Rigidity in children’s drawings and its relation with representational change

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Received 1 May 2002; revised 27 June 2003

Abstract

Four studies tested the application of Karmiloff-Smith’s Representational Redescription (RR) model (1990, 1992, 1999) to the drawing domain. In particular, we tested her claim that young children are inhibited in their attempts at changing their graphic representations (representational change) due to being constrained by the order in which the elements of the representation are drawn (procedural rigidity). The first study required 60 children (4- to 6-year-olds and an older comparison group of 8-year-olds) to make three drawings of a familiar and novel topic. From these drawings each child was measured for procedural rigidity. In a further drawing the child was asked to modify their usual representation of each topic. Regression analyses revealed procedural rigidity levels were not predictive of manipulation performance. A second study, testing 75 4- to 6-year-olds and a third study, testing 30 3- to 4-year-olds, revealed that when young children were specifically asked to manipulate rigid sub-procedures on a familiar topic they were indeed able to do so. Finally, a fourth study (testing 40 5-year-olds and 40 8-year-olds) removed the notational trace in drawing (a possible aid for procedural interruption) but this still produced no evidence of a relation between procedural rigidity and representational change. We suggest how the concept of procedural rigidity might be re-interpreted for the drawing domain so that the RR model can remain as a domain-general theory of cognitive development. We also suggest the development of information processing may be crucial for flexibility in drawing.

Keywords: Representational redescription; Rigidity; Children’s drawings; Information processing; Representational change

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Introduction

One of the most influential theories, post-Piaget, to tackle the issue of cognitive development is a model expounded by Karmiloff-Smith, 1986, 1990, 1992, 1999 labelled “Representational Redescription” (RR) theory. According to this theory internal representations are progressively redescribed into more flexible states. Karmiloff-Smith (1992) states that a child will achieve “behavioral mastery” over a representation by compiling an automated routine for the consistent and successful externalization of that representation. Such a routine is not consciously accessible, but is merely an isolated (“procedurally rigid”\(^1\)) unanalyzable whole. This implicit phase representation is then redescribed into an explicit phase representation (whereby the representation becomes conceptual or meaningful) via a series of three levels. The first level of redescription (level E1) involves the representation’s components becoming data structures available to the rest of the system, resulting in common links with other explicit phase representations being made. Further redescription allows the representation to become consciously accessible (level E2) and open to verbal report (level E3). Karmiloff-Smith (1990) has stated that procedural rigidity may still act as a constraint on E1 representations, although it is significantly relaxed thereafter (at levels E2 and E3) and so no longer inhibits representational change. Indeed, according to Karmiloff-Smith (1990) rigidity is never lost and can still be beneficially utilised for tasks requiring speed and efficiency.

Karmiloff-Smith (1979a) initially developed this model in relation to the development of spoken language. However, Karmiloff-Smith (1992) contends the RR process is in fact a domain-general mechanism, occurring recursively on all representations within the cognitive system. Whereas spoken language leaves no external mark, Karmiloff-Smith (1990) argued the physical trace created by the child in the notational domains could be used as an indicator of the corresponding internal representation’s RR level. More specifically, Karmiloff-Smith states in children’s drawings, “an analysis of the types of modification that they produce makes it possible to capture essential facets of the constraints on representational flexibility” (1992, p. 157). In an influential test within the drawing domain, Karmiloff-Smith (1990) asked 54 4- to 10-year-olds to draw a man, and a man “who does not exist” (and also to do the same for an animal and a house). The younger children (4- to 6-year-olds) tended to make size, shape or deletion changes to elements within their drawings which, according to Karmiloff-Smith, suggested that these elements were available as data to the rest of the system (an E1 representation). However, as these young children’s modifications did not necessitate an interruption of the usual drawing procedure (e.g., the elements were still drawn in the same order), Karmiloff-Smith concluded they were still constrained by procedural rigidity emanating from the implicit phase. In contrast, older children exchanged position of elements or added extra elements from the same representation (e.g., a man with two heads)

\(^1\) Karmiloff-Smith (1990) used the term, “sequential constraint.”
or included cross-category insertions that involved synthesising two different representations (e.g., a house with wings). Thus, the older children demonstrated both intra- and inter-representational flexibility due to the relaxation of procedural constraints. Karmiloff-Smith then tested the possibility that the superficial changes made by the 4- to 6-year-olds had not been due to a lack of inventiveness. She asked eight 5-year-olds to draw “a man with two heads.” In line with the “procedural rigidity” account, seven out of the eight children drew the second head after completing the usual man drawing and then drew a second body attached to the second head (i.e., once the second head had been drawn they were compelled by their procedure to draw a second body also).

Subsequent research (e.g., Berti & Freeman, 1997; Morse & Bremner, 1998; Picard & Vinter, 1999; Spensley & Taylor, 1999; Zhi, Thomas, & Robinson, 1997) has failed to substantiate evidence for procedural rigidity in drawing. Using manipulation tasks, these studies have shown that young children are: (1) able to achieve a flexible product if the instructions and materials make it clear what type of manipulation is required, and (2) capable of inserting novel items mid-way through the drawing process.

This research established that drawings are not governed by totally rigid procedures, which Karmiloff-Smith (1992) herself accepted in her comment that “it turns out that the sequential constraint... is, particularly in domains like drawing, considerably weaker than I originally predicted” (Karmiloff-Smith, 1992, p. 162). Karmiloff-Smith (1992, 1999) has suggested the reason for the lack of data to substantiate compiled procedures in drawing (i.e., a totally rigid procedure) concerns the permanent notational trace. It is Karmiloff-Smith’s view that this may act as a cue for procedural interruption, thereby negating the demonstration of a totally compiled procedure. This qualification of a “weaker” constraint in drawing still allows, however, for a significant proportion of rigidity in drawing behaviour. Indeed, even as recently as 1999 Karmiloff-Smith alluded to the possibility that procedural rigidity may relate to sub-routines in drawing (e.g., a procedure for drawing the head rather than rigidity in the whole drawing procedure of a man, Karmiloff-Smith, 1999). Surprisingly, there is very limited data on rigidity levels in usual (pre-manipulation) drawings (see Picard & Vinter, 1999; Spensley & Taylor, 1999; Zhi et al., 1997). Nor has it been assessed whether rigidity in usual drawings does act as an inhibitor of representational change.

We suggest that a significant proportion of rigidity within the drawing process may still be indicative of an implicit phase or E1 level representation. This alternative weaker version of procedural rigidity allows for some variation in the usual drawing procedure. Study 1 aimed to test this idea by examining whether the level of rigidity within usual drawings is a predictor of both product and process flexibility in manipulation drawings (such flexibility is presumed to be an indicator of an E2 or E3 level representation). Studies 2 and 3 assessed children’s ability to interrupt one specific area of rigidity (i.e., a rigid sub-routine) to test Karmiloff-Smith’s (1999) revised view of rigidity pertaining to specific sub-routines in drawing. Finally, Study 4 aimed to test the notion that the external trace in drawing is responsible for the weaker rigidity exhibited by young children in this notational domain.
Study 1

Karmiloff-Smith (1992) revised her claim that drawings were compiled procedures and accepted that rigidity may well be weaker in notational domains like drawing. This weaker version of the original RR theory would still predict, however, that higher levels of rigidity in children’s usual drawings of a topic would be positively related to inflexibility on a manipulation task. Therefore the aim of the first study was to directly test for evidence of a weaker version of procedural rigidity in the drawing domain. As yet only primitive attempts have been made to assess whether children’s usual drawings are procedurally rigid to begin with and these studies have revealed conflicting results. Spensley and Taylor (1999) assessed the order of all elements depicted across one usual and three manipulation drawings of the human figure and found little evidence of procedural rigidity. In line with Karmiloff-Smith’s (1990) approach, Zhi et al. (1997) only monitored the sequence order of the relevant “core” items (e.g., body parts) and did find evidence of sequentially ordered elements. However, Zhi et al. (1997) examined rigidity in different types of human figure drawings and so failed to establish whether young children’s usual drawings of the same topic are procedurally rigid. We aimed to assess rigidity levels in such drawings by asking children to draw themselves and then monitoring the sequence of the core items only. To maximise the likelihood of testing children who are procedurally rigid we tested a group of 4- to 6-year-olds (see Karmiloff-Smith, 1990). An older group (8-year-olds) was also tested for evidence of children having moved on to one of the later explicit levels (E2 or E3); they may show less procedural rigidity in usual drawings and greater product and process flexibility on a manipulation task. Therefore, procedural rigidity and age were examined for the extent to which they explained performance on the manipulation tasks.

