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Children's Spatial Analysis of Hierarchical Patterns: Construction and Perception

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Two experiments were reported that aimed at investigating the development of spatial analysis of hierarchical patterns in children between 3 and 9 years of age. A total of 108 children participated in the drawing experiment, and 224 children were tested in a force-choice similarity judgment task. In both tasks, participants were exposed to consistent and inconsistent targets for short (300-ms) and long (3-s) durations. The drawing task showed that 3-year-old children either preferred to draw the local level or reproduced both levels in a nonintegrated manner. Coordination between the 2 processes started to emerge at 4 years of age, and 6-year-old children produced essentially correct integrated responses. The similarity judgment task confirmed that local processing dominated at 3 years of age. Preference for global processing appeared at 5 years of age, and it gained in strength later. Significant effects of stimulus consistency and stimulus duration were also found. In particular, the use of inconsistent patterns in the similarity judgment task revealed a phenomenon of local-to-global interference in the 3-year-olds.

Keywords: local processing, global processing, hierarchical patterns, drawing, perceptual development

Drawing behavior has attracted the interest of developmental psychologists from the turn of the last century (e.g., Freeman, 1980; Lange-Küttner & Vinter, 2008; Luquet, 1927; Willats, 2005). An original use of this nonverbal behavior was to investigate the development of spatial analysis of hierarchical patterns in children (Dukette & Stiles, 2001; Lange-Küttner, 2000; Porter & Coltheart, 2006). The concept of hierarchical patterns can be traced back to Navon (1977), who designed compound figures made of large global letters (e.g., a large H that constitutes the global level) composed of small local letters that could be consistent (e.g., small Hs) or inconsistent (e.g., small Ss) with the global level to test the so-called "global precedence effect" (see also Kimchi, 1992; Martin, 1979; Navon, 2003). Indeed, Navon (1977, p. 354) argued that "perceptual processes are temporally organized so that they proceed from global structuring toward more and more fine-grained analysis." This hypothesis claims that when processing a visual object or a visual scene, the global properties are processed first, and the local properties are analyzed later. The originality of envisaging this issue through drawing behavior relies on the fact that drawing a hierarchical pattern, from memory or in a copying task, requires the integration of both processes, regardless of their respective priority in the very act of perceiving.

To our knowledge, only two studies have investigated how typically developing children draw hierarchical patterns. Lange-Küttner (2000) asked children 5, 6, or 11 years of age and adults to copy an inconsistent hierarchical letter pattern (a large H made of small Ss). She reported that 5-year-old children drew only the global shape of the pattern (H) in more than 70% of the cases and that correct reproduction of both levels was observed at 11 years of age. Dukette and Stiles (2001) asked children 4–8 years of age and adults to copy inconsistent hierarchical patterns or to draw them from memory. Under constrained task conditions (a memory condition compared with a copying condition), the youngest children had more difficulties in reproducing the global shape than the local elements, though they were able to attend to both levels of analysis. When making the local level more salient by decreasing the density of elements, the local advantage increased and was still observed at 8 years of age. These results diverge from those by Lange-Küttner (2000). It is thus yet unclear whether young children would manifest an initial local or global bias in their drawing of hierarchical patterns and to what extent both levels would be present in the drawings.

The other studies that have used drawing behavior for investigating this question were concerned with neuropsychological issues. Several authors reported that children with William syndrome (WS) were more accurate in drawing the elements than the global shape of patterns (Bellugi, Sabo, & Vaid, 1988; Birhle, Bellugi, Delis, & Marks, 1989), whereas individuals with Down syndrome performed better in drawing the global shape than the local elements (Bellugi, Bihrle, Jeringan, Trauner, & Doherty, 1990; Bellugi, Lichtenberger, Jones, Lai, & St. George, 2000). Farran, Jarrold, and Gathercole (2003) confirmed the finding with individuals with WS and reported another interesting result: This

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local bias was shown only in drawing, not in a perceptual task requiring stimulus identification. Farran et al. suggested that the local bias observed in drawing was not due to perceptual processing but from a difficulty in integrating the parts into a whole when producing a drawing. However, Porter and Coltheart (2006) reported a local advantage in the drawings of individuals with WS and also a local bias in a nonconstructional task. This latter result questions the hypothesis that the local bias in drawing could be due to the constructional nature of this task. To our knowledge, there is no study with typically developing children in which performance was compared in a perceptual and in a constructional drawing task using the same hierarchical patterns and manipulating the same factors. In the present two studies, we aimed at investigating whether young children would display a global or a local bias in drawing hierarchical patterns and whether this bias would be specific to the constructional nature of the drawing task or would be identical in a perceptual task. Note that it was necessary to use a between-subjects design to prevent practice and priming effects between the drawing and perceptual tasks, yet limiting the comparison between drawing and perception.

The studies that have investigated this question of perceptual processing in typically developing children using perceptual tasks are more numerous than those based on drawing behavior. Most of them have concluded in favor of an initial local processing bias. In a force-choice matching task, Kramer, Ellenberg, Leonard, and Share (1996) asked children from 4 to 12 years of age to express similarity judgments by designating which of two geometrical figures was most like the target hierarchical pattern. Under 7 years of age, children tended to display a local preference bias. In Dukette and Stiles's (1996) study, 4- to 6-year-olds and adults had to select the figure most similar to the target among two possibilities in four different conditions: one in which a global bias was expected, one in which a local bias was induced, and two conditions that did not intend to induce any specific choice because the two choice items presented provided equivalent matches to the global and local levels of the target. All participants selected global responses, except in the local-induced condition, in which they showed a local bias. When the density of elements in the whole figure was reduced, the 4-year-old children did express more local choices than older children in the two conditions that did not intend to induce any specific choice. These results suggested that young children were capable of processing both levels of organization, though local processing had an initial advantage. Finally, Burack, Enns, Iarocci, and Randolph (2000) showed that age-related performance improvements in a visual search task were more important in global than in local processing between 6 and 10 years of age.

