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Relationships Between Procedural Rigidity and Interrepresentational Change in Children's Drawing Behavior

Delphine Picard
University of Montpellier III

Annie Vinter
University of Bourgogne, France

The present experiments were aimed at testing Karmiloff-Smith's (1992) assumption that representational flexibility in drawing behavior requires the relaxation of a sequential constraint. A total of two hundred and forty 5- to 9-year-old children produced cross-category drawings (e.g., a house with wings) in 4 conditions. The results indicated that procedural rigidity declined as representational change improved. The decline in procedural rigidity occurred before representational change attained its highest level. This decline was related to a greater ability to manage early interruptions of the procedures, not to a greater ability to modify the usual feature sequencing. It was concluded that rigidity in routine development could act as a sequential constraint on interrepresentational change.

Drawing behavior has the dual characteristic of being an offline product and an online process. The former relates to the representational content that can be inferred from the marks left on the paper; the latter refers to the sequential organization of the movements through which a drawing is gradually produced (see for instance Goodnow & Levine, 1973). Karmiloff-Smith (1990) developed an original perspective in which the dual nature of drawing behavior is used to illustrate important modifications in the representational and procedural systems that take place during development. She asked children who had acquired full behavioral control over how to draw certain familiar objects to introduce innovations in their habitual way of drawing them (draw "nonexistent objects"). Both a stable endproduct (e.g., a canonical drawing of a familiar object) and a stable online process (in terms of the sequencing of graphic units) was taken as evidence of full behavioral control of drawing. On the basis of these criteria, children as young as 5 demonstrated behavioral control. For instance, children aged 5 usually draw a house starting with a squared body and a triangular roof. They then go on drawing the chimney (often attached perpendicular to the roof) and windows and door inside the body (windows being often attached to the corners of the body) (see also Picard & Vinter, 2005).

Karmiloff-Smith (1990) showed that the changes introduced by young children (4 – 6 years) in response to the "draw nonexistent objects" instructions involved deletions and changes in the size and shape of elements (intrarepresentational innovations). Older children (8 – 10 years) changed the position and orientation of elements and added elements from other conceptual categories, resulting in greater interrepresentational flexibility. Interrepresentational innovations involved the insertion of elements from a different conceptual category; they consisted, for instance, in drawing a house with wings or a man with horse legs. In contrast, intrarepresentational changes were confined to the components of a given graphic representation; these innovations consisted, for instance, in drawing a house without windows and door (deletion), or a house with oval windows (change of shape of elements). Karmiloff-Smith (1990) further reported that the innovations produced by the young children were subject to a sequential constraint (a sequentially fixed ordering of elements inherent in the procedural level), whereas the older children's ability to establish interrepresentational links was associated with the relaxation of this sequential constraint.

Fitting these findings into her developmental model, Karmiloff-Smith (1992) accounted for them in terms of a transition from an implicit to an explicit level of knowledge (E1). The implicit level corresponds to the phase where children possess well-established graphic routines in which elements are drawn in a fixed order. The explicit level is attained when graphic routines become flexible and available to each other. This transition occurs through what she called a representational redescription (RR) process, an endogenous process that intervenes once

Correspondence concerning this article should be addressed to Delphine Picard, Department of Psychology, University of Montpellier III, Route de Mende, 34199 Montpellier, France. Electronic mail may be sent to delphine.picard@univ-montp3.fr.

the child has reached behavioral mastery in one domain. The RR process frees the graphic routines of two constraints that are present at the implicit level: a constraint of independence, occurring between routines (so that they cannot share common pieces of knowledge), and a constraint of sequentiality, occurring within a routine (so that it cannot be run with deviations from its sequential schema). A main point in this model is that representational change remains limited as long as the sequential constraint is in effect.

Karmiloff-Smith's (1992) influential model, which tackles the general question of cognitive development and its possible application to drawing, gave rise to a large number of studies on children's graphic innovation abilities (Barlow, Jolley, White, & Galbraith, 2003; Berti & Freeman, 1997; Phillips, Halford, & Wilson, 1998; Picard & Vinter, 1999; Spensley & Taylor, 1999; Vinter & Picard, 1996; Zhi, Thomas, & Robinson, 1997). As a whole, these studies showed that (1) the constraint of independence between routines suggested by Karmiloff-Smith can indeed account for increasing representational changes with age, although sensitivity to verbal drawing instructions is thought to play a role, (2) the constraint of sequentiality within routines is not as strong as it was assumed to be, although the experimental findings lead to different conclusions on this issue, and (3) the role of a sequential constraint on representational change is not as clear-cut as predicted.

Regarding the constraint of independence between routines, studies replicating Karmiloff-Smith's original experiment involving general drawing instructions (1990; Berti & Freeman, 1997; Spensley & Taylor, 1999; Vinter & Picard, 1996) confirmed that interrepresentational changes (i.e., changes based on the crossing of categorical boundaries within the representation system) emerge late in age, at around 9–10 years. By contrast, intrarepresentational flexibility was present at an early age (4–5 years). Intrarepresentational flexibility was related to changes confined to the components of a given graphic representation, and evolved from element-based modifications (5 years) to whole-based (7 years) and part–whole-based (9 years) modifications of the habitual drawing schema (see Vinter & Marot, 2007, for a similar evolution in a different drawing task). For instance, element-based modifications consisted in drawing a house with oval windows. Whole-based modifications consisted in drawing a house with a global oval shape for instance. Part–whole-based modifications consisted in drawing a house with the roof instead of the body, windows inside the body with chimney on top, and door inside the roof for instance. However, providing children with more specific drawing instructions than Karmiloff-Smith's "nonexistent objects" instructions allowed interrepresentational changes to be observed in very young children (see Berti & Freeman, 1997; Spensley & Taylor, 1999).

Investigations carried out at the procedural level have provided evidence against the idea that drawing can be thought of as a "compiled procedure", that is, the procedure cannot be interrupted once initiated (as first proposed by Karmiloff-Smith, 1990, but then revised by the author herself, 1992, 1999). Children as young as five were indeed shown to interrupt midprocedure to insert novelty in a variety of drawing tasks: drawing "nonexistent objects" (Spensley & Taylor, 1999; Vinter & Picard, 1996), "a man with two heads" (Berti & Freeman, 1997; Spensley & Taylor, 1999; Zhi et al., 1997), an object "with something missing" (Berti & Freeman, 1997; Picard & Vinter, 1999; Spensley & Taylor, 1999), and "a man that resembles an animal" (Berti & Freeman, 1997; Spensley & Taylor, 1999). However, some data have confirmed that interruptions of a familiar routine at its very beginning increased between 5 and 7 years of age while end-routine modifications decreased at the same period under conventional nonexistent objects' drawing instructions (Vinter & Picard, 1996).

Moreover, attempts to address the question of a potentially fixed ordering of the elements in a routine have led to inconsistent conclusions, depending on how the behaviors were measured. For instance, Spensley and Taylor (1999) assessed the order of all elements depicted under normal and innovation drawing conditions and found little evidence of procedural rigidity. By contrast, Zhi et al. (1997) recorded the drawing order of the basic elements only and found evidence of a sequentially ordered routine in young children. Recently, Barlow et al. (2003) examined the number of pairs of elements drawn in a same order in three successive free drawings of a familiar object (a man). The authors reported that the routine was held relatively constant across drawings, suggesting that a sequential constraint could apply to this drawing behavior. This last experiment supports Karmiloff-Smith's (1999) proposal that there might be a series of subroutines in children for drawing familiar objects rather than a whole rigid routine.

The relationships between flexibility expressed at the representational and procedural levels appear somewhat obscure. Some data seem to indicate that representational flexibility, at least when operating within a given level (intrarepresentational), does not change fundamentally as a function of the load incurred by the procedural aspects of the drawing activity. Picard and Vinter (1999) compared children's ability to produce graphic deletions in a conventional context (children drew partially visible objects based on verbal requirements) and in a context that minimizes the cost due to the very act of drawing (children produced deletions with an eraser on predrawn models). They found that young children did not produce more sophisticated graphic deletions in the latter than in the former contexts.

Researches have found little evidence indicating that the relatively fixed ordering of drawing features in usual graphic routines acts as a sequential constraint on representational change. Barlow et al. (2003) showed that the level of procedural rigidity observed in children's usual graphic routines of a familiar object (a man) did not significantly predict their ability to produce representational modifications in a subsequent task (e.g., drawing a man holding a ball with both hands). Zhi et al. (1997) observed that the majority of the children (3–4 years old) did not modify the order in which they usually drew components of the man when they depicted a man with two heads. Interestingly, this similar ordering occurred whether children succeeded or failed at the innovation task.

By contrast, researches have found evidence to suggest that representational change could be limited by a sequential constraint involving reticence at interrupting a usual graphic routine early in the drawing. For instance, Zhi et al. (1997) observed that, in young children, failure at drawing a man with two heads was associated with the drawing of two complete men, as if, once activated, the man drawing procedure had to be run in its entirety. By contrast, they showed that success at the task was associated with early insertions of the second head. Picard and Vinter (1999) noted similar associations between sophisticated deletions and early routine interruptions.