Previous research has tended to test for flexibility on familiar topics only. Therefore this study examined whether young children would be more rigid on a familiar topic that is commonly drawn by children (a human figure) compared to a novel drawing (a Christmas cracker of equal complexity to the human figure as both had the same number of elements). Because it was unlikely that children would have depicted a cracker prior to the experimental procedure this topic was considered novel. Also we were interested in possible differences regarding children’s ability to modify these two topics. The RR theory might predict for the familiar topic a relation between high levels of rigidity and an inability to modify this familiar representation. We expected the novel drawing to elicit low levels of rigidity possibly because children may not achieve full behavioral mastery when drawing this topic. The RR model makes no specific predictions about young children’s manipulation ability on novel topics. However, if procedural rigidity is not operating on a novel representation then young children should find it easier to manipulate in comparison with a procedurally rigid topic (i.e., the human figure).

In regard to the modification tasks, we wanted to explicitly state the manipulation; open-ended tasks such as “draw a man that doesn’t exist” may confuse children and also may depend on a child’s inventiveness. The manipulations chosen were within the bounds of reality to ensure that they made sense to the child.
Karmiloff-Smith (1990) noted that young children did not make the types of modifications that involved a disruption to the usual procedure. Our manipulation tasks required both the addition of a novel element and some position/orientation change to the usual elements which according to Karmiloff-Smith (1990) demonstrates a fully explicit representation. Hence, for the human figure, we asked children to draw a person holding a ball with both hands. For the cracker, children were asked to draw the cracker in split form (i.e., after it had been pulled) with a toy ball showing between the two halves of the cracker.

Method

Participants

Sixty participants (34 boys and 26 girls) ranging from 4 years 5 months to 8 years 10 months were chosen from three local primary schools in an English city in a stratified sample of 15 children in four age groups. Two children were replaced after the first drawing occasion due to difficulties in depicting all parts of the novel topic. There were 15 4-year-olds (9 boys and 6 girls, $M = 4;9$, $SD = 2$ months), 15 5-year-olds (10 boys and 5 girls, $M = 5;5$, $SD = 3$ months), 15 6-year-olds (7 boys and 8 girls, $M = 6;6$, $SD = 3$ months) and for the older age group 15 8-year-olds (8 boys and 7 girls, $M = 8;4$, $SD = 3$ months). Most of the children were Caucasian.

Materials

The materials used were white blank A4 paper, HB pencils, 3-D models and a video camera. Models consisted of a human figure doll (with moveable arms), a ball (size-scaled to be held by the doll), an intact special Christmas cracker, an identical Christmas cracker in two halves and another ball (size-scaled to be put in between the two halves of the split cracker). Both the human figure and the special cracker had seven parts (excluding ball): human figure (head, facial features, body, two arms and two legs) and cracker (two gold ends, two red cones, middle section, head and facial features). Models in their manipulated format as shown for the manipulation task resembled the illustrations shown in Fig. 1.

![Fig. 1. Illustrations of the manipulation models shown in Study 1.](image-url)
Procedure

All children were seen individually on three separate occasions. In the first session each child was given a sheet of plain A4 paper and pencil, and instructed to draw the human figure and cracker (counterbalanced order). For the human figure drawing they were asked, “I want you to draw a picture of yourself—a picture of you” (the 8-year-olds were told to draw a “simple picture of you, a picture of the whole of you with your face and body,” as a pilot study revealed the former instruction tended to induce detailed drawings of the face only from similar aged children). No model was shown for the drawing of the human figure. The experimenter then turned the piece of paper face down. The experimenter then introduced the “special cracker,” describing the (7) different parts that the cracker contained. The cracker was then removed and the child was asked to recall the parts. If the child failed to name all the parts the experimenter then repeated the procedure of showing the model with instructions. Any child who still failed to name all of the parts was not included in the experiment (this occurred on two occasions only). Children naming all seven parts were asked to draw the special cracker. If a child omitted parts in this drawing the model was shown again with a further discussion about parts (10 children required this further clarification on the first cracker drawing only). The model was then removed and the child was given a new sheet of paper to draw the cracker (all children were able to draw all seven parts on this final time).

This procedure was then repeated a week later and then again on a third occasion within two weeks later. Subsequent attempts by the child to draw the cracker did not require the detailed discussion conducted in the first session, but before each drawing the experimenter again drew attention to all of the different parts of the cracker. Immediately after this third set of usual drawings, the manipulation tasks were introduced (in a counterbalanced order) one at a time. For both manipulation tasks models were shown (see Fig. 1) and instructions were given. For the person manipulation each child was told to “draw a picture of a person holding one ball with both hands together.” For the cracker manipulation it was emphasised “that it is the same special cracker as before but now the cracker has been pulled or split in half and the toy (ball) that was inside has fallen out.” The child was then asked to draw the split cracker with the toy ball in the middle. For both manipulation tasks the model was removed before the child started to draw.

For all the drawings the order of the elements drawn was recorded in written form by the experimenter. Furthermore, a video recording was made of the production of each drawing to obtain an objective record of order. Each child was thanked for every drawing produced.

Scoring of drawings

Classification of procedural rigidity in the usual drawings

The drawings were examined for the pairs of elements that were drawn together (in the same order) throughout all three drawings (e.g., if the body was drawn immediately after the head on all three usual drawings in the same order then this
would constitute a rigid pair). For each topic, therefore, the participant obtained a score ranging from 0 to 6 pairs (as each topic had seven elements). Other items not essential to the human figure or the special cracker drawings were not counted as part of the sequence of the participant’s drawing (e.g., clothes, hats, etc.). Eleven out of 60 children included non-essential items but this affected only one child’s rigidity score. Inspection of this child’s drawing revealed that an overestimation of rigidity had occurred in that the depiction of buttons had interrupted a rigid pair on one drawing. If facial features were not drawn altogether (e.g., if a child drew part of the facial features, then drew the body and afterwards continued drawing the rest of the facial features) the facial features as an item was recorded only when it was first drawn. All other subsequent facial feature items, wherever they appeared in the drawing sequence, were then ignored. Roughly a third (18/60) of the total sample split facial features, although again only a small proportion of children’s rigidity scores were affected (4/60) and all concerned an overestimate of rigidity by one pair only (i.e., because some facial feature item which was ignored under our rigidity measure had been inserted between a rigid pair). For those children who drew less than seven elements their pair (rigidity) score was converted to a score out of six by a percentage formula (in Study 1 only 3 out of 60 children had their rigidity score converted).

Classification of the manipulation task drawings

Product success. Product success was measured on a scale of 1–4 for the human figure manipulation—usual arms outstretched not touching the ball (1 score), ball placed on one or both of the usual outstretched arms (2 score) constituted a primitive attempt at integration of the human figure and novel item. However, these drawings did not involve a manipulation to the usual human figure drawing as the arms were not modified (all children drew outstretched arms in their usual drawings). Partial manipulations (3 score) involved either an insufficient attempt at manipulating both arms, manipulated yet elongated arms or where either one or both arms had been inwardly oriented but other outstretched arms had also been depicted. A full manipulation (4 score) entailed both arms being placed (at least partially) on the body, in an inward fashion, touching the ball.

The special cracker manipulation was measured on a scale of 0–3—no ball depicted (0 score, this only occurred in one instance), ball drawn within an intact cracker (1 score); these drawings therefore did not necessitate a manipulation of the usual cracker drawing. Partial manipulations (2 score) involved the ball being positioned correctly within either two complete pieces that were still joined together by an outline of the whole cracker or two incomplete separate halves (i.e., a simple pen-lift had occurred to create a gap/split). A full manipulation (3 score) included two complete and separate halves (plus the new item placed appropriately). Examples of the range of product success scores for the children’s manipulation drawings are shown in Fig. 2.