However, the reverse finding of an initial global bias has also been revealed in the literature. When children were asked to decide under short exposure times whether two patterns were the same on the basis of the local elements or of the global shape, 6- and 10-year-olds demonstrated a strong global bias, stronger than the one showed by adults (Mondloch, Geldart, Maurer, & de Schonen, 2003). Children were also less accurate on local than on global trials, contrary to adults. At 14 years of age, performance looked adult-like. This developmental pattern suggests a slower improvement with age in local than in global processing. Kimchi, Hadad, Behrmann, and Palmer (2005) demonstrated that both developmental trends were indeed likely to emerge, depending on contextual and task factors, in particular whether local elements in the hierarchical patterns were few large or many small. More recently, Scherf, Behrmann, Kimchi, and Luna (2009) argued that it is the formation of a precise integrated shape representation that would develop until late in adolescence. Finally, Poirel, Mellet, Houdé, and Pineau (2008) showed that a developmental change in preferential processing level occurred early in the first years of life, revealing a clear local preference at 4 years of age, followed by a global preference at 6 years of age.

What the literature makes clear is that many parameters determine whether a local or global bias emerges at the different ages in a perceptual task. In particular, the exposure duration of the patterns seems especially relevant to differences in the findings (Kimchi, 1992). None of the drawing studies carried out with typically developing children have tested the effect of stimulus duration. Yet, several studies have shown that short exposure times facilitated global precedence in adults when the density of local elements was standard (e.g., Kinchla & Wolfe, 1979; Martin, 1979; Navon, 1977; Paquet & Merikle, 1984). We therefore decided to present the hierarchical patterns under short or long exposure durations in both the drawing and perceptual tasks. Furthermore, Navon (1977) tested the interference effects between local and global levels comparing performance when consistent or inconsistent patterns were shown to the participants and revealed global-to-local interference (see also Kimchi, 1988, 1992; Martin, 1979). None of the drawing studies run with typically developing children have compared performance with consistent and inconsistent patterns. Thus, the question is still open as to know whether typically developing children would manifest possible interference effects in their drawings of inconsistent hierarchical patterns. Finally, Poirel et al. (2008) demonstrated that a change in perceptual bias occurred early, between 4 and 6 years of age. We included children as young as possible in our experiments. Children at 3 years of age are able to draw circles and squares. We built hierarchical patterns using these two shapes and tested children between 3 and 9 years of age.

Drawing hierarchical patterns requires children to process both levels of organization and to integrate one to the other. We focused on these two aspects and not on the accuracy with which each level was reproduced. Accuracy in drawing depends on several factors that do not all relate to how information is encoded (e.g., Miyahara, Piek, & Barrett, 2008; Vinter & Mounoud, 1991). Thus, we performed an analysis based on the categories of drawings made by children at the different ages. Young children seem able to attend to both the global and local levels (Dukette & Stiles, 2001). However, if these levels are introduced in their drawings, we expected that young children would not be able to integrate them but would produce drawings with the local elements and the global shape juxtaposed or combined following other topological relationships. Several drawing studies have indeed revealed convergent findings showing that young children parse compound spatial patterns in independent parts, entertaining simple topological relationships (e.g., Akshoomoff & Stiles, 1995; Picard & Vinter, 1999; Tada & Stiles, 1996; Vinter & Marot, 2007). Thus, young children should draw preferentially isolated elements rather than the global shape. However, consistent patterns should enhance the production of integrated drawings, and short pattern durations should reinforce global processing.

Finally, our sample of children included both girls and boys because boys have been reported to make significantly more global perceptual judgments than girls (Cahill, 2003; Kramer et al., 1996). This finding is consistent with developmental models that suggest an early left-hemisphere advantage for girls and a right-hemisphere advantage for boys (Coluccia, Iosue, & Brandimonte, 2007). However, Dukette and Stiles (1996) mentioned exactly the reverse result in 4- to 6-year-olds and in adults in a force-choice matching task, with female participants making more global level matches than male participants. Gender differences were therefore worth investigating.

Experiment 1: Drawing Hierarchical Patterns in Children

Method

Participants. A total of 108 right-handed Caucasian children (55 girls, 53 boys), between 3 and 9 years of age, participated in the experiment. They were divided into seven age groups (3-year-olds: $n = 15$, $M = 3.3$ years, $SD = 0.3$, nine girls, six boys; 4-year-olds: $n = 16$, $M = 4.6$ years, $SD = 0.28$, eight girls, eight boys; 5-year-olds: $n = 15$, $M = 5.6$ years, $SD = 0.31$, eight girls, seven boys; 6-year-olds: $n = 15$, $M = 6.4$ years, $SD = 0.32$, seven girls, eight boys; 7-year-olds: $n = 15$, $M = 7.5$ years, $SD = 0.28$, seven girls, eight boys; 8-year-olds: $n = 16$, $M = 8.6$ years, $SD = 0.27$, eight girls, eight boys; 9-year-olds: $n = 16$, $M = 9.4$ years, $SD = 0.33$, eight girls, eight boys). Each age group corresponded to one school level (3- to 5-year-olds: nursery and kindergarten levels). Handedness was assessed by testing children on eight items from Bryden's (1977) test, four unimanual items (drawing, throwing a ball, holding scissors, and brushing teeth), and four bimanual items (closing a bottle, hitting a nail with a hammer, lighting a match, and drying a plate with a tea cloth). Only children who obtained a score ≥6 were selected. The handedness test was carried out in a preexperimental session and completed 1 week before the experiment. None of the children were educationally advanced or retarded, and their vision was normal. Children were largely from middle socioeconomic status families. They were tested individually in a quiet room at their schools. Informed written consent was obtained from parents of each child participating in the study.

Material. Stimuli were displayed as bitmap files and were presented on a 36-cm × 27-cm computer screen. Four targets were used in the familiarization phase: a big circle or square (diameter/side's length: 4 cm) and a set of five randomly arranged small circles or squares (diameter/side's length: 3 mm); all four targets were traced in a dashed line.

