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The Development of Context Sensitivity in Children's Graphic Copying Strategies

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The authors report on a series of 5 experiments in which 462 5- to 10-year-old children and 109 adults were required to copy geometric figures either with no constraints or following prior exposure to primes consisting of different parsings of the figures. The analysis focused on the graphic strategies adopted by the participants to copy the models. Three developmental steps were revealed in the baseline copying condition. Priming experiments demonstrated that the age-developmental step correspondence varied as a function of the type of prime used. However, the impact of priming differed according to age. It was limited at 6 years, whereas its size was noticeable at the other ages. These results are discussed in the light of developmental models that hypothesize a major role either for endogeneous factors in cognitive development or for exogeneous and contextual factors.

Keywords: development, graphic strategies, priming, drawing

Where do developmental changes come from? This essential question for developmental theorists has received a variety of answers, all of which can be located between two contrasting positions. The first position, best illustrated by the Piagetian or neo-Piagetian approaches, claims that developmental changes find their origin within the internal cognitive organization (creation of new schemes, mental operations, or representations) through continuous interactions with the environment (e.g., Case, 1985; Morra, 2005; Mounoud, 1988; Piaget, 1952). Notions such as those of stages or steps are relevant within this perspective, and the relationship between the age variable and developmental changes has to be defined. The second position argues that developmental changes are the product of context-dependent dynamic interactions acting at multiple levels (Thelen & Smith, 1994). Variability is the most important notion within this framework, and within certain limits, no fixed-age developmental changes can be expected because of a constant sensitivity to context. These two positions can be contrasted along a dimension conferring a major role on either endogeneous or exogeneous factors in main developmental changes. Somewhere between them, closer to the first position than to the second position, lies the representational redescription model (Karmiloff-Smith, 1992). In this model, the author proposes that developmental changes are, to some extent, caused by endogeneous factors; however, they do not affect the whole system simultaneously but rather by domain, and they are open to contextual influences except at the second phase described by the model, in which the cognitive system closes on itself. Thus, relations between age and developmental steps may be defined domain by domain, and deviations may appear more easily at certain phases than at others. The overlapping waves theory formulated by Siegler (1996) also can be located somewhere between the two previously mentioned positions, not far from the second one. Siegler's theory suggests that the age–developmental changes relationship does not lead to characterizing steps but to revealing changes in the quantitative use of different strategies during development. At each age, children are characterized by a diversity of modes of thought, and their choice of one or the other of these modes in a given context is a function of a combination of multiple factors that make one more adaptive than another. Although Siegler (1996) developed the overlapping waves metaphor to account for intraindividual variability under repeated testings (microgenetic studies), he himself applied it also to interindividual differences as they occurred across ages (e.g., Siegler, 1987, 1996). In the present article, we confront some of these theoretical views with regard to the development of graphic strategies in children and adults. The first experiment establishes how strategies evolve with age when participants have to copy seriated geometric models. In the following four experiments, we manipulated context by using a kind of priming procedure during which participants are asked to copy specific parsings of the models. The exposure to these parsings should enhance specific strategies for the copying of the entire models if the age–graphic strategies relation is sensitive to context, as predicted by the dynamic and Siegler models. However, if some endogenous constraints operate at certain periods in such a way that the cognitive system becomes closed to external influences, as argued by the Karmiloff-Smith model, the impact of contextual manipulation should differ as a function of age.

Graphic Strategies Used for Copying Seriated Patterns

In a clever series of experiments, Van Sommers (1984) explored the relations between the perceptual, cognitive, and motor processes involved in the act of drawing. This author demonstrated that the way in which adults proceed in constructing a drawing reflects their conceptualization of the depicted pattern. This influ-

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ence of conceptualization on the drawing syntax has been confirmed in children (Tada & Stiles, 1996; Vinter, 1999). In the case of drawing a pattern made of rectangles arranged in the form of ascending or descending stairs (see Figure 1), Van Sommers (1984) showed that the main graphic strategies used by adults resulted from the combination of executive constraints (reducing the "cost" by avoiding pen lifts, for instance) and perceptual forces that emerge from the global configurational organization of the figure. Some of these strategies (see Figure 2 for illustrations) involved building the drawing region by region, starting with the largest rectangle and attaching smaller three-sided rectangles or starting with the smallest rectangle and embedding one side of each into a larger rectangle. In two other strategies, the pattern is processed partly or wholly as a single unit enclosed in a frame, with the shared boundaries represented as added internal segments. We suggest that the first type of strategy reflects a conception of the pattern as composed of *N* rectangles that are assembled and seriated (analytic approach first, followed by holistic approach), whereas the second type of strategy involves a conscious focus on the entire configuration, which is then decomposed into parts (holistic approach first, then coordinated to an analytic approach).

The study of the copying of these seriated patterns is most interesting in children, because this task should elicit a wide variety of strategies. It should be made clear that we used this specific copying task as a kind of marker for the study of cognitive development, similar to several other tasks that have been used (for instance, the tower of Hanoi, the balance scale, and number-conservation tasks), because they can be clearly defined and easily replicated. Of course, this Van Sommers (1984) drawing task is not the kind of everyday drawing task in which young children

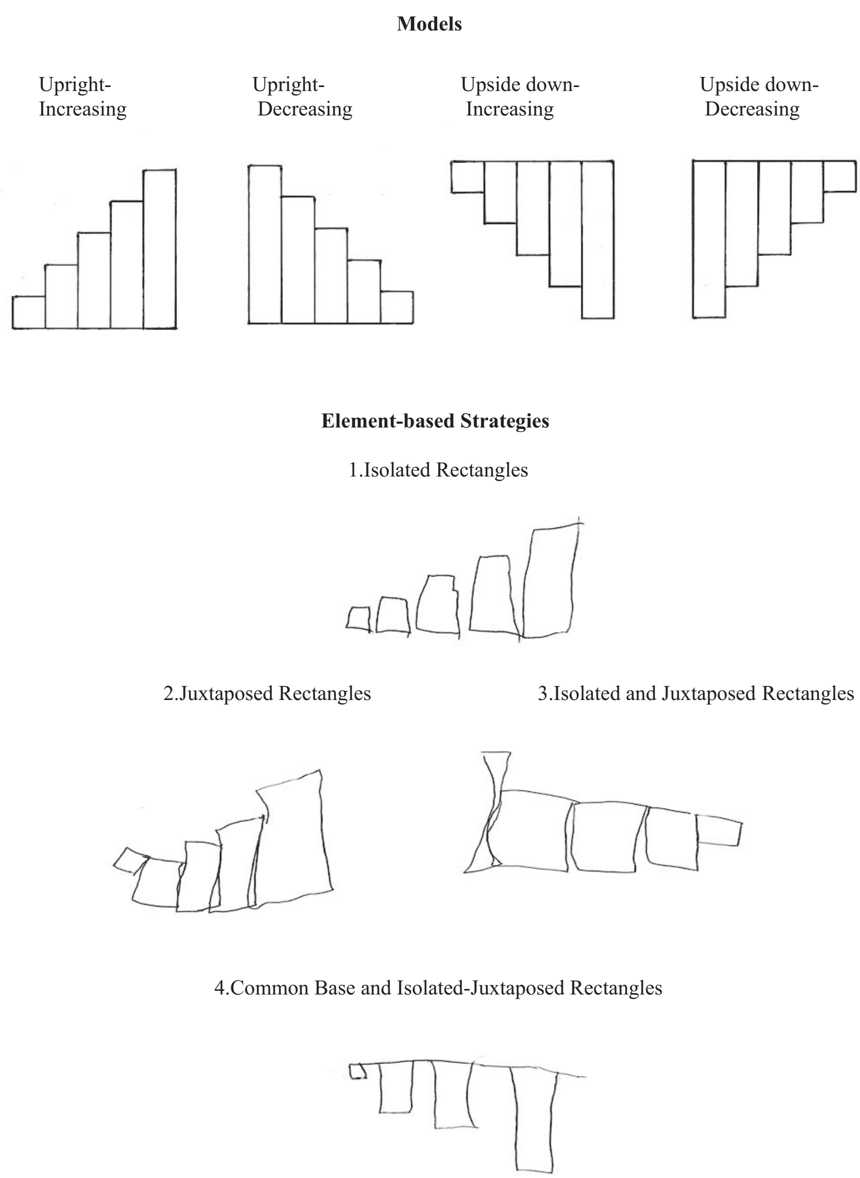

Figure 1. Illustration of the seriated models and of the element-based strategies.