Process success. Process success concerned the point at which the new item (i.e., the ball) had been inserted, that is at the start (first element depicted), middle or at the end (the last item drawn).
Results

The first author classified order of elements at the time each drawing was made by the child. An independent judge then classified element ordering for 25% of the total drawings from the video recordings. There was agreement in 94% of these judgements. Disagreements were then settled by referring to the video evidence. The first author and an independent judge classified product success in 100% of the manipulation drawings for which there was agreement in 98% of the judgements.

Procedural rigidity in the usual drawings

Forty-two percent of the whole sample (40% of the 4- to 6-year-olds) produced a totally rigid sequence across the three human figure drawings (i.e., 42% received a pairs score of 6 on the procedural rigidity measure), with only one child (5-year-old) doing so for the cracker drawing.
A two-way (mixed) ANOVA examined the effects of age and topic on rigidity. There was a significant main effect of topic, $F(1, 56) = 75.27, MSE = 1.9, p < .01$, $\eta^2 = 0.57$. Children were less rigid when depicting the usual cracker drawing. There was no age effect, $F(1, 56) = 0.04, MSE = 2.41, p = .99, \eta^2 < 0.01$, and no interaction found, $F(3, 56) = 0.89, MSE = 1.9, p = .45, \eta^2 = 0.05$. Thus, there was no age-related development in terms of rigidity levels for either topic.

**Product success in the manipulation drawings**

Table 1 presents the product success scores for the human figure and cracker manipulation drawings, respectively. Two one-way (between subjects) ANOVAs were conducted to examine the effect of age on product success. Firstly, for the human figure manipulation there was a significant age effect, $F(3, 56) = 7.84, MSE = 0.87, p < .01, \eta^2 = 0.29$. Post hoc Tukey tests revealed that the 6- and 8-year-olds scored significantly higher than both the 4- and 5-year-olds. Secondly, for the cracker manipulation there was also a significant age effect, $F(3, 56) = 3.58, MSE = 0.41, p = .02, \eta^2 = 0.16$. Post hoc Tukey tests highlighted only one significant age shift between the 4- and 8-year-olds. In order to assess whether product success was related to topic, the product success scores were collapsed to produce a dichotomous measure for each topic: human figure-successful (3–4), unsuccessful (1–2); cracker-successful (2–3), unsuccessful (0–1). Success was related to whether at least a partial manipulation of their original representation had been attempted. On the person manipulation 40% of 4-year-olds, 47% of 5-year-olds, 67% of 6-year-olds and 93% of 8-year-olds were classed as successful. The 4- to 6-year-olds results were collated and a $2 \times 2 \chi^2$ revealed that the 8-year-olds were more successful on the human figure ma-

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nipulation task in comparison to the 4- to 6-year-olds, $\chi^2 = 8.48$, $df = 1$, $p < .01$. However, for the cracker manipulation 80% of the 4-year-olds, 93% of the 5- and 6-year-olds and 100% of the 8-year-olds were classed as successful. A modified $2 \times 2 \chi^2$ revealed no significant difference between the 4- to 6-year-olds and the 8-year-olds on the novel manipulation task, $\chi^2 = 1.79$, $df = 1$, $p > .10$. Clearly, there was greater success on the cracker manipulation.

The relation between procedural rigidity and product/process success

Two-step hierarchical regression analyses were conducted in order to determine the extent to which procedural rigidity (0–6 score) and age (in months) predicted product success for both the human figure (1–4) and cracker (0–3) manipulation tasks. These hierarchical regression analyses were performed on the 4- to 6-year-olds’ data only (i.e., the 8-year-olds were removed) so that only the relevant age group with respect to procedural rigidity was tested. For the human figure, procedural rigidity did not predict product success, $F(1,43) = 0.17$, $p = .68$, adjusted $R^2 = 0.02$, but when age in months was entered a significant increment of 18% of the variance was explained, $F(1,42) = 11.16$, $p < .01$, adjusted $R^2 = 0.18$. For the cracker topic, procedural rigidity did not predict product success, $F(1,43) = 0.85$, $p = .36$, adjusted $R^2 < 0.01$, and when age in months was added the accounted variance approached significance with age in months explaining a further 7% of the variance, $F(1,42) = 2.91$, $p = .06$, adjusted $R^2 = 0.08$. We can therefore conclude that for 4- to 6-year-olds age in months, but not their procedural rigidity, was a strong predictor of product success on the manipulation tasks for both topics.

Finally, we determined whether procedural rigidity was related to process success. That is, were the procedurally rigid 4- to 6-year-olds only adding the modification at the end due to their rigidity level? For this analysis procedural rigidity was collapsed into a dichotomous variable: a procedurally rigid child had a 4–6 pairs score, with a non-procedurally rigid child having a 0–3 pairs score. Also, in order to be consistent with Karmiloff-Smith’s (1990) view that start interruptions are evidence that procedural constraint has been relaxed (i.e., “this involves a subroutine interrupting the procedural sequence” Karmiloff-Smith, 1990, p. 73) data for the start and mid category interruptions were collapsed within each topic and compared to the numbers of children making end interruptions. On the manipulation of the familiar topic roughly two-thirds of both the procedurally rigid (20/31) and non-procedurally rigid (10/14) 4- to 6-year-olds made start/mid interruptions. Similarly for the cracker manipulation the vast majority of young children from both rigidity categories, procedurally rigid (8/9) and non-procedurally rigid (31/34), made start/mid interruptions also. Indeed, two modified $2 \times 2 \chi^2$s revealed that for both the familiar topic, $\chi^2 = 0.12$, $df = 1$, $p > .70$, and novel topic, $\chi^2 = 0.17$, $df = 1$, $p > .50$, procedural rigidity category was not related to the 4- to 6-year-olds’ levels of process success. The data show clearly that those children who produced more procedurally rigid routines in their usual drawings were no more likely (compared to non-procedurally rigid children) to make end modifications in the manipulation tasks.
Discussion

We found that for both topics the majority of 4- to 6-year-olds did not produce a totally rigid procedure. This suggests that representations are not simply sustained by procedural routines. There was also no age-related development in rigidity, that is older children did not exhibit less rigidity, although Karmiloff-Smith (1990) has stated that rigidity is not necessarily lost once redescription has occurred. The most important finding from this study was that procedural rigidity did not predict children’s ability to manipulate their representations of either topic, nor was it associated with end-interruptions. Therefore, the proposed “weaker” version of procedural rigidity was not supported.

With respect to children’s ability to modify their representations older children (8-year-olds) were better able to manipulate their original representations in order to reflect the human figure and cracker manipulation models. It seems unlikely that young children simply misunderstood the task requirements as all children were shown a model and given specific instructions, and indeed all children appeared to understand our manipulation tasks. Also the manipulations were both within the bounds of reality and specific in nature (as opposed to Karmiloff-Smith’s “draw a strange man” task) and therefore were unlikely to confuse the child. The manipulation tasks did not require the addition of any complex new elements. Because only those children who could already draw a satisfactory representation of both topics (in their pre-manipulated form) were allowed to attempt the manipulation tasks, it cannot be concluded that young children failed on the tasks due to poor drawing ability. This re-emphasises the existence of a developmental shift in representational flexibility, and that differences in procedural rigidity did not account for this development.

The finding that young children achieved greatest success on the novel manipulation task could be accounted for by the RR theory as a result of behavioral mastery not being achieved for the cracker (i.e., procedural rigidity had not yet formed). Therefore, the RR theory could explain young children’s successful performance on the unfamiliar manipulation product in terms of simply creating a new procedure for this manipulated cracker, rather than operating on their original cracker representation. Alternatively, the poorer performance on the familiar manipulation task may simply be due to the human figure’s habitual status in the young child’s drawing repertoire (see Zhi et al., 1997).

The main point, however, is that proportion of rigidity on either topic was not a predictor of representational change in terms of product or process success on the manipulation tasks. Nevertheless, Study 1 did not test the possibility that procedural rigidity may only constrain specific areas within a drawing (see Karmiloff-Smith, 1999). We aimed to address the issue of specific sub-routines in Study 2.

Study 2

Karmiloff-Smith recently asked, “Is there really a man-drawing procedure, or rather a series of sub routines for drawing the head, the body and the limbs?” (Kar-
miloff-Smith, 1999, p. 325). So rather than the entire drawing process being fixed, procedural rigidity may relate to particular rigid sub-routines.