The four targets shown in the test were as follows: a square made of small squares (consistent stimulus) or of small circles (inconsistent stimulus), and a circle made of small circles or of small squares. Illustrations of the targets can be seen in Figure 1 (see the correct integrated responses). The global shape was 4 cm of height and width. Each small local shape was 3 mm high and 3 mm wide. There were 26 local elements in each larger shape, which corresponded to a standard condition with respect to the density effect (Kimchi, 1988; Martin, 1979). The target appeared centered in the upper half of the monitor screen. The location of the monitor was adjusted so that the viewing distance was at 60 cm. The middle of the screen corresponded to the participant's body midline.

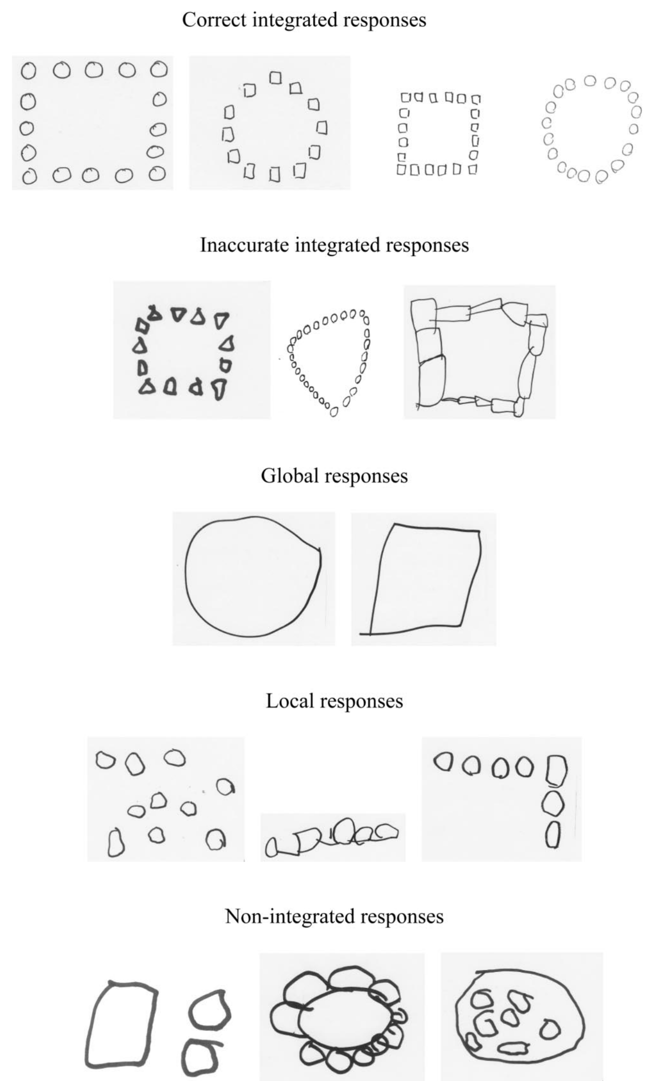

Figure 1. Illustrations of the five categories of drawings produced by children in Experiment 1.

Procedure. In a short familiarization phase, the children were introduced to the instructions and experimental conditions. They were instructed to copy as accurately as possible the model that appeared on the screen. They were told to concentrate their attention on the screen because the models would stay visible for a very short time on some trials. The experimenter gave them a sheet of paper (A5 format) and a black pencil and asked them to adopt a comfortable and stable posture for drawing. The four familiarization targets appeared for either a long (3-s) or short (300-ms) duration. The order of presentation of the stimuli was randomized. When the model disappeared, the participants were asked to make their drawing without any time constraints. When the drawing was finished, the experimenter took away the sheet of paper, gave a new one to the participants, and waited for their ready-signal before triggering the display of the next model. The children produced eight drawings in the familiarization phase. All children noticed the difference in size of the figures and reproduced a big and a small circle or square.

The procedure was basically the same in the experimental phase. The children were told that they would now see patterns such as a big square or circle made of small squares or circles. The experimenter showed them an example of the patterns to ensure that they were aware of the presence of the two levels of organization. The children were asked to focus their attention on the monitor screen and to copy the pattern as accurately as possible. They produced a total of 16 drawings (2 consistent and 2 inconsistent patterns × 2 durations × 2 trials). A complete random order was used for the targets' presentation.

Data coding. The drawings were sorted into five categories, illustrated in Figure 1:

- *Correct integrated response*: The overall global shape as well as the local elements were correctly reproduced (we did not code whether the size or the number of elements or the regularity of the distance between elements or the accuracy of the right angles in the squares were correct).
- *Inaccurate integrated response*: The drawings comprised a global shape made of small elements (the two levels were present and integrated). However, the global shape was deformed or the local shapes were deformed or both the global and local shapes were deformed (they were ellipses or rectangles, for instance). Only shape deformations were considered here.
- *Global response*: The overall global shape was reproduced with a continuous line, and the local elements were absent. We did not differentiate the cases in which the shape was deformed (the 3-year-old children were not all able to draw squares correctly).
- *Local response*: A series of small circles or squares was reproduced. The overall global shape was absent. The elements were either isolated or linked one to the other, or they formed a part of the target. The shape of the local elements was not coded. As illustrated in Figure 1, most of the drawings were ambiguous, mixing circles, ellipses, deformed squares, or rectangles.
- *Nonintegrated response*: The local elements were either juxtaposed or superposed to the global shape or nested (the superposed drawings were rare).

Two judges coded the drawings independently. They were naïve to the experimental conditions (type of model shown, duration of exposure) in which each drawing was produced. Their percentage of agreement was 91%. The disagreements were settled by the two judges working together, before data analysis.

The data were analyzed with nonparametric tests because homoscedasticity was not held in most of the cases. The Kruskal–Wallis test (*H* value) was used to test overall age differences, the Mann–Whitney test (*U* value) was used to test gender differences or age differences between two groups, and the Wilcoxon signed-rank test (*T* value) was used to test consistency and duration effects. We followed Neuhaüser and Ruxton's (2009) advice for the use of appropriately rounded mean frequencies prior to the ranking procedure.

Results and Discussion

Gender did not yield significant differences (all $ps > .10$) and was ignored in the reported analyses. Figure 2 depicts the results as a function of age and consistency for the integrated and nonintegrated responses.