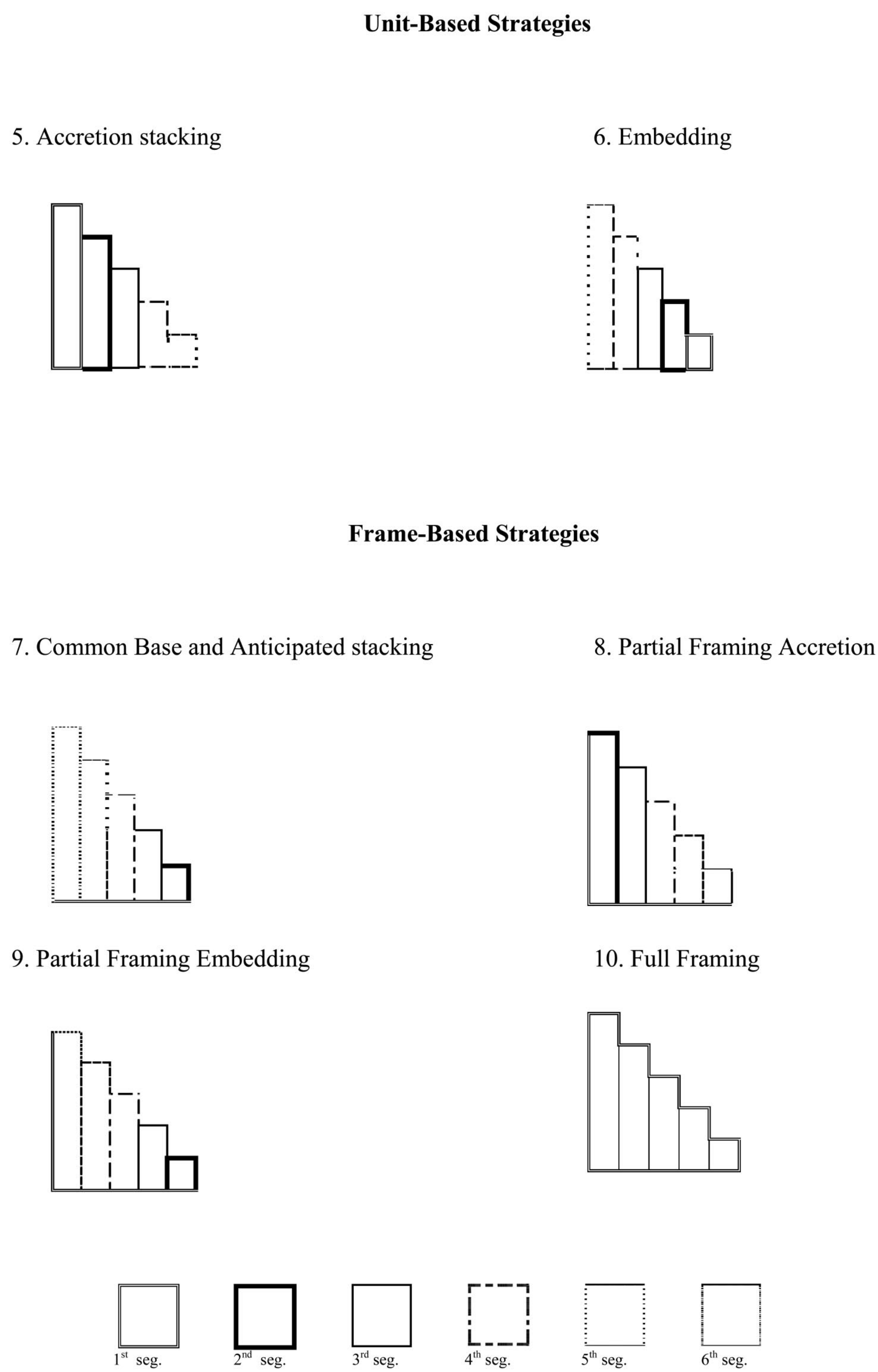

Figure 2. Illustration of the building of the unit-based and frame-based strategies.

typically engage, and consequently, our study tells more about cognitive development than about drawing development, per se. Indeed, the opposition that we just pointed out between holistic and analytic processing is a classical observation in developmental psychology, although some confusion is apparent. For some authors (e.g., Kemler Nelson, 1984, 1989), development proceeds from the holistic to the analytic mode of processing; others believe that it acts in the opposite direction (e.g., Carey & Diamond, 1977; Young & Deregowski, 1982), whereas for others again, the opposition is to be highly sensitive to contextual factors (e.g., Sugimura

& Inoue, 1988; Tada & Stiles, 1996; Tada & Stiles-Davies, 1989). Stiles and colleagues (e.g., Akshoomoff & Stiles, 1995a, 1995b; Dukette & Stiles, 1996) showed that young children are capable of attending to local and global information, but, when asked to copy spatial patterns, they tend to parse out simpler and more independent parts and to use simpler relations than do older children. Using a Navon figure-copying task (Navon, 1977), Lange-Küttner (2000) revealed that local processing largely dominates at 5 years of age, whereas an integration of local and global information is apparent at 11 years of age. A globally similar conclusion emerged from an interesting analysis proposed by Lange-Küttner, Kerzmann, and Heckhausen (2002) for the "draw-a-person" task, in which the use of contour line is construed as revealing whole integration and the production of specific shapes for representing body parts is considered as indicating the differentiation of parts. Part–whole integration does not appear to be predominant until 9–10 years of age, although better performances were produced with increased task constraints (e.g., "Draw a person with a swimsuit.").

More precise expectations can be derived from Lange-Küttner's (1997, 2004) work on the development of pictorial spatial–axis systems. Lange-Küttner showed that young children draw single pictorial patterns within a graphic space conceptualized as containing implicit spatial relationships among objects, with objects juxtaposed with respect to one another or dispersed in this aggregate space (Lange-Küttner, 2004). Considering that young children also process predominantly local information, we would expect to observe specific graphic strategies in young children, not described by Van Sommers (1984), in which rectangles (local information) are juxtaposed in a simple manner, one with respect to the other (aggregate pictorial space). Then, an axial space develops between 7 and 11 years of age, in which explicit spatial relationships are introduced within the pictorial space. Lange-Küttner (1997, 2004) showed that these relations defined first a horizontal-axes system (i.e., top and bottom references); then an orthogonal-axes system (i.e., "bird's-eye view"); and, finally, a diagonal-axes system (i.e., viewpoint perspective with convergence). As whole and part–whole relationship processing also progresses during this period, we can expect strategies involving region-by-region building of the whole pattern and ensuring base alignment of the rectangles (horizontal-axes system) followed by strategies decomposing the whole pattern according to an orthogonal-axes system. Consequently, analyzing how children and adults proceed for the copying of these seriated patterns appears a suitable empirical way of testing the age–graphic strategies relationship. However, this relationship could be highly sensitive to context, a point tackled through four priming experiments.

Contextual, Training, and Priming Efects

Contextual effects of different kinds have been widely demonstrated in drawing behavior. Based on the drawing stages first described by Luquet (1927), various researchers have studied the importance of contextual effects in the progression from the *intellectual realism stage* at which children (5–8 years of age) draw what they know and the *visual realism stage* at which children draw what they see (8–9 years of age; Barrett, Beaumont, & Jennett, 1985; Cox, 1992; Davies, 1983; Nicholls & Kennedy, 1992; Sutton & Rose, 1998). This body of research has shown that modifying the familiarity or complexity of the model, the verbal instructions, or the episodic information provided to children before they draw elicits a high level of variability. Similarly, in the development of drawing syntax (Goodnow & Levine, 1973), adherence to the graphic rules can be elicited more or less easily in participants at various ages through an appropriate manipulation of the figural properties (e.g., number and length of the segments) and of the type of task (e.g., free or copying or memory task; Baldy & Chatillon, 1994; Thomassen & Tibosh, 1991; Vinter, 1994). The experiments conducted in the wake of those initiated by Karmiloff-Smith (1990, 1992) also lead to contrasting conclusions with regard to the stability of the relation between age and developmental step. Karmiloff-Smith (1990) studied the development of graphic routines for drawing familiar objects as if those familiar objects "did not exist." Children younger than 8 years of age demonstrated a flexibility limited to the intrarepresentational level (working on elements coming from the same category). Older children produced more elaborate innovations, such as inserting elements coming from different conceptual categories (e.g., adding wings to a house). However, in further experiments, researchers revealed that procedural and representational flexibility may be more important in young children than was initially supposed (Barlow, Jolley, White, & Galbraith, 2003; Berti & Freeman, 1997; Picard & Vinter, 1999; Vinter & Picard, 1996; Zhi, Thomas, & Robinson, 1997). Spensley and Taylor (1999) have even claimed that young children are able to produce any type of innovation, if explicitly requested to do so. Barlow et al. (2003) reported clear effects of object's familiarity on procedural flexibility.

Training and priming effects also have been demonstrated on drawing behavior. Phillips, Inhall, and Lauder (1985) assessed the effects of different kinds of training on the ability to draw a cube or a pyramid. Some of these training regimes had long and lasting effects; others did not. What seemed to matter was the nature of the description of the patterns made apparent during training. However, these effects were specific to the particular task and were not transferable. An improvement in children's performance in cube drawing was equally observed following a previous task in which the children had to copy line diagrams of cubes (Bremner, Morse, Hughes, & Andreasen, 2000). A deterioration in performance can also result from prior experience. For instance, prior visual inspection and prior naming of the model to be drawn have been shown to enhance the production of object-specific drawings in young children (Bremner & Moore, 1984; Lewis, Russell, & Berridge, 1993). Outside the drawing research domain, Schyns and Rodet (1997) carried out a well-designed series of experiments (see also Schyns, Goldstone, & Thibaut, 1998; Schyns & Murphy, 1994) demonstrating that the immediate appearance of patterns can be modified by prior experience and, particularly, by a participant's personal history in terms of the way the patterns or parts of the patterns are categorized. Experience with objects can change the features involved in the input analysis. Thus, the way a pattern is parsed is not rigidly fixed but depends on the participant's prior experience. In four priming experiments, we tested whether children and adults exposed to specific parses of the seriated patterns would be subsequently inclined to resort to graphic strategies directly suggested by the primes.

Experiment 1: Figure Copying and Graphic Strategies

The copying of seriated models can reveal how children conceive of complex entities that present both a salient overall structure (e.g., stairs) and a familiar local structure (e.g., rectangles). In view of the literature, we expected the 5-year-old children to produce graphic strategies that testify to elementary representations of the models as a set of juxtaposed or independent rectangles, presenting a loose and aggregate spatial organization. Considering the developing ability to master whole–part relationships and explicit spatial relationships, we might expect from older children graphic strategies that construe models as single decomposable entities. In the experiment, we used four different orientations of the pattern to elicit variations in the strategies. Van Sommers (1984) reported that adults modified their strategies when copying ascending or descending forms, keeping constant a global left-to-right progression in the drawing of the figure. If such a bias is important to account for at least part of strategy variability, we can expect it to be less important at 5–6 years than later because these children are newly engaged in handwriting learning.

