Cognition, 34 (1990) 57–83

Constraints on representational change: Evidence from children's drawing*

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Received November 27, 1987, final revision accepted May 15, 1989

Abstract

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

This paper uses children's drawing as clues to general constraints on internal representational change and flexibility. Fifty-four children between 4 and 11 years of age each produced six drawings. They were first asked to draw a house, and then to draw a house that does not exist. The same procedure was used for man and animal. The technique forced children into operating on their normal, efficient drawing procedures, and allowed the researcher to ascertain the types of constraint that obtain on representational change and flexibility. Striking developmental differences emerged between the 4- to 6-year-old age group and the 8- to 10-year-old age group. Changes introduced by the younger children involved deletions and changes in size and shape, whereas older children changed position and orientation of elements and added elements from other conceptual categories, resulting in ever-increasing inter-representational flexibility. Development is accounted for in terms of reiterated cycles of change from internal representations specified as a sequentially fixed list, embodying a constraint that was inherent in the earlier procedural representations, to internal representations specified as a structured, yet flexibly ordered set of manipulable features. The constraints are considered to be general and are compared

*I should like to express my thanks to the staff and pupils of Marlborough School, Harrow, and the King Alfred School, London, for their willing cooperation when I collected the data in their schools. Lesley Howard and Yara-Natasha Karmiloff are warmly thanked for acting as independent judges for the initial data analysis. A paper based on this research was presented at the Workshop on the Production of Drawings: Developmental Trends and Neurological Correlates, held at San Diego, January 1987. I would like to acknowledge helpful comments from the participants at that meeting, particularly Larry Fenson, Joan Stiles-Davis, Dennie Wolf, and Jean Mandler, who also provided feedback on the subsequent manuscript. I would also like to thank Mike Anderson, Susan Carey, Mani Das Gupta, Norman Freeman, Samuel Guttenplan, Mark Johnson, John Morton, Dick Neisser, Elizabeth Pemberton, David Premack, Neil Smith, Aaron Sloman, Liliana Tolchinsky-Landsmann and two anonymous reviewers for comments on an earlier draft. Address correspondence to Annette Karmiloff-Smith, MRC-CDU, 17 Gordon Street, London, WC1H OAH, U.K. Email: KARMILOFF @ UK.AC.UCL.EUCLID.

with work on seriation and number in children, and on phonological awareness and musical ability in adults. The results are integrated into a general model of developmental change which is compatible both with initial modularity and with subsequent domain-general constraints.

Introduction

Why study children's drawing? One reason is to explore the acquisition of drawing skills per se, that is, spatio-geometric relations, part–whole relations, planning strategies, motor execution, cross-cultural influences, artistic talent, etc. (e.g., Bialystok & Olson, 1987; Freeman, 1980; Freeman & Cox, 1985; Gardner, 1980; Goodnow, 1977, 1978; Luquet, 1927; Millar, 1975; Moore, 1986; Pemberton, 1987; Piaget & Inhelder, 1948; Stiles-Davis, 1987; Van Sommers, 1984; Willats, 1977). Research of this type aims primarily at describing the slow developmental progression towards adult-like geometric and pictorial competence.

Another reason to focus on children's drawing is to use it as a source of evidence with respect to more general processes of notational competence and representational change (Bolger, 1988; Bolger & Karmiloff-Smith, 1989; Catan, 1987; Cohen, 1985; Goodnow & Levine, 1973; Karmiloff-Smith, 1979b, c, 1984). The present study is of this second type: children's drawings being used to analyse internal representational[1] change and flexibility, and the constraints thereupon.

There is considerable debate (see Freeman, 1987, for full discussion) about the extent to which children's drawings can be used as data about internal representations (Kosslyn, Heldmeyer, & Locklear, 1977; Laszlo & Broderick, 1985; Olson & Bialystok, 1983). However, these reservations concern the possibility of being able to directly externalize the content of internal representations of spatial relations. This is not my concern. Rather than focusing on the *content* of children's *inadequate* drawings, here I explore the processes that children can call forth for changing their already successful drawing procedures, when they are set new goals.

The present study was designed to test further hypotheses emanating from a model of representational change used to account for certain aspects of the lexico-morphology of language acquisition (Karmiloff-Smith, 1979a, 1986),

[1]It is important to note that the use of the term "representation" differs according to the focus of study (for discussion, see Mandler, 1983; Sperber, 1985). In the traditional drawing literature, "representation" is usually employed to refer to the externalized form that children put to paper, that is, the depiction. In this article, I will use the term "representation" solely in the sense of something internal to the child's mind.

as well as of children's problem solving (Karmiloff-Smith, 1979b, 1984). While the study of children's drawing tests the plausibility of the model in yet another domain, the present focus is on the identification of the specific constraints on representational change. In previous work on children's spontaneous theories about physical causality and language, it was established that an endogenous process of representational change does indeed take place (Karmiloff-Smith, 1979a, b, 1984, 1986; Karmiloff-Smith & Inhelder, 1974) and may, in some cases, even give rise to a form of cognitive encapsulation that mimics the modular organization of input systems (Karmiloff-Smith, 1985; Karmiloff-Smith, Johnson, Bartrip, Cuckle, & Karmiloff, 1989). However, important questions remained unaddressed. Why does representational change take developmental time? What are the constraints on representational change, i.e. on the child's capacity to operate on the knowledge components embedded in earlier, efficiently functioning procedures?