These studies were mainly concerned with simple representational modifications occurring at the intrarepresentational level. It is likely that these modifications were not complex enough to necessitate the relaxation of a sequential constraint linked to a relatively fixed ordering of elements within a routine. According to the RR model, independence between routines and sequentiality within drawing routines are simultaneously relaxed at level E1 and beyond. Karmiloff-Smith suggested that intra- and interrepresentational both necessitate E1 level RR. Interrepresentational flexibility results from the crossing of categorical boundaries within the representation system, and therefore testifies to the violation of the constraint of independence between representations. Intrarepresentational flexibility was found to emerge earlier in children than interrepresentational flexibility (Vinter & Picard, 1996). In our view, intrarepresentational flexibility does not necessarily require the relaxation of the constraint of independence between representations, as the innovations are produced within a single (and potentially independent) representation. It is therefore possible that the role played by a sequential constraint in children's ability to produce representational changes in drawings is restricted to the interrepresentational level mainly. It is also possible that the relatively fixed sequencing of elements within a usual routine does not act as a sequential constraint, whatever the complexity of the representational change, and that the sequential constraint concerns only the child's ability to produce early interruptions of a usual routine. Focusing on interrepresentational changes constitutes a relevant alternative way to explore this possibility.

The extent to which a sequential constraint (involving the conservation of a fixed pairing of elements in the usual routine and/or the complete development of a usual routine before an innovation is introduced) can limit the expression of interrepresentational flexibility in drawing is the main issue addressed in this paper. Four studies are reported. In all four, 5- to 9-year-old children had to produce cross-category insertions (e.g., a house with wings), but different drawing conditions were set up. The drawing conditions varied qualitatively as a function of the nature of the drawing activity. They also each incurred a certain cost in terms of representational and procedural demands. In Experiment 1, a free drawing context was used. This condition clearly implies that children rely on established routines, and has the highest cost in terms of representational and procedural demands. In the other three studies, external models of cross-categorical objects were provided to the children.

Little attention has been paid to the impact of the availability of external models at both the representational and procedural levels of children's drawing behavior although some research has been carried out involving external models (e.g., three-dimensional [3D] miniaturized model of a man holding a ball, Barlow et al., 2003; line drawing, or clay models of a woman with two heads, Zhi et al., 1997). The models were put out of view when children were verbally instructed to draw the modified objects. Karmiloff-Smith (1990) used a copying-from-model task in her follow-up experiment to check whether a small group of 5-year-old children ($n = 8$) were able to draw a man with two heads from a model (presumably, a line drawing model). In the present study, children drew cross-categorical objects with different kinds of external models in view. Examining drawings based on different external models may provide further insight into the relationships between flexibility at the representational and at the procedural levels and could lead to further insights concerning Karmiloff-Smith's views.

The external models were clay objects (Experiment 2), photographs of the clay objects (Experiment 3), and two-dimensional (2D) line drawings of the objects (Experiment 4). Children's differential sensitivity to external models has already been well documented in the drawing literature (see for example Bremner, Morse, Hughes, & Andreasen, 2000; Chen, 1985; Cox, 1992; Picard & Durand, 2005). In comparison with the free drawing condition (Experiment 1), drawing from a 3D model (Experiment 2) reduces the cost of imagining how to modify an object to make it strange. But it does not eliminate the cost of performing relatively complex operations to transform what is seen into a drawing. Also, when drawing 3D objects, children need to be aware of conventions for portraying depth, and need to attend to appearance (Chen, 1985). Drawing from photographs (Experiment 3) has a lower cost due to the fact that 3D information has already been translated into 2D information on the paper. However, even when photographs are available, children still have to break the pictures down into a set of representational units and convert the object's boundaries into lines. Finally, copying 2D line drawings (Experiment 4) eliminates the cost of converting boundaries into lines, and has the lowest cost in terms of representational and procedural demands among the four drawing conditions. This last drawing condition requires mainly that children figure out how to replicate an already visible 2D pattern (Chen, 1985).

Comparisons between the four drawing conditions make it possible to assess the extent to which gradually changing the nature of the drawing task promotes representational change and/or procedural rigidity. In each drawing condition, we measured a score for representational change and two scores for procedural rigidity that correspond to each facet of Karmiloff-Smith's potential sequential constraint and assessed the relations between these scores. The first measure of procedural rigidity, *routine conservation*, provides an indication of the amount of feature sequencing that remained unchanged between the normal (baseline) and the modified drawings. The second measure, *routine development*, informed us about how much of the routine was produced before interruption. We hypothesized that if a sequential constraint acts as an inhibitor for interrepresentational change, then scores for representational change and procedural rigidity should be negatively correlated: the greater the representational flexibility, the lower procedural rigidity. From a developmental perspective, the increase with age in representational scores should be a concomitant of a decrease with age in scores for procedural rigidity. This pattern of results was expected in the free drawing condition (Experiment 1) as the task has the highest cost in terms of representational and procedural demand. When the drawing task was gradually made easier to the child (Experiment 2 to Experiment 4), scores for representational change should gradually improve with age up to ceiling scores, while scores for procedural rigidity should gradually decrease with age up to their lowest level. If the two phenomena are concomitant, then relaxation of a sequential constraint can be considered as necessary for the expression of interrepresentational flexibility.

Experiment 1: Drawing From Imagination

We designed Experiment 1 to investigate 5- to 9-year-old children's ability to make cross-category insertions in a free-drawing context. We used two familiar categories of objects (house and mushroom) and asked the children to make two types of cross-category insertions (simple and complex). The two object categories were familiar to the children and could be adequately drawn from the age of 5 on. Although children have reached behavioral mastery for the drawing of the two objects, the house is a more often practiced figure than the mushroom in their daily drawing activity. Moreover, the two objects differed in terms of number of features to be put in a sequence. The mushroom, given its small number of features, could induce more rigid routines than the house. Indeed, the small number of features to be put in a sequence for the mushroom drawing reduces the "degrees of freedom" available to the child. The simple cross-category insertions involved drawing a "house with wings" and a "mushroom with arms." These drawings can be produced quite easily by children as young as five (see Berti & Freeman, 1997) by adding the extracategorical features (wings, arms) to the core features of the objects (house frame, mushroom stem) at the end of the routine. The complex cross-category insertions involved drawing a "boot-house" and a "castle mushroom." These complex drawings required higher level modifications of the objects, at both the representational and procedural levels.

Our main hypothesis assumed that scores for representational change would increase with age, and that this increase would be a concomitant of a decrease with age in scores for procedural rigidity. Scores for procedural rigidity could also vary as a function of the object—being higher for the mushroom than for the house drawing, and according to the type of cross-category insertion—being higher for simple than for complex cross-category insertions.

Method

Participants. Sixty right-handed children participated in Experiment 1. They were twenty 5-year-olds (10 girls and 10 boys, mean age = 5.5), twenty 7-year-olds (11 girls and 9 boys, mean age = 7.4), and twenty 9-year-olds (12 girls and 8 boys, mean age = 9.5). None of the children were ahead or behind in school, or had any psychomotor drawing or handwriting disorders. Their vision was normal or corrected to normal. Children were essentially Caucasian and from middle socioeconomic status (SES) families. They were observed individually in a quiet room inside their school, with both active parental consent and assent.

Materials. No specific materials were required for the experiment, except white sheets of paper (size: 21 cm × 14.8 cm) and a normal pencil (HB).

Procedure. We told the children that they would have to draw different objects, some normal and others strange because of magic transformations. The normal objects were a ''house'' and a ''mushroom.'' For these objects, we simply asked the children ''can you draw a house?'' for instance. The strange objects included a ''house with wings,'' a ''mushroom with arms,, a ''boot house,, and a ''castle mushroom.'' The first two objects were referred to as simple cross-categorical objects. The last two were called complex cross-categorical objects. For the simple cross-categorical objects, we used the following instructions: ''Now, I'd like you to draw a strange house (a strange mushroom), a house with wings (a mushroom with arms). Can you draw a house with wings (a mushroom with arms)?'' Note that the instructed drawings chosen enabled the child to put the unusual element at the end of the procedure. For the complex cross-categorical objects, we used the following instructions: ''Now, I'd like you to draw a boot house (a castle mushroom), that is, a very strange house (mushroom), a house (mushroom) that has been transformed into a boot (castle), so that it looks like a boot (castle). Can you draw a boot house (castle mushroom)?'' Different authors have used similar kinds of instructions for complex cross-categorical objects (Berti & Freeman, 1997; Picard & Vinter, 2006). Afterwards, we asked the children to talk about their production. The presentation order of the set of objects ($n = 6$) was random for each child. There were no time limits for completing the drawings. The experimenter was trained to record online the order in which the features that made up each individual drawing were produced (e.g., for the house drawing, 1—body, 2—roof, 3—chimney, 4—smoke, 5—left window, and so on). A feature was given a rank when it was first depicted, even if its depiction was not completed before the child went on to another feature. We checked the online recording offline with video recordings of the experimental session, and corrected errors (4%) before the data analysis.

Scoring representational change. We examined the drawings to identify the types of extracategorical features they included and how these extracategorical features were combined with the normal object features. Extracategorical features were wings and feathers for the house with wings, arms, and hands with fingers for the mushroom with arms, boot, heel, and laces for the boot house, and towers, flags, and drawbridge door for the castle mushroom. Among these features, some were basic because they were systematically present in the children's drawings (wings, arms, boot, and towers with slots). Others were considered accessory (feathers, hands, heel, laces, flags, and drawbridge door), because they were not systematically observed. The so-called basic extracategorical features could be drawn separately from the normal features with closed schematic forms, or they could be drawn together with the normal features by means of a single modulated contour line. The latter strategy—use of contour line—testifies to higher representational flexibility in children compared with the former—use of closed schematic forms—(Barrett & Eames, 1996; Lange-Küttner, Kerzmann, & Heckhausen, 2002; Reith, 1988; Spielman, 1976).