Method

Participants. One hundred right-handed children (55 girls and 45 boys), aged between 5 and 10 years, participated in the experiment. They were divided into four age groups (Group 1: $M = 5.2$ years of age, $n = 24$, 14 girls and 10 boys, range = 4 years, 11 months to 5 years, 9 months; Group 2: $M = 6.3$ years of age, $n = 26$, 16 girls and 10 boys, range = 6 years to 6 years, 8 months; Group 3: $M = 8.4$ years of age, $n = 26$, 13 girls and 13 boys, range = 8 years to 8 years, 11 months; Group 4: $M = 10.3$ years of age, $n = 24$, 12 girls and 12 boys, range = 10 years to 10 years, 11 months). None of these children were educationally advanced or retarded or had psychomotor deficits in drawing or handwriting. Their vision was normal or corrected to normal. Children were essentially from middle socioeconomic status (SES) families. Forty-seven percent of the children were firstborn, 39% were second born, and 14% were third born or later. They were observed individually in a quiet room inside their schools. Each age group corresponded to one school level, the youngest children coming from the last kindergarten grade. A group of 24 young right-handed adults (16 women and 8 men) was also studied ($M = 20.6$ years of age, range = 18–27 years of age). These participants were volunteer students at the university, and they received course credits in exchange for their participation in the experiment. No further information regarding participants' characteristics was available.

Materials. Four models, borrowed from Van Sommers' study (1984), were individually printed in black ink at the center of small white cards (12 cm × 12 cm). Each model was composed of five vertical rectangles of different lengths (1, 2, 3, 4 and 5 cm) and of 1 cm breadth. The five rectangles were grouped to form an increasing or decreasing sequence of lengths, presented upright or upside down. The models are represented in Figure 1. The participants had to reproduce the models on small sheets of white paper (A5 format), one model per sheet. Seven other geometrical figures representing simple and nonmeaningful combinations of verticals and horizontals (kinds of mazes) were added as distractors and were presented in the same way as the target drawings. Four of them were presented before the copying task. The remaining three items were systematically introduced between two targets in order to reduce a conservative tendency shown in adults to keep their way of drawing a model constant across successive repetitions (Van Sommers, 1984).

Procedure. The participants were informed that they would copy a series of geometrical models. When they were ready, the experimenter showed them a model and explained that they were expected to reproduce it as accurately as possible on their response sheets. The instructions focused only on accuracy. Given the difficulties in making clear to young children the meaning of "accurately" it is worth specifying how the instructions were given: "You have to do the same drawing, exactly the same, and exactly as nice as it is here on my sheet of paper. It has to be identical. So look carefully, and draw the same thing on your sheet of paper." The model was located in front of the participant, who was free to place the response sheet in any position below the model. When the participant had finished, the experimenter removed the model and the response sheet before proceeding to the next item. No feedback was given to the participants about their performance. The four target models were intermixed with three distractors, and the order of presentation of the two kinds of models was randomized across the participants. The task always began with the copying of four distractors (the following experiments began with the copying of four primes). While the participant made the copy, a second experimenter coded the entire movement sequence used by the participant online, recording starting locations, movement direction, and order of strokes. The experimental session also was videotaped, and the online codings made by the second experimenter were checked and, if necessary, corrected offline. The data analysis was based on the revised codings. The movement sequences for the distractors were not checked and were not included in the data analysis.

Results

Coding of the graphic strategies. We made a complete inventory of the different graphic strategies used by the participants when copying each model. Six of the strategies (numbered 5 to 10) corresponded to the list established by Van Sommers (1984). The remaining strategies (numbered 1 to 4) were new. They are detailed in the subsequent paragraph. Rarely, the participants used a combination of some of these strategies. We coded only the predominant strategy for each participant. Rarely, too, the coding was made impossible because of global errors or because of the use of a segment-by-segment drawing strategy. Computed on the entire data set, the interjudge agreement was 93.35%, and the Kappa coefficient for interrater reliability was .95, $p < .01$.

The first four strategies, illustrated in Figure 1, share the fact that they involve a representation of the model as a series of individual rectangles, sharing a more or less loosely defined relation in terms of length. They can be considered *element-based strategies*. Strategy 1, Isolated Rectangles, involves drawing a series of isolated rectangles without any attempt to group them, or some of them, together. Strategy 2, Juxtaposed Rectangles, involves drawing a series of rectangles placed side by side and retracing over an already present side of a rectangle when drawing the next one. Strategy 3, Isolated and Juxtaposed Rectangles, involves drawing a series of rectangles, some juxtaposed with others and some isolated. Strategy 4, Isolated or Juxtaposed Rectangles, involves sharing a common base: drawing the base of the figure first and then tracing the rectangles of the series (the three remaining sides) in isolation or in juxtaposition, and less usually, drawing the base after the rectangles.

In the next two strategies, illustrated in Figure 2, the model is correctly represented as a unique or whole pattern made up of a series of rectangles sharing one side, and the drawing is constructed by taking the rectangle located at the extremity of the series as a unit block. These can be seen as *unit-based strategies.* Strategy 5, Accretion Stacking, involves drawing the largest unit (rectangle) of the series intact first and accreting the next (a three-sided rectangle) to it. Strategy 6, Embedding, involves drawing the smallest unit of the series intact first and then drawing the next in such a way that the smaller intact unit is embedded in the broken boundary of the larger.

The final four strategies (see Figure 2) involve drawing the frame of the model, either totally or partially, thus leading to a decomposition of the model into parts. All these strategies share the fact of being either *frame based* or *part–whole based*. Strategy 7, Common Base and Anticipated Stacking, consists of drawing the base of the model then drawing the smallest unit while anticipating the omission of a side in such a way that the next unit is stacked onto it. Strategy 8, Partial Framing and Accretion, and Strategy 9, Partial Framing and Embedding, involve drawing the side and the base of the model first as a partial frame and then using either an Accretion or Embedding strategy. Another possibility is that the base only of the model is drawn first, and an Accretion (Base and Accretion) or Embedding (Base and Embedding) strategy follows. Strategy 10, Full Framing, involves drawing the full frame first and then inserting the divisions. The drawings also were coded for errors of copying (e.g., errors of symmetry, errors in respect to the seriation, errors in the number of rectangles). These data are not discussed here due to space limitations. The developmental course of each strategy was similar within a category, and there was no effect of Model Order on the use of the categories of strategy (Marot, 2004).

Statistical analyses. We counted how many participants used each category of strategy (element-based, unit-based, frame-based) across the four models that they had to copy. These numbers did not differ significantly as a function of the model, whatever the category (20–30 participants for the element-based category, 66–76 participants for the unit-based category, 21–29 participants for the frame-based category, $\chi^2_3 < 7.8$, $p_s > .05$). A score varying between 0 and 4 was then attributed to participants in each category according to the number of times that they applied the category across the four models. A multivariate analysis of variance (MANOVA) was conducted on these scores with Age (5 years) as a between-subjects factor. Figure 3 (top panel, Baseline exp.) depicts the results for the present experiment as a function of age.

Age was significant whatever the category considered. The mean score of element-based strategies was high at 5 years of age (M = 2.71) and very small at 8 years of age (M = 0.23), $F(4, 119) = 26.2$, $p < .01$. Post hoc comparisons showed that the decrease between 5 and 6 years of age and the decrease between 6 and 8 years of age was significant (Scheffé test, $p_s < .01$). The unit-based strategies exhibited a bell-shaped development, with a highly significant increase in occurrence between 5 years of age (M = 1.29) and 8 years of age (M = 3.27), followed by a significant drop between 10 years of age (M = 3.08) and adulthood (M = 1.21), $F(4, 119) = 9.1$, $p < .01$. Finally, the frame-based strategies were absent at 5 years of age, were sometimes produced at 10 years of age (M = 0.92), and increased dramatically in the adults who used them in more than half of their production (M = 2.79), $F(4, 119) = 19.1$, $p < .01$.

To examine the variability associated with these categories, we counted how many participants adhered to only one of the categories across the four models, how many participants adhered to a combination of two categories, and how many participants adhered to the three categories. Table 1 displays the results for all experiments.

In the present base experiment, 92 of 124 participants (74.2%) were classified in only one category, attesting to a large intraindividual homogeneity in terms of categories. The unit-based category was the most common, accounting for 44.3% of the participants. However, this distribution was dependent on age, with 58.3% of the youngest children belonging only to the element-based category, 60.5% of the 6- to 10-year-olds belonging only to the unit-based category, and 54.2% of the adults belonging only to the frame-based category. None of the participants produced strategies that could be assigned to the three different categories or to both extreme categories (element- and frame-based together). The 5- and 6-year-olds (13 of 50) showed strategies pertaining to both the element- and the unit-based categories more often than did the older participants (2 of 74), $\chi^2(1, N = 124) = 15.2$, $p < .01$, whereas these older participants produced strategies belonging to both the unit- and frame-based categories more often (16 of 74) than did the younger participants (1 of 50), $\chi^2(1, N = 124) = 9.7$, $p < .01$.

The number of strategies used by participants independent of the category to which it referred was analyzed (see the list of strategies presented previously). An analysis of variance (ANOVA) was run with Age (5 years) as a between-subjects factor. Figure 4 depicts the results for the different experiments. In the present base experiment, there was a significant increase in the number of strategies used between 5 and 6 years of age, $F(4, 119) = 2.9$, $p < .05$. The adults displayed the largest number of strategies.

Finally, if the orientation of the model did not affect participants' behavior when the categories of strategy were considered, it might nonetheless have an impact at the level of the single strategies used. Indeed, the changes of graphic strategy were a function of the model's orientation in children aged 8–10 years and in adults. Among the participants who introduced variations in their strategies, 43 of 65 systematically copied the increasing models with a strategy involving the Embedding procedure (see Figure 2, Embedding, Partial Framing Accretion, or Partial Framing Embedding), whereas they consistently copied the decreasing models with a strategy involving the Accretion procedure. In contrast, only 7 of 32 children aged 5 or 6 years performed in the same systematic way, $\chi^2(1, N = 97) = 16.8$, $p < .01$. This was the only model effect shown in the results.