Whilst full details of the model can be found elsewhere (Karmiloff-Smith, 1986, in press), certain theoretical issues are particularly relevant to the present study and will be reiterated briefly here. How is knowledge acquired? There are, in my view, three ways. One is to have the knowledge innately specified, that is, via evolutionary processes. Another is to add new representations on the basis of interactions with the external physical and socio-cultural environments. However, a third and important way to gain new knowledge is to exploit the knowledge already represented, that is, to engage in an endogenous process of internal representational change. The model hypothesizes a phase of development in which knowledge is represented procedurally, followed by a phase of representational redescription at which point the knowledge embedded in the previously efficiently functioning procedures becomes available as a data structure to other parts of the cognitive system. In other words, elements of the same knowledge are re-represented at different levels of abstraction. The distinction is somewhat similar to that used in artificial intelligence research. As pointed out by Rutkowska (1987), program procedures in artificial intelligence usually have a dual function: (1) they can be activated to generate processes; or (2) they can be manipulated or reorganized by other procedures, in which case they are being treated as part of the program's data. My argument is that part of cognitive development consists in building the second of these two functions for each procedure, by redescribing the procedure at a higher level of abstraction such that the knowledge is then represented at two different levels. The pervasiveness – although not the existence – of this process of representational redescription may well be unique to the human species and account for representational flexibility and creativity (Karmiloff-Smith, 1979b).

It is with these theoretical distinctions in mind that a domain of study was chosen in which it was already known that early in development children develop efficiently functioning procedures. If, as the model maintains, behavioural mastery is a prerequisite for subsequent representational change, then subjects who can already successfully perform a task should be ripe for displaying such change. Four-year-olds' capacity to draw familiar objects with automaticity turned out to be an ideal choice in this regard.

Previous research has demonstrated that once the child has reached behavioural mastery the resulting compiled procedures undergo representational redescription, after which the knowledge embedded in them becomes available to other parts of the system (Karmiloff-Smith, 1979a, b, 1986). Logically there are many formats in which such knowledge could be available. The specific hypothesis to be tested here is that, as the child becomes able to operate on the knowledge embedded in a procedure, the redescribed representation of the knowledge is initially specified in such a way as to restrict both intra- and inter-representational flexibility. What is meant by this? The hypothesis is that at the first level of redescription the internal representation is specified as a sequentially fixed list, embodying a constraint that was inherent at the procedural level. This constraint means that there is relatively little intra-representational flexibility, that is, the child is limited with respect to changes she can introduce into the representation. Inter-representational flexibility is also constrained at this level, that is, the child cannot link the new representation to other representations outside the domain. Later in development, it is hypothesized that via further redescription this sequential constraint is relaxed, yielding an internal representation specified as a structured yet flexibly ordered set of manipulable features. This not only makes possible intra-representational flexibility within a domain, but opens the system to inter-representational flexibility, that is, across different domains. Let us now look at how these hypotheses were tested in the empirical study.

Population

Fifty-four children between the ages of 4 and 11 were tested. There were 22 children in the 4–6-year-old group (mean age: 5;4), 15 children in the 8–9-year-old group (mean age: 8;2), and 17 in the 9–10-year-old age group (mean age: 10;4). Since the results of the 8- and 10-year-olds were to all intents and purposes identical, these have been grouped (N = 32) for the purposes of analysis and contrasted with the 4–6-year-olds (N = 22).

In keeping with my research strategy for exploring representational change in both language and problem solving (Karmiloff-Smith, 1979a, b, 1984), I have chosen an age group at which children are already successful at producing the particular drawings and also have adequate conceptual knowledge about the objects being drawn. This contrasts with the usual focus of drawing research which traces the errorful, laborious process that ultimately leads to behavioural success (e.g., Freeman & Cox, 1985). All subjects of the present study had already reached behavioural mastery for the chosen drawing procedures, making it possible for the analysis to concentrate on subsequent representational change.

Method

Subjects were first asked to produce copies of drawings of four geometric forms, to ensure that their overall drawing levels were within their age norms and that they had no motor or planning problems. Then each subject was asked to draw a house and, after her or his drawing was removed, to "draw a house that doesn't exist". The same procedure was used for drawing a man and an animal. The order of the three categories (man, house, animal) was randomly varied across subjects. To ensure that children understood what was expected of them, several different formulae were used with every child, in random order, such as "an X that doesn't exist", "an X you invent", "a pretend X", "an X we have never seen before", etc. In all, 324 drawings of X's that exist and X's that do not exist were produced and fully analysed.

The rationale behind the experimental design was as follows: over time in early childhood, children spontaneously build procedures for drawing a house, a man, an animal. This often involves a laborious developmental process, but by around 4–5 years of age children can run these procedures efficiently and in an automatized fashion. When children are asked to draw a house, for example, they do so rapidly and well. When they are asked to draw a house that does not exist, they are forced into operating in some way on their internal representation. As long as one focuses on subjects who have no difficulty in the actual planning and execution of the drawing itself, then an analysis of the types of modification that children produce will allow the researcher to capture essential facets of the constraints on representational change.

One of the techniques piloted used the instructions "draw me a different X", but this gave rise to almost no developmental differences. For example, with the instruction "different" children changed from one to several windows, from no chimney to one chimney, from no hat to a hat, etc. However, with the final technique adopted (e.g., "draw me an X that doesn't exist"), children altered fundamental features of househood, manhood or animalhood and, as we shall see, huge developmental differences emerged between the age groups, not in "success" at producing an X that doesn't exist, but in the types of change that children of different ages introduced.

The technique used here of explicitly instructing the child to make changes differs somewhat from those used in previous research in which I analysed *spontaneous* changes in output and their internal representational implications (Karmiloff-Smith, 1979a,b, 1984, 1986). Having established by the earlier work that change does occur spontaneously after behavioural mastery, it was now possible to choose the relevant age and domain to be sure of tapping already compiled procedures ripe for different degrees of internal change. Predictions could therefore be made as to when representational redescription should occur, and subjects were selected accordingly. Let me stress that by my instructions I am inducing the external manifestation of change, not the already existing internal capacity for it.

Results

All 54 subjects tested corresponded to their age norms in copying the four geometric forms and were therefore included in the study. We shall first briefly look at the results as they pertain to children's capacity to produce the requested drawings, and subsequently analyse in detail the precise nature of the changes that children introduced.