We scored representational change using the following 5-point scale for each topic: no extracategorical features inserted into the drawing (0 points), basic extracategorical features inserted by means of closed schematic forms (1 point), basic extracategorical features inserted by means of closed schematic forms and accessory extracategorical features added (2 points), basic extracategorical features inserted by means of contour lines (3 points), and basic extracategorical features inserted by means of contour lines and accessory extracategorical features

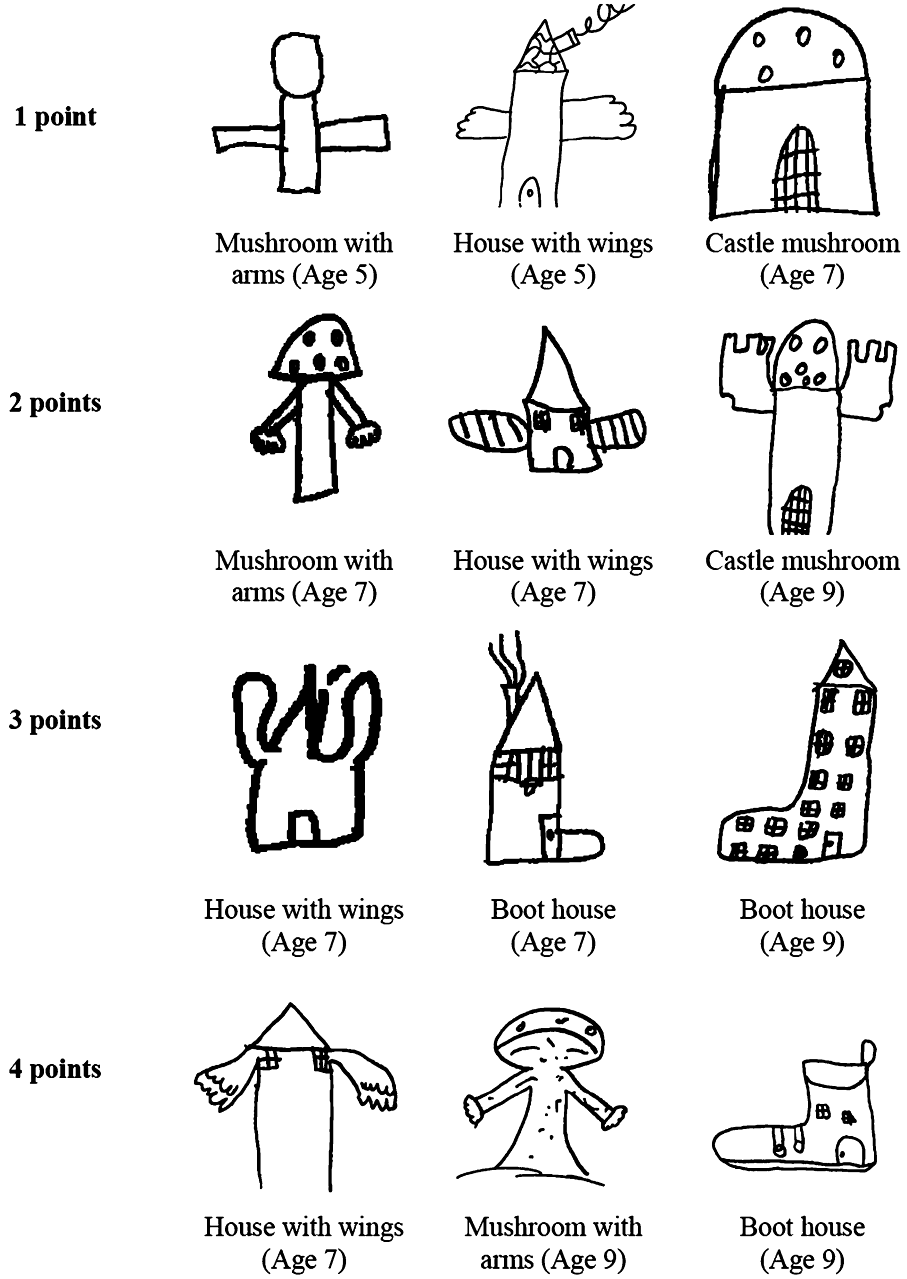

Figure 1. Illustrations of scores 1–4 on representational change (Experiment 1).

added (4 points). Figure 1 illustrates examples of the range of representational-change scores. Note that only 2 children of 5 years failed to introduce extra-categorical features when producing the boot house and the castle mushroom; hence, they were attributed a score of 0 on these two topics. Two judges worked independently to score the drawings. The interjudge agreement was high, 97.2%, and κ coefficient for interrater reliability was .98, $p < .01$. The few disagreements obtained were settled by discussion before data analysis.

Scoring procedural rigidity. Procedural rigidity was inferred from two measures: routine conservation and routine development. *Routine conservation* was measured by the number of pairs of normal features drawn in the same order as in the normal drawings (baseline), regardless of when extracategorical features were produced in the drawing sequence. Our measure is similar to Barlow et al. (2003)'s measure for procedural rigidity in that we considered pairs of normal elements that hold constant across drawings. However, contrary to Barlow et al., we took the measure in the cross-categorical drawings (not in successive drawings of a normal object). Because the total number of normal features could differ from object to object and from child to child, we divided this number by the total number of pairs of normal features (corresponding to the total number of normal features—1). The derived score for routine conservation ranged between 0 and 1. The higher the score, the more rigidly features were sequenced in the routine. For instance, a given child exhibited the following feature-production order for the normal house: 1—body, 2—roof, 3—chimney, 4—smoke, 5—left window, 6—right window, 7—door, 8—doorknob, and for the house with wings, 1—body, 2—left wing, 3—right wing, 4—roof, 5—chimney, 6—left window, 7—right window, 8—door, and 9—doorknob. The score was 1 (7/7) for this child, indicating that routine conservation was at its maximum.

Routine development was measured by the number of normal features drawn in a sequence before an extracategorical feature was drawn in the routine. Our measure provides a more precise account of when the routine is interrupted than previous categorical measures for early, middle, or late routine interruptions (see e.g. Berti & Freeman, 1997; Picard & Vinter, 1999). Again, because the total number of features could differ from object to object and from child to child, we divided this number by the total number of normal features drawn. The derived score for routine development ranged between 0 and 1. The higher the score, the more fully developed the routine before interruption. In the previous example, the score was 0.14 (1/7) for this child, showing that the interruption occurred rather early in the routine. Two judges working independently scored the drawings. The interjudge agreement was off 94.6%, and κ coefficient for interrater reliability was .95, $p < .01$. Disagreements were settled by discussion before data analysis.

Although they rely on some of the same raw measures (i.e., the number of features produced in each drawing), routine conservation and routine development can be considered independent. The number of pairs of normal features drawn in habitual order (measured in routine conservation) does not depend on the number of normal features drawn in a sequence before an extracategorical feature was drawn (measured in routine development). As demonstrated in the example below, high routine conservation can be associated with low routine development for a given child.

Results

Table 1 shows the mean scores on representational change, routine conservation, and routine development obtained in the free condition. Each score was subjected to a 3 × 2 × 2 (Age × Object × Status) mixed analysis of variance (ANOVA) with

Table 1
Mean Scores on Representational Change, Routine Conservation, and Routine Development Obtained in the Drawing From Imagination Condition (Experiment 1)

	House				Mushroom					
	Simple		Complex		Simple		Complex			
Age	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Representational change										
5 years	1.10	.45	2.10	1.29	1.50	.51	1.55	1	1.56	.81
7 years	1.35	.81	2.85	0.49	2.10	.55	2.25	1	2.14	.71
9 years	1.10	.31	3.10	0.64	2.20	.62	2.20	0.70	2.15	.57
Mean	1.18	.52	2.68	0.80	1.93	.56	2.00	0.90	1.95	.69
Routine conservation										
5 years	0.86	.27	0.79	0.36	0.90	.31	0.70	0.47	0.81	.35
7 years	0.89	.17	0.74	0.25	0.95	.22	0.80	0.41	0.84	.26
9 years	0.86	.21	0.87	0.19	0.85	.37	0.85	0.37	0.86	.28
Mean	0.87	.21	0.80	0.27	0.90	.30	0.78	0.42	0.84	.29
Routine development										
5 years	0.70	.36	0.63	0.44	0.88	.21	0.73	0.39	0.73	.35
7 years	0.75	.35	0.28	0.30	0.86	.26	0.70	0.40	0.65	.33
9 years	0.66	.38	0.12	0.04	0.83	.22	0.72	0.38	0.58	.25
Mean	0.70	.36	0.34	0.26	0.85	.23	0.71	0.39	0.65	.31

object (house; mushroom) and cross-category status (simple; complex) as within-subject factors. An α level of .05 was used for all statistical tests. The results showed that the representational-change scores were age-dependent, $F(2, 57) = 10.09$, $MSE = 0.89$, $p < .001$, $\eta^2 = .11$. As hypothesized, the 7-year-old children scored higher ($M = 2.14$) than the 5-year-old children ($M = 1.56$; planned comparison, $p = .001$), while their mean score did not differ significantly from that of the 9-year-old children ($p = .93$). The representational-change scores also varied as a function of cross-categorical status, $F(1, 57) = 56.15$, $MSE = .65$, $p < .001$, $\eta^2 = .46$, being higher for complex ($M = 2.34$) than for simple status ($M = 1.55$). A significant object $\times$ status interaction was obtained, $F(1, 57) = 76.79$, $MSE = .40$, $p < .001$, $\eta^2 = .39$. Post hoc analyses (Tukey tests) revealed that cross-categorical status had a significant impact on the house drawings ($p < .01$), but not on the mushroom drawings ($p = .94$). The highest representational-change score was obtained for the complex house ($M = 2.68$).

