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How Meaning Modifies Drawing Behavior in Children

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Two hundred and nine children aged 6–10 years and 40 adults were asked to draw perceptually ambiguous drawings to which two different meanings could be attributed, each meaning inducing a particular parsing of the model. These models were presented with one meaning in a first phase and another meaning in a second phase. For each, we analyzed whether participants modified their movement sequences in ways that were determined by the model's meaning. The results showed that the participants' drawing was to some degree sensitive to meaning at all ages. However, sensitivity to meaning differed as a function of the model and, more precisely, of the type of parsing induced by meaning. Thus, the way information is segmented into representational units may account for the relation between the *what* and the *how* of drawing.

INTRODUCTION

Because drawing is a goal-directed behavior that takes place both in space and time, it can be studied from two different perspectives: within a "product-oriented" approach, dealing with the *what* of drawing (the trace left on the paper), and as part of a "process-oriented" approach, dealing with the *how* of drawing (the organization of the movement used for drawing). The first approach has received considerable attention from developmentalists since the pioneering work of Luquet (1927). Theorists have proposed different stage, or at least step-like, theories of drawing development. Some describe general stages and emphasize a contrast between a stage in which children draw "what they know" and a stage where they draw "what they see" from a particular point of view (Freeman, 1980, 1993; Freeman & Janikoun, 1972; Luquet, 1927; Osterrieth, 1976; Piaget & Inhelder, 1956). Recently, Cohen and Bennett (1997) showed that even adults do not always draw what they see and suggested that misperceptions of the object constitute the main source of drawing errors. Others suggest more specific steps, often related to two prototypical drawing models: the human figure (Barrett & Eames, 1996; Cox, 1992; Fenson, 1985; Kellogg, 1969) and the cube (Caron-Pargue, 1985; Willats, 1977, 1984).

Stage theories have, however, been severely challenged by an impressive series of studies that demonstrate just how context- or task-dependent children's drawing skills are (Cox, 1992; Davis, 1983). The empirical investigation of the context of drawing has led to the study of the role of factors as diverse as verbal instructions (Barrett, Beaumont, & Jennett, 1985; Beal & Arnold, 1990), episodic information given to the child prior to drawing (Moore, 1987), sociocommunicative context (Light & McEwen, 1987), and the characteristics of the model to be drawn, such as familiarity and dimensionality (Barrett & Light, 1976; Cox, 1981, 1985; Nicholls & Kennedy, 1992). Globally, this body of research has shown that young children are able, under certain conditions, to abandon their mental models and to draw what they see quite accurately, despite a limited repertoire of graphic devices or primitives for the depiction of the features of complex objects (Crook, 1985). Even so, recent evidence suggests a sequential cumulative progression in drawing development. For example, Barrett and Eames (1996) consistently observed a progression from the ability to copy closed geometric forms to open geometric forms, followed by a segmented human body, and finally an outline of the human body.

Stage theories and studies of context are generally limited to the *what* level. Some developmentalists, however, have adopted a process-oriented approach to drawing development, which includes aspects of behavior as diverse as movement sequencing and movement kinematics (see, e.g., Meulenbroek & Van Galen, 1986; Vinter & Mounoud, 1991). The *how* of drawing related to movement sequencing—the focus of this report—may be investigated either at a global level, that of the graphic routine, or at a more local level, that of the graphic rules. Karmiloff-Smith (1990, 1992) described the development of graphic routines in two main phases. Based on a predominance of bottom-up processes, repeated practice leads children to construct, more or less laboriously, efficient routines for the drawing of familiar objects or topics. Although a noteworthy level of behavioral mastery is achieved at around 4–5 years of age, graphic routines in young children tend to be rigid and lack flexibility at both the representational and procedural levels. Subsequent processes release the graphic routines from two constraints: an independence constraint occurring between routines and a sequentiality con-

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straint occurring within a routine (Karmiloff-Smith, 1992). As a result, representational content relating to one routine may be inserted into another and procedural flexibility increases (for further comments on this perspective, see also Karmiloff-Smith, 1994; Vinter & Perruchet, 1994). Some of the results reported by Karmiloff-Smith (1990) have been replicated and they also appear to be strongly context- or task-dependent: flexible routines may be elicited in young children under certain conditions (Vinter & Picard, 1996; Zhi, Thomas, & Robinson, 1997).

According to Goodnow and Levine (1973), children apply syntactical rules when they organize their sequence of movements in drawing production. More recently, Van Sommers (1984, 1989) extended the list of graphic production rules and provided an interesting cognitive framework for understanding the act of drawing. These rules refer to the selection of a starting location for each drawn segment (e.g., at the top of the segment), the choice of movement direction or progression (e.g., left to right), and the global ordering of the elementary movements forming the drawing sequence (e.g., anchoring the next segment to the one previously drawn). Developmental trends in the way in which children respect these rules (Minary & Vinter, 1996; Nihei, 1983; Ninio & Lieblich, 1976; Thomassen & Teulings, 1979; Vinter, 1994) are also, to some degree, sensitive to features such as handedness, education, or culture (Nachson, 1983; Simner, 1981; Vinter & Meulenbroek, 1993). Most of these rules seem to be motivated by bottom-up influences, such as economy and the search for reduced costs in movement planning and execution (Thomassen & Tibosh, 1991).

Using evidence from a task requiring the copying of geometrical figures, Vinter (1994) suggested that the evolution of graphic syntax[1] results from changes occurring at the planning level, in particular the size of the planning unit processed by the child. Young children (4–5 years) plan the syntactical aspects of movement essentially segment by segment, without considering the entire sequence at the figure level. Syntax planning at the figure level appears to characterize the drawing of 6- to 8-year-old children (e.g., threading, that is, drawing continuously without penlifts). The syntactical choices made by older children resemble those of adults: that is, they were based on a combination of global planning (figure level) and local planning (segment level), thus inducing a flexible use of the graphic rules.

To summarize, developmental trends, though highly sensitive to context, appear to emerge in drawing, whether we consider the *what* or the *how* of drawing. These two facets of drawing must be related. However, it is not yet clear how the *what* (or representational content) and the *how* (or movement sequencing organization) interact, compete, or facilitate each other in the production of a drawing. Is there, for instance, any relation between the tendency of young children in a free-drawing condition to rely on what they know about the object rather than what they see and their tendency to produce a somewhat fixed sequence of movements? Some data in the literature already suggest that these two facets are related (Goodnow, 1978; Taylor & Bacharach, 1982). Ingram (1985) showed that the semantic content of objects—what they effectively represent—affects the way they are drawn by children. In a first experiment, children were asked to reproduce two plain-faced but different-sized blocks joined by a bridging pin under different spatial arrangements; in a second experiment, doll-like features were added to the smaller of the two blocks. The doll-like object induced the youngest children (3 years) to draw tadpole stereotypes, whereas the more abstract object led them to rely on spatial information. The impact of meaning was also observed in the way children organized the temporal sequence of drawing. However, the extent to which the *what* affects the *how* of drawing cannot be assessed adequately in this experiment because the display to be drawn actually changed from one condition to the other, introducing modifications at the syntactic level independent of meaning. There is thus today no study in the literature requiring children to draw two identical designs to which two different meanings are attributed.

The question of the relations between the *what* and the *how* of children's drawing can be directly tackled by considering the relations between semantics and syntax, as Van Sommers (1984) did, in studies of adults. In a series of elegant experiments, Van Sommers explored the relations among the perceptual, decision, and motor processes involved in the act of drawing. Because meaning or semantics may govern how the model is parsed or segmented into components, Van Sommers asked adults to reproduce models that were given one of two different labels. He then analyzed whether the participants modified their graphic execution as a function of the model's meaning. He found that, for most designs, meaning was expressed through stroke order, which governed the basic segmentation of the model; graphic production rules determined how the movement was finally executed.

[1] The use of the term *syntax* may be inappropriate in this context, but it is common in the drawing literature, where it designates how movements are ordered and sequenced, including the graphic rules (Goodnow & Levine, 1973).

This sensitivity of lower levels of behavioral organization to higher-level influences has been described in other areas of research. With regard to action, Marteniuk, McKenzie, Jeannerod, Athenes, and Dugas (1987) demonstrated an interesting relation between higher-order factors and movement planning and execution. They analyzed the kinematics of an identical reaching movement when this movement was followed by one of two different actions, either fitting or throwing. They reported that the final goal of the overall sequence of action, its "meaning," influenced the kinematics of the initial reaching movement. With regard to perception, the intrusion of meaning at very elementary levels is well established in the literature (Goldstone, 1995). Knowledge of categories, for instance, influences figure/ground segregation (Petersen & Gibson, 1994), showing that conceptual factors may determine how perceptual information is parsed. More generally, recent experiments by neuroscientists have revealed that top-down processes, such as attention, can shape perception and influence neural activity in the early processing stages of the visual cortex (Desimone & Duncan, 1995; Motter, 1994; see also Barinaga, 1997). Thus, it would not be surprising that meaning would affect graphic syntax, even in children. The present study explores the sensitivity of graphic syntax to meaning in childhood using Van Sommer's procedure, which is appropriate for demonstrating that meaning may influence not only production of errors, but also movement sequencing. This procedure also offers a means for investigating the interplay during development between top-down and bottom-up influences.