To give an example of what would count as "a house that does exist" versus "a house that does not exist", the following criteria were taken into account. For a normal house: rectangular shape, roof, door, window, and optionally: chimney, curtains, various numbers of windows, normal decorative objects such as a doorknob. To draw successfully a house/man/animal that does not exist, subjects must introduce appropriate changes while simultaneously retaining core concepts of househood/manhood/animalhood. For example, to count as "a house that doesn't exist", children had to place the roof, door, window, chimney, etc. in the wrong position or orientation, delete some essential feature, change the usual shape of the house to, say, a circle, add some unusual feature such as eyes or wings to a house or, in the case of a "man that doen't exist", add two heads, etc.

Two analyses were carried out, first with respect to success at drawing an X which did/did not exist, and second with respect to the types of change children introduced. We will start with the first analysis. Two independent judges categorized children's productions as an existing house (man or animal) or as a non-existing house (man or animal). Inter-judge agreement was very high: .94 with respect to the younger age group's productions and .98 with respect to older children. Disagreements were settled with a third per-

Table 1. *Percentage success rates for drawings of non-existing houses, men and animals*

Age group (years)	Number of subjects	Unsuccessful on all three categories (%)	Successful on one category (%)	Successful on two categories (%)	Successful on all three categories (%)
4–6	22	9	5	36	50
8–10	32	0	6	3	91

son. In fact, the only disagreements concerned the category "animal", which is understandable given the wide range of possible drawings from, say, bird to elephant. From the very high inter-rater agreement levels, it is obvious that no difficulties were encountered in judging whether children's productions successfully met the analytical criteria.

One hundred percent of subjects produced adequate drawings of existent houses, men and animals. Table 1 gives the results of children's ability to produce the various drawings of the non-existent categories. Of the total population of 54 subjects, only 2 were unable to draw any non-existent X's. Previous work has shown that behavioural mastery is a prerequisite to the first level of representational redescription (Karmiloff-Smith, 1979b, 1984, 1986), and these two children may not quite have reached behavioural mastery; that is, their normal drawing procedures may not have been entirely compiled and automatized. However, the focus of the present paper is not on whether or not children succeeded in drawing a non-existent house, man or animal. As the results show, most of the children did. Indeed, 91% of the 8- to 10-year-olds and 50% of the 4- to 6-year-olds succeeded on all three categories and, if one adds those subjects who succeed on house and man, but fail on animal,[2] then 94% of the older group and 91% of the younger group were successful. The important question here is, given that the vast majority of children did succeed in introducing appropriate changes, what types of change did they make?

We now turn to the second and more important analysis which concerns the different types of modification children introduced into their drawings and the extent to which developmental constraints obtain in children's capacity

[2]It should further be noted that the category "animal that doesn't exist" was not as clear-cut as house and man. The reason for this is obvious since "animal" can be anything from a bird to an elephant, that is, involving totally different drawings. Had I abstracted the animal data and only analysed the house and man data, then agreement between judges and all relevant statistics would have been even clearer.

to operate on the knowledge components embedded in earlier, efficiently functioning procedures. The following types of change were observed:

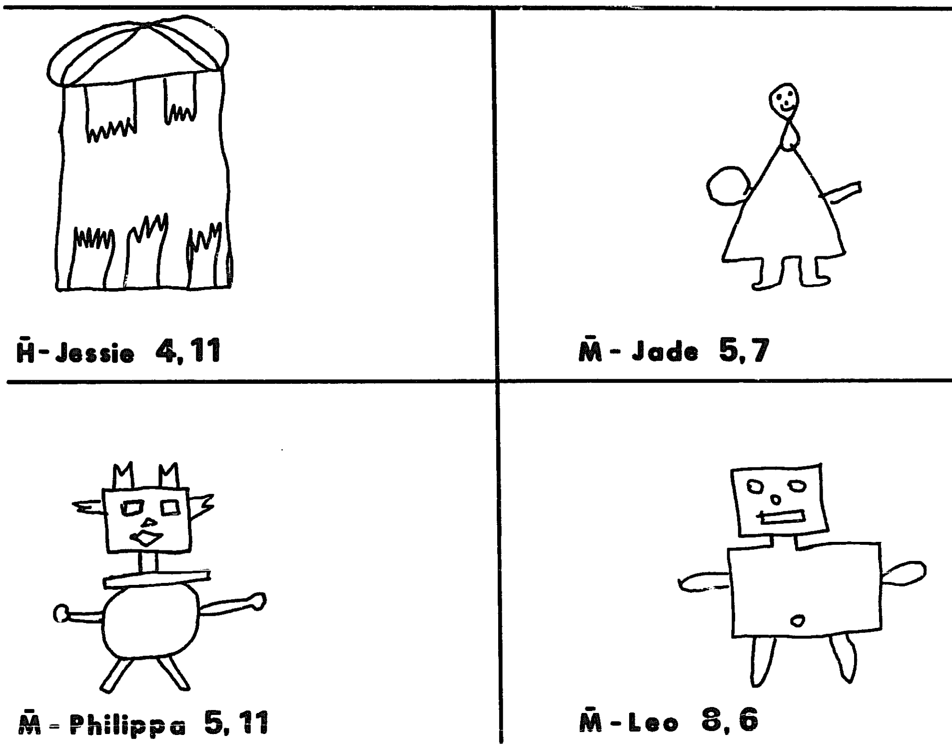
- shape and size of elements changed
- shape of whole changed
- deletion of elements
- insertion of new elements
- position/orientation changed
- insertion of elements from other conceptual categories
- other (e.g., dinosaur, mermaid, which are conventionalized forms and could, of course, already exist as independently stored procedures – in fact, this turned out to be irrelevant because it represented such a minute percentage of the results as to be unquantifiable).

Figures 1 to 6 illustrate the different types of change. Figure 1 gives examples of children who changed the shape and/or size of elements but left the contour outline unchanged. Figure 2 provides examples of drawings in which children changed the shape of the whole. Figure 3 gives illustrations from children who deleted elements from their drawing procedure. Figure 4 shows, by contrast, how children inserted new elements into their productions. Drawings from subjects who changed the orientation/position of elements or the whole are given in Figure 5. Finally, Figure 6 shows examples of productions in which children inserted elements from other conceptual categories.