At the procedural level, the results showed that conservation of normal-feature sequencing was strong (mean score .84). The scores did not vary significantly as a function of age, $F(2, 57) = 0.24$, $MSE = .17$, $p = .78$, $\eta^2 = .05$. A significant effect of cross-categorical status, $F(1, 57) = 8.69$, $MSE = .06$, $p < .01$, $\eta^2 = .66$, indicated that the routine-conservation scores were higher for simple ($M = 0.88$) than for complex status ($M = 0.79$).

The extent to which the normal routine was developed before extracategorical features were inserted was affected by age, $F(2, 57) = 4.07$, $MSE = .11$, $p < .05$, $\eta^2 = .05$. The routine-development scores were lower as a whole at age 9 ($M = 0.58$) than at age 5 ($M = 0.73$, planned comparison, $p < .01$). These scores also varied across objects, $F(1, 57) = 31.88$, $MSE = .13$, $p < .001$, $\eta^2 = .41$, being higher for the mushroom ($M = 0.79$) than for the house ($M = 0.52$), and status, $F(1, 57) = 31.78$, $MSE = 0.12$, $p < .001$, $\eta^2 = .38$, being higher for simple ($M = 0.78$) than for complex objects ($M = 0.53$).

The relationships between procedural rigidity and representational change were assessed through correlation analyses. When all ages and objects were taken together, the routine-development scores were negatively and significantly correlated with the representational-change scores (Pearson's correlation coefficient, $r(59) = -.39$, $p < .05$), so that the greater the routine development, the lesser the representational change. The correlation reached its highest level on the complex house, $r(59) = -.56$, $p < .05$. The same analysis was not carried out on the routine-conservation scores because they were generally very high in all age groups.

Discussion

The results of Experiment 1 showed that cross-category innovations can be elicited in young children when they are given explicit instructions and when no external model is provided (for similar results, see Berti & Freeman, 1997; Picard & Vinter, 2006; Spensley & Taylor, 1999). Our main hypothesis assumed that scores for representational change would increase with age, and that this increase would be a concomitant of a decrease with age in scores for procedural rigidity. The results obtained confirmed this hypothesis for one of the two measures of procedural rigidity. Children's ability to produce interrepresentational changes improved with age, and paralleled their increased ability, as they grew older, to produce early interruptions of their routine in order to insert extracategorical features. Age 7 characterized these main developmental changes. As expected, we found a significant negative correlation between the scores on representational change and routine development, so that the more developed the routine, the less sophisticated the representational change. These tight relations were the most striking for the boot house drawing, with this object obtaining the highest representational-change scores and the lowest routine-development scores. The high flexibility observed for this item may be related to the fact that the boot house drawing is quite familiar in cartoons.

Contrary to what was expected at all ages, the children tended to maintain a high degree of conservation of feature sequencing in their normal routine. Karmiloff-Smith (1990) stated that children who have developed beyond the procedural rigidity phase still utilize this rigidity for tasks requiring speed and efficiency. This could explain the age-independent findings on routine conservation observed in the free-drawing condition. However, this does not explain why children demonstrated increasing procedural flexibility with respect to early interruptions of the routines that was related to increasing representational flexibility as they grew older. Indeed, if children used rigid graphic routines because our task required speed and efficiency, it seems odd that this rigidity appeared only on routine conservation scores and not on routine development scores. It is therefore not clear as to whether routine conservation is a relevant indicator of a sequential constraint acting on children's representational behavior.

As hypothesized, routines devoted to the production of the mushroom were procedurally more rigid than routines of the house drawing. Whatever the age, higher scores for routine conservation and routine development characterized the mushroom as compared with the house drawing. We suggest that the mushroom induced more rigid routines than the house because its small number of features (three in general) to be put in a sequence reduced the "degrees of freedom" available to the child. The results also confirmed our expectation of a higher procedural rigidity for drawing simple than complex cross-category objects. Again, this greater procedural rigidity was observed on both routine conservation and routine development scores whatever the age. Simple insertions allowed for higher procedural rigidity because the routines could be run as usual and the extracategorical features simply added at the end of the procedure.

Experiment 2: Drawing From External Clay Models

In Experiment 1, we found that cross-category innovations can be elicited in young children in a free context. However, the young children obtained relatively low scores for representational change and high scores for procedural rigidity. Zhi et al. (1997) showed that young children could benefit from prior exposition to a clay model of an imaginary object (a woman with two heads) as compared with a condition where they had to produce the drawing directly from imagination. In Experiment 2, children were provided with 3D clay models of cross-category objects and were asked to draw from these models. The task was made easier for children in that they did not have to imagine how to modify the normal objects to make them strange. This drawing from model task nevertheless remains difficult as children have to perform relatively complex operations to transform what was seen into a drawing. It was hypothesized that reducing task difficulty by providing children with clay models of the objects would promote (to a certain extent at least) their scores for representational change and concomitantly would reduce their scores for procedural rigidity.

Method

Participants. Sixty right-handed children volunteered to participate. None of them had participated in Experiment 1. They were divided into three age groups of 20 children each: 5-year-olds (mean age: 5.4), 7-year-olds (mean age: 7.4), and 9-year-olds (mean age: 9.6). There were an equal number of boys and girls in each age group. None of the children were ahead or behind in school, or had any psychomotor drawing or handwriting disorders. Their vision was normal or corrected to normal. Children were essentially Caucasian and from middle SES families. They were observed individually in a quiet room inside their school, with both active parental consent and assent.

Materials. The materials consisted of clay models of a house, a house with wings, a boot house, a mushroom, a mushroom with arms, and a castle mushroom (see photographs in Figure 2). The clay models were made to be very similar to the

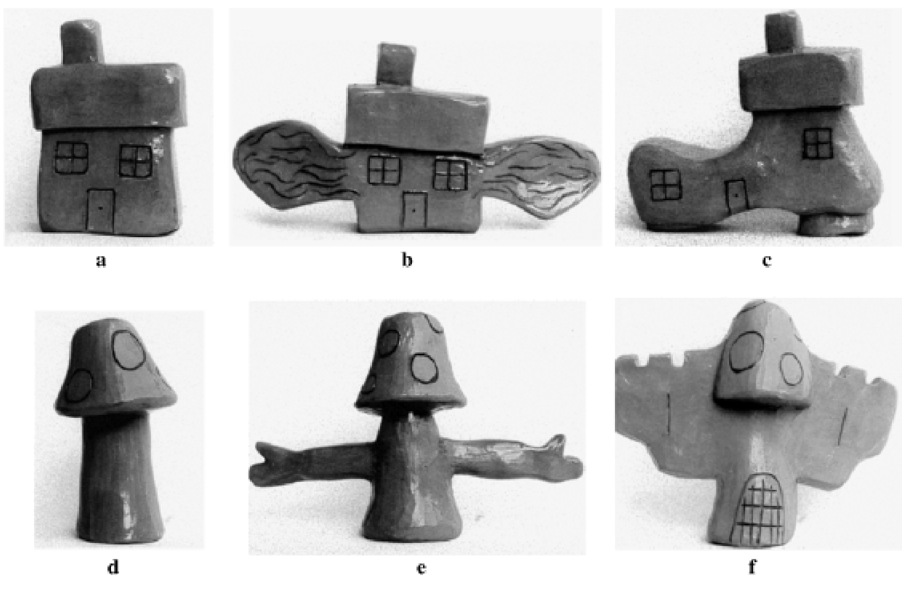

Figure 2. Clay models used in Experiment 2 (a = house; b = house with wings; c = boot house; d = mushroom; e = mushroom with arms; f = castle mushroom). Photographs of the clay models were used in Experiment 3.

children's most sophisticated depictions of these objects. The house had a square body, a rectangular roof, two windows with panes, a door with a doorknob, and a chimney. The house with wings included two wings with marked feathers; the wings were on each side of the body. The boot house had a boot with a heel. The toe of the boot was on the left side of the body. The windows and door were not in the same position as on the normal house. The mushroom was made up of a stem and a cap with spots. The mushroom with arms had two arms that ended with hands and fingers. The arms were on each side of the stem. Finally, the castle mushroom had two slotted towers with a drawbridge door and two loopholes. The slotted towers were on each side of the stem and cap.

Procedure. We presented the models upright, one at a time in front of the child (at about 50 cm away and at eye level), in a random order. We told the children that they would see different objects, some ordinary and others with funny features. We named each model before we instructed the children to "draw it as accurately as possible." The time available for drawing with the models in view was unlimited, and no feedback or comments were given during the experiment. The children drew the models on separate sheets of white paper with a normal pencil (HB). On average, the experiment lasted 15 min per child. As in Experiment 1, the experimenter recorded the individual feature-production order.