Study 2 aimed to address this issue by measuring 4- to 6-year-olds’ rigid sub-procedures (i.e., a pair of elements which was drawn together and in the same order on all three usual drawings) and then assessing their ability to manipulate a particular fixed sub-routine. The latter was done by giving a manipulation item specific to the area of the child’s rigidity. If children did not modify the rigid sub-procedure in the manipulation task, they were then afforded a second attempt, with specific instruction to re-order the rigid elements. The specific instruction was given to ensure that any failure on their first manipulation drawing was due to being unable to re-order their fixed pair, rather than simply because they misunderstood the task requirements or chose to make the interruption elsewhere. As all children showed some procedural rigidity for the human figure but not for the cracker in Study 1, children were tested in Study 2 on human figure drawings only.

Method

Participants

Seventy-five participants (37 boys and 38 girls) ranging from 4 years 0 months to 6 years 7 months were selected from three local primary infants schools in an English city in a stratified sample of 25 children in three age groups. There were 25 4-year-olds (9 boys and 16 girls, $M = 4;6$, $SD = 3$ months), 25 children 5-year-olds (13 boys and 12 girls, $M = 5;4$, $SD = 3$ months), and 25 children 6-year-olds (15 boys and 10 girls, $M = 6;3$, $SD = 2$ months). Most of the children were Caucasian.

Materials

The materials used were white blank A4 paper, HB pencils, a 3-D human figure doll (with moveable arms—as used in Study 1), additional parts for the doll, and a video camera. The additional parts for the doll included a ball, a piece of brown material (i.e., the beard), a cardboard red bow tie, three cardboard red buttons, a pair of plastic shoes and one pair of black shoelaces (all appropriately size-scaled to the doll).

Procedure and scoring

The instructions for the three drawings of the human figure were essentially the same as described in Study 1, except that children were asked to draw a man over two sessions. On the first drawing children were instructed, to “draw a picture of a man.” On the second occasion (a week later) the child was asked to draw a man and then given a further piece of paper and told to “draw another picture of a man, the same as before, except this time we can call this picture the first man’s friend.” This was done so that the child would not think that their first drawing had been unsatisfactory. These three drawings of a man were then analysed to establish which pairs of elements always appeared together and in the same order. For each child one pair of rigidly ordered elements was then chosen by the experimenter to be the pair that would require interruption in the manipulation task (all children
Each rigid pair was assigned an item designed specifically to interrupt it. These were as follows: head to facial features (beard), facial features to body (bow tie), body to arm, arm to arm, arm to leg (man holding ball), body to leg (buttons) and leg to leg (shoes, or if these were already depicted, shoelaces). Although a child’s area of rigidity restricted which items could be chosen, roughly equal numbers of each manipulation item were randomly assigned to the total sample of participants. Pairs of elements that had extraneous items inserted in between them in the usual drawings were not chosen for manipulation because it could be argued that such pairs were not initially rigid.

On the third occasion, a week later, children were informed that this time they were going to draw a man “but with something added on.” A brief explanation of the new element was then given and all children agreed they understood what the new element was. The new item (e.g., bow tie) was then placed on the doll. A model (with the new item) was presented to clarify the drawing requirements. The model was then removed and the child asked to draw a picture of the doll with the new item (e.g., “can you draw a man wearing a bow tie”). Under these “free instructions” no direction was given as to when to draw the new item. Children who did not re-order their rigid pair in this drawing were then asked specifically to do so (“specific instructions”) in a follow-up drawing (e.g., “can you draw the bow tie immediately after you have drawn the face and then draw the rest of the man”). Any questions were then dealt with (and more elaborate instructions were given if necessary) before the child drew.

Each drawing session was video recorded. In the manipulation task (under the free or specific instructions) the experimenter classified each child as either successful or unsuccessful depending on whether the child inserted the new item between the rigid pair, or if he or she had successfully re-ordered the chosen rigid pair with another usual element of the human figure drawing.

Results

The first author classified order of elements at the time each drawing was made by the child. An independent judge then classified element order for 25% of the total drawings from the video recordings, for which there was agreement in 90% of the judgements. The video was then referred to in order to settle disagreements.

Firstly, under the free instructions, only 17 out of the 75 participants spontaneously modified their rigid sub-procedure. A further 49 4- to 6-year-olds were then successful at re-ordering after the specific instructions. Therefore a total of 66 out of 75 participants were successful at re-ordering after both the free (or if required) specific instructions had been given. Apart from one exception all the 5- to 6-year-olds demonstrated that they could re-order. The 5- and 6-year-olds’ results were collapsed and compared with that of the 4-year-olds’ performance in a modified $2 \times 2 \chi^2$. This revealed a significant relation between age and level of success, $\chi^2 = 14.01$, $df = 1$, $p < .01$. A one group $\chi^2$ revealed no significant difference in the numbers of children being successful or not among the 4-year-olds, $\chi^2 = 3.24$, $df = 1, p = .07$ with 17/25 4-year-olds successfully re-ordering their rigid pair. It ap-
pears, therefore, that 5- to 6-year-olds can manipulate their rigid routines when directed to do so. Despite narrowly missing significance, the 4-year-olds’ performance followed the same trend as that of the older children, that is the majority were successful at re-ordering after the specific instruction had been given.

Discussion

The data from Study 2 demonstrate that children were able to access and interrupt their rigid sub-routines, which questions further the validity of procedural constraint operating in the drawing domain. Nevertheless, many children of all age groups did not spontaneously interrupt their rigid pair, only doing so when specifically directed to. This is consistent with previous findings based on the drawing product of modification tasks, where performance improves if young children are given specific instructions (Zhi et al., 1997; Spensley & Taylor, 1999). Thus, it seems that many children chose under the free instructions to maintain their fixed sub-routines. This preference may be due to graphical ease, particularly in cases where the elements have a natural drawing order. Topics that are habitually drawn, such as the human figure, are likely to compound these rigid sequences. Although the new items in the present study were conceived to split up a rigid pair, most could be drawn without doing so (e.g., in the head to facial features pair the beard could be drawn last while making a drawing that reflected the model). Perhaps in order to minimise the cognitive load of the task, the child may choose to draw the new element(s) after completing his or her normal drawing process (i.e., their rigid pair). Such choices give the impression of inflexibility, but our children’s overwhelming ability to interrupt these sequences when specifically asked belies this initial interpretation. In Study 3 we examined younger children’s ability to re-order their rigid sub-routines to test whether procedural constraint is evident but occurs earlier in drawing than Karmiloff-Smith (1990) suggested.

Study 3

Although even the youngest children showed good evidence of flexibility in Study 2, they were the least likely to re-order their rigid routines. A possible interpretation is that the 4-year-olds were just in the process of relaxing (redescribing) procedural rigidity. Testing even younger children may capture procedural constraint. In Study 3 we examined this possibility by replicating Study 2 but using a younger age group (3- to 4-year-olds).

Children around this age typically produce the tadpole form of the human figure: an enclosed circle as a head (with some facial features), with legs (and possibly arms) protruding from the head. Children who depict this type of human figure have been well documented in their resistance to include the “missing” body (see Cox, 1993; Freeman, 1980). Such rigid behavior led Spensley and Taylor (1999) to test whether young children, who typically draw the tadpole figure, embodied the implicit phase in human figure drawing. Spensley and Taylor assessed whether 3- to 4-year-olds
could interrupt their human figure drawing procedure by including a novel item. From a very small sample, five children drew representational human figures (although it is not clear what proportion, if any, drew tadpole figures), but all were found to have inserted the new element mid-procedure. However, Spensley and Taylor did not initially monitor a series of pre-manipulation drawings to examine which rigid sequences each child produced. Thus, we cannot be sure from their very small sample to what extent 3- to 4-year-olds are rigid in their human figure drawings and whether they are able to interrupt any rigid sub-procedures they may have within this representation.

By using the same method in Study 2 we investigated evidence for the implicit phase (or level E1) on younger children. Thus a particular area of rigidity was chosen for all drawers (tadpole or otherwise) and using the same additional items as used in Study 2 all children were required to interrupt a rigid pair.

**Method**

**Participants**

Thirty participants (9 boys and 21 girls) ranging from 3 years 4 months to 4 years 11 months were selected from three primary infants schools in an English city in a stratified sample of 15 children in two age groups. There were 15 3-year-olds (6 boys and 9 girls, $M = 3; 8, SD = 2$ months) and 15 children 4-year-olds (3 boys and 12 girls, $M = 4; 6, SD = 4$ months). Most of the children were Caucasian.