Discussion

In this first experiment, we focused on the relationship between age and developmental changes by analyzing the evolution of graphic strategies. Three successive steps appeared. The first one was typical in the 5-year-old children who predominantly used element-based strategies, which share the characteristic of involving a representation of the model as a series of individual rectangles, with a more or less loosely defined length relation. The resulting product was an incorrect reproduction of the model. These strategies show that the local organization (rectangles) dominated over the overall structure, although the latter was not ignored, as most productions of the young children (around 67%) respected the seriated structure of the patterns. These results echo those obtained in studies revealing that although local processing dominates in young children, the children are also able to integrate some global features into their drawings (e.g., Akshoomoff & Stiles, 1995a; Dukette & Stiles, 1996; Lange-Küttner, 2000). The

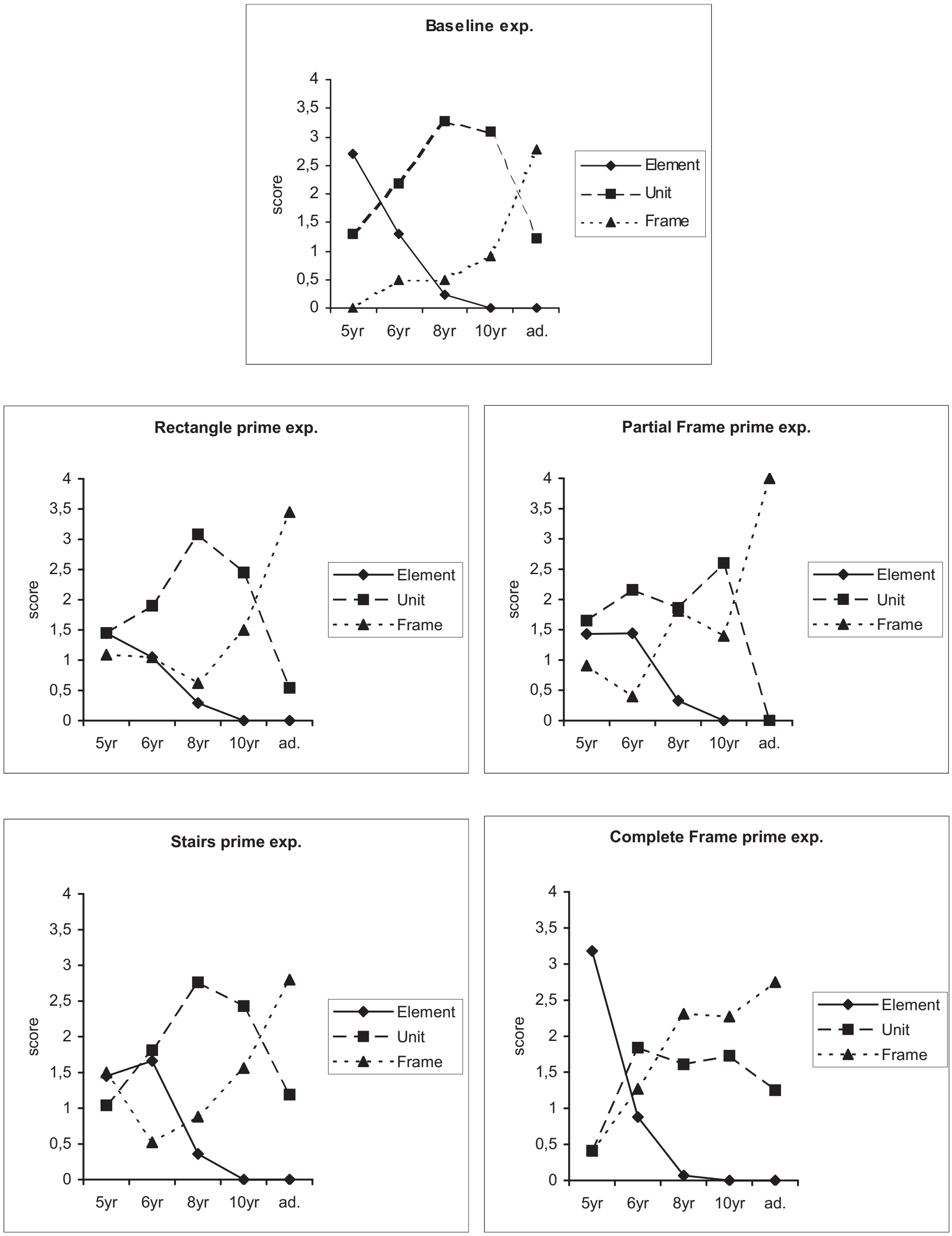

Figure 3. Mean scores of element-based, unit-based, and frame-based strategies as a function of age in the Baseline experiment (top panel) and in the priming experiments (Rectangle prime experiment, top left; Partial frame prime experiment, top right; Stairs prime experiment, bottom left; Complete frame prime experiment, bottom right). exp. = experiment. yr = year; ad = adult.

rectangles were simply juxtaposed in the pictorial space, thereby conceptualizing this space as an aggregate space (Lange-Küttner, 1997, 2004).

The age of 6 years marked a transition, and a second step corresponded to the graphic production of the 8- and 10-year-olds. The strategies typical of this unit-based step showed that the model was appropriately conceived of as a series of rectangles aligned on a base, sharing one side and displaying a length seriation. The pattern is represented as a whole entity, projected into a pictorial space organized along horizontal axes (Lange-Küttner, 1997).

Table 1
Percentage of Participants, by Experiment and Age, Adhering to Only One Category of Strategies or Adhering to a Combination of the Categories

Age (years)	Element-based only	Unit-based only	Frame-based only	Element-/unit-based	Element-/frame-based	Unit-/frame-based	Adherence to the three categories
Baseline experiment							
5	58.3	16.7	0.0	25.0	0.0	0.0	0.0
6	15.4	46.1	7.7	26.9	0.0	3.8	0.0
8	0.0	69.2	3.8	7.7	0.0	19.2	0.0
10	0.0	66.7	12.5	0.0	0.0	20.8	0.0
Adult	0.0	20.8	54.2	0.0	0.0	25.0	0.0
Rectangle prime experiment							
5	18.2	27.3	13.6	13.6	22.8	4.5	0.0
6	10.0	20.0	20.0	35.0	5.0	5.0	5.0
8	4.2	75.0	12.5	4.2	0.0	4.2	0.0
10	0.0	55.0	30.0	0.0	0.0	15.0	0.0
Adult	0.0	4.5	72.7	0.0	0.0	22.7	0.0
Partial frame prime experiment							
5	21.7	34.8	13.0	13.0	13.0	4.3	0.0
6	0.0	20.0	4.0	60.0	0.0	12.0	4.0
8	0.0	33.3	38.1	14.3	4.8	9.5	0.0
10	0.0	45.0	25.0	0.0	0.0	30.0	0.0
Adult	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Stairs prime experiment							
5	18.2	18.2	27.3	13.6	18.2	0.0	4.5
6	19.0	19.0	4.8	33.3	9.5	9.5	4.8
8	4.0	44.0	8.0	12.0	4.0	28.0	0.0
10	0.0	52.2	34.8	0.0	0.0	13.0	0.0
Adult	0.0	0.0	47.6	0.0	0.0	52.4	0.0
Complete frame prime experiment							
5	72.7	4.5	0.0	4.5	4.5	4.5	9.1
6	11.5	26.9	19.2	15.4	3.8	7.7	15.4
8	0.0	26.9	46.1	7.7	0.0	19.2	0.0
10	0.0	27.3	45.4	0.0	0.0	27.3	0.0
Adult	0.0	20.0	55.0	0.0	0.0	25.0	0.0

However, in these strategies, the participants remained quite rigidly centered on the basic unit that constitutes the pattern, that is, the rectangle. A third step was identified in the adults, who mainly reproduced the models on the basis of frame-based strategies. A decomposition of the model into parts is involved in these strategies, which share the characteristic of processing the model, either partially or totally, as a single entity enclosed in a frame, with the common boundaries represented as added internal segments. The ways in which the parts are arranged indicate the management of parts–whole relationships as well as an organization of the pictorial space according to an orthogonal axes system. This step was still emerging at around 10 years of age in our experiment. Thus, the developmental process may be summarized as a movement from processing elements to processing chunks of elements that form global units and then to processing wholes and parts. In the meantime, as revealed by Lange-Küttner (1997, 2004), the pictorial space seems to evolve from an aggregate space to an explicit space structured first by horizontal axes and then by orthogonal

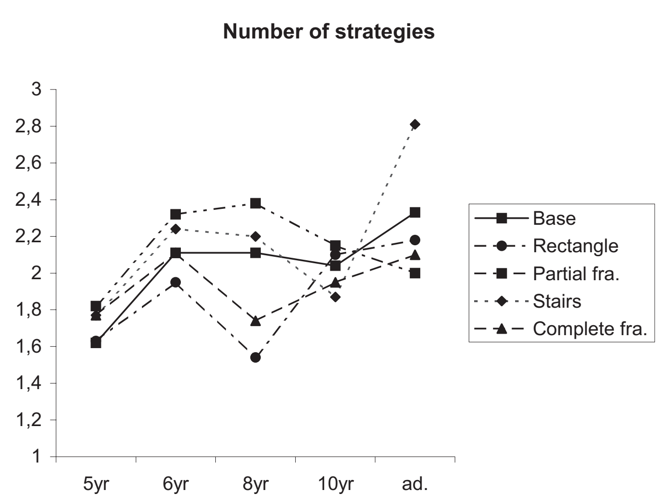

Figure 4. Mean number of strategies used as a function of age and experiments. fra. = frame; yr = year; ad = adult.

axes. Very similar evolutions have been revealed in other drawing studies (Akshoomoff & Stiles, 1995a; Lange-Küttner, 2000; Picard & Vinter, 1999; Tada & Stiles, 1996; Vinter & Picard, 1996).

These results can be interpreted to provide support for stagelike developmental approaches. The overlap between the three developmental steps is minimal, and the association of one step with a specified age period is quite clear. The element-based strategies are nonexistent in children at 10 years of age and in adults; 5-year-old children do not produce the part–whole-based strategies. However, Siegler's (1996) overlapping waves theory also finds some clear support in our data. No category of strategy appeared to be suddenly replaced by another; on the contrary, they overlapped. Each age was characterized by the use of two categories of strategy. The number of strategies increased with age, and their use related partially to the model's structure in the older participants, who changed more systematically of strategy according to its increasing or decreasing structure than did the younger participants. These results are in line with the Siegler (1996) perspective, showing that strategies become better tuned to the model's properties with time.