Scoring the drawings. Scoring was similar to that in Experiment 1;therefore, a direct comparison of the drawings produced in a free context with those produced from the clay models was possible. Figure 3 illustrates examples of drawings scored at each level of representational change. Note that we attributed scores 2 and 4 when all the accessory extracategorical features were found in a given drawing. Two judges worked independently to perform the scoring. Interjudge agreement was obtained in more than 95% of the cases (κ coefficients for interrater reliability superior to .95, $p < .01$). Disagreements were settled by discussion before data analysis.

Results

Table 2 shows the mean scores on representational change, routine conservation, and routine development obtained in the drawing from clay models condition. Each score was subjected to a 3 × 2 × 2 (Age × Object × Status) mixed ANOVA with object (house; mushroom) and cross-category status (simple; complex) as within-subject factors. An α level of .05 was used for all statistical tests. Results indicated that the representational-change scores were age-dependent, $F(2, 57) = 13.24$, $MSE = 1.55$, $p < .001$, $\eta^2 = .31$. The scores were lower at age 5 ($M = 2.52$) than at age 7 ($M = 3.29$) (planned comparison, $p < .01$), but did not differ significantly at ages 7 and 9 ($p = .31$). The representational-change scores also varied across status, $F(1, 57) = 39.38$, $MSE = 0.58$, $p < .001$, $\eta^2 = .34$, with higher scores for complex ($M = 3.40$) than for simple status ($M = 2.79$). A significant Object × Status interaction was obtained, $F(1, 57) = 14.39$, $MSE = 0.61$, $p < .001$, $\eta^2 = .13$. Post hoc analyses (Tukey tests) revealed that cross-categorical status had a significant effect on the house drawings ($p < .01$), but not on the mushroom drawings ($p = .37$). Again, the highest representational-change score was obtained for the complex house ($M = 3.82$).

From a procedural point of view, the results in Table 2 indicated high routine-conservation scores (M = 0.75), with no significant difference between the age groups, $F(2, 57) = 1.82$, $MSE = 0.15$, $p = .17$, $\eta^2 = .15$. The routine-conservation scores varied across status, $F(1, 57) = 9.29$, $MSE = 0.06$, $p < .01$, $\eta^2 = .32$, with higher scores for simple ($M = 0.80$) than for complex status ($M = 0.70$). The routine-conservation scores also varied across objects, $F(1, 57) = 7.16$, $MSE = 0.08$, $p < .01$, $\eta^2 = .32$, being higher for mushrooms ($M = 0.80$) than for houses ($M = 0.70$).

As a whole, the routine-development scores (see Table 2) were low ($M = 0.35$), with no significant difference between the age groups, $F(2, 57) = 0.13$, $MSE = 0.14$, $p = .87$, $\eta^2 = .003$. These scores varied across objects, $F(1, 57) = 35.57$, $MSE = 0.07$, $p < .001$, $\eta^2 = .46$, being higher for mushrooms ($M = 0.46$) than for houses ($M = 0.25$), and status, $F(1, 57) = 36.11$, $MSE = 0.06$, $p < .001$, $\eta^2 = .42$, being higher for simple ($M = .45$) than for complex status ($M = .26$). A significant negative correlation was obtained between the representational-change scores and the routine-development scores—Pearson's correlation coefficient, $r(59) = -.55$, $p < .05$—indicating that the greater the routine development, the lesser the representational change.

In order to assess the benefits of having external models, we also conducted ANOVAs that included the drawing condition (2: from the imagination, from clay models) as a between-subject factor. The data set from Experiment 1 was therefore included in the second set of ANOVAs. As hypothesized, having a clay model improved the mean scores on representational change ($M = 3.10$) as compared with those observed in a free context ($M = 1.95$), as indicated by a main effect of the drawing condition, $F(1, 114) = 129.50$, $MSE = 1.22$, $p < .001$, $\eta^2 = .52$. The

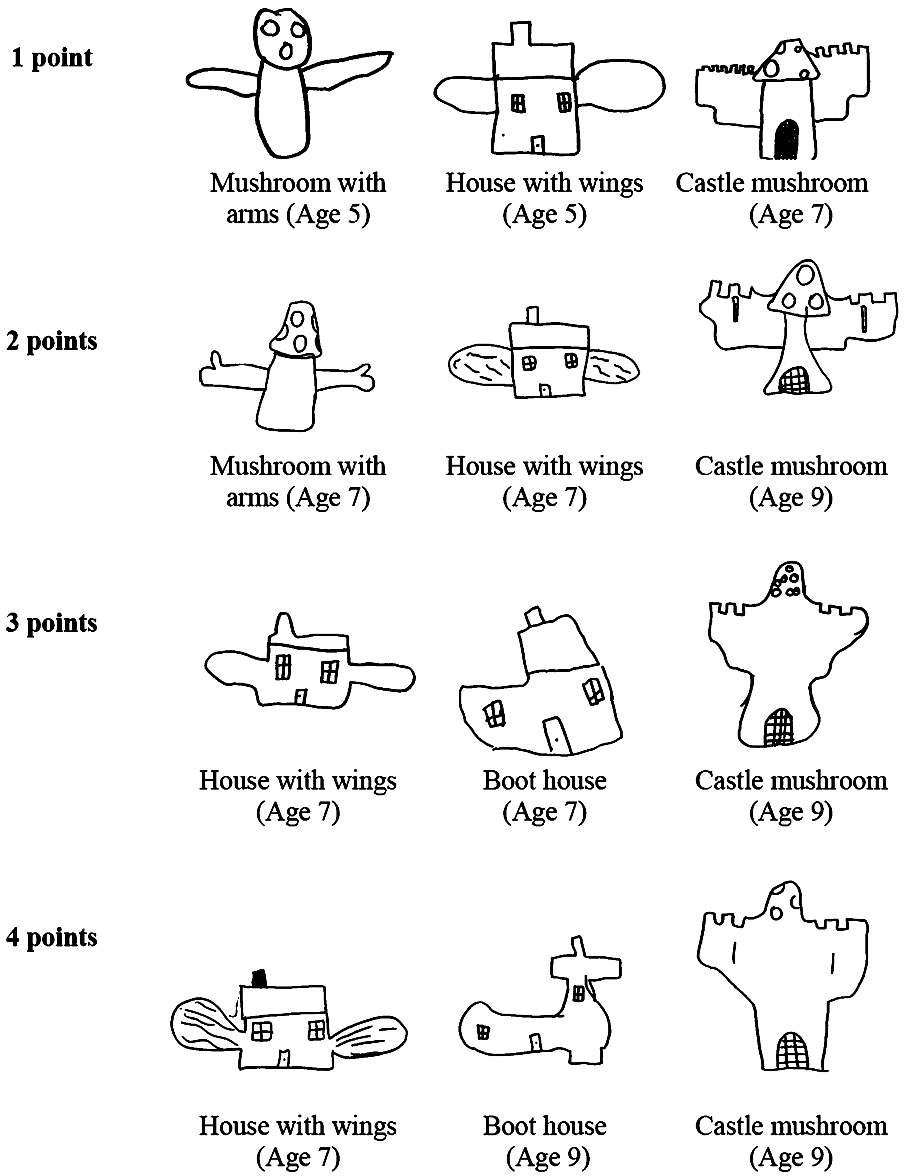

Figure 3. Illustrations of scores 1–4 on representational change (Experiment 2).

drawing condition also had a significant impact on procedural rigidity scores. The scores for routine conservation obtained in Experiment 2 ($M = .75$) were lower than those obtained in the drawing-from-imagination condition ($M = 0.84$), $F(1, 114) = 5.13$, $MSE = 0.16$, $p < .05$, $\eta^2 = .24$. The scores for routine development were lower in Experiment 2 ($M = 0.35$) than in the free condition ($M = 0.65$), $F(1, 114) = 84$, $MSE = 0.12$, $p < .001$, $\eta^2 = .41$.

Discussion

Having external clay models of the objects to be drawn was beneficial to the children from both a representational and a procedural point of view. Their representational-change scores were higher in this drawing condition than in Experiment 1, while both their routine-conservation scores and routine-development scores were lower. At the procedural level, their drawing behavior was relaxed, especially with regard to early routine interruptions, and to a lesser extent with regard to deviations from normal feature sequencing. As in Experiment 1, greater procedural rigidity characterized the mushroom drawing as compared with the house. Also, the routines were modified to a lesser extent when simple rather than complex insertions were produced. In line with our hypothesis, we found a

Table 2

Mean Scores on Representational Change, Routine Conservation, and Routine Development Obtained in the Drawing from the Clay Models Condition (Experiment 2)

	House				Mushroom					
	Simple		Complex		Simple		Complex			
Age	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Representational change										
5 years	2.20	0.89	3.50	.83	2.20	0.77	2.20	1.32	2.52	.95
7 years	2.85	1.04	3.95	.22	3.00	1.03	3.35	0.93	3.29	.80
9 years	3.40	0.94	4.00		3.10	1.02	3.45	1.00	3.49	.74
Mean	2.82	0.96	3.82	.35	2.77	0.94	3.00	1.08	3.10	.83
Routine conservation										
5 years	0.75	0.18	0.69	.22	1.00		0.78	0.41	0.80	.20
7 years	0.76	0.18	0.68	.18	0.80	0.41	0.85	0.37	0.77	.28
9 years	0.72	0.25	0.63	.18	0.80	0.41	0.60	0.37	0.69	.33
Mean	0.74	0.20	0.67	.19	0.87	0.27	0.74	0.43	0.75	.27
Routine development										
5 years	0.45	0.38	0.20	.26	0.41	0.32	0.39	0.31	0.36	.32
7 years	0.39	0.38	0.09	.13	0.58	0.34	0.41	0.23	0.37	.27
9 years	0.25	0.20	0.15	.14	0.65	0.30	0.32	0.25	0.34	.22
Mean	0.36	0.32	0.14	.18	0.55	0.32	0.37	0.26	0.35	.27

negative correlation between the scores on representational change and routine development.