In children, the organization of graphic syntax itself is developing. Threading appears at around 5–6 years and decreases in strength after 8 years (Ninio & Lieblich, 1976; Simner, 1984). Starting at the top of the figure increases gradually between 4 and 8 years (Vinter, 1994). The stronger the graphic rules, the weaker the influence of meaning should be in situations where meaning and graphic rules are in conflict. A more specific prediction may be formulated in relation to threading, which is known to dominate drawing sequencing strategy in children aged around 6–7 years (Nihei, 1983; Vinter, 1994). These young children should be less inclined than older ones to modify their syntax as a function of meaning when the particular parsing of the object imposed by the meaning would lead to discontinuous drawing movements. However, if no such opposition emerges, even the drawing behavior of young children should be sensitive to meaning.

Furthermore, the more routinized and encapsulated drawing is, the less the potential impact of meaning on graphic syntax. In her investigation of drawing, Karmiloff-Smith (1992) described a transition from data-driven to theory-driven information processing between 4–5 and 7–8 years. Young children, therefore, may be less sensitive to meaning than older children because their flexibility is limited by the dominance of data-driven processes. Paradoxically, however, this model may also give rise to the opposing hypothesis. If the data-driven phase involves the building of isolated graphic routines, with one procedure corresponding to one represented object, a change of meaning should elicit a change of procedure, at least in cases where the represented object is familiar. Young children would tend to draw what they know rather than what they see because they follow unflexible familiar routines. Given this line of reasoning, meaning should influence graphic syntax in young children. In synthesis, two contradictory hypotheses may be tested in a study of young children: the way they draw may either be immune to meaning or sensitive to it.

These predictions will be examined in a study that requires children, aged 6–10 years, and adults to produce drawings to which two different meanings can be attributed. These drawings were taken from Van Sommer's experiment (1984). Each meaning suggests a different parsing of the model and, in most cases, an opposition between either a single representational unit or two representational units.

METHOD

Participants

Two hundred and nine right-handed children (104 males) between 6 and 10 years of age participated in the experiment. They were divided into five age groups (*mean* age = 6 years: $n = 41$, 19 males, *range* = 5 years 10 months to 6 years 2 months; *mean* age = 7.1 years: $n = 42$, 21 males, *range* = 6 years 10 months to 7 years 3 months; *mean* age = 8.2 years: $n = 42$, 21 males, *range* = 7 years 11 months to 8 years 3 months; *mean* age = 9.1 years: $n = 42$, 22 males, *range* = 8 years 10 months to 9 years 2 months; *mean* age = 10.2 years: $n = 42$, 21 males, *range* = 9 years 10 months to 10 years 3 months). Note that although 20 5-year-old children were observed, a majority of them did not clearly "perceive" both meanings in the drawings. Because of this limitation, we decided to exclude this age group from the analysis of the results.

None of the children was educationally advanced or retarded or had psychomotor deficits in drawing or handwriting. 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 sample of 40 right-handed adults (20 males) was also studied (*mean* age = 26.5 years, *range* = 19–32 years). They were volunteer students at the university and were not informed of the purpose of the study. None of them had any special training in drawing.

Material

Five models, drawn from Van Sommers' study (1984), were individually printed in black ink on small white sheets of paper (12.5 × 7.5 cm), together with their respective meaning printed horizontally below the drawing. The drawings were all of a similar size, approximately 3 × 3 cm. A total of 10 models (five drawings with two meanings) constituted the target material presented to participants. They were simple to reproduce, and both their meanings, which corresponded to familiar objects or events, were easy to grasp, at least by 6 years of age.

Figure 1 depicts the models and meanings as shown to the participants. The letters appearing on the models at each intersection will be used later to

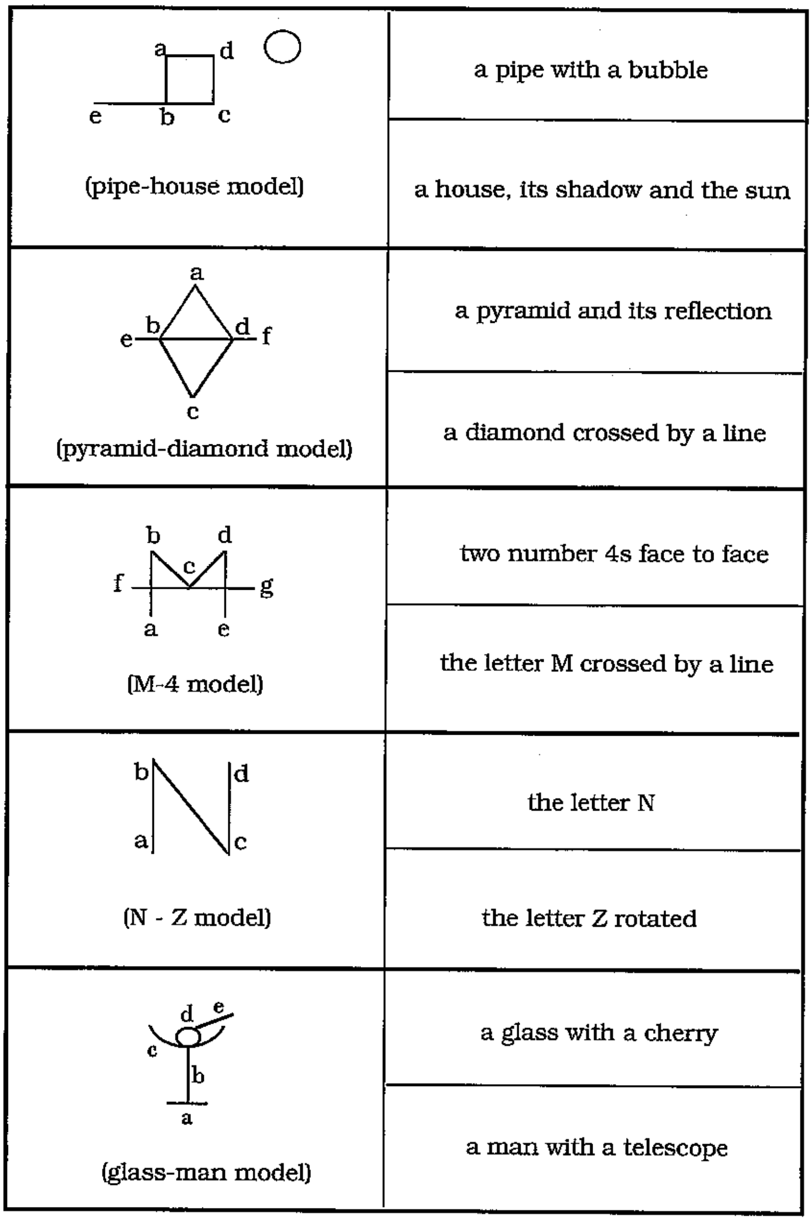

Figure 1 Illustration of the models and their meanings.

describe certain analytical measures regarding sequences of movements.

Ten other very simple schematic drawings were added as fill-in stimuli (two series of five drawings) and were presented in the same way as the target drawings, with their meaning printed below them. These fill-in drawings took the form of a tree with leaves, a cup, a vase with flowers, a human figure, and a clock for one series, and a bottle, a table with a chair, a pan, a television screen, and a window with curtains for the second. They were added to lengthen the experimental session, particularly the time interval between the presentation of the two repetitions of each target drawing. Their presence also made the experimental manipulation of the change of meaning less apparent.

Procedure

When the participants were asked to reproduce the models, they were told that a rough but correct reproduction of the shape of the model was expected. No other information was given to participants before the models were shown to them in succession, and they were free to proceed as they wanted in their drawings without time constraints.

The participants had white sheets of paper at their disposal (12.5 × 7.5 cm), one sheet for each drawing. When they were ready, the experimenter showed them a model and explained the intended meaning of the drawing to them. This meaning corresponded to the text printed on the figure (the experimenter never used any manual gestures to clarify the correspondence between the meaning and the model). A trial began only when the experimenter was sure that the participant had understood the model in terms of its meaning. When in doubt, the experimenter asked the participant to repeat the meaning and to indicate the correspondence between the meaning and the different parts of the figure on the model. This was necessary for eleven 6-year-old, eight 7-year-old and three 8-year-old children. The same procedure was used for the fill-in drawings, but none of them required further explanation regarding their meaning. The model was located in front of the participant, who was free to place the response sheet in any position below the model. When they had finished, the experimenter removed both the model and the response sheet before proceeding with the next item.