The histogram in Figure 7 gives the breakdown per age group for the different types of change. The figures represent the percentage of children making a particular category of change as a function of the total number of children analysed. The independent judges reached .84 and .91 agreement respectively on this second analysis when categorizing the younger and older age groups' productions with respect to type of change. Differences were settled in consultation with a third person. The categories were not treated as mutually exclusive, since children often introduced several types of change in a drawing (e.g., changed both the contour outline and deleted an element or inserted a cross-category element). However, a second analysis treating the categories as mutually exclusive (scoring only the most advanced type of change) yielded the same overall pattern of developmental differences.

Any drawing which did not meet the judges' criteria for a house/man/animal which does not exist was excluded from the analysis. This involved 21 out of a total of 214 drawings of houses/men/animals which did not exist. These were excluded because when a drawing includes changes, such as adding a hat to a man or a chimney in the correct position on a house, such changes do not constitute modifications to househood/manhood/animalhood. Indeed, as pointed out at the beginning of this section, additions had

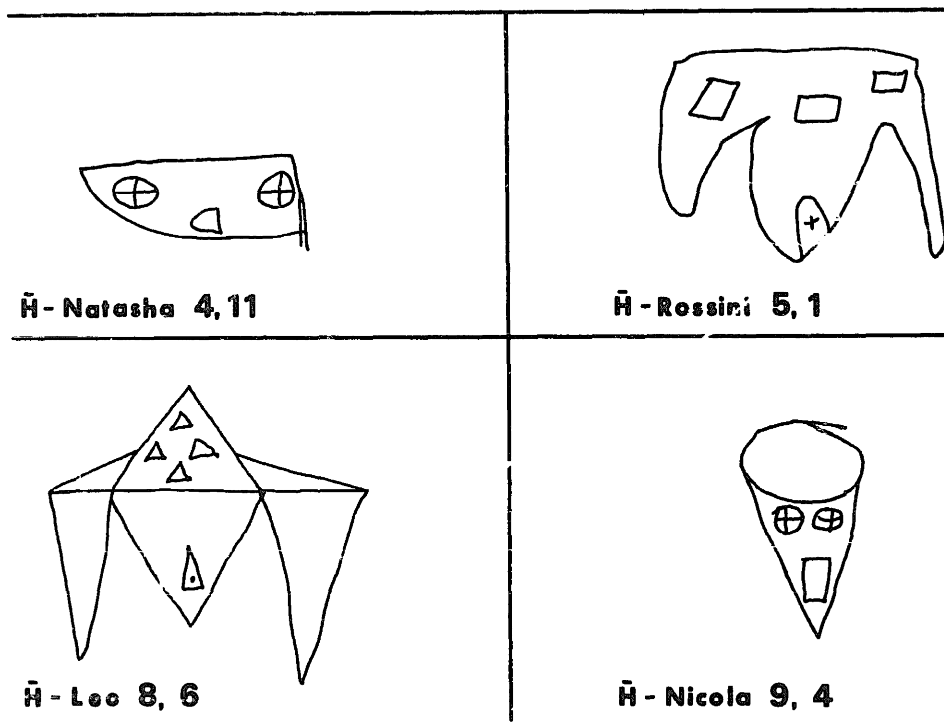
Figure 1. *Shape and/or size of elements changed (ages are in years, months).*



to violate in some way househood, manhood or animalhood whilst retaining other core aspects of the concept. Thus, a chimney added to a second house-drawing would not represent a house that does not exist. By contrast, a pair of eyes added to a house would, as would the addition of a chimney upside down on the bottom of the house. Likewise with deletions. Deleting a hat or walking stick in a second man-drawing would not constitute a violation of an aspect of manhood and would therefore not be a successful drawing of a man that does not exist. By contrast, deleting eyes or mouth or adding extra ones would.

The results in Figure 7 show that children of all ages made changes that fall under the categories up to and including "deletion of elements"; that is, children of all age groups changed the shape/size of elements, the shape of whole and they deleted essential elements. However, a systematic analysis of deletions shows important differences between the two age groups (see discussion below). With respect to insertions of elements, position/orientation changes, and cross-category insertions, Figure 7 shows a dramatic contrast between the two age groups. The differences are highly significant (χ^2 = 17.64379, d.f. = 1, $p < .0001$).

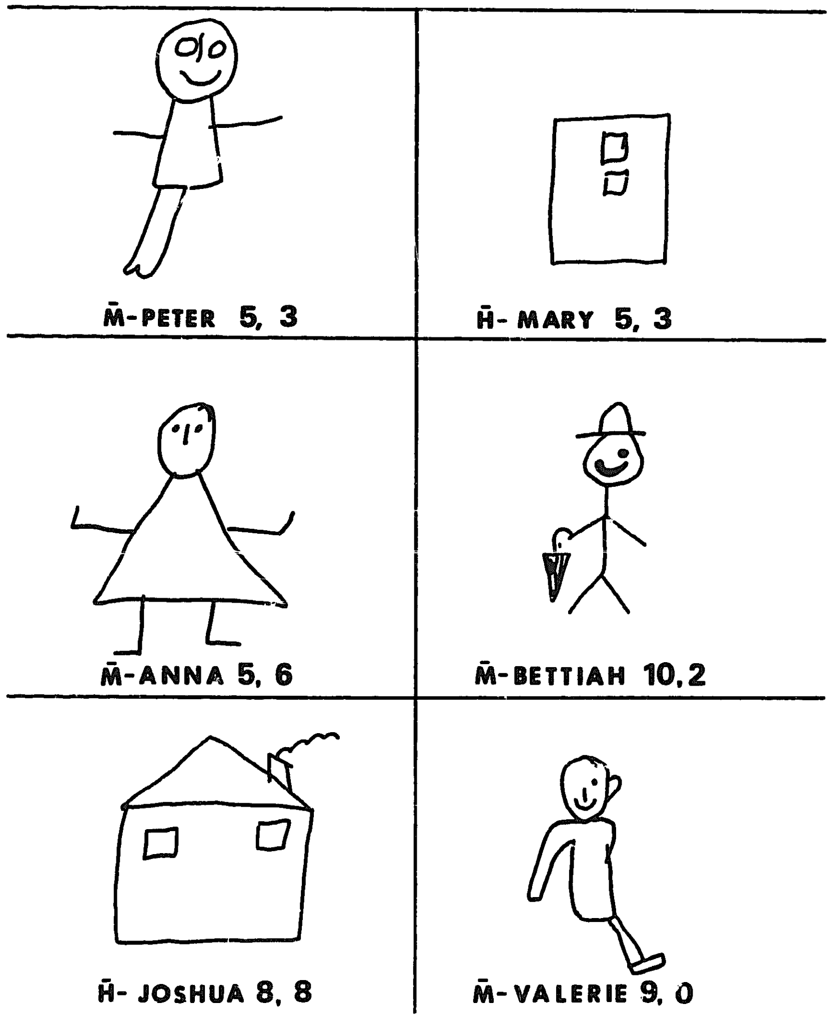
Figure 2. *Shape of whole changed (ages are in years, months).*