The frequency of *correct integrated* responses varied significantly across the age groups, $H(6, N = 108) = 83.8$, $p < .01$, increasing between 3 and 9 years of age. The transitions between 3 and 4 years of age ($U = 36.5$, n1 = 15, n2 = 16), then between 5 and 6 years of age ($U = 40$, n1 = n2 = 15), and finally between 6 and 9 years of age ($U = 4$, n1 = 15, n2 = 16) were significant (all $ps < .01$). Children produced more frequently correct integrated drawings in response to consistent ($M = 64.1\%$, $SD = 39.4$) than to inconsistent ($M = 56.9\%$, $SD = 37.1$) targets, $T(N = 108) = 406$, $p < .01$. No other significant differences were found (all $ps > .30$). The occurrence of *inaccurate integrated* responses differed across ages, $H(6, N = 108) = 46.3$, $p < .01$, increasing between 3 ($M = 4.3\%$, $SD = 10.9$) and 5 ($M = 40.8\%$, $SD = 23.9$) years of age ($U = 23$, n1 = n2 = 15, $p < .001$), then diminishing as depicted in Figure 2B. The decrease between 5 and 7 years of age was already significant ($U = 44.5$, n1 = n2 = 15, $p < .001$). These inaccurate integrated responses were more frequently produced when drawing inconsistent ($M = 21.2\%$, $SD = 23.3$) than consistent ($M = 14.3\%$, $SD = 20.8$) targets, $T(N = 108) = 466$, $p < .01$. No other significant differences were reported. Note that a qualitative analysis of the shape deformations did not reveal any systematic deformations of one level (local or global) as a function of the other (as, e.g., diffusion from the global shape to the local one or vice-versa). As depicted in Figure 2C, the *nonintegrated* responses dropped out rapidly between 3 and 4 years of age and disappeared at 6 years of age. The differences between the age groups were significant, $H(6, N = 108) = 50.5$, $p < .01$.

Figure 3 reports the results as a function of age and duration for the global and local responses.

The *local* responses were seen in almost 50% of the drawings made by the youngest children, and they decreased progressively until 6 years of age, $H(6, N = 108) = 62$, $p < .01$. There were no significant differences because of consistency or duration (all $ps > .40$), but as shown in Figure 3A, the short durations tended to elicit more local responses ($M = 54.4\%$, $SD = 37$) than did the long durations ($M = 40.8\%$, $SD = 43.4$) at 3 years of age, $T(N = 15) = 4.5$, $p = .06$. No other differences were significant (all $ps > .10$). Figure 3B shows that the *global responses* were rare and were produced only by the 3- to 4-year-olds (8% on average), $H(6, N = 108) = 18$, $p < .01$. There were no other significant effects (all $ps > .10$).

Dukette and Stiles (2001) and Lange-Küttner (2000) also studied the integration of local and global information in children's drawing. Our results are similar to those of Dukette and Stiles in that from 4 years of age, children incorporated both local and global elements into their drawings. On the other hand, Lange-Küttner found that 5-year-olds often drew using only the global elements of the stimulus. We never observed the use of only global elements at any of age, and Dukette and Stiles did not report only global elements in drawings in their study.

In the current study, if children used only a single dimension, it was invariably the local dimension. These unidimensional responses were seen primarily at 3 years of age, were rare at 4 years of age, and completely disappeared between 5 and 6 years of age. In our study, the integrated responses, either correct or inaccurate, developed rapidly between 3 and 5 years of age. At 6 years of age, children produced correct integrated responses in more than 70%

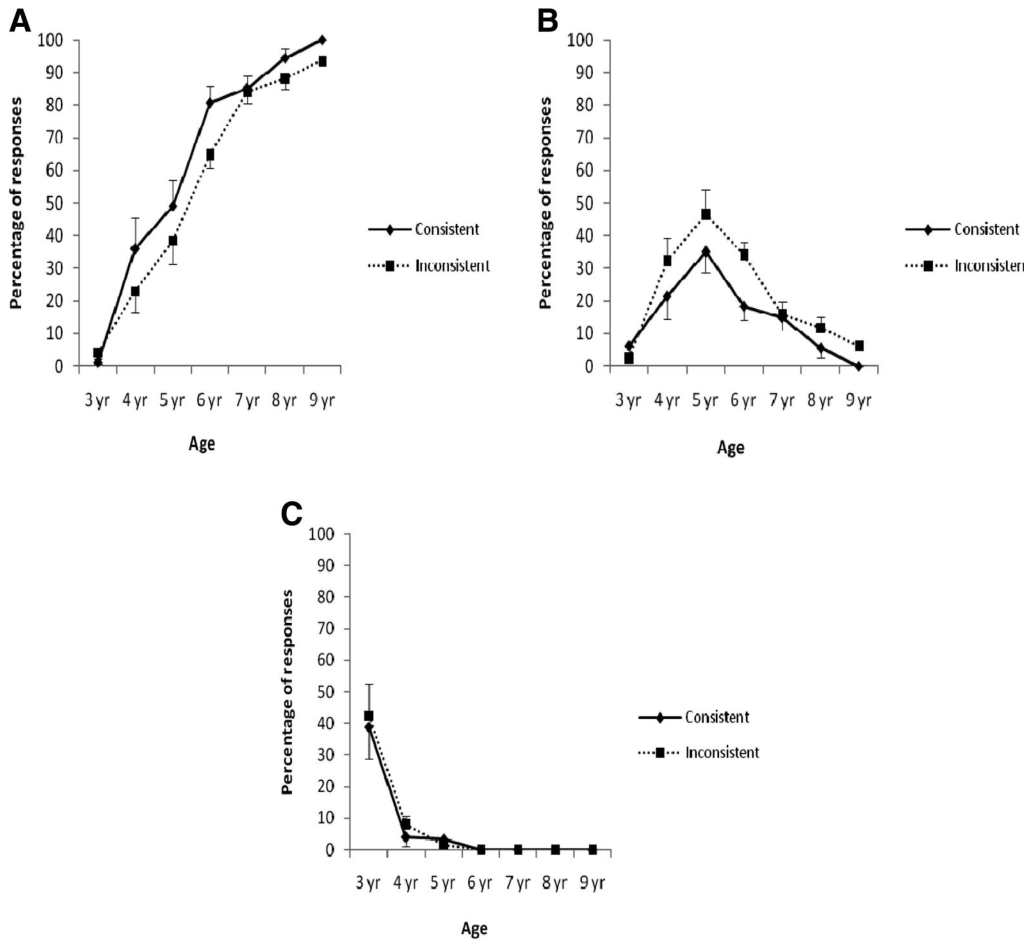

Figure 2. Experiment 1: Frequencies of integrated and nonintegrated drawings as a function of age and target's consistency (A: correct integrated responses; B: inaccurate integrated responses; C: nonintegrated responses). Bars indicate standard errors.

of the cases, and these responses characterized almost 100% of the drawing production at 9 years of age.