At the start of the experiment, the participants did not know that they would be exposed to models twice, with a change of meaning. In an initial session, they drew the five target models with one definition intermixed with five fill-in drawings. The order of presentation of the models was randomized across the participants. This session lasted between 10 and 20 min. There was then a pause, during which the experimenter talked with the children about their school, what they liked to study, and other subjects and, with adult students, about the university, the psychology course, and so forth. This pause lasted between 10 and 25 min, depending on how willing the children or students were to talk about these topics with the experimenter. In the second experimental session, the same series of five target drawings were presented with the second meaning, mixed with another five distractors in a random order. The experimenter made sure that the new meaning was understood before the participant started drawing. Most of the participants spontaneously told the experimenter that they recognized the models, but they did not necessarily remember the first meaning given to the target drawings. A within-participants design was selected for the meaning manipulation because of the need to assess flexibility of syntactical organization together with sensitivity to meaning. If anything, it would underestimate the effect of meaning, if participants tended to maintain their initial movement sequencing.

The order of meanings was counterbalanced for each age group, one half of the participants starting with one meaning, the other with the second one. We did not include a control condition in which the participants were required to draw the models without any meaning because attribution of meaning to drawings is natural. A control condition would consequently assess the effects of both the geometry and the spontaneous emergence of meaning, which could vary from one participant to another.

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. This second experimenter was one among 10 undergraduate students specially trained for this activity. These students were naive to the aims of the study, and they never experienced any difficulty in coding. The experimental session was videotaped and the online codings made by the second experimenter were checked by another student and, if necessary, corrected offline.[2] Data analysis was based on the revised codings.

[2]Ten naive undergraduate students were involved in this task, each of them observing online around 25 participants (coming from all age groups). Their participation in the study was part of an exam. Each of them also checked on the videotapes the online codings of around 250 drawings performed by participants other than those they directly observed. The movement sequences for the fill-in drawings were not analyzed. The occurrence of disagreements of any type was very low, ranging from 0% to 10.40% (*mean* = 4.40%, *SD* = 2.10%).

Coding of the Drawing Sequences

We first made a complete inventory of the different graphic strategies used by participants when copying each model, recording in a computer the precise syntax used by each participant for the copying of the target drawings (see Figure 1). Each production was coded by the sequence of letters passed along the drawing track, with a comma for each penlift; e.g., for the pyramid-diamond model, the sequence *ab, ad, cb, cd, ef* described precisely how a participant drew the model. Forty-two types of sequences were observed for the *pipe-house*, 41 for the *pyramid-diamond*, eight for the *N-Z*, 51 for the *M-4*, and 48 for the *glass-man* models. Of course, the frequency of occurrence of each sequence was highly variable, some of them being observed only rarely. For a drawing consisting of four segments, 384 different sequences are potentially possible (Thomassen & Tibosh, 1991); thus, our participants used a considerably reduced set of possibilities.

The presence or absence of specific criteria in this unedited set of strategies was then tested for each model.[3] Detailed criteria were defined, describing the order in which certain critical segments were linked together when the model was copied, and specific a priori predictions were formulated with respect to the impact of meaning. These criteria are listed below, using the decomposition of the model into segments by means of letters, as illustrated in Figure 1. Note that "drawn in sequence" does not necessarily imply that a continuous movement was used.

1. *pipe-house*:
   - *abcd* drawn in sequence, expected for the house meaning, where it corresponds to the house.
   - *eb* drawn in isolation (no *ebc* or *eba* drawn in sequence), expected for the house meaning, where it represents the shadow.
   - *ebc* drawn in sequence, expected for the pipe meaning, where it corresponds to the base of the pipe.
2. *pyramid-diamond*:
   - *abcd* in sequence, expected for the drawing of the diamond.
   - *abd, bcd* drawn in isolation, expected for the pyramid, corresponding to the pyramid on the one hand, and to its reflection on the other.
   - *ef* drawn last, expected for the diamond, corresponding to the crossing line.
3. *M-4*:
   - *abcde* drawn in sequence, expected for M-meaning, and corresponding to the letter M.
   - *fg* drawn after *abcde*, expected for M-meaning, representing the crossing line.
   - *abcf* drawn in sequence and *cdeg* drawn in sequence, expected for 4-meaning, corresponding to each number 4, respectively.
4. *N-Z*:
   - *ba* drawn first, expected for N-meaning, corresponding to the usual writing of this letter in capitals.
   - number of movements (1, 2, or 3): the number should be lower for the Z-meaning than for the N-meaning, because Z, but not N, is usually traced without pen-lifts.
5. *glass-man*:
   - *abd* drawn in sequence, expected for glass-meaning, corresponding to the glass.
   - *abc* drawn in sequence, expected for man-meaning, representing the basic structure of a man.
   - *de* drawn in sequence, expected for glass-meaning, corresponding to the cherry.

A mean index of sensitivity to meaning was computed from these criteria. For each participant and model, we coded 1 when a criterion was present for one meaning in conformity with the hypothesis and absent for the other meaning (e.g., *abd* drawn in sequence for the glass-meaning, but not for the man-meaning). The other combinations were coded 0. A mean degree of sensitivity to meaning by participant was thus computed, averaging across the criteria. This index is highly conservative because it considers the cases in which a criterion is present in response to both meanings to have the value 0. It assesses the sensitivity to meaning as it is expressed by the flexibility of drawing behavior at an intraindividual level.

RESULTS

Global Sensitivity to Meaning

The global sensitivity to meaning was assessed by means of an index that averaged the scores obtained for the different criteria set out in the method section. We conducted an ANOVA with age (6) and order (2) as between-participants factors and model (5) as a within-participant factor. Order did not introduce any significant main effect, $F < 1$, and did not interact with the other factors, $ps > .26$. This factor was therefore ignored in the subsequent model by model analysis. Figure 2 depicts the mean index of sensitivity to meaning as a function of age and model. Table 1 displays the means and the standard deviations for each value presented in the different figures reported in the present paper.

[3] An analysis based on the main drawing strategies produced by participants was also performed. It is not reported here because of the redundancy of the results obtained with the criterion-based analysis.

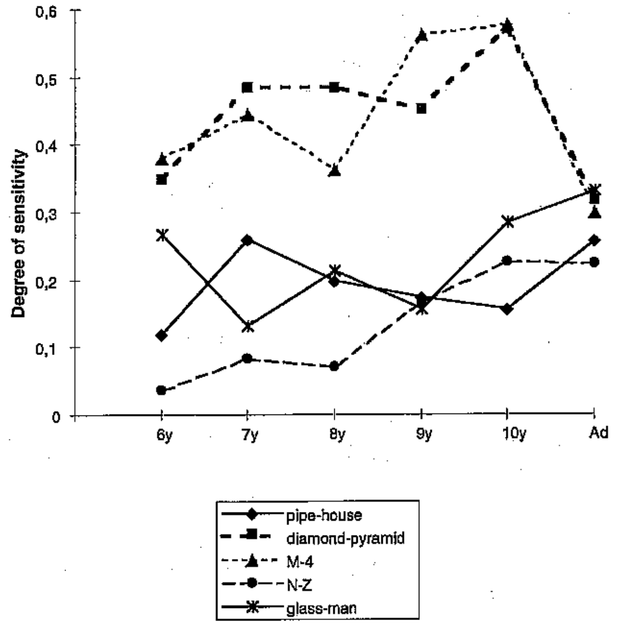

Figure 2 Mean degree of sensitivity to meaning as a function of age and models.

Sensitivity to meaning increased significantly with age, $F(5, 237) = 2.7, p < .05$. A mean index of .23 was recorded at 6 years, and the value reached .36 at 10 years. The scores of the oldest children were higher than those of adults (.36 versus .29), but the difference did not reach significance (Newman-Keuls test, $p = .10$). Considering that this index of sensitivity is conservative, the results are strong evidence that the drawing behavior of the participants was flexible enough to reflect, to a certain extent, the parsing induced by each meaning. The sensitivity to meaning was also highly dependent on the model, $F(4, 948) = 44.4, p < .001$, and the following average order between models was observed: N-Z (.13), pipe-house (.19), glass-man (.23), M-4 (.44), and pyramid-diamond (.44). Of greater interest is the significant age × model interaction, $F(20, 948) = 2.5, p < .001$. As shown in Figure 2, while the N-Z, M-4, and diamond-pyramid models induced a greater meaning effect with increasing age, this was not the case for the glass-man and pipe-house models, for which the effects were more stable across age. Furthermore, children showed two categories of response, those revealing a noticeable meaning effect (diamond-pyramid, M-4), and the others, showing a reduced effect; no such difference induced by the different models was observed in adults, who revealed a much more homogenous impact of meaning across the models. The significant age × model interaction justified a detailed analysis of the effect of meaning for each model.

Effect of Meaning for Each Model

The pipe-house model. Three analytical criteria were examined for this model. The effects of age and meaning can be seen in Figure 3. We expected the horizontal base (*ebc*) to be drawn more often in sequence for the pipe than for the house. The results (Figure 3, graph A) confirm this expectation, $F(1, 243) = 19.6, p < .001$. However, a significant age × meaning interaction, $F(5, 243) = 2.2, p < .05$, showed that the impact of meaning was verified only at 7 and 8 years and in adults, as confirmed by post-hoc tests (Newman-Keuls, $ps < .05$). No clear effect of meaning was recorded in the other age groups.