Although children of all ages used deletions, this category turned out to be particularly interesting across the two age groups. It is not possible to make a formal statistical analysis of the differences in the sequence of deletions between the two age groups, because video recordings were not taken. However, written notes were made on the protocols wherever deemed necessary (e.g., "added wings at the end of the drawing", "left leg was last thing drawn"). These notes, together with a systematic analysis of what can be inferred from the product of many of the drawings (see, for example, Figure 3), made it possible to assert with some assurance that older children frequently deleted in the middle of their drawing procedure, whereas the younger age group made deletions of elements which are drawn towards the end of a procedure and did not continue drawing after deletions. The subjects in the follow-up study, for which sequence was carefully recorded on a copy drawn by a second experimenter during their productions, confirmed this.

The very few 4- to 6-year-olds who made changes classifiable in the last three categories (insertions of elements, position/orientation changes, cross-category insertions) all added elements after finishing a normal X, for example by adding a chimney emerging horizontally from the side wall of a house,

Figure 3. *Deletion of elements (ages are in years, months).*

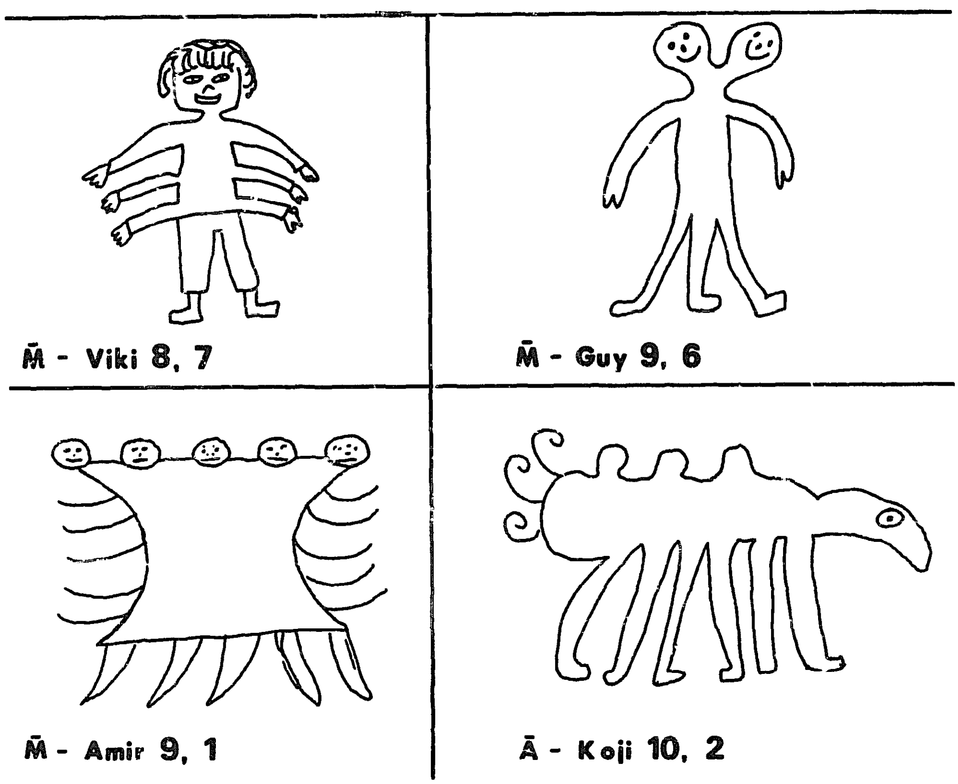


or a smile on a house, and did not make insertions into the middle of their drawing procedure as did older children when drawing, for instance, a man with two heads.

Follow-up experiment

A second experiment was carried out to verify whether the absence of certain changes made by otherwise successful 4- to 6-year-olds was merely due to a lack of inventiveness, that is, that they simply had not thought of making

