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

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Abstract

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

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

Introduction

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

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

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

Handedness

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

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

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

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

Sex

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

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

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

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

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

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

Proposed study

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

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

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

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

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

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

Participants and Methods

Participants

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

Materials

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

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

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

Insert Figure 1 about here

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

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

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

Procedure

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

Instructions

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

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

Experimental design and scoring

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

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

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

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

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

7. Placement order: The depiction order of the three planes (A, B and C) represents the transcription strategy. This variable will show us the different graphic strategies adopted by the children. For example, a BAC strategy will represent a drawing where the child starts to draw the house (i.e., the main element), followed by the river and finishes by drawing the trees (i.e., the background). However, due to the diversity of the strategies encountered during the assessment, we chose to combine all the results with a low frequency into one category. This category was named “other” and included the following strategies: ACB, B, CAB, CBA (see Table 1 for all the indicators used in the MCA analysis with their respective categories and frequencies).
8. Spatial arrangement: This characterizes the orientation of the drawing based on all the elements. We divided this variable into three categories: A, B and C. Category A was defined as when the river is depicted on the left side of the house and/or the trees are on the right side (a leftward orientation). Category B was 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 was defined as when the river is depicted on the right side of the house and/or the trees are on the left side (a rightward orientation of the drawing).

Insert Figure 2 about here

Statistical analysis

Our statistical analysis was divided into two parts. The first one consisted of conducting an exploratory analysis allowing us to investigate the children's graphical patterns. We conducted a cluster analysis to classify our participants into different groups. Each of these groups represent participants with common graphical characteristics. These common characteristics allowed us to uncover specific graphical patterns. However, since we have a large number of variables, it is better to perform a dimensional reduction of variables before the clustering (Mitsuhiro & Yadohisa, 2015). Therefore, the exploratory analysis consisted of two parts

The first part of the analysis was conducting a Multiple Correspondence Analysis (MCA) to perform the dimensional reduction, and to examine the relationship between our several nominal variables (i.e., sex, handedness, and the graphical variables). The MCA is a multivariate exploratory analysis that does not need any distributional assumptions and is used to investigate the relation between the variable response categories (Greenacre, 1984; Sourial et al., 2010). It allows us to map our data as points in a low-dimensional space, enabling us to examine underlying structures (i.e., dimensions) best suited to uncover the correlations between our variables (Mitsuhiro & Yadohisa, 2015)

The second part of the exploratory analysis consisted of conducting a Hierarchical Clustering (HC) to group our participants according to their similarities along the relevant dimensions obtained by the MCA. The statistical analyses were done using R 4.0.3 (R Core Team, 2020). All the study's variables are nominal. The MCA and HCPC functions of the FactoMineR package were used to conduct the MCA and the clustering analyses (Lê et al., 2008). In addition, we used the factoextra, FactoInvestigate, and ade4 packages to optimise our interpretations and graphical representations of the MCA (Dray & Dufour, 2007; Kassambara & Mundt, 2017; Lê et al., 2008; Thureau & 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

Results

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

Insert Table 1 about here

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

Insert Figure 3 about here

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

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

Insert Figure 4, Figure 5 about here

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

Insert Figure 6 about here

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

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

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

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

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

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

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

Insert Figure 7 about here

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

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

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

Insert Table 2 about here

Overall, the five obtained clusters corresponded to five groups of participants characterized by both the direction and the degree of their handedness. For the right-handers, cluster 1 represents the strong right-handers and cluster 2 represents the weak right-handers. For the left-handers, cluster 4 represents the weak left-handers and cluster 5 represents the strong left-handers. The overall exploratory results show that the 3D/2D depiction task successfully categorised participants according to handedness and sex. The second part of our statistical analysis is testing these findings with GLM in which handedness and sex are the predictors. A significance threshold of 0.05 was adopted for all statistical analyses. For *post-hoc* tests, the *p* values are adjusted using Holm's correction. In the following section, we will present only the significant models and their follow-up *post-hoc* tests (see Table 3 for the model coefficients, and Table 4 for the predicted probabilities).

Complementarity

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

Density

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

Origin point

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

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

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

Progression axis

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

Insert Table 3 and Table 4 about here

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

Discussion

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

Sex

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

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

Handedness

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

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

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

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

Limitations and perspectives

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

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

Conclusion

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

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Declaration of interest statement

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

Data Availability Statement

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

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Figure 1a. 3D model

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

Figure 2. Examples of the 2D transcription

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.

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

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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.

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

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

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

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

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)

Right point of origin	Boys	0.59 (0.38 – 0.77)
	Girls	0.31 (0.11 – 0.62)
	Boys	0.41 (0.23 – 0.61)
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**

1231 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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Appendix 3

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

Note. R²: effect size of each category

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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Appendix 5

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

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

Appendix 6

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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Appendix 7

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

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

Appendix 8

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

Appendix 9

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