Second, we expected participants to draw the *abcd* block in sequence in the house condition. The results displayed in Figure 3 (graph B) confirm this hypothesis in adults, $F(1, 39) = 14.7, p < .001$, but not in children, as attested by a significant age × meaning interaction, $F(5, 243) = 2.6, p < .02$. The decreasing age trend was, however, significant for this criterion that involves threading behavior, $F(5, 243) = 6.5, p < .001$. Finally, we expected to observe the third criterion, which consisted of drawing the left part of the horizontal base *eb* without connecting it directly to the *abcd* block, in the house condition. The results (Figure 3, graph C) confirm this expectation, $F(1, 243) = 41.08, p < .001$. The age × meaning interaction was not significant, $F(5, 243) = 1.2, p = .29$, though the effect was lower at 6 and 9 years than at the other ages. A separate analysis of adults performance confirmed the presence of an impact of meaning, $F(1, 39) = 13, p < .001$.

The pyramid-diamond model. Three analytical criteria were defined for the present model, and Figure 4 shows the change in the frequency of their occurrence as a function of age and meaning.

The first criterion (graph A) coded the continuity in the drawing of the *abcd* unit, which, as expected, was more frequently observed in association with the diamond-meaning, $F(1, 243) = 139.4, p < .001$. This was also the case for adults analyzed separately, $F(1, 39) = 6, p < .02$. Although the effect appeared stronger in children than in adults, the age × meaning interaction failed to reach significance, $F(5, 243) = 1.7, p = 12$. The second criterion (graph B) coded separate production of the upper and lower parts of the *abcd* unit. In line with the expectancy of a meaning effect, this behavior was more frequently recorded in the pyramid condition, $F(1, 243) = 151.6, p < .001$. The effect was again present in adults considered separately, $F(1, 39) = 13, p < .001$, but the age ×

Table 1 Means and Standard Deviations (in Parentheses) of Each Value Reported in the Different Fgures (from Figure 2 to Figure 7)

	6 years	7 years	8 years	9 years	10 years	Adults
Mean Sensitivity (Fig. 2)						
Pipe-house	.12 (.15)	.26 (.14)	.19 (.18)	.17 (.16)	.15 (.13)	.25 (.20)
Diamond-pyramid	.34 (.18)	.48 (.20)	.48 (.18)	.45 (.17)	.57 (.16)	.31 (.15)
M-4	.34 (.24)	.35 (.24)	.31 (.23)	.59 (.25)	.59 (.25)	.35 (.24)
N-Z	.03 (.08)	.08 (.13)	.07 (.12)	.16 (.17)	.22 (.20)	.22 (.19)
Glass-man	.26 (.18)	.13 (.14)	.21 (.16)	.15 (.15)	.28 (.19)	.33 (.21)
Pipe-house model (Fig. 3)						
Pipe-meaning						
Criterion A	.83 (.19)	.83 (.18)	.93 (.13)	.80 (.19)	.64 (.24)	.95 (.11)
Criterion B	.83 (.19)	.74 (.22)	.50 (.25)	.59 (.25)	.59 (.24)	.27 (.22)
Criterion C	.00	.02 (.07)	.05 (.10)	.09 (.15)	.09 (.15)	.05 (.11)
House-meaning						
Criterion A	.80 (.20)	.52 (.25)	.78 (.20)	.74 (.22)	.59 (.25)	.70 (.23)
Criterion B	.73 (.22)	.81 (.20)	.45 (.25)	.59 (.25)	.50 (.25)	.55 (.25)
Criterion C	.12 (.16)	.31 (.23)	.24 (.21)	.19 (.20)	.26 (.22)	.30 (.23)
Diamond-pyramid model (Fig. 4)						
Diamond-meaning						
Criterion A	.63 (.24)	.66 (.23)	.59 (.25)	.57 (.25)	.57 (.25)	.40 (.25)
Criterion B	.36 (.24)	.33 (.23)	.40 (.25)	.43 (.25)	.43 (.25)	.60 (.24)
Criterion C	.70 (.23)	.76 (.21)	.54 (.25)	.62 (.25)	.70 (.23	.55 (.25)
Pyramid-meaning						
Criterion A	.29 (.23)	.19 (.20)	.12 (.16)	.14 (.17)	.09 (.15)	.20 (.20)
Criterion B	.71 (.23)	.81 (.20)	.88 (.16)	.86 (.17)	.90 (.15)	.85 (.18)
Criterion C	.44 (.25)	.38 (.25)	.21 (.20)	.19 (.20)	.07 (.13)	.20 (.20)
M-4 model (Fig. 5)						
M-meaning						
Criterion A	.92 (.13)	.76 (.21)	.76 (.21)	.62 (.25)	.69 (.23)	.25 (.21)
Criterion B	.88 (.16)	1.00 (.0)	.98 (.07)	.95 (.11)	.93 (.13)	1.00 (.0)
Criterion C	.05 (.10)	.02 (.07)	.00	.00	.02 (.07)	.05 (.11)
4-meaning						
Criterion A	.56 (.25)	.33 (.23)	.45 (.25)	.19 (.20)	.26 (.22)	.05 (.11)
Criterion B	.44 (.25)	.57 (.25)	.59 (.25)	.31 (.23)	.26 (.22)	.65 (.24)
Criterion C	.39 (.25)	.36 (.24)	.31 (.23)	.59 (.25)	.59 (.25)	.35 (.24)
N-Z model (Fig. 6)						
N-meaning						
Criterion A	.07 (.13)	.14 (.17)	.31 (.23)	.45 (.25)	.52 (.25)	.80 (.20)
Criterion B	1.09 (.37)	1.21 (.51)	1.52 (.67)	1.66 (.75)	1.73 (.73)	2.25 (.77)
Z-meaning						
Criterion A	.05 (.10)	.19 (.20)	.31 (.23)	.33 (.23)	.43 (.25)	.70 (.46)
Criterion B	1.09 (.37)	1.21 (.41)	1.42 (.63)	1.57 (.70)	1.59 (.73)	2.00 (.78)
Glass-man model (Fig. 7)						
Glass-meaning						
Criterion A	.14 (.16)	.07 (.13)	.12 (.16)	.05 (.10)	.05 (.10)	.05 (.11)
Criterion B	.61 (.25)	.76 (.22)	.74 (.22)	.86 (.17)	.66 (.23)	.70 (.23)
Criterion C	.80 (.20)	.88 (.16)	.93 (.13)	.95 (.10)	.90 (.15)	.80 (.20)
Man-meaning						
Criterion A	.27 (.22)	.21 (.20)	.16 (.18)	.07 (.13)	.26 (.22)	.30 (.23)
Criterion B	.44 (.25)	.66 (.23)	.52 (.25)	.71 (.22)	.36 (.24)	.30 (.23)
Criterion C	.56 (.25)	.81 (.20)	.66 (.23)	.81 (.20)	.62 (.25)	.80 (.20)

meaning interaction was not significant, $F(5, 243) = 1.3, p = .26$.

Finally, participants were expected to draw the horizontal bar *ef* at the end of the sequence in the diamond condition, and the results (Figure 4, graph C) provide evidence for this hypothesis, $F(1, 243) = 135.1, p < .001$. The effect was also significant in adults alone, $F(1, 39) = 14.5, p < .001$. Although the effect seemed lower at 6 and 9 years, the Age × Meaning interaction proved to be only marginally significant, $F(5, 243) = 2, p = .07$. Clearly, the way this pattern was parsed to drawing was highly sensitive to meaning, and the effect was much greater in the oldest children than in adults.

The M-4 model. Three analytical criteria were examined for this model. The first criterion required the *abcde* unit to be drawn in sequence without penlifts, whatever the order in which this sequence was per-

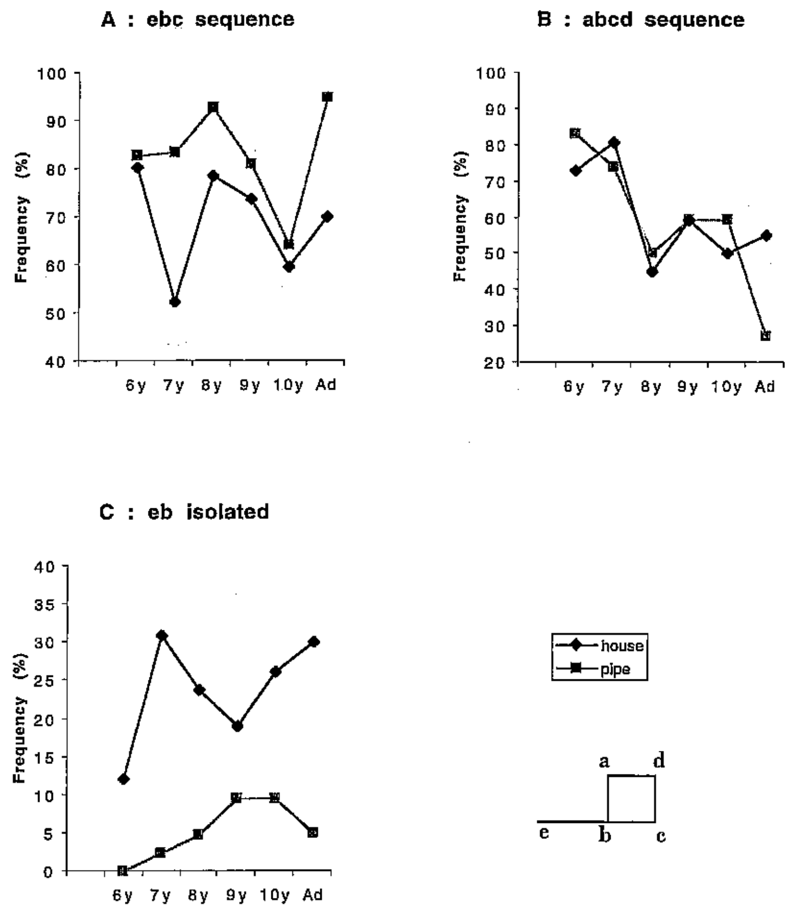

Figure 3 Mean frequency of occurrence (in %) of each criteria (A, B, C) defined for the pipe-house model as a function of age and meaning.