For a better insight into the age–developmental step relation, it appears crucial that researchers test its stability through appropriate contextual manipulation. The type of contextual manipulation in which we were interested was related to the possibility of enhancing or inhibiting the use of the observed strategies. If this use reflects how the model is parsed into units, a priming procedure—during which participants are asked to copy specific parsings of the models—may be appropriate for enhancement of later specific strategies. In the following four experiments, we investigated whether children and adults exposed to specific parses of the seriated models (e.g., the frame or the stairs) would be inclined subsequently to resort to graphic strategies that testify to the integration of these parses into their conceptualization of the patterns. In agreement with Wohlwill's (1970, 1973) suggestion that genuine developmental changes are those that occur whatever the conditions of experience, no significant impact of the priming procedure can be expected from stagelike developmental theories. However, following the Karmiloff-Smith (1992) model, this impact should be age dependent.

Experiment 2: Priming With the Rectangle-Accreted Parse

The prime used in the second experiment, a rectangle to which an open rectangle was attached, was expected to enhance unit-based strategies because it corresponds exactly to the beginning of a unit-based strategy, namely the Accretion Stacking strategy (see Figure 2). If open to contextual influences, young children should abandon the element-based strategies for unit-based strategies, which belong to their repertoire as revealed by the previous experiment. The behavior of the older children should not be affected greatly by the exposure to this prime because they already make considerable use of unit-based strategies. It should not affect the adults' behavior either, if adults have stabilized their behavior around the best compromise with respect to all the possibly contradictory forces acting on graphic syntax.

Method

Participants. Eighty-six right-handed children (45 boys and 41 girls) between 5 and 10 years of age participated in the experiment. They were divided into four age groups (Group 1: $M = 5.5$ years of age, $n = 22$, 10 boys and 12 girls, range = 5 years to 5 years, 10 months; Group 2: $M = 6.4$ years of age, $n = 20$, 10 boys and 10 girls, range = 6 years to 6 years, 9 months; Group 3: $M = 8.5$ years of age, $n = 24$, 12 boys and 12 girls, range = 8 years, 1 month to 8 years, 11 months; Group 4: $M = 10.7$ years of age, $n = 20$, 13 boys and 7 girls, 10 years to 10 years, 11 months). Fifty-one percent of the children were firstborn, 32% were second born, and 17% were third born or later. A group of 22 young right-handed students (6 men and 16 women) was also studied ($M = 24.6$ years of age, range = 20–27 years of age). The selection criteria of the participants and the conditions of experimentation were the same as those used in Experiment 1. No further information regarding participants' characteristics were available.

Materials. Four primes, shown in Figure 5 (part A), were used in this experiment. They consisted of the largest rectangle of the seriated model, to which the next open two-sided rectangle was accreted in four different orientations. These primes were presented to the participants in a first phase, followed by a phase in which participants were required to copy the four seriated models. Similar to Experiment 1, each prime was individually printed in black ink in the center of small white cards (12 cm × 12 cm). The dimensions of the primes were identical to the corresponding components in the seriated models (see the *Method* from Experiment 1). Three distractors were also added between every two seriated models, as in Experiment 1.

Procedure. The procedure was the same as in Experiment 1 except for the following deviation. Instead of asking the participants to copy four distractors in a first phase, they were required to copy the rectangle-accreted prime in four different orientations (random order of presentation across participants). No new strategies for the copying of the seriated models appeared in comparison with Experiment 1. The strategies were again grouped into the three qualitatively different categories by two independent judges (91.6% of agreement, $\kappa = .93$, $p < .01$). We checked that there was no main effect of model on the distribution of participants across the three categories. Participants obtained a score varying between 0 and 4 in each category. It is worth noting that a specific error appeared at 5 years of age (12.5%) only, in which the second rectangle to be drawn was left open at the bottom or top because of a segment omission (see illustration in Figure 6). This error indicated a direct effect of the prime in which the second rectangle was indeed open and revealed a propensity of these children to start seriated-pattern copying with the component used as a prime.

Results

Statistical analyses. We conducted the data analysis by systematically comparing the present condition with the baseline condition provided by Experiment 1 by means of a MANOVA run with Age (5 years) and Condition (2) as between-subjects factors on the scores in the three drawing categories (see Figure 3, rectangle prime experiment).

Condition reached significance for the element-based strategies, $F(1, 222) = 4.1$, $p < .05$, the scores being inferior following priming ($M = 0.55$) than without ($M = 0.85$). This decrease was due to the youngest children ($M = 1.45$ at 5 years of age in the priming condition vs. $M = 2.71$ in the baseline condition), as attested to by a significant Age × Condition interaction, $F(4, 222) = 3.0$, $p < .05$. Contrary to our hypothesis, the use of unit-based strategies did not vary significantly as a function of Condition, $F(1, 222) = 2.3$, $p > .10$. By contrast, the choice for the frame-based strategies was sensitive to Condition, $F(1, 222) = 11.15$, $p < .001$, increasing in the priming experiment ($M = 1.54$) when compared with baseline ($M = 0.94$). Five-year-olds did use this type of strategy in the priming condition ($M = 1.09$) even

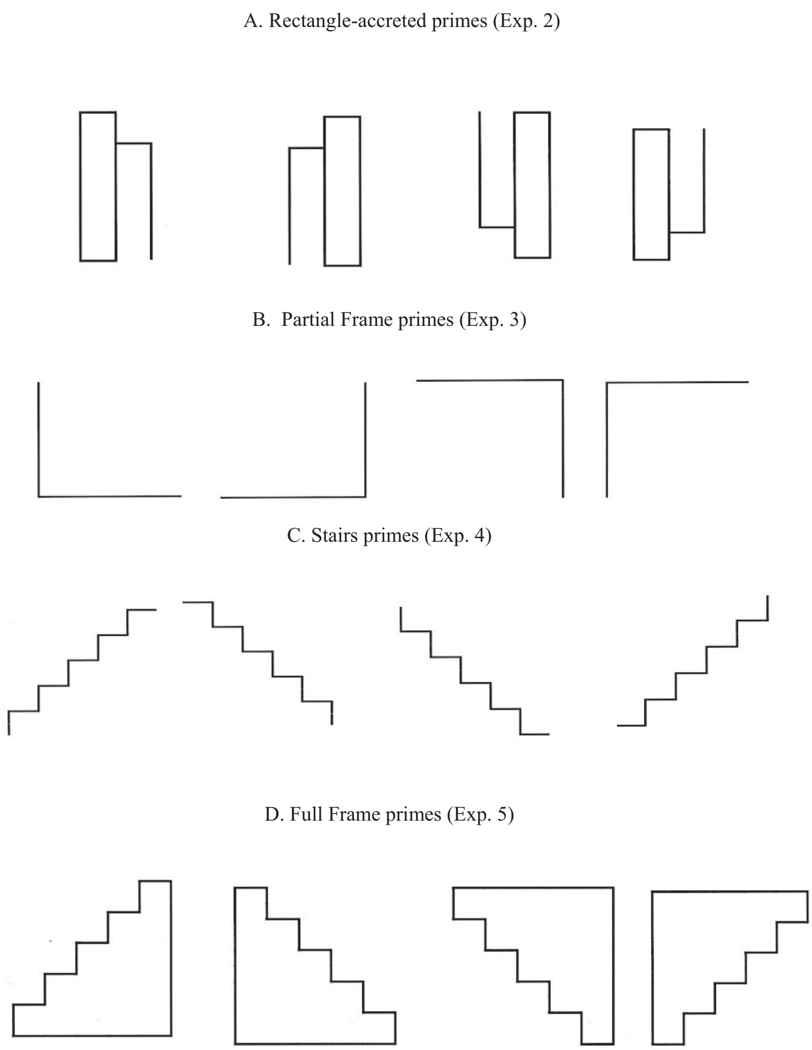

Figure 5. Illustration of the primes used in Experiments 2, 3, 4, and 5. Exp. = experiment.

though they did not use it in the baseline condition, $F(1, 44) = 12.6$, $p < .01$. An analytic look at the performances of these young children showed that they used the Base and Accretion strategy (see Experiment 1) in the priming experiment (16.6%) but not in the baseline condition (0%). However, when they adopted this strategy, in most cases (approximately 85%) they started by drawing the largest rectangle first, then they drew the next accreted rectangle that they sometimes left open (provoking the segment omission error). They proceeded in this way until they drew the last rectangle before finishing by drawing the base.

We also compared the baseline and priming conditions with respect to the variability of the participants' distribution across the graphic categories (see Table 1). Although the global percentage of participants using only one category remained high and unchanged (73.1% in the present experiment, 74.2% in the baseline condition), the distribution of individuals across the three categories was modified in the way reported previously. Table 1 confirms that at an individual level, the 5-year-olds adhered much less frequently to the element-based category after priming (4 of 22) than without priming (14 of 24), $\chi^2(1, N = 46) = 7.7$, $p < .01$. Another noticeable difference between the two experiments was that a significant number of children aged 5 years displayed both element- and frame-based strategies in the priming condition (5 of 22), whereas this diversity of behavior did not appear in baseline (0 of 24), $\chi^2(1, N = 46) = 6.1$, $p < .05$. The oldest participants (children 10 years of age and adults) also were more likely to apply uniquely frame-based strategies after priming (22 of 42) compared with baseline (16 of 48), $\chi^2(1\ N = 90) = 3.3$, $p = .06$. The 6-year-olds displayed a larger performance variability in the present condition.