The present findings support the idea that a sequential constraint, at least that limiting the early interruptions of a procedure, needs to be relaxed for interrepresentational flexibility to be expressed. However, if the drawing from clay models condition promoted the scores for representational change at each age, this drawing condition resulted in reducing the scores for routine development so that age-related differences no longer occurred. Indeed, the children's ability to make complex representational changes was still age-dependent, whereas their ability to produce early routine interruptions was no longer subject to age differences. This indicates that early interruptions of the procedure were managed in all children, but only the older children demonstrated a concomitant management of complex representational change. We suggest that early interruptions of the procedure might be necessary but insufficient for interrepresentational innovations.

Experiment 3: Drawing From Photographs

In Experiment 3, children were asked to draw from photographs of the clay models used in Experiment 2. Compared with clay-model drawing, drawing from photographs has a lower cost due to the fact that 3D information has already been translated into 2D information on the paper. It is possible that the young children in Experiment 2 failed to display high representational scores because they had to cope with this depiction problem (see e.g. Chen, 1985; Freeman, 1980). However, even when photographs are available, children still have to break the pictures down into a set of representational units and convert the object's boundaries into lines. If young children's representational limitations are partialy rooted in 3D-to-2D translation difficulties, then the availability of photograph models should be beneficial from a representational point of view. The benefit should be accompanied by a further decrease in the procedural-rigidity scores in line with the hypothesis that sequential constraints need to be fully relaxed for high-level representational changes to be expressed.

Method

Participants. Sixty right-handed children volunteered to participate. None had participated in the first two experiments. They were divided into three age groups of 20 children each: 5-year-olds (11 girls and 9 boys, mean age = 5.5), 7-year-olds (10 girls and 10 boys, mean age = 7.4), and 9-year-olds (10 girls, 10 boys, mean age = 9.5). None of the children were ahead or behind in school or suffered from any psychomotor drawing or handwriting disorders. Their vision was normal or corrected to normal. Children were essentially Caucasian and from middle SES families. They were observed individually in a quiet room inside their school, with both active parental consent and assent.

Materials and procedure. The materials consisted of color photographs of the clay models (see Figure 2). The procedure was similar to that described in Experiment 2, except that the photograph models were laid down on the table in front of each child. The drawings were scored for representational change, routine conservation, and routine development using the same criteria as in the previous experiments. Interjudge agreement was attained in more than 95% of the cases (κ coefficients for interrater reliability superior to .95, $p < .01$). Disagreements were settled by discussion before data analysis.

Results

The results are presented in Table 3. Each score was subjected to a 3 × 2 × 2 (Age × Object × Status) mixed ANOVA with object (house; mushroom) and cross-category status (simple; complex) as within-subject factors. An α level of .05 was used for all statistical tests. Results indicated that the representational-change scores were age-dependent, $F(2, 57) = 19.34$, $MSE = 1.53$, $p < .001$, $\eta^2 = .50$, with lower scores at age 5 ($M = 2.52$) than at age 7 ($M = 3.24$; planned comparison, $p < .01$). The scores varied across cross-categorical status, $F(1, 57) = 25.73$, $MSE = 0.59$, $p < .001$, $\eta^2 = .26$, being higher for complex ($M = 3.42$) than for simple status ($M = 2.91$). A significant Object × Status interaction was, however, obtained, $F(1, 57) = 17.09$, $MSE = 0.52$, $p < .001$, $\eta^2 = .15$. Post hoc analyses (Tukey tests) revealed that the effect of status was observed for the house ($p < .01$), but not for the mushroom ($p = .78$). The highest representational-change score was recorded for the boot house ($M = 3.68$).

At the procedural level, the results indicated high scores on routine conservation (M = 0.79), with no significant difference between the age groups, $F(2, 57) = 1.21$, $MSE = 0.06$, $p = .30$, $\eta^2 = .03$. A significant status effect, $F(1, 57) = 13.07$, $MSE = 0.07$, $p < .001$, $\eta^2 = .41$, indicated that the scores were higher for simple ($M = 0.85$) than for complex status ($M = 0.73$). The routine-conservation scores also varied across objects, $F(1, 57) = 10.44$, $MSE = 0.10$, $p < .01$, $\eta^2 = .47$, being higher for mushrooms ($M = 0.86$) than for houses ($M = 0.72$).

The routine-development scores in the drawing-from-photographs condition were low as a whole ($M = 0.38$), with no significant difference between the age groups, $F(2, 57) = 1.90$, $MSE = 0.13$, $p = .16$, $\eta^2 = .03$. These scores varied across objects, $F(1, 57) = 38.76$, $MSE = 0.14$, $p < .001$, $\eta^2 = .46$, being higher for the mushroom ($M = 0.50$) than for the house ($M = 0.26$), and status, $F(1, 57) = 23.55$, $MSE = 0.09$,

Table 3
Mean Scores on Representational Change, Routine Conservation, and Routine Development Obtained in the Drawing from Photographs Condition (Experiment 3)

	House				Mushroom					
	Simple		Complex		Simple		Complex			
Age	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Representational change										
5 years	1.85	0.93	3.20	1.06	2.50	1.05	2.55	1.10	2.52	1.03
7 years	2.90	1.12	3.85	0.37	3.00	1.17	3.20	0.83	3.24	0.87
9 years	3.55	0.76	4.00		3.50	0.89	3.60	0.50	3.66	0.54
Mean	2.77	0.94	3.68	0.48	3.00	1.04	3.12	0.81	3.14	0.82
Routine conservation										
5 years	0.75	0.22	0.62	0.23	0.90	0.31	0.75	0.44	0.75	0.30
7 years	0.83	0.18	0.65	0.17	0.90	0.31	0.85	0.37	0.81	0.26
9 years	0.83	0.22	0.63	0.18	0.90	0.31	0.85	0.37	0.80	0.27
Mean	0.80	0.21	0.63	0.19	0.90	0.31	0.82	0.39	0.79	0.27
Routine development										
5 years	0.41	0.36	0.26	0.31	0.71	0.35	0.38	0.34	0.44	0.29
7 years	0.34	0.39	0.16	0.14	0.62	0.31	0.34	0.15	0.36	0.25
9 years	0.25	0.31	0.16	0.12	0.71	0.62	0.30	0.18	0.35	0.31
Mean	0.33	0.35	0.19	0.19	0.68	0.43	0.34	0.22	0.38	0.29

$p < .001$, $\eta^2 = .42$, being higher for simple ($M = 0.50$) than for complex objects ($M = 0.26$). When all ages and objects were taken together, a significant negative correlation was obtained between the scores on representational change and routine development, Pearson's correlation coefficient, $r(59) = -.43$, $p < .05$.

In order to assess the benefits of photographs, we compared the data set from the present experiment with that of Experiment 2 (drawing from the clay models condition). We therefore conducted ANOVAs that included the drawing condition (2: from clay models, from photographs) as a between-subject factor. Contrary to our expectations, the scores for representational change did not differ significantly from those obtained in the drawing-from-models condition, $F(1, 114) = 0.37$, $\text{MSE} = 1.54$, $p = .54$, $\eta^2 = .004$. The drawing condition had no significant impact on the scores for routine conservation, $F(1, 114) = 1.46$, $MSE = 0.11$, $p = .23$, $\eta^2 = .04$, and routine development, $F(1, 114) = 0.50$, $MSE = 0.13$, $p = .47$, $\eta^2 = .005$.

Discussion

The Experiment 3 findings were very similar to those obtained in Experiment 2. Contrary to our expectations, reducing the cost incurred by the necessity of translating 3D information into 2D plan information by providing the children with photographs rather than clay models did not change their basic drawing behavior. That children did not benefit from photographs as compared with clay models is not consistent with previous research on the accuracy of drawing produced from 3D objects and from photographs of the same objects (e.g. Chen, 1985; Picard & Durand, 2005). These experiments showed that overall children more frequently produced accurate (view-specific) depictions of objects when they drew from photographs rather than from real objects. However, improvement in performance was essentially observed when complex objects were to be drawn (Chen, 1985). Thus, drawing performance does not systematically increase when a photograph rather than a real object is provided as a model. In the present experiment, it is possible that children did not process our miniaturized objects in the same manner as they would process 3D real objects. It can also be the case that the availability of photographs was not sufficient to improve scores for representational change because children's depiction abilities were much more limited by a difficulty in converting boundaries into lines than in converting 3D information on the 2D plan of the paper. We tested this hypothesis in Experiment 4.