formed. Figure 5 (graph A) shows that, as expected, this behavior was mainly observed in association with the M-meaning, $F(1, 243) = 103.6, p < .001$. The effect was also significant in adults considered separately, $F(1, 39) = 9.7, p < .01$. No significant age × meaning interaction emerged, $F(5, 243) = 1.1, p = .35$. This criterion involves threading behavior, and graph A reveals a significant decreasing trend for its occurrence across age, $F(5, 243) = 15.2, p < .001$.

Children and adults tended to draw the horizontal bar *fg* after the *abcde* unit when the M-meaning was presented (graph B), $F(1, 243) = 227.8, p < .001$. A significant age × meaning interaction, $F(5, 243) = 3.0, p < .05$, shows that the impact of meaning for this criterion was stronger at 9 and 10 years than in younger children and adults; however, the effect was confirmed at all ages (Newman-Keuls test, $ps < .05$). A separate ANOVA conducted with adults only confirmed the presence of the effect in this group, $F(1, 39) = 21, p < .001$.

Finally, the third criterion concerned the decomposition of the *abcde* unit into two symmetrical parts, which we expected to be drawn separately in response to the 4-meaning. Figure 5 (graph C) shows that this behavior was sensitive to meaning as expected, $F(1, 243) = 156.9, p < .001$. It was more pronounced at 9 and 10 years than in 6- to 7-year-olds and adults, $F(5, 243) = 2.9, p < .01$. However, post-hoc comparison tests revealed significant meaning-induced differences at all ages (Newman-Keuls test, $ps < .05$). Again, the effect was globally higher in the oldest children than in adults, where it was nevertheless significant, $F(1, 39) = 11.3, p < .01$.

The letter N-letter Z model. The first criterion analyzed for the N-Z model required the left vertical *ab* to be drawn first in an isolated movement. Figure 6 (graph A) shows that the expected meaning effect in favor of the N interpretation proved to be only marginal, $F(1, 243) = 3.2, p < .07$, although it was valid for adults, $F(1, 39) = 4.3, p < .04$. The increasing trend with age reached significance for this criterion that involves discontinuity in drawing movement, $F(5, 243) = 17.4, p < .001$.

The N-meaning was expected to induce a higher number of drawing movements than the Z-meaning, due to syntax usually employed when these letters

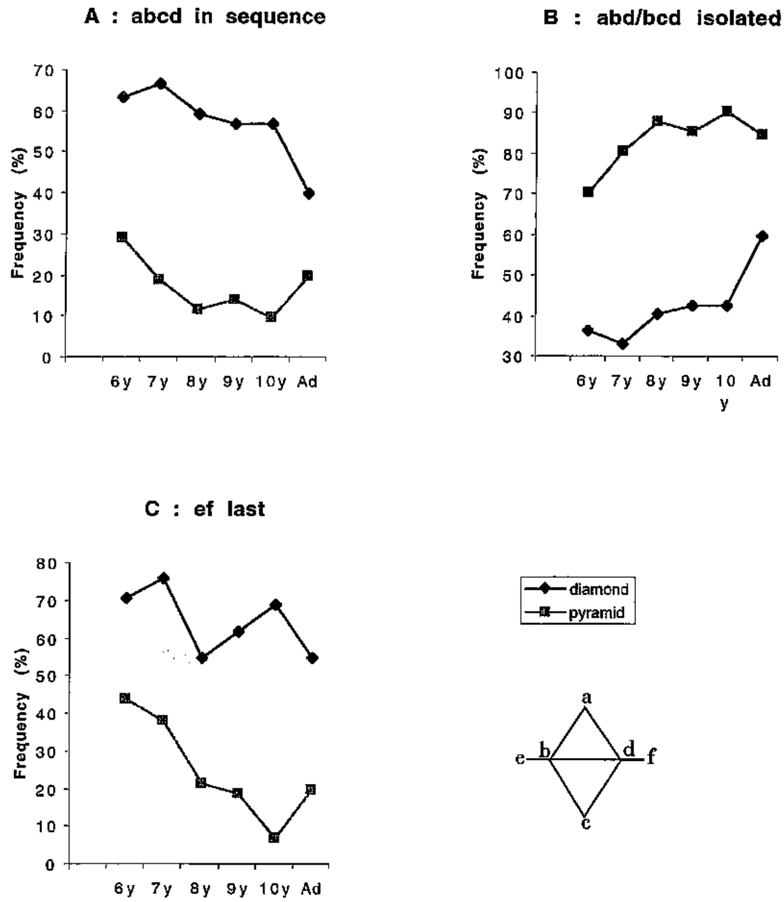

Figure 4 Mean frequency of occurrence (in %) of each criteria (A, B, C) defined for the diamond-pyramid model as a function of age and meaning.

are written as capitals. As illustrated in Figure 6 (graph B), the results supported this hypothesis, $F(1, 243) = 5.7, p < .01$. It was again verified in adults when a separate analysis was carried out, $F(1, 39) = 5$, $p < .03$. This second criterion is very close to the first one, and results revealed again a significant increasing trend over age for its occurrence, $F(5, 243) = 17.7$, $p < .001$. For both criteria, the age × meaning interaction was not significant.

The glass-man model. Three criteria were defined for this model. We examined whether the man-meaning more frequently caused participants to draw the *abd* unit (head, trunk-legs, and feet) in sequence, whatever its location in the overall sequence. Figure 7 (graph A) confirms a global sensitivity of this criterion to meaning, $F(1, 243) = 22, p < .001$. The age × meaning interaction failed to reach significance, $F(5, 243) = 1.6$, $p = .15$, although it was only at 10 years that the effect of meaning seemed noticeable. In adults, as expected, meaning had a clear impact for this criterion, $F(1, 39) = 8.5, p < .01$.

Drawing in sequence the *abc* unit, which could represent the glass, occurred more often in the glass-condition, $F(1, 243) = 42.5, p < .001$. As seen in graph B, this effect was observed more frequently at 10 years and in adults. Although the age × meaning interaction failed to reach significance, $F(5, 243) = 1.8$, $p = .10$, post-hoc comparisons (Newman-Keuls test) confirmed that the effect of meaning was significant only at 10 years and in adults (*ps* $< .05$). The last criterion, drawing the *de* unit (the cherry) in sequence, was more frequent in the glass condition. This behavior was quite commonly adopted by participants, $F(1, 243) = 43.2, p < .001$. The age × meaning interaction was not significant, $F(5, 243) = 1.2$, $p = .31$. The effect was present in adults alone, $F(1, 39) = 4.3, p < .05$. Note that we also checked a posteriori whether children tended to start more frequently with the unit *d* (the head) in response to the man-meaning than to the glass-meaning, as they usually do when drawing a human figure. It was the case at all ages, though this behavior was much less frequent than would be expected (6 years: 11 versus 6; 7 years: 7 versus 3; 8 years: 9 versus 5; 9 years: 7 versus 1; 10 years: 11 versus 3; adults: 14 versus 4). These low frequencies may be a consequence of the high schematism of our