**Materials and procedure**

The materials and procedure were as described in Study 2.

**Results**

The first author classified order of elements at the time each drawing was made by the child. An independent judge then classified element order for 25% of the total drawings from the video recordings, for which there was agreement in 87% of the judgements. The video was then referred to in order to settle disagreements.

As in Study 2, children were more likely to retain their rigid sub-procedures, under the free instructions, rather than re-order them. It was found that 23.3% did reorder their rigid pair which is similar to the 4- to 6-year-olds’ results in Study 2 (22.7%). A total of 23 out of 30 participants were successful at re-ordering after both the free (or if required) specific instruction had been given (with 10/15 3-year-olds and 13/15 4-year-olds successfully re-ordering). A modified $2 \times 2 \chi^2$ found no relation between age and success, $\chi^2 = 1.62, df = 1, p > .05$. On the data collapsed for age, significantly more successful attempts at re-ordering their rigid pair were made, $\chi^2 = 8.53, df = 1, p < .01$.

Although we have found little evidence of inflexibility in our sample of 3- to 4-year-olds, it is possible that procedural rigidity relates more to drawing form than age. We therefore examined the tadpole drawers only, and found that out of 11 tad-
pole drawers seven successfully manipulated the chosen rigid procedure. Therefore it cannot be concluded that tadpole drawers are procedurally rigid.

Discussion

Studies 1 and 2 found no evidence of procedural rigidity inhibiting modification ability between 4 and 6 years of age, the age group Karmiloff-Smith (1990) suggested it applied to. On the basis of the data from Study 3 it does not apply to younger children either. It seems that in children’s early experiences of producing a recognisable representation they have sufficient access to manipulate it. Therefore the present data strongly suggests that procedural rigidity does not exist in any form within the drawing domain. The need for specific instruction was again highlighted. As in Study 2, children maintained their rigid routines under the free manipulation instructions, but demonstrated their ability to re-order when specifically directed to do so.

Another particular interest in studying 3- to 4-year-olds was that some of these children draw a different form of the human figure (a tadpole) compared to older children. As has been debated in the literature, the criteria of behavioral success is a tricky one, particularly in the drawing domain in which variable forms of a representation exist (Karmiloff-Smith, 1999; Spensley & Taylor, 1999). In terms of testing the RR theory it is an important concept to define, as the implicit phase is said to be evident once behavioral mastery is achieved (but see revisions made by Karmiloff-Smith (1994, 1999)). We concur with Spensley and Taylor’s view that there are a series of behavioral successes in children’s drawings throughout the development of their representations. As the tadpole drawing is one of the first representations of the human figure children produce, the tadpole drawer is a likely candidate for the initial form of behavioral mastery that the implicit phase is dependent upon. However, our data showed that many of the tadpole drawers, like the conventional figure drawers, could re-order their rigid routines.

Studies 1–3 have shown that young children are flexible in both their usual and manipulation drawing process. However, Karmiloff-Smith (1992, 1999) later stated that lack of rigidity in children’s drawings may be due to the permanent external mark acting as a cue for procedural interruption. Study 4 aimed to test these claims.

Study 4

Karmiloff-Smith (1992, 1999) revised her (1990) initial view that representations are produced as a compiled procedure, run as an unanalyzable whole, in which the components are not accessible. She went on to claim that “...Drawings and all forms of external notation leave a trace...An interruption in an ongoing drawing leaves a trace of where the drawing was cut off, and it acts as a potent cue about where to continue” (Karmiloff-Smith, 1992, pp. 161–162). Therefore, Karmiloff-Smith (1992) believes that rigidity may be less prominent in notational domains although she does not appear to totally rule out compiled procedures in certain notational domains as Tolchinsky-Landsmann and Karmiloff-Smith (1992) found
evidence for procedural rigidity in young children’s attempts at written language and number. However, Karmiloff-Smith (1992) still maintained that sequential constraint should be explored in areas where no external notation is involved (i.e., counting, music and spoken language). Indeed, clear support for an implicit/explicit shift in spoken language has been shown both micro- and macro-developmentally by Karmiloff-Smith (1979b). However, other research on physics comprehension (Messer, Joiner, Light, & Littleton, 1998) has only found evidence to substantiate the explicit levels of the theory, and suggested extra transitional levels are required (Pine & Messer, 1999, 2000).

The removal of the notational trace in a drawing has not been previously attempted in order to test Karmiloff-Smith’s (1992, 1999) claims that the external mark acts as a cue for procedural interruption. Asking young children to make totally “invisible” drawings may elicit a compiled procedure (or at least high levels of procedural rigidity) in their usual drawings, which in turn should inhibit interruption/ manipulation ability. Half of the sample in this study were asked to create their drawings using an “artpad” (that left no external trace) linked to a computer that recorded the completed drawing. In addition to the representational change task used in the previous studies (the “man with ball” manipulation), Karmiloff-Smith’s (1990) original tasks from her second study (e.g., a “man with two heads” and a “house with wings”) were also used. Unlike the previous studies, instructions rather than models were used in the present study for all drawings, including the manipulation tasks, in order to be sure that children were operating on their human figure representation rather than simply creating a new procedure when copying from their memory of the model (see Karmiloff-Smith, 1990). As in Karmiloff-Smith’s (1990) second study, 5-year-olds were tested for evidence of procedural rigidity, and a comparison group of 8-year-olds were also sampled.

**Method**

**Participants**

Eighty participants (41 boys and 39 girls) ranging from 5 years 4 months to 5 years 11 months (5-year-olds) and 8 years 0 months to 8 years 11 months (8-year-olds) were chosen from four local primary schools in an English city. Stratified sampling was used in order to choose 40 children in two age groups, each group being divided equally into the notational or non-notational drawing condition. There were 20 5-year-olds in the notational condition (8 boys and 12 girls, $M = 5;9$, $SD = 2$ months), 20 5-year-olds in the non-notational condition (10 boys and 10 girls, $M = 5;9$, $SD = 2$ months), 20 8-year-olds in the notational condition (11 boys and 9 girls, $M = 8;6$, $SD = 3$ months) and 20 8-year-olds in the non-notational condition (12 boys and 8 girls, $M = 8;8$, $SD = 3$ months). Most of the children were Caucasian.

**Materials**

The materials used were white blank A4 paper, HB pencils (notational condition), a laptop computer, artpad attachment with mouse-pen, computer drawing package (Photoshop 6.0) and a video camera.
Procedure

The instructions for the three usual drawings of the human figure were the same as described in Study 2 for children in the notational condition. In addition to the human figure drawing, children were asked to draw a picture of a house (counterbalanced order). Children in the non-notational condition were introduced to the artpad with the explanation that “this is just like drawing with a pencil and paper except this will be a magic drawing as you will not be able to see it until you have finished.” Any questions about using the artpad were dealt with before the same instructions to draw a man and house were given and each child was then allowed to view their finished drawings. These drawings were then saved and printed out later by the experimenter. On the second occasion (a week later) each child was asked to draw a man and a house and then, on a separate piece of paper (or new document), was asked to draw “the same house again, as I need you to draw two houses this time” or in the case of the man drawing “another picture of a man, the man’s friend.”

On the third and final session a week later, children were informed that this time they were going to draw “some different pictures” (i.e., the three manipulation tasks, which were also counterbalanced). For the “man holding a ball” manipulation the child was instructed “can you draw me a picture of a man holding a ball with both hands, with the ball placed in front of his tummy.” For the “man with two heads” task the child was told that “this is a silly picture” and was then asked to “draw a man with an extra head—one man with two heads.” Finally, for the “house with wings” manipulation, children were again informed that this was a “make-believe drawing” and were asked to “draw a house with some wings on each side—a flying house.” In order to clarify what was required each child was told “wings are a bit like wobbly arms.” All children were able to successfully draw wings. As in the previous studies, the experimenter noted (in written form) sequence order for all drawings and each session was also video recorded. Each child was thanked for every drawing produced.