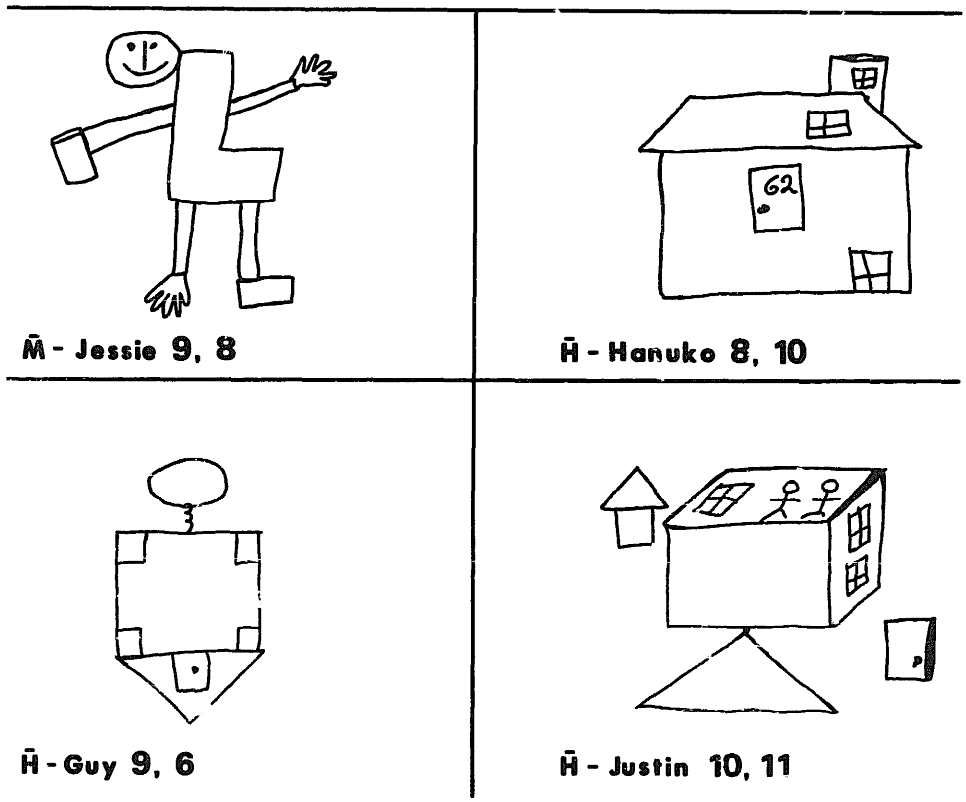
Figure 4. *Insertion of new elements (ages are in years, months).*



insertions and cross-category changes when drawing X's that did not exist, or whether a deeper reason lay behind this. Ten 5-year-olds (mean age 5;7) were first tested with the above experimental technique. Eight of the subjects were retained because they successfully made changes to all three drawings but only changes that involved size, shape and deletion. These children were then asked to "draw a man with two heads" and to "draw a house with wings"; that is, they were explicitly instructed to introduce types of change typical of the spontaneous productions of older subjects.

As the first young subject began to draw a second head, I was reminded of T.E. Huxley's lament: "the great tragedy of science; the slaying of a beautiful hypothesis by an ugly fact"! However the first subject, and all but one of the seven others tested, then went on laboriously and very slowly to draw two bodies, two arms and legs on each body, etc.; that is, they used a complete man-drawing procedure for each head, and they kept starting again because dissatisfied with the result. They manifested similar difficulties simply copying a model provided by the experimenter and succeeded only very laboriously and slowly. By contrast, when 8- to 10-year-olds interrupted se-

Figure 5. *Position/orientation changed (ages are in years, months).*

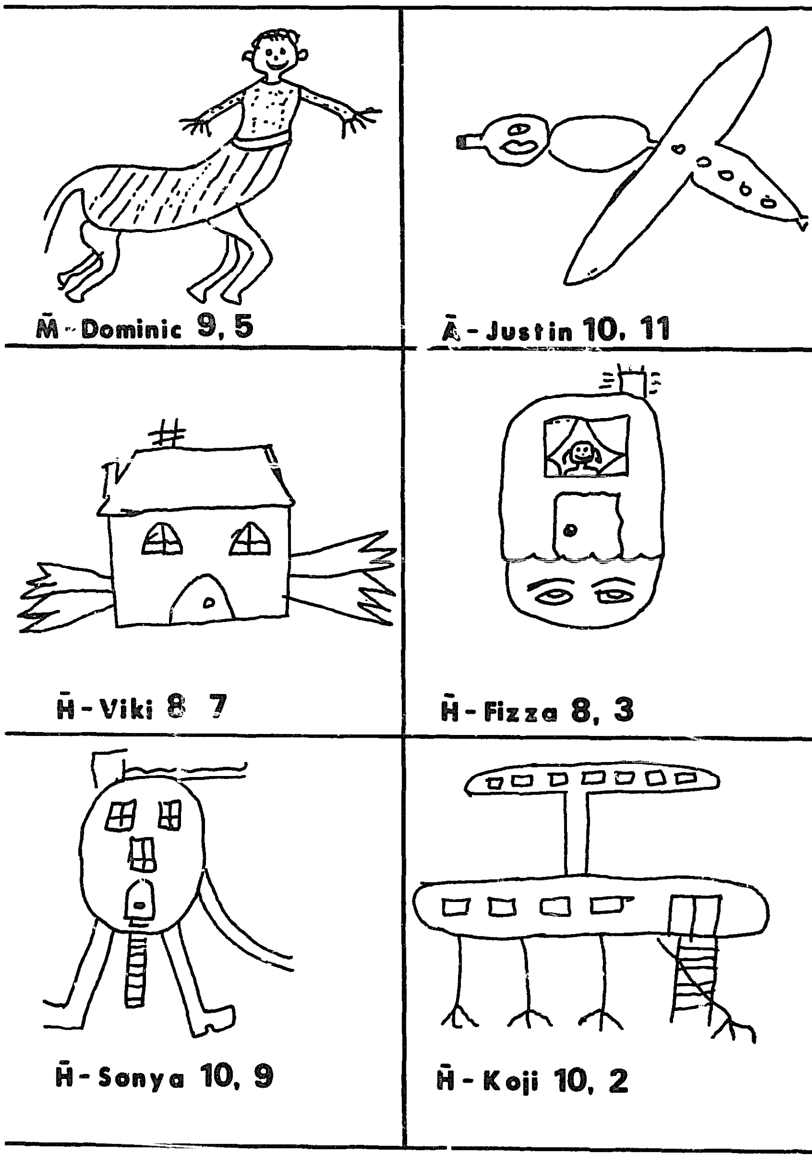


quential order to insert a new subroutine for drawing a second head, they continued drawing a single body with the speed of their normal drawing procedure. Moreover, when the 5-year-olds were asked to draw "a house with wings" (a spontaneous cross-category response also typical of older subjects' solutions), they all did so rapidly and successfully. The reason for these differences will be discussed in the final section, to which we now turn.