Would the developmental trajectory shown in this drawing experiment be revealed in a perceptual task? The perceptual task used in Experiment 2 was based on patterns' similarity judgments.

Experiment 2: Perceptual Similarity Judgments of Hierarchical Patterns in Children

The results of Experiment 1 suggest that local processing dominated first and that local and global processing started to be integrated at 5 years of age. Would a similarity judgment task show that global processing preference emerged somewhere around 5 years of age? We designed the similarity judgment task so that it was as similar as possible to the drawing task. The same consistent or inconsistent target patterns that were used in Experiment 1 were shown to children in Experiment 2 under the same exposure duration conditions. Children had to decide which figure, among four choices, was the most similar to the target. Following Poirel et al. (2008) and our findings in Experiment 1, we expected to observe a local bias in the choices made by the youngest children, which should be stronger under long than short target exposure durations. The results of Experiment 1 suggest that this local bias decreased in strength rapidly between 3 and 5 years of age. Dukette and Stiles (1996) reported a preference for global responses from 4 years of age. We expected the transition between local and global preference processing to be located somewhere between 4 and 5 years of age. As we have seen in Experiment 1 that consistent targets enhanced the integration between local and global processing in young children, the preference for global responses should be reinforced by pattern consistency.

Method

Participants. A total of 224 right-handed Caucasian children (112 girls, 112 boys), between 3 and 9 years of age, participated in the experiment. They were divided into seven age groups of 32 children each, half female and half male (3-year-olds: M = 3.5 years, SD = 0.29; 4-year-olds: M = 4.6 years, SD = 0.27; 5-year-olds: M = 5.5 years, SD = 0.27; 6-year-olds: M = 6.6 years, SD = 0.3; 7-year-olds: M = 7.5 years, SD = 0.28; 8-year-olds: M = 8.4 years, SD = 0.29; 9-year-olds: M = 9.5 years, SD =

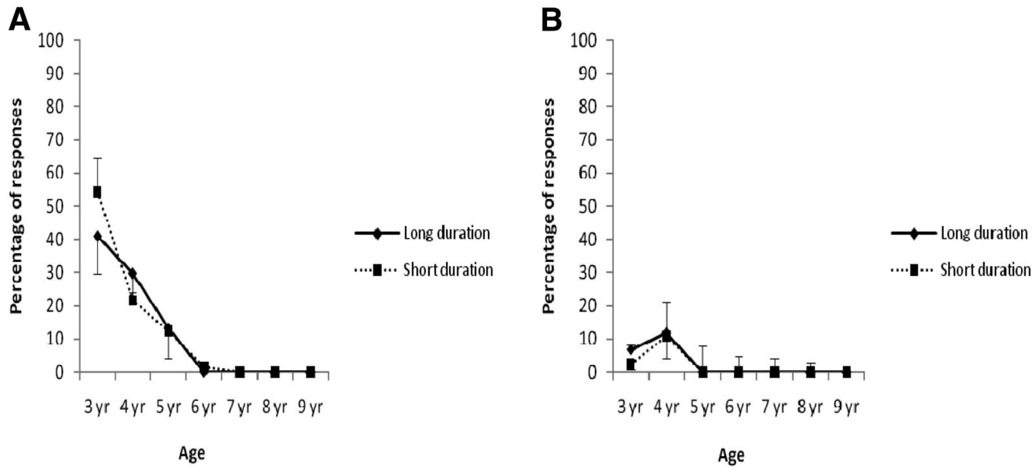

Figure 3. Experiment 1: Frequencies of local and global drawings as a function of age and target's duration (A: local responses; B: global responses). Bars indicate standard errors.

0.3). The criteria used to select the children were exactly the same as those described in Experiment 1. Participants in Experiment 2 were not in Experiment 1.

Material. As in Experiment 1, the stimuli were displayed as bitmap files and were presented on a 36-cm × 27-cm computer screen. Two targets were shown in the familiarization phase: a circle and a square (diameter/side's length: 4 cm), traced in a continuous line. The same stimuli traced in a dashed line, together with a cross and a star (same size, traced in a dashed line), were used for the responses' choices. When the circle (or square) was presented, for instance, a dashed circle (or square), a dashed square (or circle), the cross, and the star were the choices.

The four targets shown in test were exactly the same as those used in Experiment 1. The responses' choices included a square, a circle—both traced in a continuous line (height/width of 4 cm)—a set of seven small squares (3 mm), and a set of seven small circles (3 mm), traced in a continuous line and randomly arranged within a virtual 4-cm × 4-cm frame. Pilot testing showed that several local elements randomly displayed were a much more efficient stimulus than only two or three local elements. We used seven elements because we observed that young children drew on average seven elements in Experiment 1 when they produced local responses. The target appeared centered in the upper half of the screen, and the four responses appeared below the target, centered in the lower half. The location of the computer monitor was adjusted so that the viewing distance was at 60 cm, and the middle of the screen corresponded to the participant's body midline.

Procedure. During the initial phase children were familiarized to the material and the instructions. They were presented with a target stimulus (circle or square) and were asked to select, among four choices (see material), the stimulus that was the most similar to the target.[1] The experimenter told the participants to focus their attention to the screen because the target would appear for a very short time in some cases. This phase included four trials (circle or square, presented in the two durations), and it was repeated once when children selected the wrong choices. The target remained visible for 3 s or for 300 ms, followed by an 800-ms blank screen, which was followed by the four choices. Children used a mouse to select the stimulus they considered most similar to the target, with children who were unable to use the mouse using their index finger to indicate their choice. In this last case, the experimenter clicked on the choice that the child has pointed to. The participants were asked to keep their position constant throughout the experiment. The experimenter checked the participant's position before triggering the next trial. Most children 3 years of age and some of the 4-year-olds needed a repetition of the familiarization phase.