Experiment 4: Copying Line Drawings

In Experiment 4, we finally provided the children with line drawings of the objects. This last drawing condition eliminates the cost of converting boundaries into lines (present in Experiment 3), and has the lowest cost in terms of representational and procedural demands among the four drawing conditions. Copying line drawings requires mainly that children figure out how to replicate an already 2D pattern (Chen, 1985). Karmiloff-Smith (1990) herself noted that young children could succeed on cross-category insertions if they are allowed to copy. This copying condition should result in ceiling scores for representational change at all ages. If high-level representational abilities are dependent upon sequential constraints, then the routine-conservation and routine-development scores should decrease even more.

Method

Participants. Sixty right-handed children volunteered to participate. None of them had participated in the other studies. They were divided into three age groups of 20 children each: 5-year-olds (mean age = 5.3), 7-year-olds (mean age = 7.3), and 9-year-olds (mean age = 9.3). There were an equal number of boys and girls in each age group. None of the children were ahead or behind in school or had any psychomotor drawing or handwriting disorders. Their vision was normal or corrected to normal. Children were essentially Caucasian and from middle SES families. They were observed individually in a quiet room inside their school, with both active parental consent and assent.

Materials and procedure. The materials consisted of 2D-line drawings of a house, a house with wings, a boot house, a mushroom, a mushroom with arms, and a castle mushroom (see Figure 4). The experimenter made these drawings with a black pencil by looking at the photographs. A single contour line was used to attach the extracategorical features to the normal features. The procedure was the same as in Experiment 3. The drawings were scored for representational change, routine conservation, and routine development, using the same criteria as in the previous experiments. Interjudge agreement was attained in more than 95% of the cases (κ coefficients

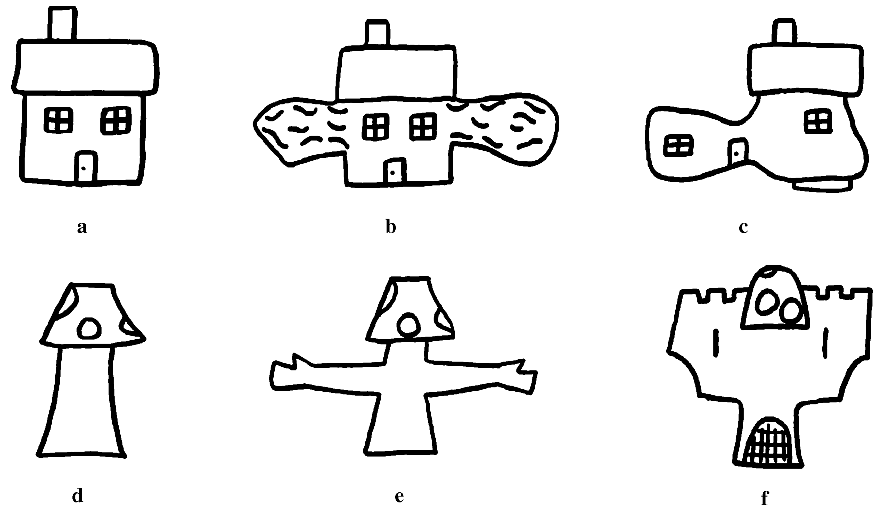

Figure 4. Line drawings used in Experiment 4 (a: house, b: house with wings, c: boot house, d: mushroom, e: mushroom with arms, f: castle mushroom).

for interrater reliability superior to .95, $p < .01$). Disagreements were settled by discussion before data analysis.

Results

Table 4 shows the mean scores on representational change, routine conservation, and routine development for each age and object in the copying condition. Each score was subjected to a 3 × 2 × 2 (Age × Object × Status) mixed ANOVA with object (house; mushroom) crossed with cross-category status (simple; complex) as within-subject factors. An α level of .05 was used for all statistical tests. Results indicated that the representational-change scores observed in the present drawing condition were still age-dependent, $F(2, 57) = 10.79$, $MSE = 0.24$, $p < .001$, $\eta^2 = .60$, being once again somewhat lower at age 5

Table 4
Mean Scores on Representational Change, Routine Conservation, and Routine Development obtained in the Line Drawing Copying Condition (Experiment 4)

	House				Mushroom					
	Simple		Complex		Simple		Complex			
Age	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Representational change										
5 years	3.40	.88	3.65	.49	3.80	.62	3.60	.50	3.61	.62
7 years	3.90	.45	3.90	.31	4.00		3.85	.37	3.91	.28
9 years	3.90	.45	3.85	.37	4.00		4.00		3.94	.20
Mean	3.73	.59	3.80	.39	3.93	.20	3.82	.29	3.82	.37
Routine conservation										
5 years	0.73	.18	0.72	.20	0.55	.51	0.55	.51	0.64	.35
7 years	0.75	.22	0.61	.18	0.85	.37	0.85	.37	0.76	.28
9 years	0.73	.20	0.56	.11	0.65	.49	0.60	.50	0.64	.32
Mean	0.74	.20	0.63	.16	0.68	.46	0.67	.46	0.68	.32
Routine development										
5 years	0.18	.20	0.13	.18	0.49	.25	0.38	0.20	0.29	.21
7 years	0.14	.06	0.11	.15	0.40	.17	0.28	0.12	0.23	.12
9 years	0.15	.07	0.19	.16	0.50	.28	0.23	0.22	0.27	.18
Mean	0.16	.11	0.14	.16	0.46	.23	0.30	0.18	0.26	.17

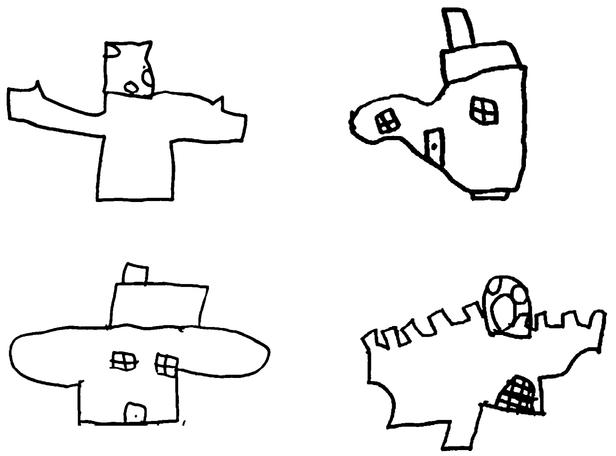

Figure 5. Examples of drawings produced by 5-year-old children in Experiment 4.

($M = 3.61$) than at age 7 ($M = 3.91$; post hoc Tukey test, $p < .01$). The scores did not vary significantly across status or object (ps > .05). An inspection of the drawings revealed that some of the youngest children demonstrated poor motor control when trying to copy the models accurately using contour lines (as compared with the older children). Irregularities in the drawings were observed (see illustrations in Figure 5).

At the procedural level, the results revealed relatively high scores on routine conservation ($M = 0.68$), with no significant difference across age groups, status, or object (ps > .05). The scores for routine development were low ($M = 0.26$). They were not affected by age ($p > .05$), but they varied across objects, $F(1, 57) = 109.72$, $MSE = 0.03$, $p < .001$, $\eta^2 = .75$, and status, $F(1, 57) = 19.83$, $MSE = 0.02$, $p < .001$, $\eta^2 = .12$.

Routine-development scores were higher for mushrooms ($M = 0.38$) than for houses ($M = 0.15$). They were also higher for simple ($M = 0.31$) than for complex status ($M = 0.22$). A significant interaction between the two variables was obtained, $F(1, 57) = 10.72$, $MSE = 0.03$, $p < .01$, $\eta^2 = .08$. Post hoc analyses (Tukey tests) indicated that the routine-development scores did not vary significantly across status for the house (simple: $M = 0.16$ vs. complex: $M = 0.14$, $p = .95$); for the mushroom the scores were higher for simple than for complex status (simple: $M = 0.46$ vs. complex: $M = 0.30$, $p < .05$).

Data from the copying condition were compared with those obtained in Experiment 3 through ANOVAs. As hypothesized, the availability of line drawings led to an increase in the mean representational-change scores ($M = 3.82$) as compared with those observed in the previous experiment ($M = 3.14$). A main effect of the drawing condition (2: copying line drawings, drawing from photographs) was obtained, $F(1, 114) = 57.23$, $MSE = 0.88$, $p < .001$, $\eta^2 = .45$. This last copying condition was also beneficial at the procedural level as compared with the drawing from photograph condition. The routine-conservation scores obtained in Experiment 4 were lower ($M = 0.68$), $F(1, 114) = 12.91$, $MSE = 0.11$, $p < .001$, $\eta^2 = .28$, as were the routine-development scores ($M = 0.26$), $F(1, 114) = 17.48$, $MSE = 0.09$, $p < .001$, $\eta^2 = .11$, than those obtained in the Experiment 3 (Ms = 0.79 and 0.38, respectively).

Finally, to obtain a whole picture of how drawing from imagination (Experiment 1), clay models (Experiment 2), photographs (Experiment 3), and line drawings (Experiment 4) compare with one another on the various dependent measures, we carried out ANOVAs including drawing condition (4 modalities) as a between-subject factors. This factor had a significant impact on each score: representational change, $F(3, 228) = 137.38$, $MSE = 1.05$, $p < .001$, $\eta^2 = .46$, routine conservation, $F(3, 228) = 7.71$, $MSE = 0.14$, $p < .001$, $\eta^2 = .19$, and routine development, $F(3, 228) = 61.93$, $MSE = 0.10$, $p < .001$, $\eta^2 = .21$. Post hoc analyses (Tukey tests) indicated that among scores for representational change, the lowest were obtained in the free context ($M = 1.95$), and the highest in the copying condition ($M = 3.82$; all ps < .001). Intermediate scores were found in the drawing from clay models ($M = 3.10$) and drawing from photographs conditions ($M = 3.14$), with no difference between these last two conditions ($p = .88$). It is worth reminding that the scores for representational change were age-dependent in each drawing condition.