Discussion

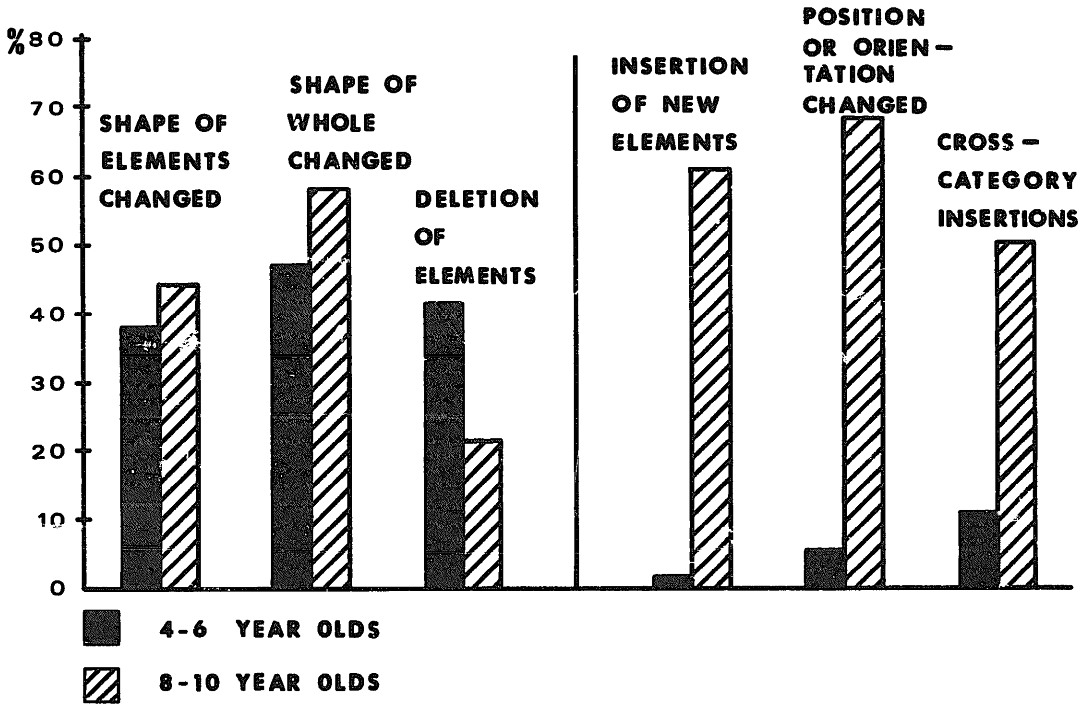
In the 1960s and early 1970s, mainstream research in cognitive development focused on early and middle childhood, the neonate and infant being considered a sensori-motor organism with no built-in symbolically represented knowledge. By contrast, the last decade has seen a flourishing of infancy research, mainly within a nativist framework. The infant has been shown to be born with an impressive repertory of domain-specific knowledge and computational capacities (e.g., Anderson, 1988; Baillargeon, 1986; Diamond &

Figure 6. *Insertion of cross-category elements (ages are in years, months).*



Gilbert, in press; Johnson et al., 1989; Leslie & Keeble, 1987; Mandler, 1988; Mehler et al., 1988; Spelke, 1982). It might therefore seem that middle childhood should be relegated to a relatively secondary position in developmental theorizing. However, it is important to bear in mind that the greater the proportion of biologically specified properties of the infant mind, the more constrained its system is likely to be (Chomsky, 1988). In other words, despite the initial adaptive advantage, the consequence of the efficiency and automa-

Figure 7.



ticity of the infant's cognitively encapsulated systems is that they are relatively rigid. This means that the more complex a picture ultimately built of the innate capacities of the infant mind, the more important it is for developmentalists to focus on explaining the subsequent flexibility of the mind. Representational change, and constraints thereupon, thus constitute an essential complement to the current focus on infancy.

This paper set out to explore constraints on representational change beyond infancy; that is, how procedures are not only activated and run, but how knowledge embedded in procedures gradually becomes available, after redescription, as part of the system's data structures. Note that the original procedures continue to be available as compiled units, that is, children can still run, say, their normal house-drawing procedure. It is a redescription of the procedures that is operated on to introduce change.

It has been shown that two sequential constraints obtain. One is at the procedural level, a procedure being by definition a set of sequential instructions. The second sequential constraint operates at the first level of representational redescription. The results of the present study show that for younger children redescribed components of the drawing procedure are available as data and can therefore take new variables with respect to size and shape, for instance. However, the order in which components are operated on is constrained by the same sequential specification as at the procedural level. The striking developmental difference brought to light here suggests that children's subsequent redescriptions of representations are not constrained by a sequential specification, thus allowing for intra- and inter-representational flexibility.

The difference between levels of redescription was particularly clear in the case of deletions and insertions. Figure 3 gave some typical examples of the difference between younger and older children's capacities. Younger children deleted at the end of procedures, involving no interruption in sequential order (see, for example, Peter, 5;3 years). Older children tended to delete at any point in the procedure and to continue with the rest of the drawing (see, for example, Valerie, 9;0 years). Whilst changes in position and orientation do not necessarily involve interruption of sequence and treating components as separate entities, in many cases of the 8- to 10-year-olds they did (see, for example, Jessie, 9;8 years and Justin, 10;11 years, in Figure 5). Very few younger children used within- or cross-category insertions and those who did made their additions at the end of their drawing procedure. By contrast, older children interrupted sequence to add extra heads or arms (see, for example, Viki, 8;7 years and Guy, 9;6 years in Figure 4, and Sonya, 10;9, in Figure 6). When, as is the case for 8- to 10-year-olds, the sequential constraint is relaxed, this does not mean that sequence is no longer represented, but rather that it does not rigidly constrain output. Obviously we continue to use sequence when it is appropriate, as is the case for some of the changes introduced by older subjects. Moreover, the relaxation of the sequential constraint does not only mean that children become capable of interrupting sequence and introducing sub-routines. It results in much greater intra- and inter-representational flexibility, allowing children to access elements from other conceptual categories and establish inter-representational links – an essential component of human creativity.