The instructions given in the test phase were identical to those in the familiarization phase. Four targets were shown in the test phase: Two were consistent stimuli (circle made of small circles or square made of small squares), and two were inconsistent stimuli (circle made of small squares or square made of small circles). They were displayed either for 3 s (long duration) or for 300 ms (short duration), and the four choices appeared after a blank screen of 800 ms and remained visible on the screen until the children selected one response. The experimenter waited for the participants' ready signal before triggering the next trial. Each target was presented twice at each duration. The targets as well as the durations were randomized across the 16 trials. Four choices were presented to the participants: a circle, a square, a set of small circles, and a set of small squares. One corresponded to a global response (e.g., choice for the square when a square made of circles or squares was shown), one was a local response (e.g., choice for the set of squares when a square made of squares or a circle made of squares was presented), one was an erroneous global response (e.g., selection of the circle when the square made of squares or circles was displayed), and one was an erroneous local response

[1] The exact instructions given to participants were *clique avec ta souris sur le dessin qui ressemble le plus au modèle que tu as vu* ("click with your mouse on the drawing that is the most similar to the model you have seen"). To the youngest children who had difficulties in understanding the verb *ressembler* and who did not use the mouse, we used an expression drawn from child-language and said *montre moi le dessin qui ressemble le plus au modèle que tu as vu, celui qui est le plus pareil* ("show me the drawing that is the most similar to the model you have seen, the one that is the most the same").

(e.g., choice for the set of circles in response to a square or a circle made of small squares). In the case of inconsistent targets, the erroneous global responses could reveal diffusion from the local to the global level, and the erroneous local responses could reveal diffusion from the global to the local level. They were simply false responses in the case of consistent targets. The location of the four responses was randomized.

Results and Discussion

Figure 4 depicts the frequencies of global, erroneous global, and erroneous local responses as a function of age and consistency, and of local responses as a function of age and duration.

The proportions of *global responses* (see Figure 4A) differed significantly across ages, $H(6, N = 224) = 62.3, p < .01$, with a rapid increase located between 3 and 5 years of age ($U = 268$, $n1 = n2 = 32, p < .01$). The consistent targets elicited more global responses ($M = 65.7\%$, $SD = 37.6$) than did the inconsistent ones ($M = 62.5\%$, $SD = 41.5$), $T(N = 224) = 1{,}214, p < .05$. It was only at 3 years of age that significant differences related to consistency were observed, $T(N = 32) = 20, p < .01$. No other differences were significant, whether duration or gender was concerned (all $ps > .20$). Figure 4B shows that the *local responses* decreased progressively with age, with the 3-year-olds selecting them in 46% of the cases and the oldest children selecting them in 16% of the cases. The differences between ages were significant, $H(6, N = 224) = 35.7, p < .01$. These responses were more frequent when the targets remained visible for long ($M = 35.5\%$, $SD = 41$) rather than short ($M = 24.2\%$, $SD = 34.1$) durations, $T(N = 224) = 1{,}127, p < .01$. This effect of duration was significant at all ages between 3 and 6 years of age (all $ps < .05$). There were no significant differences as regards to consistency or to gender (all $ps > .40$).

As shown by Figure 4C, the choice for *erroneous global responses* differed significantly between the age groups, $H(6, N = 224) = 56.8, p < .01$, being observed essentially at 3 years of age. These responses were also less frequent when the duration was long ($M = 3.7\%$, $SD = 11.9$) rather than short ($M = 6.5\%$, $SD = 13.6$), $T(N = 224) = 449, p < .01$. Finally, the choice for *erroneous local responses* also differed significantly along ages, $H(6, N = 224) = 45.9, p < .01$, decreasing