As observed previously, the number of strategies used increased with age in the present priming experiment, $F(4, 103) = 3.2$, $p < .05$, mainly between children 8 years of age and adults (see Figure 4). This number was significantly inferior in the priming condition (1.54) compared with baseline (2.11) at 8 years, $F(1, 48) = 13.5$, $p < .01$. Finally, among the participants who introduced variations in their strategies, those aged 8 years and older were significantly more likely (24 of 45) than were the younger participants (5–6

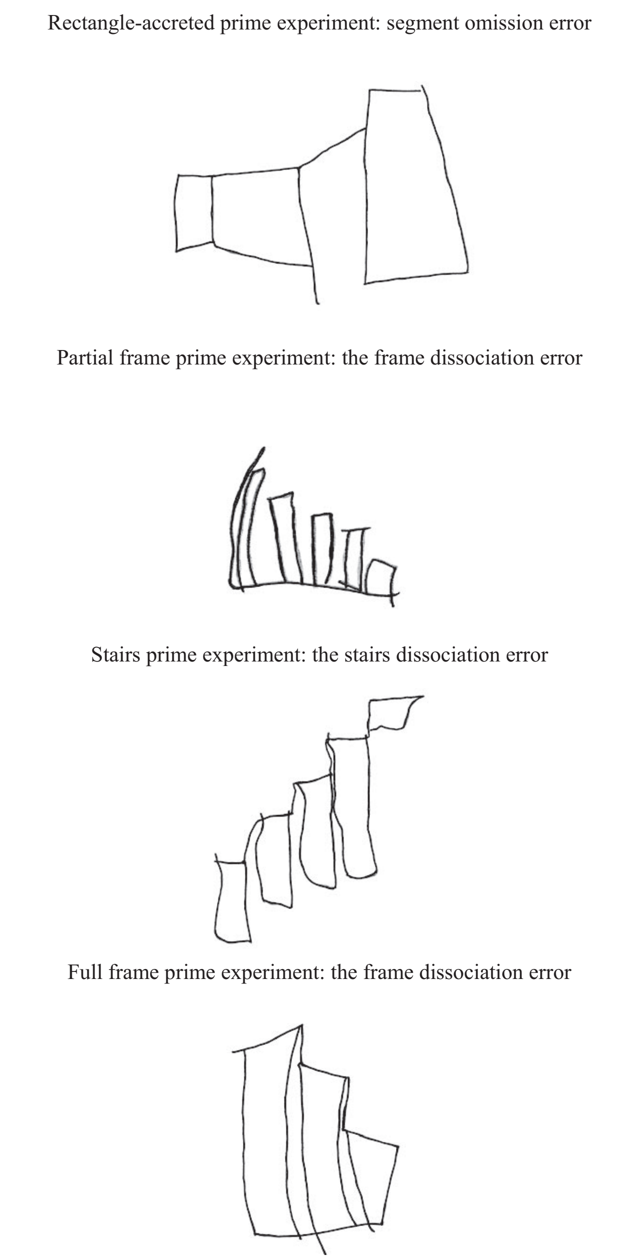

Figure 6. Illustration of the specific copying errors observed in the priming experiments.

years of age, 1 of 24) to modify their strategy systematically as a function of the model's orientation in the precise way mentioned in the previous experiment, $\chi^2(1, N = 69) = 16.4$, $p < .01$.

Discussion

Asking children and adults to copy a rectangle-accreted configuration before the seriated models induced significant changes in their strategies. A significant number of 5-year-old children abandoned the element-based strategies, but this modification was not to the benefit of the production of unit-based strategies. Instead, there was an increase in the frame-based strategies, more particularly the Base and Accretion strategy. However, as already pointed out, this strategy was developed mainly according to a schema by which the Accretion procedure was executed first, followed by the drawing of the base. This observation means that the youngest children initiated their drawings in exactly the same way as they did when copying the primes. In children 8 years of age, almost no change from the baseline level occurred except for a reduction in the number of strategies used. It should be remembered that use of the unit-based strategies was already high at this age. Finally, although the impact of priming was reduced in children 10 years of age and in the adults, it acted in an unexpected fashion. Instead of reinforcing the use of the unit-based strategies, it led the participants to move away from these strategies in favor of the frame-based strategies. Thus, the greatest impact of the rectangle-accreted prime was recorded in children 5 years of age. The primes selected for the following three experiments should enhance frame-based strategies and, consequently, should be efficient in older children and in adults because these strategies belong to their repertoire.

Experiment 3: Priming With the Partial Frame Parse

The partial frame of the seriated model was used as a prime in this experiment, and we expected it to elicit frame-based strategies. Given that this prime should facilitate the perception of the global unified structure of the models, we expected a major impact of the priming phase in children 8–10 years of age and in adults, reinforcing the production of frame-based strategies to the detriment of the unit-based strategies.

Method

Participants. Eighty-nine right-handed children (41 girls and 48 boys) between 5 and 10 years of age participated in the experiment. They were divided into four age groups (Group 1: $M = 5.4$ years of age, $n = 23$, 10 girls and 13 boys, range = 5 years to 5 years, 10 months; Group 2: $M = 6.5$ years of age, $n = 25$, 12 girls and 13 boys, range = 6 years to 6 years, 10 months; Group 3: $M = 8.6$ years of age, $n = 21$, 8 girls and 13 boys, range = 8 years to 8 years, 11 months; Group 4: $M = 10.5$ years of age: $n = 20$, 11 girls and 9 boys, 10 years to 10 years, 11 months). Forty-six percent of the children were firstborn, 40% were second born, and 14% were third born or later. A group of 22 young right-handed adults (17 women and 5 men) was also studied ($M = 23.4$ years of age, range = 20–27 years of age). No further information regarding participants' characteristics was available.

Materials and procedure. The four primes are depicted in Figure 5 (Panel B). The materials and procedure were exactly the same as those used in Experiments 1 and 2.

Results

The coded strategies, 93.1% of interjudge agreement, $\kappa = .95$, $p < .01$, were the same as those used in the previous experiments. The results, displayed in Figure 3 and Table 1, are presented following the same previous schema. Again, we sometimes observed a specific error at 5 years of age only (the frame dissociation error; see illustration in Figure 6), in which the children started by drawing the partial frame and continued by drawing isolated rectangles.

Condition failed to reach significance for the element-based strategies, $F(1, 225) = 2.1$, $p > .10$, although a slight decrease in their production was recorded in the priming condition ($M = 0.64$) when compared with the baseline condition ($M = 0.85$). However, the Age × Condition interaction was significant, $F(4, 225) = 3.6$, $p < .01$, with a sizeable impact of the priming phase being observed at 5 years of age only (a drop from a score of 2.71 to 1.44 after priming). The unit-based strategies were also sensitive to Condition, $F(1, 225) = 7.7$, $p < .01$, falling to a score of 1.65 in the priming experiment as opposed to 2.21 in the baseline condition. A significant Condition × Age interaction showed that the 8- to 10-year-olds and the adults produced fewer unit-based strategies in the priming condition than they did in the baseline condition, whereas a stability was observed in the youngest children, $F(4, 225) = 2.85$, $p < .05$. Finally, a strong reinforcement of the frame-based strategies appeared in the priming condition in comparison with the baseline condition, $F(1, 225) = 21.0$, $p < .01$, and a significant Age × Condition interaction showed that this increase was not observed at 6 years of age, $F(4, 225) = 2.4$, $p < .05$.

The results displayed in Table 1 confirm that the frame-based category became the dominant category to which participants aged 8 years and older systematically adhered (55.5% vs. 23% in baseline). Another point revealed by Table 1 concerns the 6-year-olds, only a few of whom could be consistently assigned to only one category of strategies (6 of 25 in priming vs. 18 of 26 in baseline), $\chi^2(1\ N = 51) = 8.8$, $p < .01$. Most of them switched between element-based and unit-based categories. By contrast, all adults belonged only to the frame-based category. Numerous 5-year-olds abandoned the use of the element-based strategies in the present priming condition (5 of 23 in priming vs. 14 of 26 in baseline), $\chi^2(1, N = 49) = 6.5$, $p < .05$, and some of them again displayed the largest range of behavior, associating element- and frame-based strategies.

Although significant between 5 years and 8 years (1.82 to 2.38; see Figure 4), $F(2, 66) = 3.2$, $p < .05$, a trend was observed only in the evolution of the number of strategies between children aged 5 years and adults, $F(4, 106) = 2.0$, $p = .09$. The present condition was the one in which adults introduced the least variety in their strategies. Finally, in a way similar to the results obtained in the baseline condition, the 8- to 10-year-olds were significantly more likely (16 of 38) than were the 5- to 6-year-olds and adults (6 of 52) to systematically adopt strategies containing the Accretion procedure for the decreasing models and the Embedding procedure for the increasing models, $\chi^2(1, N = 90) = 11.1$, $p < .01$.

Discussion

As in the previous experiment, the priming phase exerted a large influence on the drawing behavior of the youngest children, who greatly reduced their use of element-based strategies in favor of frame-based strategies. However, the element-based and unit-based strategies remained, globally, the most frequently produced strategies at this age. No effect of priming appeared at 6 years of age. Their scores in the three categories were remarkably stable between the baseline and priming conditions. However, cross-category variability increased at this age in the priming experiment. Most children switched between the categories instead of preferentially opting for the unit-based strategies. By contrast, the older participants (8 years of age, 10 years of age, and adults) did change their graphic behavior in a uniform way following the priming phase. To a greater or lesser extent, they abandoned the unit-based strategies in favor of frame-based strategies. In the adults, the priming effect was very large. Among the children, the greatest impact of priming was seen at 8 years, the age at which, by contrast, the priming manipulation used in Experiment 2 failed to induce significant modifications of the drawing strategies. However, recall that the first prime tested was likely to enhance unit-based strategies that were already frequently used by 8-year-olds.

Experiment 4: Priming With the Stairs Parse

In the previous experiment, we confirmed that the graphic behavior of the youngest children was highly susceptible to external influences, although the integration of these influences may have caused some specific errors. However, we may well ask whether a failure to modify graphic strategies as a function of the primes might be observed when the difference between the primes and the dominant parsing of the models (into rectangles) at this age increases. In the present experiment, we asked our participants to copy the stairs section of the seriated models during the priming phase. Although this task corresponds to a salient parsing of the models, it may be difficult to integrate if children subsequently organize their strategies in such a way that they start with this section. Thus, we did not expect a significant impact of priming in the youngest children, whereas an enhancement of the production of frame-based strategies was expected particularly in the older children and in the adults because the level of occurrence of these strategies was relatively low in the baseline condition.