Scoring of drawings

Classification of procedural rigidity in the usual drawings

Procedural rigidity. As in Study 1, procedural rigidity on the three usual human figure drawings was scored for 0–6 rigid pairs. For the human figure drawing eight out of 80 participants split the facial features item, although only one participant’s rigidity score was overestimated due to this split. The house drawing was deemed to have seven parts (square outline, roof, two upstairs windows, two downstairs windows, and a door) so was also scored on a scale of 0–6 rigid pairs. Six children on the human figure drawing and 42 children for the house drawing added extraneous items. This meant an overestimate of rigidity (by one rigid pair) had occurred for three and 13 children in the human figure and house drawings respectively. Three children, for the house drawing only, possessed a further rigid pair due to the extra item always being placed together with an element from the previous list. As in the previous studies, children who depicted fewer than seven items, for either topic, had
their rigidity total converted to a score out of six using a percentage formula (this applied to three children for the human figure and 20 children for the house drawing, out of the 80 children tested).

Classification of the manipulation task drawings

Product success. The “man holding a ball” manipulation task was measured on the same scale of 1–4 as described in Study 1 (see Fig. 2). The “man with two heads” task was measured on a scale of 0–3—no second head inserted or body parts duplicated (0 score), second head inserted but not attached to the original figure (1 score), the first head attached in the usual position, with the second head drawn in an alternate location, that is simply “added on” when attached to the usual human figure schema (2 score). These drawings did not demonstrate any manipulation of the usual human figure. A manipulation (3 score) involved changing their usual human figure representation (e.g., repositioning the first head to accommodate the second so that both heads appear equally balanced at the top of the body).

The “house with wings” task was measured on a 1–3 scale (as no children failed to depict wings no zero scores were obtained)—wings inserted but not attached to the house (1 score), wings attached onto a closed outline of the house (2 score); both of these drawing types did not show a manipulation to the usual house schema. A manipulation (3 score) involved changing their usual house representation (e.g., inserting the wings such that they were drawn as an integral part of the house outline). As in Study 1, therefore, we considered a product manipulation to involve a change to the child’s existing schema, rather than just the addition of extra elements. Fig. 3 displays examples of the children’s manipulation drawings (from both drawing conditions) for the “man with two heads” and “house with wings” tasks.

Process success. As in Study 1 the process success measure concerned the point at which the new item (e.g., the ball, second head, or wings) had been inserted (e.g., start, middle, or end). If the two heads were the first and second elements drawn on the “man with two heads” manipulation then this was classified as a start interruption.

Results

The first author classified order of elements at the time each drawing was made by the child. An independent judge then classified element ordering for 25% of the total drawings from the video recordings. There was agreement in 88% of the judgements. Disagreements were then settled by referring to the video evidence. An independent judge then classified product success in 100% of the manipulation drawings for which there was agreement with the first author in 97% of the judgements. The first author’s ratings were used for the data analysis.

Procedural rigidity in the usual drawings

The procedural rigidity measure examined the numbers of pairs of elements that always appeared in a set sequence in all three of the usual drawings for each topic. In
the non-notational condition, only 30% of the 5-year-olds for the man drawing and 25% of the 5-year-olds for the house drawing had a totally fixed drawing routine (i.e., six rigid pairs). In the notational condition 50% of the 5-year-olds for the man drawing and 25% of the 5-year-olds for the house drawing had a totally fixed drawing procedure.

A three-way (mixed) ANOVA was conducted in order to examine the effects of age category, drawing condition and topic on rigidity scores. Table 2 displays the rigidity score means for each age group in both drawing conditions for each topic. There was a significant main effect for drawing condition, $F(1, 76) = 11.97$, $MSE = 3.02$, $p < .01$, $\eta^2 = 0.14$. Contrary to Karmiloff-Smith’s (1992) prediction
children were more rigid in the notational condition. There was also a main effect of topic, \( F(1, 76) = 4.23, MSE = 2.86, p = .04, \eta^2 = 0.05 \). Children were more rigid when depicting the usual human figure drawing. There was a drawing condition and topic interaction, \( F(1, 76) = 8.40, MSE = 2.86, p < .01, \eta^2 = 0.10 \). There was also a three-way interaction between age, drawing condition and topic, \( F(1, 76) = 5.90, MSE = 2.86, p = .02, \eta^2 = 0.07 \). Simple effects (two-way mixed ANOVAs) were conducted to investigate the effects of drawing condition and topic on rigidity scores for each age group separately. \( \alpha \) was adjusted using a Bonferroni correction to 0.025. For the 5-year-olds, the main effect for drawing condition (with greater rigidity levels found in the notational condition) just failed to reach significance, \( F(1, 38) = 5.23, MSE = 2.6, p = .03, \eta^2 = 0.12 \). There was no topic effect, \( F(1, 38) = 3.61, MSE = 2.96, p = .28, \eta^2 = 0.03 \) and also no interaction between drawing condition and topic, \( F(1, 38) = 0.31, MSE = 2.96, p = .75, \eta^2 < 0.01 \). For the 8-year-olds there was a main effect of drawing condition, \( F(1, 38) = 6.74, MSE = 3.43, p = .01, \eta^2 = 0.08 \). The 8-year-olds were more rigid in the notational group. There was no topic effect \( F(1, 38) = 9.11, MSE = 2.76, p = .07, \eta^2 = 0.08 \). However there was a significant interaction between drawing condition and topic, \( F(1, 38) = 14.73, MSE = 2.76, p < .01, \eta^2 = 0.28 \). Simple interactions revealed that the 8-year-olds were more likely to be rigid in the notational condition compared to the non-notational condition on the man drawing, \( F(1, 38) = 25.65, MSE = 2.44, p < .01, \eta^2 = 0.4 \). On the house drawing there was no significant difference between the two types of drawing condition, \( F(1, 38) = 0.33, MSE = 3.75, p = .57, \eta^2 < 0.01 \).

Therefore the overall finding indicated that for the 5-year-olds higher rigidity scores were elicited in the notational condition compared to the non-notational condition for both topics. This finding was replicated for the 8-year-olds on the human figure topic only.

<table>
<thead>
<tr>
<th>Table 2</th>
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<tbody>
<tr>
<td>Product success score means (and SD) for each age group in both drawing conditions (Study 4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Descriptive statistics for rigidity scores (0–6 pairs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing conditions</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>Notational</td>
</tr>
<tr>
<td></td>
<td>Non-notational</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>8</td>
<td>Notational</td>
</tr>
<tr>
<td></td>
<td>Non-notational</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Total</td>
<td>Notational</td>
</tr>
<tr>
<td></td>
<td>Non-notational</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
</tbody>
</table>

Note. MB denotes “man with ball” task (scored 1–4), M2 denotes “man with two heads” task (scored 0–3), and HW denotes “house with wings” task (scored 0–3).
Product and process success in the manipulation drawings

Table 3 presents the product success means for each of the three manipulation tasks. Two-way (between subjects) ANOVAs were performed in order to examine the effects of age and drawing condition on product success for each of the three manipulation tasks. Firstly, for the “man with ball” manipulation, there was a main effect of age, \( F(1,76) = 9.8, \text{MSE} = 0.67, p < .01, \eta^2 = 0.11 \). The older children (8-year-olds) attained significantly higher product success scores than the 5-year-olds for this manipulation. Secondly, for the “man with two heads” manipulation, there was a significant main effect for drawing condition, \( F(1,76) = 5.01, \text{MSE} = 0.81, p = .03, \eta^2 = 0.06 \). Children in the notational condition achieved higher product success scores. Finally, on the “house with wings” manipulation there was no effect of age or drawing condition on product success.

The majority of children (regardless of age) in both drawing conditions for the human figure manipulations made start/mid interruptions. In the non-notational condition 80 and 70% of the 5-year-olds (compared to 60 and 70% in the notational condition) made start-mid interruptions in the “man with ball” and “man with two heads” tasks respectively. Two \( \chi^2 \)'s confirmed that process success was not related to notational condition for the 5-year-olds on either the “man with ball” task, \( \chi^2 = 1.90, df = 1, p = .17 \) or the “man with two heads” task, \( \chi^2 = 0, df = 1, p = 1.00 \). With respect to the 8-year-olds, 70 and 85% in the non-notational condition (compared to 100% and 80% in the notational condition) made start-mid interruptions in the “man with ball” and “man with two heads” tasks, respectively. Two modified \( \chi^2 \)'s revealed that there was no relation between notational condition and process success for the older children on the “man with ball” task, \( \chi^2 = 1.25, df = 1, p > .30 \). However, on the “man with two heads” task a modified \( 2 \times 2 \chi^2 \) revealed that older children in the non-notational condition were more likely to make start/mid interruptions compared to those older children in the notational condition.