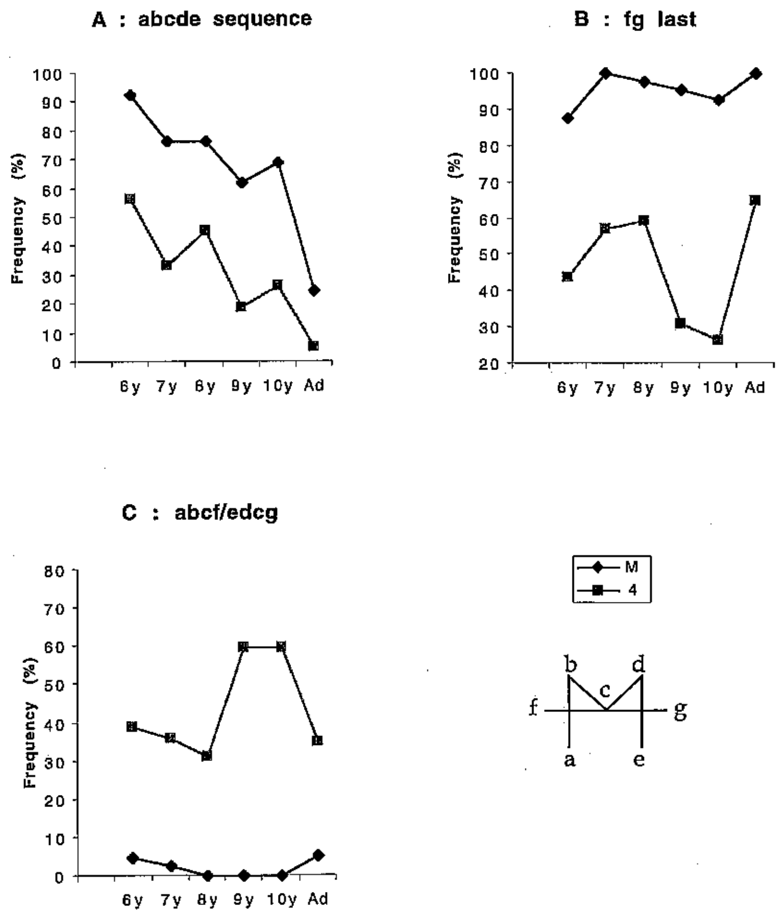

Figure 5 Mean frequency of occurrence (in %) of each criteria (A, B, C) defined for the M-4 model as a function of age and meaning.

model, which could have prevented participants from using their usual routines. Geometrical factors may also be invoked. In the standard condition of man-drawing, the head is the topmost part of the figure. In our model, the telescope is the topmost part, and the arms are at the same height as the head.

Summary of the main results. The present experiment showed that sensitivity to meaning generally increased with age, and developmental trends differed as a function of the type of model. The models that elicited a difference in syntax in conformity with meaning from 6 years onward were the M-4 and the diamond-pyramid models. However, for the former model, the effect was stronger at 9 and 10 years than at the other ages. In these models, one meaning could be expressed by delineating a unique representational unit by threading and the other by segmenting the model into two parts; neither, however, could be drawn entirely by threading, because of the horizontal stroke present in both. This need for the horizontal stoke could have induced the young children to segment the figure in conformity with meaning despite their strong tendency to thread. Indeed, the two other models that could be drawn entirely continously, even though one of their meanings should be expressed by discontinuity (pipe-house, N-Z), did not elicit any conclusive meaning effect at 6 years, probably because of the predominance of threading.

As shown by Figure 2, the sensitivity to meaning develops progressively with age for the N-Z model. A necessary condition for this development is the flexible use of threading, expected for the Z-meaning but not for the N-meaning. It was only at 10 years and in adults that an effect of meaning was noticeable in performance. This model was the only one for which the change of meaning did not suggest two different segmentations of the model, but a change in perspective. To perceive the Z-meaning, a mental rotation of the model is required. This was expected to be expressed through the progression of drawing movement.

As in the M-4 and pyramid-diamond models, the change of meaning in the pipe-house model suggested an opposition between one or two representational units. However, it did not give rise to the same clear developmental trend. The impact of meaning in-

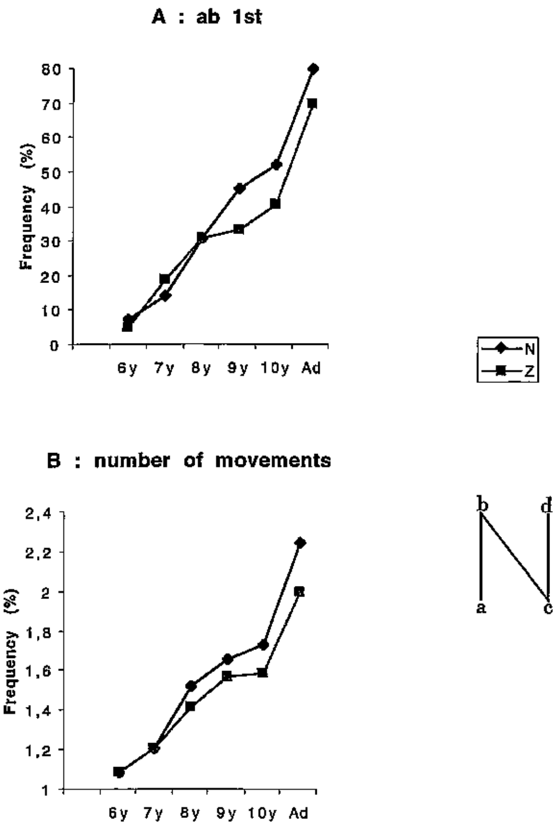

Figure 6 Mean frequency of occurrence (in %) of each criteria (A, B) defined for the N-Z model as a function of age and meaning.

creased between 6 and 7 years: a decrease of the tendency to thread facilitated the drawing of two units with the house-meaning. A consistent effect was yet still not observed in 8- and 9-year-old children, who appeared to adopt threading again. Only adults satisfied all the criteria defined for this model.

The last model, the glass-man, could not be drawn by threading and the change of meaning should affect stroke sequence. It induced globally a positive meaning effect when each criteria was analyzed. However, it seemed to exert a stronger positive meaning impact at 6 years than at 7, 8, 9 years (see Figure 2). This impact was similar to the one observed at 10 years and in adults. The youngest children obtained a rather high mean index of sensitivity because they satisfied the two criteria defined for testing for the impact of the glass-meaning (see graphs B and C of Figure 7). This is because they tended to anchor each element in a bottom-to-top progression, in which *abc* was drawn in sequence as well as *de*, thus satisfying two of the three criteria analyzed for this model. Such an anchored strategy could be functionally equivalent to threading (a continuous progression through adjacent strokes). The occurrence of this anchored strategy declined after 6 years; it was only at 10 years that all criteria were satisfied. It is therefore likely that for this model, the impact of meaning was incidentally increased at 6 years because of the use of anchoring.

DISCUSSION

Van Sommers (1984) has suggested that, in adults, the organization of movement sequences emerges from the cooperation or competition between two opposite forces: one acts in a bottom-up direction, regrouping geometrical and formal executive constraints (the graphic production rules, for example); the other operates in a top-down direction, the semantic force. Semantic considerations essentially determine the order of strokes, imposing a particular segmentation or parsing on the structure of the model; in some cases, semantically based movement sequences may lead to the violation of certain syntactical regularities dictated by the geometry of the model. The relations between semantics and syntax in children is therefore worth investigating because they offer a way of reconciling the *what* and the *how* of drawing and may help us to infer certain tendencies in the dynamics between the bottom-up and top-down influences that are active during behavioral development.

Before discussing the children's results, it is worth pointing out that most of the results described by Van Sommers (1984) have been replicated in our study. As in Van Sommer's study, the adults in our experiment tended to modify their movement sequences in conformity with semantics, and these sequences were organized on the basis of representationally defined units (e.g., the house and the shadow). The grouping of segments to form representational units was expressed through the order in which the segments were drawn. However, we observed a less strong meaning effect than he did. The two studies differed in several methodological points that may account for this difference: absence versus presence of distractors, number of models to draw, and intergroup versus intragroup design. This last point appears most important because, as we have already mentioned, the within-participants design assesses the sensitivity to meaning in terms of the flexibility of graphic behavior, and this assessment may therefore be partly contaminated by the rigidity of graphic procedures.

Various factors may account for the way meaning can influence graphic syntax during the developmental period studied in the present experiment. As expected, graphic rules acted as a strong bottom-up constraint on children's performance, sometimes

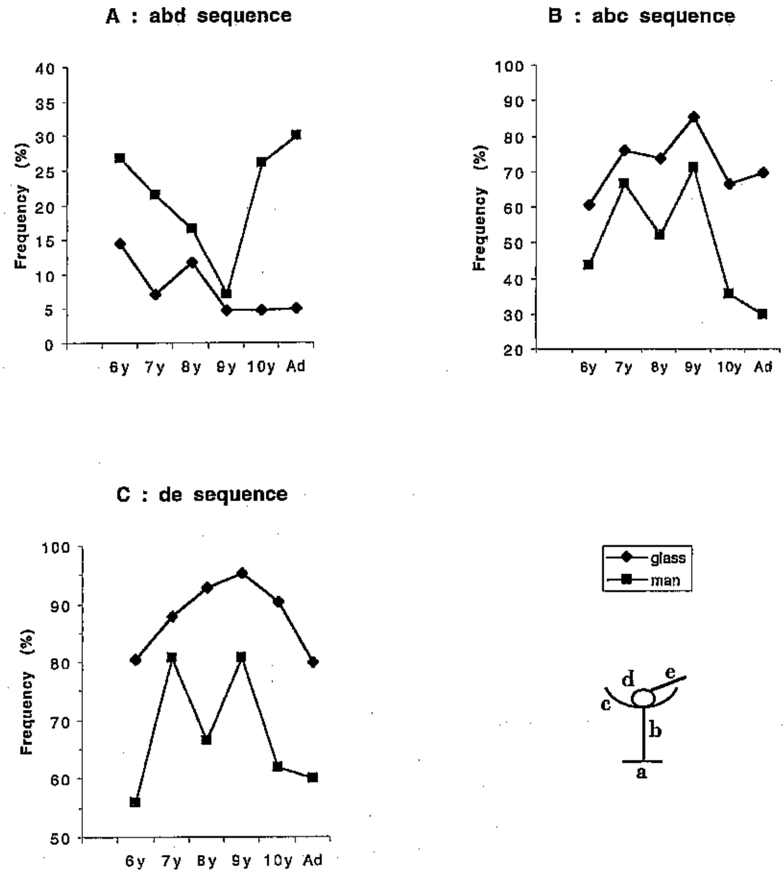

Figure 7 Mean frequency of occurrence (in %) of each criteria (A, B, C) defined for the glass-man model as a function of age and meaning.

