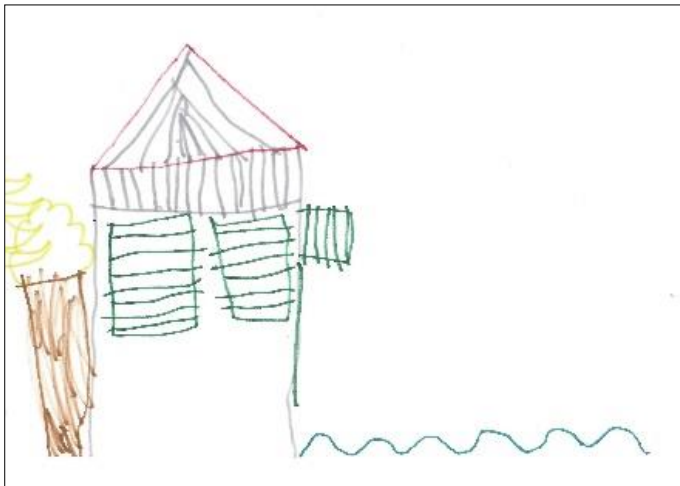
Density and complementarity of the graphic content:

- The density of the graphic content is determined by placing a square grid on the drawing (1 cm x 1 cm)) and as a function of the two horizontal and vertical axes passing through the center of the drawing. This device allows to objectify the surface occupied by the structures constitutive of the graphics on both sides of the axes. The complementarity is relative to the degree of complexity of the different elements arranged on either side of the main plane (the house). The evaluation of a higher degree of complexity on one side or the other of the house thus determines a left or right complement versus a balanced complement for an equivalent level of complexity on both sides.

See the following examples:



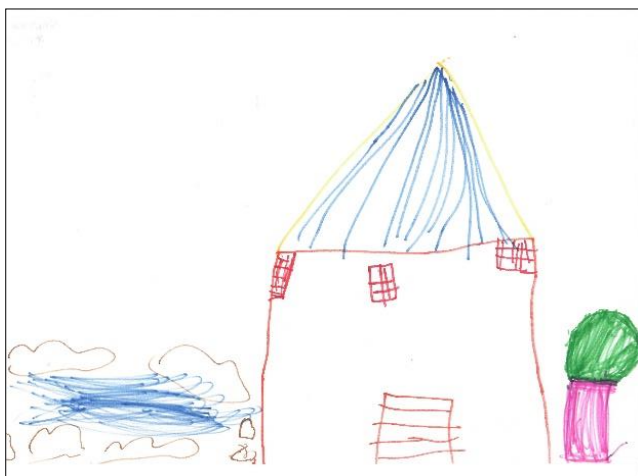
Left density and right complementarity



Left density and left complementarity



Right density and left complementarity



Right density and balanced complementarity

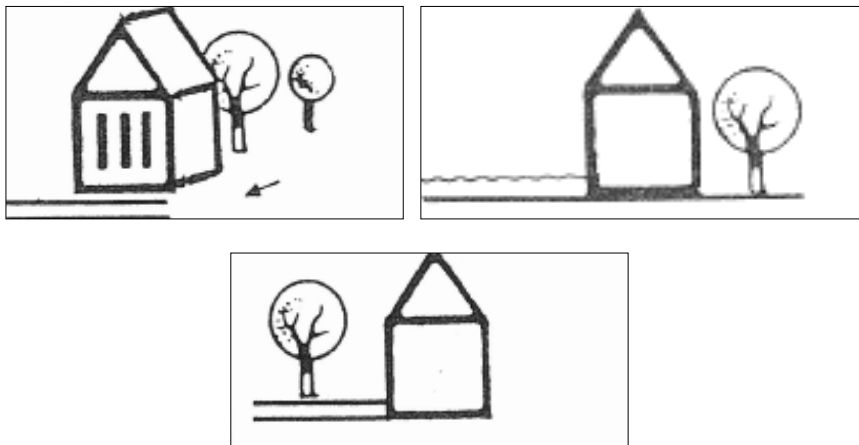


Balanced density and complementarity

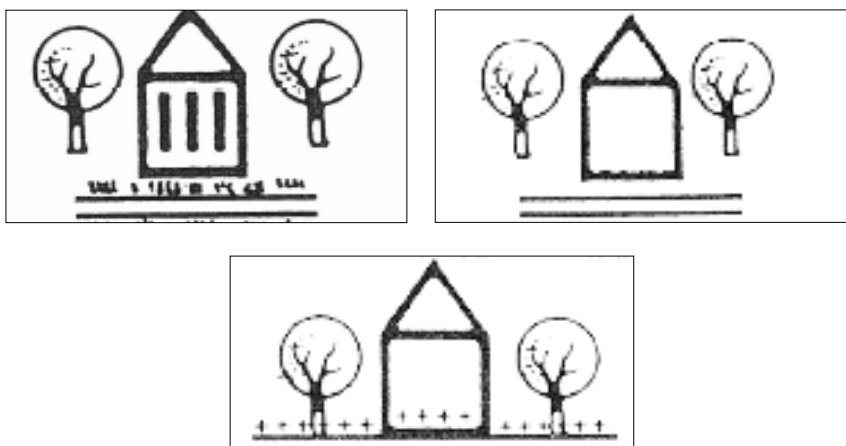
Spatial arrangement:

This characterizes the orientation of the drawing (directionality) based on all the constitutive elements.

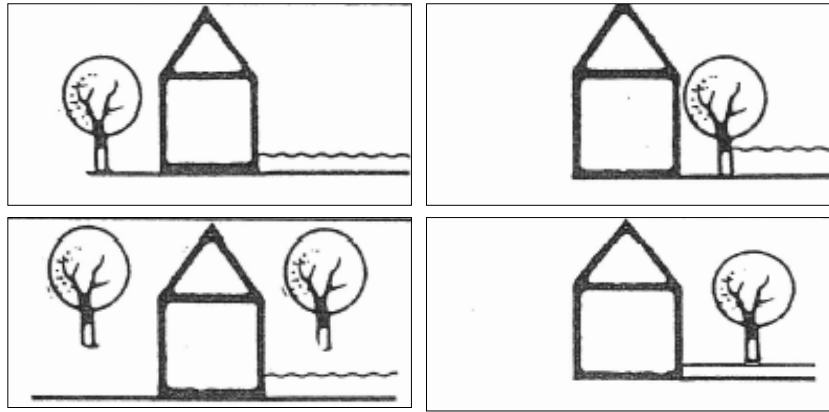
- Category A is defined as when the river is depicted on the left side of the house and/or the trees are on the right side, giving a leftward orientation.



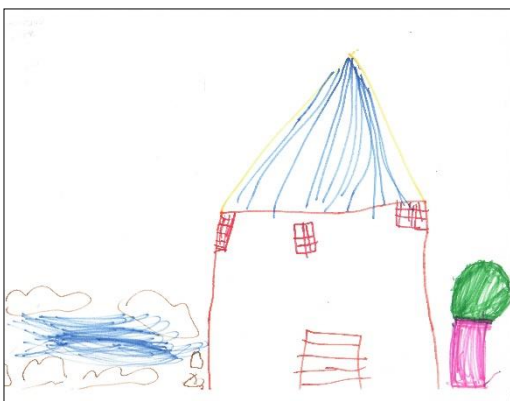
- Category B is defined as a symmetrical drawing where the house and river are in the middle of the picture and the trees are present on both sides of the house.



- Category C is defined as when the river is depicted on the right side of the house and/or the trees are on the left side, giving a rightward orientation.



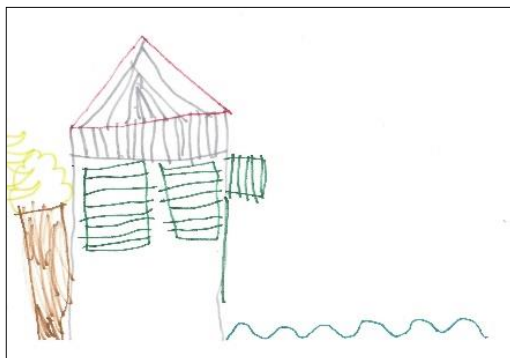
For example:



Spatial arrangement A



Spatial arrangement B



Spatial arrangement C