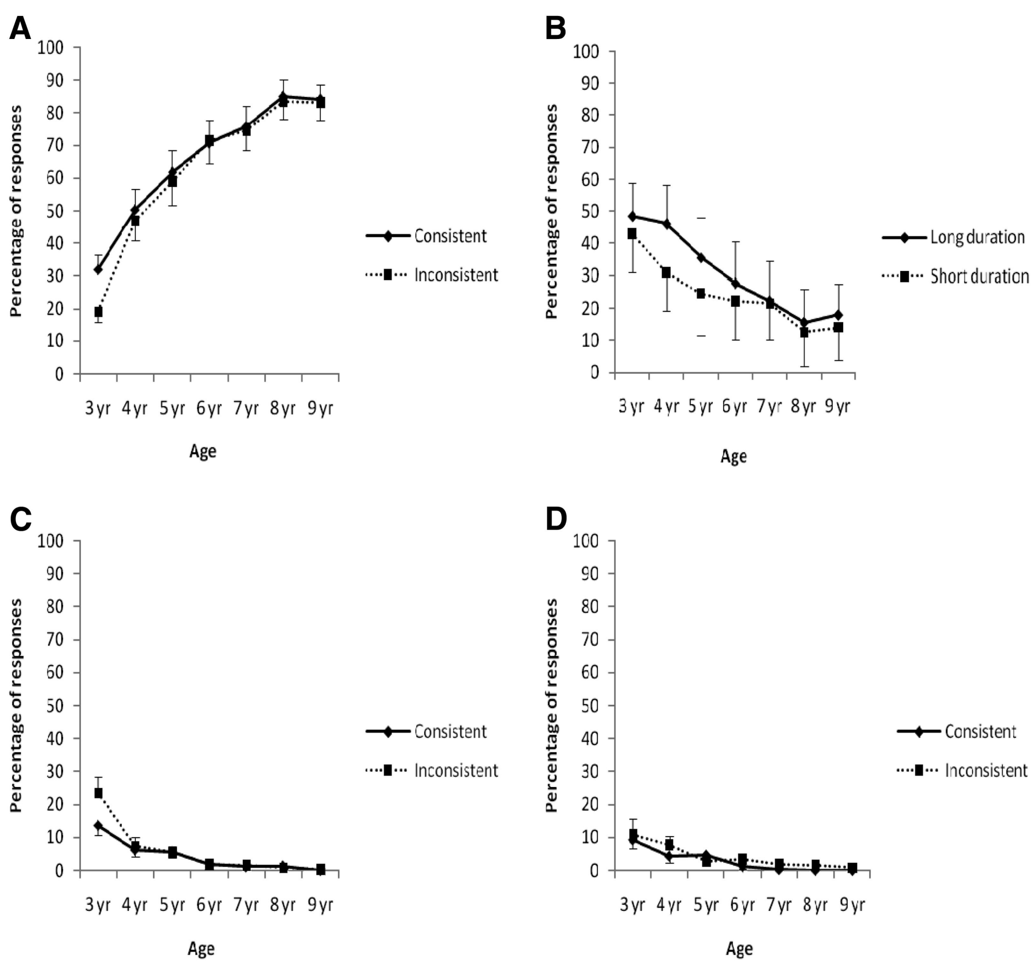

Figure 4. Experiment 2: Frequencies of responses as a function of age and target's consistency (A: global responses; C: erroneous global responses; D: erroneous local responses) or as a function of age and target's duration (B: local responses). Bars indicate standard errors.

progressively with age. On average, the inconsistent targets ($M = 4.2\%$, $SD = 8.7$) elicited more erroneous local responses than the consistent targets ($M = 2.8\%$, $SD = 8.6$), $T(N = 224) = 502$, $p < .05$, as well as the short durations ($M = 4.9\%$, $SD = 10.7$) in comparison with the long ones ($M = 2.1\%$, $SD = 7.6$), $T(N = 224) = 428$, $p < .01$. Again, we failed to find significant gender differences (all $ps > .10$).

The errors produced by the 3-year-olds are worth focusing. These children pointed significantly more often to the erroneous global responses for the inconsistent targets ($M = 23.4\%$, $SD = 27.2$) than for the consistent ones ($M = 13.6\%$, $SD = 16.6$), $T(N = 32) = 48$, $p < .05$. The occurrence of erroneous global responses for the inconsistent targets was also significantly higher than the frequency of the other error types, whether the erroneous local responses associated to the inconsistent patterns ($M = 10.9\%$, $SD = 12.2$), $T(N = 32) = 89$, $p < .05$, or whether the erroneous local responses associated to the consistent targets ($M = 9.3\%$, $SD = 15$), $T(N = 32) = 84$, $p < .05$, were concerned. Thus, the inconsistent targets provoked specifically the production of erroneous global responses in the 3-year-old children.

In summary, the results show that when children had to decide whether a compound figure bore more similarity with its global shape or with an arrangement made of its local elements, they tended to select more and more often the global shape and less and less often the local elements as age progressed. At 3 years of age, the local responses dominated over the global responses, $T(N = 32) = 152$, $p < .05$. At 4 years of age, no significant differences appeared between these responses, $T(N = 32) = 216$, $p > .30$, and at 5 years of age, the global responses were selected twice as often than the local responses, $T(N = 32) = 144$, $p < .05$. The choice for the global responses was facilitated by pattern consistency at 3 years of age. The local responses were more frequent when the targets remained visible for longer durations in the children less than 7 years of age. Erroneous responses were rare, except at 3 years of age. At this age, the erroneous global responses were largely the most frequent errors, and they occurred significantly more often with inconsistent figures. This result is important because it reveals a phenomenon of diffusion from the local to the global level. Finally, like in the drawing experiment, no significant gender differences emerged in the present experiment. This finding corroborates the results reported in a recent study in which no gender differences in perceptual processing biases were found (Scherf et al., 2009).

General Discussion

The aim of the present studies was to investigate the development of children's spatial analysis of hierarchical patterns in a constructional and a perceptual task. The similarity judgment task revealed at which age local or global preferences emerged, and the drawing task, with its additional requirements in planning and motor demands (van Sommers, 1989), showed to what extent children were able to integrate a global and local analysis of the patterns. Two main findings emerged from these experiments. First, there were clear qualitative changes in the course of development in the relationships between the global and local modes of processing. Second, children's performance was sensitive to both pattern's consistency and target's exposure time in the two tasks.

Qualitative Changes in the Relationships Between the Local and Global Modes of Processing

The results are congruent with regard to the type of processing that dominated at the youngest age. When the 3-year-olds were asked to draw the compound models, they reproduced only local elements in 50% of the cases. It was with approximately the same frequency that they selected the local responses in the similarity judgment task. These findings support the view that the local bias in drawing was not due to the constructional nature of the task (Porter & Coltheart, 2006), though evidence obtained with a within-subjects design would be still more convincing. They also confirm that local processing dominates the global one in young children (Dukette & Stiles, 1996; Kramer et al., 1996; Poirel et al., 2008). This could be related to differential rates of development between the left and right hemispheres (Molfese & Segalowitz, 1988), to reduced oculomotor exploration involving incomplete processing of visual scenes (Kowler & Martins, 1982; Poirel et al., 2008), or to attentional functioning in young children who put more attention to parts than to the whole (Tada & Stiles, 1996). The extent to which top-down processes, such as identification or naming processes (Poirel et al., 2008), were involved was not clear in our task, as young children might have a tendency to name the most numerous elements (thus, the local elements).