favoring and sometimes preventing a meaning effect. At the youngest ages (6–7 years), where threading constituted a dominant feature of drawing, it exerted a positive effect when meaning could be expressed by continuity. The M-4 model provides a good illustration: meaning was expected to induce drawing the *abcd* unit in sequence, which was necessarily the case when threading; however, it exerted a negative effect when meaning required segmentation but the geometry of the model allowed a completely continuous drawing movement. A good example is provided by the house-meaning: segmentation was expected, although the model could be drawn continuously. At 8–9 years, the fact that threading constituted a weaker feature of drawing made it more possible for children to produce segmenting strategies. Note, however, that threading tended to be maintained in some cases, like for the pipe-house model, perhaps to guarantee drawing accuracy. Indeed, a qualitative inspection of the drawings showed that the discontinuous production of the house model at 7 years led to inaccurate drawings because of the difficulty these young children experienced in aligning *eb* and *bc* segments correctly. We hypothesize that 8- and 9-year-old children turned back to threading to ensure accurate production. The literature on handwriting development also reveals that 8- and 9-year-old children pay more attention to spatial aspects (shape and legibility of letters) than younger children (Meulenbroek & Van Galen, 1988; Mojet, 1991). In drawing, accuracy has been shown to depend on the graphic rules used (Goodnow, 1978; Taylor & Bacharach, 1982). Only at 10 years and in adulthood did threading lose its importance. Anchoring provided the second main syntactical constraint in our study. It incidentally favored a meaning effect at 6 years for the glass-meaning. However, in most cases, it had to be inhibited at certain key moments to permit the introduction of a discontinuity required by a parsing in conformity with meaning.

However, this first factor, the obedience to the graphic rules, does not fully account for the results. Why did the M-4 and pyramid-diamond models have a greater meaning effect than the other models at all ages? What was special about the N-Z model? A second determinant of drawing behavior is needed, and we suggest that it may be related to the types of representational units created by semantics and the capacity of children to use these units for planning their drawing movements. This determinant specifies what may be understood by top-down forces. The manipulation of meaning contrasts one single representational unit with two juxtaposed units in the pyramid-diamond, M-4, and pipe-house models, two differently embedded representational units in the glass-man model, and in the N-Z model, one single representational unit with its rotated image. What emerges from this analysis is that the degree of complexity of the meaning manipulation differs greatly across the models. The more difficult it was to decompose the model to express the meaning, the weaker the meaning effect was and the later the expected performance was observed during development. In the diamond-pyramid, M-4, and pipe-house models, the meanings that necessitate a decomposition of the model (pyramid, 4, and house) induce a segmentation into two units that correspond to easily perceivable juxtaposed parts of the model. A satisfactory level of adapted performance was recorded as early as 6 years for two of them: these young children were able to introduce appropriate discontinuities in their drawing in response to the 4 and diamond meanings, thereby demonstrating a certain degree of flexibility of their graphic routines. In the glass-man model, for which a significant meaning effect was observed only at 9–10 years, decomposition requires the management of the relations between each adjacent element and thus the mastery of the relations between the global figure and each element. In a copying task involving geometrical shapes, Vinter (1994) reported that a "figure-element based" planning level was not present before 9–10 years. Such a capacity would be required for meaning to have an impact in the glass-man model. In the case of N-Z model, participants have to understand the potentially meaningful value of movement direction to make it possible to simulate a transformation in their viewpoint on the model. They must thus master the relations between their own viewpoint and the figure itself. This appears to be most difficult. Results recorded in the literature on cube drawing may be cited here, since they also illustrate a passage from an "object-centred" point of view to a projective or "viewer-centred" point of view, the latter requiring the understanding of one's own viewpoint and appearing relatively late in development (Nicholls & Kennedy, 1992; Willats, 1977).

Two other potential influences need to be considered. We noted that the pipe-house and the glass-man models did not elicit a clear meaning effect at young ages. This could be due to the fact that the man and the house drawing correspond to typical, early established routines in young children. However, the dominant strategies exhibited by young children for these meanings are not those expected within this perspective. As shown by Figure 3 (graphs A and B), 6-year-old children predominantly drew the house model using a *ebcdab* sequence. This is not typical of the drawing of the house. If we consider the glass-man model, it appears that no clear strategy dominated for the man-drawing while the glass-meaning induced a frequent bottom-to-top anchored strategy. It would therefore be necessary to postulate that the strong schematization of our models prevented the children from using their familiar routines and consequently prevented the familiar meaning from having an impact. This could have contributed to reducing the impact of meaning for the two models in question.

One last determinant is that these two models (pipe-house and glass-man) depict realistic concrete objects while the others represent more abstract geometrical forms. This difference could have affected the role of meaning in performance. Sensitivity to meaning might be facilitated in the case of realistic objects while geometrical constraints might dominate in the case of geometrical designs. However, the results are not consistent with this hypothesis. The strongest effects were obtained for the M-4 and pyramid-diamond models and the lowest, on average, for the N-Z model, all geometrical models. At present, the extent to which such a factor played a role in our drawing task needs further empirical investigation.

In conclusion, the present study suggests that how meaning modifies drawing behavior in children is a complex function of essentially two factors. The first one describes the extent to which a rigid dominance of bottom-up forces, represented by graphic syntax and dependent on geometry and executive constraints, operates on behavior. The results suggest that as long as the bottom-up forces, on the one hand, and those pertaining to semantics, on the other, are acting in the same direction, the drawing behavior of even young children may appear flexible and open to semantic influence. Procedural flexibility in the graphic routines of young children was also reported in a recent study (Zhi, Thomas, & Robinson, 1997). However, if a conflict arises, the bottom-up influences take priority over top-down influences, and drawing behavior appears to be less flexible in young children (6–7 years) than among older children (10 years), a period of transition appearing at around 8 and 9 years. The strong dominance of some graphic rules at certain ages may prevent children from modifying their graphic strategies to convey different meanings. It is only when the bottom-up influences have produced a stable flexible behavior that they can be counteracted by top-down forces. At that point, children may not use threading or anchoring because of the parsing imposed by meaning, even if the geometry of the model or their own dominant tendency would dictate another approach. A similar conclusion can be drawn from Karmiloff-Smith's (1992) model, which suggests that behavior is not transformed by top-down processes until a satisfactory level of behavioral mastery has been attained by means of bottom-up processes. Consequently, at the *how* level, young children may sometimes not draw "what they know" but rather "what they see," what they see being understood in relation to the geometrical constraints contained in the model.

The second factor relates to the nature of the internal representational units children are able to elaborate and use for planning their behavior. The manipulation of meaning in our task favored a certain parsing of the model, relying on representational units of different complexity: juxtaposed units for the 4-meaning for instance, embedded units relying on different part-whole relations for the man- or glass-meaning. Modifications in the type of representational units used for planning behavior occur during development and, at least partially, account for the progressive increase of sensitivity to meaning observed in children. Transitions from "element-based" to "figure-based" toward "figure-element-based" planning have been suggested elsewhere (Vinter & Picard, 1996), the first type relying on isolated representational units, the last one on units decomposable on the basis of part-whole relations (see also Mounoud, 1984; Vinter, 1990). We suggest that the type of representational units children are able to elaborate largely determines the *what* of drawing, which may guide the *how* level and counteract bottom-up forces. In this perspective, at the *what* level, children would always draw what they know rather than what they see. The same was recently shown to be true in adults (Cohen & Bennett, 1997). How reality is parsed into representational units constitutes a key question in cognitive developmental psychology (Perruchet & Vinter, 1997), and the present study shows that the investigation of drawing behavior provides relevant information for this question.

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REFERENCES

Barinaga, M. (1997). Visual system provides clues to how the brain perceives. *Science, 275,* 1583–1585.

Barrett, M., Beaumont, A., & Jennett, M. (1985). Some children do sometimes what they have been told to do: Task demands and verbal instructions in children's drawings. In N. H. Freeman & M. V. Cox (Eds.), *Visual order: The nature and development of pictorial representation.* Cambridge: Cambridge University Press.

Barrett, M., & Eames, K. (1996). Sequential developments in children's human figure drawing. *British Journal of Developmental Psychology, 14,* 219–236.

Barrett, M, & Light, P. H. (1976). Symbolism and intellectual realism in children's drawings. *British Journal of Educational Psychology, 46,* 198–202.

Beal, C. R., & Arnold, D. S. (1990). The effect of instructions on view-specificity in young children's drawing and picture selection. *British Journal of Developmental Psychology, 8,* 393–400.