Table 3
Product success score means (and SD) for each age group in both drawing conditions on the man with ball task (MB 1–4 score), man with two head task (M2 0–3 score) and the house with wings task (HW 0–3 score) (Study 4)

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Drawing conditions</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MB</td>
</tr>
<tr>
<td>5</td>
<td>Notational</td>
<td>3 (0.92)</td>
</tr>
<tr>
<td></td>
<td>Non-notational</td>
<td>2.95 (0.89)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2.98 (0.89)</td>
</tr>
<tr>
<td>8</td>
<td>Notational</td>
<td>3.75 (0.55)</td>
</tr>
<tr>
<td></td>
<td>Non-notational</td>
<td>3.35 (0.88)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.6 (0.75)</td>
</tr>
<tr>
<td>Total</td>
<td>Notational</td>
<td>3.38 (0.84)</td>
</tr>
<tr>
<td></td>
<td>Non-notational</td>
<td>3.15 (0.89)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3.26 (0.87)</td>
</tr>
</tbody>
</table>
As the large majority of children in the non-notational group interrupted their drawing procedure, and this majority was comparable to that shown in the notational group, we can conclude that the notational trace did not act as a cue for representational change in the human figure drawing.

The “house with wings” task was associated with an increase in end-type modifications for both the 5- and 8-year-olds. In the non-notational condition, 35% of the 5-year-olds and 55% of the 8-year-olds made start/mid modifications compared to the notational condition where 45% of the 5-year-olds and 25% of the 8-year-olds made these early interruptions. Two $\chi^2$’s confirmed that there were no age differences on process success in either the notational condition task, $\chi^2 = 1.76, df = 1, p = .18$ or non-notational condition task $\chi^2 = 1.62, df = 1, p = .20$ on the “house with wings” task. Karmiloff-Smith (1990) concluded that late modifications on the “house with wings” task were associated with procedural rigidity. However we found that there was an increase in end-type modifications for both age groups on the “house with wings” task in comparison to the human figure manipulations. Therefore, we suggest that most children simply presumed that the late addition of wings was the best strategy with which to achieve a successful product for this particular task. Furthermore, whereas more 5-year-olds made end-type modifications in the non-notational condition compared to the notational condition, this difference was not striking. Indeed a $2 \times 2 \chi^2$ confirmed that the 5-year-olds’ process success category for this task was not related to notational condition $\chi^2 = 0.42, df = 1, p = .52$. Thus the notational trace did not appear to act as a cue for procedural interruption on any of the manipulation tasks.

The relation between procedural rigidity and product success

Two-step hierarchical regression analyses were conducted in order to determine the extent to which age (in months) and procedural rigidity (0–6 score) predicted product success for the “man with ball” (1–4 score), “man with two heads” (0–3 score) and “house with wings” (0–3 score) manipulation tasks. Firstly, for the non-notational condition the hierarchical regression (in which procedural rigidity was entered first) it was found that neither procedural rigidity nor age in months predicted product success on the “man with ball” or “man with two heads” manipulation. For the “house with wings” task, rigidity did significantly predict product success, $F(1, 38) = 4.46, p = .04$, adjusted $R^2 = 0.1$. When age in months was entered second this did not account for any further increment of the variance. Correlations revealed that for the 8-year-olds only there was a significant negative correlation between rigidity and product success score on the “house with wings” task, $r = -.49, n = 20, p = .03$.

With respect to the notational condition, the hierarchical regression on the “man with ball” manipulation, again showed that procedural rigidity did not explain a significant percentage of the variance in product success scores. When age in months was entered second, a significant increment of 20% of the variance was explained, $F(1, 37) = 5.71, p < .01$, adjusted $R^2 = 0.2$. For the “man with two heads” manipulation, procedural rigidity was also not a significant predictor of product success for the notational group. When age in months was entered second, this did account for a
further 16% of the variance, $F(1, 37) = 3.4, p = .04$, adjusted $R^2 = 0.11$. However, age in months alone was not a significant predictor of product success. Regression analyses could not be carried out on the “house with wings” task for the notational condition as all of the 5- and 8-year-olds achieved a score of two for product success. To conclude, therefore, young children’s rigidity scores were not related to product success in any of the drawing conditions. Rigidity was only related to product failure for the older children in the non-notational condition of the “house with wings” task.

**Discussion**

Karmiloff-Smith (1992, 1999) has stated that the domain of drawing may not be an appropriate domain to examine rigidity as the notational trace acts as a cue for interruption. Thus, she would predict that more children in the non-notational condition than in the notational condition should exhibit a totally compiled procedure (i.e., six rigid pairs). In fact, we found just the opposite: the normal drawings in the notational condition produced greater levels of rigidity in comparison to those in the non-notational condition. This may be due to the fact that the trace actually encourages rigidity because it provides the drawer with salient information about what elements have already been drawn and where to continue in the usual procedure. In contrast, if the trace is removed, then the drawer is less constrained by previous drawing decisions and may be more likely to vary the drawing process.

Similarly, the non-notational condition did not highlight any relation between rigidity and product success on any of the three manipulation tasks for the 5-year-olds (i.e., an age at which procedural rigidity is meant to inhibit representational change). Furthermore, there were no drawing condition differences for process success either. Therefore, the second predicted result that the external trace would aid manipulation and interruption ability (Karmiloff-Smith, 1992, 1999) was not substantiated either. It cannot be concluded, therefore, that the notational trace is responsible for the inhibition of procedural rigidity in the drawing domain. Finally, the findings from the notational condition for all three manipulation tasks replicated those from Study 1—that rigidity levels were not related to product success.

With respect to product success, the 5-year-olds were able to attain the same level of success as the 8-year-olds on the house with wings task. Karmiloff-Smith (1990) would have predicted this result, as all of the 5-year-olds in her study were also able to achieve a satisfactory representation of this particular drawing. Nevertheless, on the man with two heads task, the RR model would have expected the 8-year-olds to achieve higher product success scores in comparison with the 5-year-olds, but no such age effect was found. Karmiloff-Smith (1990) maintained young children failed on the two-headed figure task by adding a second body as a result of procedural rigidity. This was not replicated: only two out of 20 5-year-olds in the notational condition and three out of 20 in the non-notational condition reproduced a second set of body parts (with two 8-year-old children in the non-notational condition also making this error). It is possible that the young children in Karmiloff-Smith’s follow-up experiment mistakenly believed that the two-headed figure task did require
two complete human figures to be drawn. Perhaps our instructions to “draw one man with an extra head” made the task demands clearer.

However, despite the product flexibility achieved by some young children on the man with two heads and the house with wings tasks, there was some evidence of a developmental improvement in the product of the manipulations used in Studies 1 and 4, and particularly on the man with ball task. Indeed, research in the representational change literature has consistently shown that when manipulating a familiar schema, young children experience greater difficulty in comparison to older children. Although we have conclusively shown that any degree of procedural rigidity cannot account for the younger children’s inferior performance, alternative explanations need to be found to account for the developmental differences. In the following general discussion we shall consider why procedural rigidity in its present format does not adequately explain representational change in drawing and how rigidity might be re-interpreted for the drawing domain so that the RR model can remain as a domain-general theory of cognitive development. We suggest the development of information processing may also be crucial for flexibility in drawing.

General discussion

The findings from Study 1 revealed that rigidity levels in young children’s drawings did not predict modification ability. Therefore a possible weaker version of RR theory as applied to the drawing domain, whereby some level of procedural rigidity may represent the implicit or EI representational formats, was not supported. Studies 2 and 3 showed that, contrary to Karmiloff-Smith (1999), young children (3- to 6-year-olds) were capable of re-ordering individual rigid sub-routines. Finally, Study 4 removed the notational trace in drawing in order to assess whether the external mark is responsible for the lack of rigid procedures in drawing and, therefore, success in interruption/modification tasks (see Karmiloff-Smith, 1992, 1999). However, the findings from Study 4 failed to substantiate either of these claims. Therefore, these findings suggest that procedural rigidity, as described in the RR model, does not apply in the drawing domain.