The two scores for procedural rigidity showed the reverse pattern of results. Among scores for routine conservation, the highest were observed in the free context ($M = 0.84$), and the lowest in the copying condition ($M = 0.68$; all ps < .001). Intermediate scores were found in the drawing from clay models ($M = 0.75$) and drawing from photographs conditions ($M = 0.79$), with no difference between these last two conditions ($p = .70$). Among scores for routine development, the highest were observed in the free context ($M = 0.65$), and the lowest in the copying condition ($M = 0.26$; all ps < .001). Intermediate scores were found in the drawing from clay models ($M = 0.35$) and drawing from photographs conditions ($M = 0.38$), with no difference between these last two conditions ($p = .85$). Note that the gradual decline in scores for procedural rigidity from Experiment 1 to Experiments 2–3, and to Experiment 4 was much more pronounced for routine development than for routine conservation. It is worth reminding that routine conservation scores were never related to age whatever the drawing condition, whereas routine development scores were age-dependent in the free-drawing condition, but not in the other conditions.

Discussion

As expected, the line-drawing condition gave rise to very high scores on our representational change measure, although the youngest children's scores were slightly lower than the older children's scores. When forced to do so, the 5-year-old children could produce large representational units in their drawing, and thereby violated the constraint of independence between representations. However, these children probably resolved the copying task at a perceptuo-motor level, as suggested by the fact that they displayed poor motor control when using the contour-line technique: they proceeded step by step without overall control of their drawing movements. These findings are in line with Karmiloff-Smith's (1990) observation that young children can succeed on cross-category drawings if they are able to copy although they do so slowly and laboriously. Improvements in the representational-change scores were associated with a further decrease in the routine-conservation and routine-development scores of all children, supporting the view that high-level representational abilities are associated with low procedural rigidity.

General Discussion

Interrepresentational flexibility has been qualified as "an essential component of human creativity" (Karmiloff-Smith, 1990, p. 72). In drawing, children's ability to produce cross-category innovations typically expresses such representational flexibility. The main issue addressed in the present series of studies was the extent to which interrepresentational flexibility remains severely limited until the constraints inherent in the procedural aspects of drawing behavior are fully relaxed (Karmiloff-Smith, 1992). In a first experiment, we asked 5- to-9-year-old children to produce cross-category drawings from their imagination in order to verify that improvements in representational flexibility with age are associated with declines in procedural rigidity. In the next three experiments, we gradually reduced the demands imposed on the drawing tasks by providing the children with external models of innovative objects (clay models, photographs, and line drawings). We evaluated the impact of the availability of these external models at both the representational and procedural levels to test whether a sequential constraint could account for the children's limitations at the representational level.

As could be expected from Karmiloff-Smith's (1992) model, drawings produced from imagination (Experiment 1) exhibited age-related differences in both representational and procedural flexibility. As the representational-change scores improved with age, the routine-development scores decreased (children interrupted their routine earlier to insert extracategorical features). However, the routine-conservation scores remained stable and high at all ages (few children modified the feature sequencing in their normal routine). The availability of external models, whether made of clay (Experiment 2) or photographs (Experiment 3), resulted in an increase in interrepresentational flexibility, but the youngest children were still less inclined to break the models down into large representational units than the older children were. Drawing behavior at the procedural level was clearly relaxed at all ages with regard to early routine interruptions, whereas routine conservation only declined to a limited extent. Children's representational-change scores were still correlated with their routine-development scores, but the latter were no longer age-dependent. Interestingly, all of the children produced early routine interruptions and modified feature sequencing to a limited extent, but the 7- and 9-year-old children were the only ones to exhibit elaborate interrepresentational changes in their drawings. The children's representational-change scores finally reached the ceiling level when the children copied line-drawing models (Experiment 4), although the youngest children had difficulty managing large representational units. From a procedural point of view, very early routine interruptions were the rule, while routine conservation continued to decline but to a limited extent.

The present data show that early routine interruptions are associated with but precede elaborate interrepresentational innovations, and that high-level representational changes do not require much modification of the normal-feature sequencing in the routine. Our data are partially in line with Karmiloff-Smith's (1992) assumption that interrepresentational flexibility remains severely limited until the constraints inherent to the procedural aspects of drawing behavior are fully relaxed. On the one hand, our data do not support the view that feature-ordering rigidity could constrain representational change. Few modifications in the normal feature sequencing of the routines accompanied improved drawing ability. Because a high degree of routine conservation was consistently obtained across the studies reported here, the possibility that routine conservation acts as a constraint on representational change in children's drawing behavior must be rejected.

The high degree of routine conservation found in our experiment could be viewed instead as a manifestation of conservatism in children (van Sommers, 1984). Their conservatism also proved to us that the children were actually using their well-established routines and did not build completely new procedures for drawing the strange objects. That feature sequencing was fairly stable across successive drawings of an object for a given child does not imply, however, that there was no variability in graphic strategies at a deeper procedural level or no variability between individuals. For instance, we know that stability does not persist at the stroke level (van Sommers, 1983), and that there is variability both within and across ages in stroke production and components sequencing in drawing production (Braswell & Rosengren, 2000; Picard & Vinter, 2005).

On the other hand, our data do support the view that rigidity in routine development (i.e., how much of the routine has to be produced before interruption) could act as a constraint on representational change. That once activated, a procedure has to be developed in its entirety or at least cannot be interrupted at its early beginning can be considered as the manifestation of a sequential constraint inherent to implicit-level procedures (Karmiloff-Smith, 1990). Our data point to the fact that relaxation of such a constraint is indeed correlated with children's ability to make high-level representational changes. However, interruption of the routine in its early development preceded the production of elaborate symbolic innovations. In 1990, Karmiloff-Smith suggested that "the sequential constraint, when relaxed, constitutes one of the several processes leading to interrepresentational flexibility" (p. 79). This view implies that relaxation of the sequential constraint is necessary, although insufficient, for the expression of interrepresentational changes in children's drawing behavior. Therefore, and in line with Karmiloff-Smith's (1992) proposal, our results show that (1) rigidity in routine development could constitute a sequential constraint that limits interrepresentational change, and (2) this sequential constraint, when relaxed, might be one of the multiple factors that lead to interrepresentational flexibility.

The present studies make two important contributions to the current literature. First, our findings that children's ability to produce high-level (inter) representational changes in their drawings was not associated with important modifications of the sequencing of elements within a usual graphic routine demonstrates that routine conservation is not a relevant index of sequential constraint acting on representational change. So far, previous studies (Barlow et al., 2003; Zhi et al., 1997) have only demonstrated that feature-ordering rigidity did not act as a constraint on intrarepresentational changes, which is on a lower level of representational complexity. Our results clearly indicate that routine conservation persists not only with intrarepresentational changes but also with interrepresentational changes.

The second major contribution of the present studies involves the finding that managing early routine interruptions precedes success at producing high-level (inter) representational changes in children's drawings. Previous studies (Picard & Vinter, 1999; Zhi et al., 1997) have noted that success at producing intrarepresentational changes was generally associated with early interruptions of the routines. Our study further highlights the importance of managing early routine interruptions to produce successful interrepresentational change, and suggests that routine development could be a relevant index of sequential constraint acting on representational change. As a matter of fact, the present studies demonstrate that relaxation of a sequential constraint within drawing routines occurs earlier than that of independence between routines, and not simultaneously as suggested by Karmiloff-Smith (1990, 1992).

To conclude, data from the present study lead us to specify further the content of the RR process with respect to the relaxation of the sequential constraint. In Karmiloff-Smith's model, procedural flexibility emerges when the RR process relaxes the sequential constraint. We suggest that the RR process could include activation/inhibition processes that sustain procedural flexibility. In our view, control over activation/inhibition processes is essential to manage the interruption of a graphic procedure at any time of its development and to show procedural flexibility in the drawing domain. In this perspective, we suggest that activation/inhibition processes should be viewed as an integral part and key processes of the RR process. However, because procedural flexibility only participates in the expression of interrepresentational flexibility, other processes must be hypothesized and the content of the RR process needs to be further specified. It has recently been suggested that the RR process could include part–whole decomposition processes that are essential to the ability to produce complex cross-category drawings (see Picard & Vinter, 2006). Specifying further the content of the RR process by determining the different processes that permit flexibility to emerge in children's behavior is important, not only for our understanding of drawing development, but for that of representational development in general. Our research was confined to the drawing domain, but the conclusions drawn about the relationships between procedural and representational flexibility potentially apply beyond this specific domain.

It should finally be noted that our study was also confined to an examination of changes in representational and procedural flexibility across ages, and we did not examine variability within individuals. The growing literature on variability in children's behavior (see e.g., Braswell & Rosengren, 2000) highlights the relevance of focusing on interindividual variability to understand the factors driving to change across ages. In a dynamic systems perspective (see Thelen & Smith, 1994), variability is not only noise around a stable behavioral state but reveals when a system is in transition. Future studies on children's drawing development, and representational development in general, would benefit from an examination of variability for a more complete assessment and understanding of mechanisms of developmental changes.

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