Caron-Pargue, J. (1985). *Le dessin du cube chez l'enfant.* Berne: Peter Lang.

Cohen, D., & Bennett, S. (1997). Why can't most people draw what they see? *Journal of Experimental Psychology: Human Perception and Performance, 23,* 609–621.

Cox, M.V. (1981). One thing behind another: problems of representation in young children's drawings. *Educational Psychology, 1,* 275–287.

Cox, M. V. (1985). One object behind another: young children's use of array-specific or view-specific representations. In N. H. Freeman & M. V. Cox (Eds.), *Visual order: the nature and development of pictorial representation.* Cambridge: Cambridge University Press.

Cox, M. V. (1992). *Children's drawings.* Harmondsworth: Penguin.

Crook, C. (1985). Knowledge and appearance. In N. H. Freeman & M. V. Cox (Eds.), *Visual order: the nature and development of pictorial representation.* Cambridge: Cambridge University Press.

Davis, A. M. (1983). Contextual sensitivity in young children's drawings. *Journal of Experimental Child Psychology, 35,* 478–486.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Reviews of Neuroscience, 18,* 193.

Fenson, L. (1985). The transition from construction to sketching in children's drawings. In N. H. Freeman & M. V. Cox (Eds.), *Visual order: The nature and development of pictorial representation.* Cambridge: Cambridge University Press.

Freeman, N. H. (1980). *Strategies of representation in young children.* New York: Academic Press.

Freeman, N. H. (1993). Drawing: Public instruments of representation. In C. Pratt & A. F. Garton (Eds.), *Systems of representation in children*. Chichester: Wiley & Sons.

Freeman, N. H., Janikoun, R. (1972). Intellectual realism in children's drawings of a familiar object with distinctive features. *Child Development, 43*, 1116–1121.

Goldstone, R. L. (1995). Effects of categorization on color perception. *Psychological Science, 6*, 298–304.

Goodnow, J. (1978). Visible thinking: Cognitive aspects of change in drawings. *Child Development, 49*, 637–641.

Goodnow, J., & Levine, R. A. (1973). The "grammar of action": Sequence and syntax in children's copying behavior. *Cognitive Psychology, 4*, 82–98.

Ingram, N. (1985). Three into two won't go: symbolic and spatial coding processes in young children's drawings. In N. H. Freeman & M. V. Cox (Eds.), *Visual order: The nature and development of pictorial representation*. Cambridge: Cambridge University Press.

Karmiloff-Smith, A. (1990). Constraints on representational change: Evidence from children's drawing. *Cognition, 34*, 57–83.

Karmiloff-Smith, A. (1992). *Beyond modularity: a developmental perspective on cognitive science*. Cambridge, MA: MIT Press.

Karmiloff-Smith, A. (1994). Precis of Beyond modularity: A developmental perspective on cognitive science. *Behavioral and Brain Sciences, 17*, 693–745.

Kellogg, R. (1969). *Analyzing children's art*. Palo Alto, CA: Mayfield.

Light, P., & McEwen, F. (1987). Drawings as messages: The effect of a communicative game upon production of view-specific drawings. *British Journal of Developmental Psychology, 5*, 53–60.

Luquet, G. H. (1927). *Le dessin enfantin*. Paris: Alcan.

Marteniuk, R. G., MacKenzie, C. L., Jeannerod, M., Athenes, S., & Dugas, C. (1987). Constraints on human arm movement trajectories. *Canadian Journal of Psychology, 41*, 365–378.

Meulenbroek, R. G. J., & Van Galen, G. P. (1986). Movement analysis of repetitive writing behavior of 1st, 2nd and 3rd grade primary school children. In H. S. R. Kao, G. P. Van Galen, & R. Hoosain (Eds.), *Graphonomics: Contemporary research in handwriting*. Amsterdam: North-Holland.

Meulenbroek, R. G. J., & Van Galen, G. P. (1988). The acquisition of skilled handwriting: discontinuous trends in kinematic variables. In A. M. Colley & J. R. Beech (Eds.), *Cognition and action in skilled behavior*. Amsterdam: North-Holland.

Minary, F., & Vinter, A. (1996). The drawing of complex geometrical figures by children: How graphic strategies may be related to chronological age. In M. L. Simner, C. G. Leedham, & A. J. W. Thomassen (Eds.), *Handwriting and drawing research: basic and applied issues*. Amsterdam: IOS Press.

Mojet, J. W. (1991). Characteristics of the developing handwriting skill in elementary education. In J. Wann, A. M. Wing, & N. Sovik (Eds.), *Development of graphic skills*. London: Academic Press.

Moore, V. (1987). The influence of experience in children's drawings of a familiar and unfamiliar object. *British Journal of Developmental Psychology, 5*, 221–229.

Motter, B. C. (1994). Neural correlates of attentive selection for color or luminance in extrastriate area V4. *Journal of Neurosience, 14*, 2178.

Mounoud, P. (1984). A point of view on ontogeny. *Human Development, 27*, 329–334.

Nachson, I. (1983). Directional preferences of bilingual children. *Perceptual and Motor Skills, 56*, 747–750.

Nicholls, A. L., & Kennedy, J. M. (1992). Drawing development: From similarity of features to direction. *Child Development, 63*, 227–241.

Nihei, Y. (1983). Developmental change in covert principles for the organization of strokes in drawing and handwriting. *Acta Psychologica, 54*, 221–232.

Ninio, A., & Lieblich, A. (1976). The grammar of action: Phrase structure in children's copying. *Child Development, 47*, 846–849.

Osterrieth, P. (1976). L'étude du dessin enfantin. In H. Gratiot-Alphandery & R. Zazzo (Eds.), *Traité de psychologie de l'enfant*. Paris: PUF.

Perruchet, P., & Vinter, A. (1997). Learning and development: The implicit knowledge assumption reconsidered. In M. I. Stadler & P. A. Frensch (Eds.), *Handbook of implicit learning*. Thousand Oaks, CA: Sage Publications.

Petersen, M. A., & Gibson, B. S. (1994). Must figure-ground organization precede object recognition?: An assumption in peril. *Psychological Science, 5*, 253–259.

Piaget, J., & Inhelder, B. (1956). *The child's conception of space*. London: Routledge & Kegan Paul.

Simner, M. L. (1981). The grammar of action and children's printing. *Developmental Psychology, 47*, 846–849.

Simner, M. L. (1984). The grammar of action and children's printing. *Developmental Psychology, 20*, 136–142.

Taylor, M., & Bacharach, V. R. (1982). Constraints on the visual accuracy of drawings produced by young children. *Journal of Experimental Child Psychology, 34*, 311–329.

Thomassen, A. J. W., & Teulings, H. L. (1979). The development of directional preference in writing movements. *Visible Language, 13*, 299–313.

Thomassen, A. J. W., & Tibosh, H. J. C. (1991). A quantitative model of graphic production. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor neuroscience*. Dordrecht: Kluwer.

Van Sommers, P. (1984). *Drawing and cognition*. Cambridge: Cambridge University Press.

Van Sommers, P. (1989). A system for drawing and drawing-related neuropsychology. *Cognitive Neuropsychology, 6*, 117–164.

Vinter, A. (1990). Manual imitations and reaching behaviors: An illustration of action control in infancy. In C. Bard, M. Fleury, & L. Hay (Eds.)., *Eye-hand coordination across the life span*. Columbia: University of South Carolina Press.

Vinter, A. (1994). Hierarchy among graphic production rules: A developmental approach. In C. Faure, P. Keuss, G. Lorette, & A. Vinter (Eds)., *Advances in handwriting and drawing: A multidisciplinary approach*. Paris: Europia.

Vinter, A., & Meulenbroek, R. G. J. (1993). The role of manual dominance and visual feedback in circular drawing movements. *Journal of Human Movement Studies, 25*, 11–37.

Vinter, A., & Mounoud, P. (1991). Isochrony and accuracy of drawing movements in children: effects of age and context. In J. Wann, A. M. Wing, & N. Sovik (Eds.), *Development of graphic skills*. London: Academic Press.

Vinter, A., & Perruchet, P. (1994). Is there an implicit level of representation? *Behavioral and Brain Sciences, 17*, 730–731.

Vinter, A., & Picard, D. (1996). Drawing behavior in children reflects internal representational changes. In M. L. Simner, C. G. Leedham, & A. J. W. Thomassen (Eds.), *Handwriting and drawing research: Basic and applied issues*. Amsterdam: IOS Press.

Willats, J. (1977). How children learn to draw realistic pictures. *Quarterly Journal of Experimental Psychology, 29*, 367–387.

Willats, J. (1984). Getting the drawing to look right as well as to be right: The interaction between production and perception as a mechanism of development. In W. R. Crozier & A. J. Chapman (Eds.), *Cognitive processes in the perception of art*. Amsterdam: North-Holland.

Zhi, Z., Thomas, G. V., & Robinson, E. J. (1997). Constraints on representational change: Drawing a man with two heads. *British Journal of Developmental Psychology, 15*, 275–290.