Prior to this research no study had either examined procedural rigidity in a number of usual drawing attempts of the same topic, or attempted to relate levels of rigidity in these usual drawings to performance on a manipulation task that required redescribing the representation of that topic. Studies 1–4 demonstrated that, for the human figure topic specifically, roughly 40% of young children (4- to 6-year-olds) had a totally rigid drawing procedure across three drawings. The majority of young children, therefore, did not exhibit a totally rigid routine when drawing, and furthermore rigidity levels were not age-related (i.e., 8-year-olds demonstrated similar levels of rigidity in comparison to the 4- to 6-year-olds).

Manipulation ability, in terms of the final product, was age-related and this finding was again particularly related to the human figure topic. Older children generally produced more successful manipulation drawings and were particularly adept at modifying usual elements in a representation in order to successfully incorporate a
novel item (e.g., manipulating the arms inward on the man with ball task). However, in line with previous research (e.g., Spensley & Taylor, 1999), simply interrupting the drawing process in order to include the novel item was not problematic for young children who exhibited the same level of process success (i.e., start or mid-type interruptions) as older children. This indicated that being able to manipulate a representation may not relate to any lack of ability to re-order elements. Indeed, this was strongly supported by the crucial finding in Studies 1 and 4 that young children's rigidity levels in their pre-manipulation drawings were not related to either product or process success on the manipulation tasks. Although the aforementioned previous research had established that drawings are not governed by totally rigid procedures, it had not established whether rigidity levels in usual drawings may to some degree predict inflexibility on manipulation tasks. The research findings from Studies 1 and 4 confirmed, therefore, that a “weaker” degree of rigidity was not responsible for inhibited attempts at representational change in the drawing domain.

Superficial observation of young children’s drawings does reveal some procedural-like behaviour (e.g., a large minority of children did exhibit a fixed sequential routine, particularly when drawing the human figure topic). The human figure topic has a simple vertical structure in which all elements are connected and it is likely that the elements are drawn in a consistent fashion due to a natural drawing order. Zhi et al. (1997) also stated that the human figure was so frequently drawn by young children that it could be argued that children form a habitual routine when drawing familiar topics. However, procedural rigidity (as related to RR theory) and habit/natural drawing order offer quite different theoretical explanations for the observed children’s sequential ordering of elements. Whereas procedural rigidity is a general cognitive constraint, an habitual routine is created by the child for the sake of graphical ease and in this sense reflects more of a choice than a constraint. As the present studies seriously question procedural rigidity as a cognitive constraint on representational change, habitual routines and topics’ natural drawing order offer more likely explanations for the observation that elements of children’s graphic representations can sometimes be produced in a sequentially fixed list.

Although the present research mounts a challenge to procedural rigidity, it is possible that the problem lies in the conceptualisation of the term in the drawing domain specifically, rather than in its fundamental theoretical notion. Karmiloff-Smith (1992) accepted that the application of RR to the drawing medium was problematic, and suggested that the RR process should be examined in domains that produce no external trace. Yet, our findings from Study 4 show that the lack of procedural rigidity in drawing cannot be related to the presence of a notational trace. Freeman (1994) noted that although word order may be crucial for behavioural mastery of language this did not automatically mean that global element order was crucial in drawing. van Sommers (1984) has claimed that the product (rather than the process) produced has a conservative effect on subsequent drawings as it is the product which conveys meaning. This idea may relate directly to what is rigid in drawing. In language, words are the elements that convey meaning and order functions to structure that meaning. However, element order clearly does not structure the drawing’s meaning, that is the same product can be achieved using different drawing orders.
What does sustain the meaning of the drawing is the spatial layout or relations between the elements and furthermore, the strokes used to create these individual elements. It is therefore possible that rigidity may constrain both the spatial relations between global elements and the stroke behaviour used to construct these elements.

Studies 1–4 demonstrated that young children did find modifying usual element spatial locations difficult. It could be argued that of the tasks used in these studies the man with ball manipulation necessitated the biggest spatial location change (to the arms) and this task consistently elicited the biggest development shift in product success. Young children were not able to manipulate the arms into a different spatial location even with the aid of the specific instructions given in Study 4. In contrast, the other manipulation tasks required either no spatial manipulation (e.g., the house with wings manipulation) or only minimal spatial re-ordering (e.g., the cracker and the man with two heads manipulations), and for these tasks less marked age differences were found. It is possible then that rigidity in drawing pertains to the spatial location of elements in terms of their usual placement in relation to one another. Rigidity may also be involved at the deeper “stroke level.” It is possible that children do not have access to the individual strokes used when creating simple geometric shapes that are subsumed within a drawing’s elements. This alternative notion of rigidity (biomechanics) may relate to the direction and shape of a continuous stroke which in contrast to element-ordering is crucial for the final product and thus behavioral mastery in drawing. Indeed, work in progress suggests that this may well be the case as a detailed examination of the motor-programs used when drawing has revealed stroke rigidity in young children’s usual and manipulation drawings. Clearly stroke rigidity now requires further investigation.

In contrast to the RR model’s qualitative approach the neo-Piagetian tradition (see Case, 1985; Pascual-Leone, 1976) maintains that there is a direct link between working memory (see Baddeley & Hitch, 1974) and cognitive development. Furthermore, Morra, Moizo, and Scopesi (1988) have shown that working memory is related to children’s ability to plan their drawings and suggested that it is likely to be implicated in children’s ability to modify their usual schemas. In line with this quantitative approach researchers who have failed to find evidence for procedural rigidity in drawing (Berti & Freeman, 1997; Spensley & Taylor, 1999; Picard & Vinter, 1999) have also suggested various information-processing factors (e.g., planning, monitoring, awareness, and working memory) as alternative rationales to the data on representational change in drawing. However, Karmiloff-Smith (1999) has argued that quantitative approaches cannot satisfactorily explain certain developmental findings. She maintains that if the same quantitative development enables behavioral mastery this does not explain why some atypical subjects (i.e., with Williams syndrome or Down syndrome) “plateau” at behavioural mastery in certain domains. Karmiloff-Smith (1999) maintains that there is something qualitatively different about reflection and operation on one’s own representations (i.e., explicit level behaviour) that purely quantitative models cannot account for.

Perhaps what is now needed is a more integrated approach that combines these qualitative and quantitative shifts. Such an integrated account might suggest that memory or awareness levels may to some degree dictate the amount of information
that can be subject to the RR process. Young children probably rely on rigidity to encode information that would lead to cognitive overload if dealt with consciously (i.e., rigidity compacts information). Perhaps with gradual shifts in information processing ability this compacted information is gradually uncovered (i.e., awareness or memory levels determine what amount of information can be operated on). Furthermore, development in executive function ability may also explain why younger children show a slower and more gradual developmental pattern when mastering a representational change task in comparison to older children who can demonstrate immediate success. Indeed Zelazo and Frye (1997) concluded that although children may show conscious access to their representations they may still be susceptible to rigid behaviour due to their limited executive function capabilities. Therefore it is possible that increases in executive function capacity may well aid the RR process itself. Clearly empirical test is now required in the drawing domain in order to develop a clearer understanding of the links between qualitative and quantitative development.

We have found no evidence to support the existence of procedural rigidity as an inhibitor of representational change at the element level, as described by the RR model, in the drawing domain. Karmiloff-Smith (1992) maintained the RR process should only be examined in non-notational domains (e.g., spoken language). Yet we have also shown that the notational trace is not responsible for the lack of substantiating data on rigidity in drawings. Therefore the question of how cognition advances in notational domains at first glance appears problematic for the RR model. However, we believe that Karmiloff-Smith’s (1990) translation of procedural rigidity of elements from language to drawing may well have been inappropriate. Rigidity may operate in several fundamental aspects of depiction (e.g., in both the spatial location of elements and at the individual stroke level), and this now requires direct test. Under this account the basic notion of RR (i.e., an implicit to explicit shift via redescription), remains unchanged. Thus the RR model, in combination with information processing, may yet provide an approach that holds explanatory power for representational change in the drawing domain.

Acknowledgments

The authors thank the teachers and pupils who helped or participated in this research and Janet Barlow for assistance with the data collection. Gratitude is also expressed to David Clark-Carter for statistical advice.

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