Method

Participants. Ninety-one right-handed children (49 boys and 42 girls) between 5 and 10 years of age participated in the experiment. They were divided into four age groups (Group 1: $M = 5.3$ years of age, $n = 22$, 11 boys and 11 girls, range = 5 years to 5 years, 8 months; Group 2: $M = 6.4$ years of age, $n = 21$, 9 boys and 12 girls, range = 6 years to 6 years, 9 months; Group 3: $M = 8.6$ years of age, $n = 25$, 14 boys and 11 girls, range = 8 years to 8 years, 11 months; Group 4: $M = 10.7$ years of age, $n = 23$, 15 boys and 8 girls, range = 10 years to 10 years, 11 months). Forty-five percent of the children were firstborn, 39% were second born, and 16% were third born or later. A group of 21 young right-handed adults (8 men and 13 women) was also studied ($M = 25.8$ years of age, range = 21–28 years of age). No further information regarding participants' characteristics was available.

Materials and procedure. The four primes are depicted in Figure 5 (Panel C). They correspond to the stair part of the seriated models, presented in four orientations.

Results

The percentage of interjudge agreement reached 87.3% for strategy coding, $\kappa = .89$, $p < .01$. The results are displayed in Figure 3 and Table 1. Again, a specific error was sometimes observed at 5 years of age (7%) and at 6 years of age (2.4%), in which the children started with the stairs component and continued with the drawing of isolated rectangles (the stairs dissociation error; see illustration in Figure 6).

Although no main effect of Condition was reported for the element-based strategies, $F(1, 226) = 1.1$, $p > .25$, a significant Age × Condition interaction, $F(4, 226) = 3.85$, $p < .01$, pointed to a major decrease in this type of strategy at 5 years of age following priming, whereas these scores tended to increase at 6 years of age (1.66 vs. 0.31). Regardless of age, the unit-based strategies tended to be adopted less often in the priming experiment than in the baseline condition. More interesting, the use of frame-based strategies was greater in the priming experiment ($M = 1.45$) than in the baseline condition ($M = 0.94$), $F(1, 226) = 8.4$, $p < .01$. A borderline significant Age $\times$ Condition interaction revealed that the increase of the frame-based scores was observed in children 5 years of age, not in children 6 years of age or in adults, $F(4, 226) = 2.4$, $p = .05$. At 8 and 10 years of age, the reinforcement of the frame-based strategies was present. It is also noteworthy that participants more frequently started by drawing the stairs section in the priming condition (6.3%) than they did in baseline condition (1.65%), $F(1, 226) = 5.4$, $p < .05$.

Table 1 confirms, at an individual level, the positive impact of priming at 5 years of age on the frame-based strategies. Some of the participants (5 of 22) displayed element-based strategies as well as frame-based strategies, differentiating the priming experiment from the baseline condition (0 of 24), $\chi^2(1, N = 46) = 6.1$, $p < .05$. The distribution of the 6-year-olds appeared to be much more spread across the categories and their combinations after the priming experiment than in the baseline condition, although the use of unit-based strategies, whether unique or in combination with other strategies, remained dominant. Figure 4 reveals that the number of strategies used in the experiment increased with age (1.69 in children 5 years of age, 2.57 in adults), $F(4, 226) = 8.0$, $p < .01$. Furthermore, among those participants using a variety of strategies, the oldest participants changed their strategy as a function of the model's orientation more often (25 of 57) than children aged 5 or 6 years (4 of 29), as has been previously pointed out, $\chi^2(1, N = 86) = 7.8$, $p < .01$.

Discussion

We thought that the 5-year-olds would have been much more troubled by prior exposure to the stairs primes than they actually were. On the contrary, they demonstrated a significant decrease in the use of element-based strategies in favor of frame-based strategies to such an extent that the two occurred at a similar rate. In contrast, the 6-year-olds appeared to be largely insensitive to priming in terms of profound change of dominant strategies, despite an increase of variability. Regarding older participants, the use of the stairs primes apparently had a less noticeable impact on their graphic strategies than did the partial-frame prime in Experiment 3, although it operated in a similar way. Nevertheless, an impact did occur at the level of the genuine strategies adopted. Indeed, an analytic look at performances from the oldest participants (children aged 8–10 years and adults) showed that they used the Full Framing strategy more in the present experiment (15%) than in the baseline condition (6.4%), to the detriment of the Partial Framing With Accretion strategy, which was less present after priming (7.9%) than in baseline (19%). This usage pattern resulted in the relative stability of their frame-based scores.

Experiment 5: Priming With the Full-Frame Parse

The last priming manipulation involved the entire frame of the seriated models. In this prime, we offered a parsing of the seriated model very different from the youngest children's spontaneous mode of conceiving it. This model should enhance a frame-based strategy, which is present in older children and adults (the Full-Framing strategy). Therefore, we expected to observe a significant impact of the priming phase in the oldest participants but not in the youngest children. However, the results observed in the two previous experiments for the youngest children force us to consider that just the opposite may be true.

Method

Participants. Ninety-six right-handed children (49 girls and 47 boys) between 5 and 10 years of age participated in the experiment. They were divided into four age groups (Group 1: $M = 5.4$ years of age, $n = 22$, 7 girls and 15 boys, range = 5 years to 5 years, 7 months; Group 2: $M = 6.5$ years of age, $n = 26$, 17 girls and 9 boys, range = 6 years to 6 years, 10 months; Group 3: $M = 8.5$ years of age, $n = 26$, 14 girls and 12 boys, range = 8 years to 8 years, 10 months; Group 4: $M = 10.5$ years of age, $n = 22$, 11 girls and 11 boys, 10 years to 10 years, 9 months). Forty-seven percent of the children were firstborn, 34% were second born, and 19% were third born or later. A group of 20 young right-handed adults (11 women and 9 men) was also studied ($M = 24.5$ years of age, range = 20–27 years of age). No further information regarding participants' characteristics was available.

Materials and procedure. The four primes are depicted in Figure 5 (Panel D). They corresponded to the global full frame of the models. The procedure was the same as that used in Experiments 1–4.

Results

The percentage of interjudge agreement was 92.4% for strategy coding, $\kappa = .94$, $p < .01$. The results are displayed in Figure 3 and Table 1. Again, a specific error appeared at 5 years of age (29.5%) only, in which the children started with the drawing of the frame component and continued with the drawing of isolated rectangles (the frame dissociation error; see illustration in Figure 6).

Unlike the prior results, the element-based scores did not vary as a function of Condition (0.85 in baseline, 0.83 in priming), $F < 1$, particularly at 5 years of age. The unit-based scores declined in the priming condition (1.37) when compared with those of the baseline condition (2.21), $F(1, 230) = 16.4$, $p < .01$, primarily at ages 5, 8, and 10 years but not in the adults as shown by a borderline significant Age $\times$ Condition interaction, $F(4, 230) = 2.4$, $p = .05$. Finally, the frame-based strategies were more frequently produced in the priming condition (1.8) than in the baseline condition (0.94), $F(1, 230) = 21.8$, $p < .01$, at all ages except in the adults, $F(4, 230) = 3.2$, $p < .05$. An analysis of the results revealed that this was due to a large increase in the use of the Full-Framing strategy (22.4% in priming, 4.1% in baseline). Adults' overall insensitivity to the primes, in spite of an increase in their production of Full-Framing strategies, was explained by a simultaneous decrease in their use of other types of frame-based strategies (the Partial Framing strategies).

Table 1 confirms that the impact of priming was totally absent at 5 years of age at an individual level, most of these children (69.7%) using only element-based strategies. In contrast, a much greater number of 8- to 10-year-olds resorted only to frame-based strategies in the present experiment compared with the strategies used in the baseline condition, $\chi^2(1, N = 98) = 23.4$, $p < .01$. The 6-year-olds again departed from the other age groups in that the latter remained attached to the unit-based strategies, but their variability increased largely.

Unlike the other experiments, age was not a significant factor with respect to the number of strategies (1.77 in children aged 5 years, 2.1 in adults), $F < 1$. Finally, we again observed a systematic effect of the model's orientation on the changes of strategy in the 8- to 10-year-olds and adults (16 of 44) when compared with that of the youngest children (2 of 31), $\chi^2(1, N = 75) = 8.9$, $p < .01$, the production of the ascending models being associated with an Embedding procedure and the production of the descending models being associated with an Accretion procedure.

Discussion

As expected, the youngest children did not gain much advantage from prior exposure to the full-frame prime. The production of unit-based strategies fell after priming in comparison with baseline in favor of both the element-based strategies (regressive trend) and the frame-based strategies (progressive trend). However, this progressive trend was the smallest observed across the four priming experiments. The results exhibited by the 6-year-olds were, globally, similar to those already observed. The unit-based strategies remained dominant, but an important variability in the performances was observed at this age. The impact of priming was very large at 8 and 10 years of age. The children's production of unit-based strategies declined, to the clear benefit of the frame-based strategies. Finally, in the adults, the production of the Full-Framing strategy was enhanced by the primes, thus indicating that the procedure had a positive impact. However, this increase was paralleled by a drop in the use of other frame-based strategies but not of the unit-based strategies. In the adults, unlike in the children (6, 8, and 10 years of age), the greatest effect of priming was not elicited by the full-frame structure but by the partial-frame prime.

General Discussion

The first experiment showed that children and adults who were asked to copy accurately seriated models differed from one another with respect to the graphic strategies that they adopted. The 5-year-old children used mainly element-based strategies, reproducing the model as a series of independent rectangles. The 8-year-old and 10-year-old children used unit-based strategies, indicating that they conceived of the model as a concatenation of rectangles sharing one side. The adults opted for frame-based strategies in which they conceived of the model as a single entity enclosed in a partial or complete frame. To test whether this age–category strategies relationship reveals genuine developmental changes, we manipulated the context of copying by using a priming procedure. Our objective of this procedure was to induce prior experience of the models that would determine how they appeared to the participants and, consequently, modify their copying strategies. Accounting for a radical change in the correspondence between age and category of strategies would be problematic within stagelike models but would be predicted by models proving that behavior is fundamentally context dependent. Globally, the four priming experiments showed that the age–category of strategies relationship was modified at 5 years of age and at 8–10 years of age but not at 6 years of age and not in adults, as revealed by various significant Age × Condition interactions. These results call for a careful analysis, considering the predictions drawn from different theoretical perspectives.