However, the drawing task showed that even at 3 years of age children were capable to attend to both levels of pattern organization, as shown by Dukette and Stiles (2001) in the 4-year-olds. In around 40% of the cases, the 3-year-old children produced drawings in which both levels were present, but these were either juxtaposed or superimposed or nested. Tada and Stiles (1996) reported similar results in the copying of compound figures. Likewise, Vinter and Marot (2007) mentioned that young children tended to copy stairs-like patterns (made of embedded rectangles) as a series of independent and juxtaposed rectangles. Thus, at 3 years of age, children were capable of perceiving both the local and global organization of compound patterns, but these modes of spatial information processing operated independently, as if they did not refer to a unique entity. If we assume that global processing tends to rely on the right hemisphere and local processing on the left hemisphere (e.g., Moses et al., 2002), this independent functioning may be a consequence of the still immature interhemispheric communication in the integration of visual information. It is indeed only at around 2 years of age that processing between the two hemispheres starts to be coordinated (Liegeois, Bentejac, & de Schonen, 2000). However, other accounts for the nonintegrated drawings can be proposed. They may denote the difficulties encountered by young children when they have to combine basic geometrical shapes in their drawings (Freeman, 1980). The nonintegrated drawings can also reveal the difficulties encountered by young children in the understanding of parts–whole relationships, as shown in drawing studies (Picard & Vinter, 2007; Tada & Stiles, 1996; Vinter, 1999; Vinter & Marot, 2007) or in cognitive tasks (e.g., Inhelder & Piaget, 1964).

Important changes occurred after 3 years of age. The nonintegrated responses dropped abruptly between 3 and 4 years of age, whereas the production of integrated responses, whether correct or inaccurate, increased significantly. Whereas the 3-year-olds either considered only one component of the target (the local one) or one component at a time (nonintegrated responses), the 4-year-olds started to process the two components together. A second developmental change occurred between 4 and 5–6 years of age. It was indeed from 5 to 6 years of age onwards that children produced correct integrated responses more frequently than local responses. The global bias in drawing, as reported by Lange-Küttner (2000), was not observed at all in our own drawing study. Children at this age clearly attended to both levels of organization, and they were able to successfully plan their drawing behavior, integrating accurately the two components. No further qualitative change occurred, but a progressive performance refinement was shown between 6 and 9 years of age. It is worth pointing out that this evolution with age is highly congruent with predictions that can be drawn from some of the neo-Piagetian theories[2] that claim that 3-year-olds can focus only a single dimension of a task, whereas 5-year-olds can focus on two (Case & Okamoto, 1996; Halford, 1993; Pascual-Leone & Johnson, 2005; see Morra, 2008, for a discussion of the implications of these theories for drawing behavior).

Congruent with this developmental sequence, the local bias shown in the perceptual task in the youngest children disappeared when both levels of organization started to be integrated. A global processing preference emerged at 5 years of age in this perceptual task. This evolution with age found in the similarity judgment task appeared in line with previous findings, though some divergences were worth pointing out. The local bias lasted until 5 years of age in Poirel et al.'s (2008) study, until 6 years of age in Kramer et al.'s (1996) study, and was obtained only under low elements density in Dukette and Stiles's (1996) study. It was obtained under normal elements' density conditions and disappeared between 4 and 5 years of age in our study. However, none of these studies used the same experimental conditions. Note that the global processing preference as measured by similarity judgments does not mean that children process the global shape first and then the local elements. Other types of tasks are needed to trace the time course of each process. Using appropriate tasks, Scherf et al. (2009) have indeed shown that it is only late into adolescence that evidence of global precedence can be found. This perceptual global bias means that children are more likely to base their similarity judgments between two patterns on their global shapes than on their local elements, these two levels of organization being perfectly attended to, as shown by the drawing task.

Sensitivity to Pattern Consistency and Target's Exposure Time

As could be expected, correct integrated drawings were facilitated by consistent patterns as well as the choice at young ages for global responses in the similarity judgment task. More important, the most frequent errors in the perceptual task were the erroneous global responses made by the 3-year-olds in the face of inconsistent patterns. Adults were shown to be subject to interference effects revealing diffusion from the global (dominant level) to the local level in the face of inconsistent patterns (Kimchi, 1988; Martin, 1979; Navon, 1977). Our results suggest that a similar but reversed effect occurred at 3 years of age: Children's errors revealed diffusion from the local (dominant level) to the global level. To our knowledge, this is the first time in the literature that this effect is reported in young children. It should be further investigated, adapting the methods used with adults to these young children. Interestingly, insofar as erroneous local responses to inconsistent targets revealed global to local diffusion, this effect emerged only on average across ages, congruent with the fact that on average, global processing dominated over local processing.

In the case of drawing, pattern consistency had an impact on the integrated responses, not on the local or global responses. The inconsistent patterns elicited an increase of inaccurate integrated drawings. If we assume that these patterns required more effortful processing, interference effects between local and global processing could be enhanced by these patterns, leading to less accurate reproduction of each level.

The results obtained from the manipulation of exposure times in the similarity judgment task are informative. The choice for local responses was more frequent with long than with short durations. In adults, Kimchi (1998) demonstrated that the global configuration of patterns made of many relatively small elements was primed at short exposures, whereas the local elements were primed at longer durations. The converse pattern of results was shown with configurations made of few, relatively large elements. She suggested that grouping many relatively small elements relies on rapid and effortless processes, whereas the individuation of many small elements would occur later and would be attention demanding (see also Kimchi et al., 2005). In line with this theory, long durations should make it possible to select local responses. This is exactly what we observed in Experiment 2 in the 3- to 6-year-olds, that is, until global processing preference was clearly established. Note that the higher production of local responses under long stimulus durations in comparison with short durations clearly argues against the oculomotor hypothesis evoked earlier (Kowler & Martins, 1982; Poirel et al., 2008).

In the drawing experiment, exposure times had only a marginally significant impact. Drawing local elements tended to be more frequent after short than long durations in the 3-year-olds. This effect was in opposition with the one obtained in the perceptual experiment, but it was only marginal, making its interpretation uncertain. Further studies investigating specifically the role of exposure times in drawing hierarchical patterns are needed to make this issue clearer.

In conclusion, these studies show that from 3 years of age, children are able to attend to both levels of pattern organization, but separately. They also revealed that the local level tended to dominate as long as the two levels were not coordinated, inducing a phenomenon of local-to-global interference. Then, global processing preference followed, when the coordination between the two levels has operated. However, these developmental trends appeared sensitive to contextual factors that tapped attentional processes, such as the consistency between the local and global levels in the hierarchical pattern or the time during which it is exposed. Future research could investigate how age and attentional control interact in the balance between local and global processing, using implicit and explicit memory or learning tasks.

[2] We thank very much an anonymous reviewer for the suggestion of this explanation.

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