The results from the baseline condition provide some support to stagelike developmental models. The three discovered steps echo other developmental evolutions described in the literature (e.g., Akshoomoff & Stiles,1995a; Lange-Küttner, 2000; Picard & Vinter, 1999; Tada & Stiles, 1996), that is, basically, a movement from the processing of elements (analytic processing) to the processing of chunks of elements forming global units (holistic processing), and then to the processing of wholes and parts (integration of analytic and holistic processing). Another account of this development evolution highlights the changes intervening in the pictorial space, from an implicit aggregate space to an explicit axial space based on horizontal references and then to orthogonal references (Lange-Küttner, 1997, 2004). These developmental similarities found in different studies suggest that development may be structured by general organizational principles that are predominantly under endogeneous (internal) control, a point claimed by stagelike models. These internal changes could be related to (a) the nature and size of the internal cognitive units that enabled the participants to consciously analyze (or parse) the models (see also Dukette & Stiles, 1996; Mendoza Feeney & Stiles, 1996) or (b) general endogenous factors such as Morra's (2005) *M-capacity*, defined as the amount of attentional resources that a child can use to activate task-relevant figurative and operative schemes. However, the large impact of our contextual manipulation through prior exposure to a prime demonstrates that these classical developmental conceptions must accommodate to criticisms coming from a diverse range of theories. Of course, endorsing Morra's perspective, we could suggest that the priming phase might enhance the activation of relevant figurative schemes, releasing attentional resources for the monitoring of the executed graphic strategy. However, such facilitation effects have necessary limits within a Piagetian or neo-Piagetian framework because they are generally not supposed to provoke genuine cognitive changes (Piaget, 1971).

Children modified their graphic strategies after most of the priming sessions, at least those aged 5 and 8–10 years. At 5 years of age, this effect led to a significant increase in frame-based strategies, to the detriment of elementary strategies in all but one priming experiments. A look at the individual consistency of strategy choices confirms that some of these young children succeeded in systematically using the most sophisticated strategies. At 8 years of age, a move from unit-based to frame-based strategies was elicited by the partial-frame and full-frame primes. At 10 years of age, a similar move was provoked mostly by the full-frame prime.

Within the Siegler (1996) theory, we could suggest that, at each age, children possess a variety of strategies, differing in terms of complexity, the applicability of which results from an online evaluation of the adaptability of each available strategy in a specific context. Considering the propensity of the youngest children to start copying the seriated models with the part corresponding to the prime, it may be that continuing with a frame-based strategy was estimated, by some children, to be more economical than using another type of strategy. A similar reasoning could be proposed for older participants: The activation of part of a strategy during the priming phase made the use of a given category more likely. As expected from this theory, strategies become more adapted to the task's properties with time. Indeed, all experiments showed that the use of the strategies became tuned to the model's orientation with age. This sensitivity to orientation appeared at 8 years of age. This observation may indicate that a global organizational rule in drawing dominates the syntactic choices made by participants when they elaborate a strategy, namely, starting at the left (thus, in our case, starting with the biggest rectangle for the decreasing models and starting with the smallest rectangle for the increasing models). Thomassen and Tibosh (1991) showed that this rule, together with the threading rule, is one of the strongest rules that adults applied when they built a drawing. This syntactical bias also may reveal an influence of the developing handwriting skills, the left-to-right progression being typical of Western culture. Cross-cultural data would be interesting to gather because they could reveal how other syntactical biases may determine the use of the strategies. However, these schooling requirements or cultural factors can account for an effect of model orientation but not for the evolution of the graphic strategies themselves.

Researchers who endorse the dynamic perspective to account for these results requires them to abandon the idea of a constituted repertoire of strategies and a process for choosing the more approriate strategy, given a set of parameters. Instead, it would be suggested that, in each specific context, the participants' cognitive, perceptual, and motor capacities were dynamically assembled, enabling emergence of the strategy that actualized the best compromise, given a set of constraints. During the copying of the primes, a series of perceptual–motor coordinations was established, which partially predetermined how the participants could subsequently "move" in the drawing landscape constituted by our task. In this sense, the priming phase acted as an external aid that facilitated the production of frame-based strategies (as in Experiments 3, 4, and 5). The fact that adults constantly produced the frame-based strategy, despite context-inducing unit-based strategies (as in Experiment 1) demonstrates that they stabilized their behavior around the most powerful and stable "attractor." Indeed, the frame-based strategies are best adapted to the structural features of the models, allowing for a perfect base alignment of the rectangles. They also allow for the optimum use of preferred directions in drawing (left-to-right, top-to-bottom), as described by several authors (e.g., Goodnow & Levine, 1973), with a minimum of number of pen-lifts (6). In this sense, frame-based strategies are the best compromise between a motor economy demand and an accuracy requirement.

However, those who subscribe to these two context-dependent theories have difficulty explaining why the impact of priming was so much smaller on the 6-year-olds. Only the Karmiloff-Smith (1992) model predicted age-dependent effects of the priming phase. In this model, the first phase of development results from accumulated practice in a domain, thanks to bottom-up influences. Highly efficient data-driven processing would lead to an impact of priming, as observed at 5 years of age. The second phase results from the endogeneous release of a representational redescription process that provokes a temporary closure of the cognitive system on itself, with a predominant top-down processing. No significant effect of priming should occur during this phase, as was the case at 6 years of age. We noticed an increase of variability only at this age, as if the bottom-up influences exerted by the exposition to the primes had provoked behavioral instability. The representational redescription process continues to operate, leading to a third phase of development, in which an equilibrium between bottom-up and top-down processing is attained. An impact of priming again would be expected at that phase, and, indeed, it occurred at 8–10 years of age.

Interestingly, this model leads us to further question the results obtained at 5 years of age, asking whether these results do reveal that, upon using external aids, these young children are able to display representational abilities (part–whole relationships analysis) and a conceptualization of the pictorial space similar to those shown in older children. As pointed out on a number of occasions by Karmiloff-Smith (1992, 1999), apparently identical behaviors can be sustained by qualitatively different representational structures. It is important not to confound external behavioral outcomes and internal representational processing (see, e.g., Elman et al., 1996). We suggest that the graphic performance of the 5-year-olds following priming was made possible thanks to efficient data-driven processing as described by Karmiloff-Smith (1992). An understanding of our results could be framed as follows. When the prime corresponded to perceptually salient features that were easy to isolate (the rectangle and the stairs were optimum in this regard), the children tended to initiate their copy of the seriated models by producing the prime component first. Some of them were then unable to continue with the copying, and some typical priming-induced errors arose, coupled with the production of element-based strategies. Others, perhaps, made better use of these data-driven processes, proceeding by establishing a segment-by-segment correspondence between their drawing and the model. A frame-based strategy may have emerged, created or assembled anew during the drawing process, as suggested from the dynamic approach but independent of any internal reworking of how the patterns are conceived. Following this analysis, the 5-year-olds did not move from the element-based step, but some of them displayed more sophisticated behavior thanks to the presence of direct exogenous triggers to which they could accommodate. Phillips et al. (1985) showed a failure of different training methods with respect to cube drawing, suggesting that in these situations, children learn specific graphic descriptions.

In contrast, the positive impact of the priming phase on the 8- to 10-year-olds probably resulted from an internal reconceptualization of the models, as if the representational redescription process were exogenously elicited. Several drawing studies have shown that the management of the part–whole relations of relatively complex spatial patterns becomes established between 8 and 12 years of age (e.g., Akshoomoff & Stiles, 1995a; Karmiloff-Smith, 1990; Lange-Küttner, 2000; Picard & Vinter, 1999; Spensley & Taylor, 1999). Furthermore, the developing conception of the pictorial space as explicit axial space structured by orthogonal axes in children between 7 and 9 years of age (Lange-Küttner, 1997, 2004) could account for 8- to 10-year-olds' special sensitivity to both the partial and complete frame primes. Consequently, the manipulation of the children's personal experience of the patterns helps them build a new representation of their structure that, in turn, guides the drawing strategies. It is likely that children of these ages did not make frequent, spontaneous use of frame-based strategies in the baseline condition because the conscious apprehension of the seriated patterns as a set of concatenated rectangles of different lengths was perceptually more salient than the frame–parts decomposition.

Finally, this representational redescription model suggests that the reduced sensitivity of the 6-year-olds to priming might be due to the release of an endogeneous process of representational redescription of mature behaviors (e.g., drawing rectangles is a mastered behavior for a 6-year-old child). This internal conceptual reorganization would involve a temporary closure of the system to external inductions, thus preventing children from benefiting from the copying of the primes. A certain degree of conceptual rigidity has already been reported at this age (Karmiloff-Smith, 1992; Mounoud, 1996). This does not mean that 6-year-old children are unable to produce frame-based strategies. They would surely be able to do so in response to verbal instructions, for instance. A recent study has shown that even 3-year-old children are able to modify their drawing behavior in response to specific instructions (Barlow et al., 2003). However, this type of behavioral success could not be considered to result from an a priori reconceptualization of the models. Within this perspective, a genuine developmental change could be suspected somewhere between 5 and 6 years of age, for the specific domain of knowledge covered by our task.

In conclusion, as could be expected, support for each developmental theory can be found in a series of experiments in which the conditions of experience have been manipulated. It is a fact that more or less sizeable modifications in the relationship between age and behavior are obtained when the context is organized in such a way that participants can benefit from external information. Undoubtedly, this fact raises some difficulties for classical stagelike developmental models, whereas it consolidates support for context-dependent models. However, parts of our results also have shown that models postulating internal cognitive reorganizations at various points of development, such as the Karmiloff-Smith (1992) model, for instance, are necessary for understanding development. It would be most important for developmentalists to know to what extent these periods are truly age independent.

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