Why were the younger subjects in the follow-up experiment able to rapidly draw a house with wings although unable, except very laboriously, to draw a man with two heads? My argument is that it is for the very same reasons of constraint on sequence. In the case of a man with two heads, the sequential order of the normal drawing procedure must be interrupted. However, in the case of a house with wings, the child can add the wings at the end of a house-drawing procedure which, when called, has been run through in its entire sequence. Moreover, it is the experimenter who supplied the cross-category reference for the addition of wings which could be accessed independently of the house-drawing procedure, after it had been run.

One might argue that older subjects who insert something at the beginning of a procedure are also "merely running a procedure in its entirety". This is not so, in my view. To run a procedure, the system must call the procedure and, once called, it must run through in its entirety, if "merely run". By contrast, if, once called, something is then inserted prior to running it, this involves a subroutine interrupting the procedural sequence. The child capable of adding something to the end of a procedure, that is, merely putting a stop function on their procedure, is not yet at this level. Moreover, when young subjects are finally successful at drawing (or copying) a two-headed man, they are not using the flexibility of a redescribed man-drawing procedure that can be pursued rapidly. Rather, they are laboriously and slowly creating de novo a new procedure. This is in contrast to older children who inserted a sub-routine into their rapid drawing procedure. It would be an error of confounding external product and internal representation to think that the same product (e.g., the finished drawing of a two-headed man) is necessarily generated from identical internal representations. The same holds for identical output in language which can stem from very different internal representations (Karmiloff-Smith, 1979a).

That at the procedural level skills are sequentially constrained has been amply discussed and documented (Bruner, 1970; Dean, Scherzer & Chabaud, 1986; Fuson, Richards & Brians, 1982; Goodnow & Levine, 1973; Greenfield & Schneider, 1977; Huttenlocher, 1967; Kosslyn, Cave, Provost & von Gierke, 1988; Lashley, 1951; Premack, 1975; Restle, 1970). Logically, once the knowledge embedded in a procedure is available as part of the system's data structures, it could be represented in a variety of formats. What the present research has shown is that at the first level of redescription the internal representation of the knowledge is specified as a sequentially fixed list, embodying the sequential constraint inherent at the procedural level. In other words, as could be seen from the changes introduced by the younger children as compared to the older group, it is clear that the sequential constraint holds even beyond the procedural level.

A sequential specification can be a limitation on any system. Work on mental imagery has demonstrated that a sequential procedure for recognizing a cube, for example, is far beyond our ability to operate on as a single integrated data structure. Yet we are only aware of such limitations when asked to compute something new that requires operation on the data structure as a whole (Hinton, 1979). However, a sequential constraint is not only a limitation on a system. If a domain is sequential by its very nature, then a sequential constraint in early learning can actually potentiate progress. Although sequence may restrict flexibility, it helps to get development off the ground by inputting representations into the mind in just those areas where sequence is important, for example early language, counting, drawing. If we take the case of early language, it might be objected that whilst sequence may be important for a relatively fixed word order language like English, this would not hold for an inflected language with free word order. However, data from Slobin on the acquisition of Russian (1966) show that even where the adult model does not provide fixed word order children initially get their language off the ground by using only one of the various possible word orders. In other words, they impose on themselves, presumably because it potentiates their learning, a temporary sequential constraint. In languages where the morphology is rich and receives full stress (e.g., Turkish, see Slobin, 1982), children may prefer this as an alternative route for potentiating their initial comprehension strategies. Nonetheless sequence seems to play an initially important role in potentiating production strategies. Furthermore, outside the area of language, it has been shown that the encoding of sequence often acts as a cognitive prop for young children in their attempts to attribute cause and intention (Dasser, Ulbaek, & Premack, 1989). Thus, sequential constraints both impede and potentiate learning. Yet, as the present study shows, even under a sequential constraint changes can and do occur.

I have argued that at the level of behavioural mastery procedures are compiled and automatized. Is this not a contradiction with Van Sommers' recent claim that children do not consistently repeat the same drawing (Van Sommers, 1984)? In my view, there is no contradiction. It is important to distinguish between tasks which involve highly practised procedures (house-drawing, man-drawing, etc.) which were purposefully chosen for the present study, versus tasks involving repeated attempts at drawing something new. In the present study, children had already reached behavioural mastery, whereas Van Sommers' work involved the study of children's repeated, partially successful attempts at producing drawings of a tennis shoe, a light bulb, a tape dispenser and a paper punch. Clearly, not only children but non-artist adults would have trouble drawing any of these and would show inconsistency across different attempts. As Freeman (1987) cogently argues, learning to draw something new involves allocating mental resources to both monitoring what is emerging on the page over time against a goal-directed plan and balancing the implementation of pre-planned decisions with on-the-spot repairs on the picture plane. By contrast, an already compiled house-drawing procedure is run off fast and automatically and, although repeated drawings may involve minor changes at the level of denotation (e.g., addition of a door knob, an extra window), initially they do not involve changes in sequential order.

Here and elsewhere I have argued that certain aspects of change are endogenously driven. Freeman (1980) offers another explanation for what impedes changes in drawings of men and houses which tend to remain "formula-driven", that is, stereotyped. He argues that drawing is a non-communicative act and that, unlike language, there is rather limited scope for ongoing social interaction to alter the course of the drawing. This would tend to imply that change is exogenously driven, since lack of social interaction and correction are invoked as a reason for why drawings remain formula-driven. However, even if drawings were changed due to feedback, this is only given exogenously on the drawing product, not on the drawing process itself. The child must build up and change sequential representations endogenously. Freeman is right in stressing that children and adults continue in normal circumstances to produce formula-driven drawings if they are not artists. However, such externalized depictions are not necessarily informative about potential internal capacities. The present experiment shows that given appropriate instructions even young children can change their formula-driven drawing procedures. There is an essential difference between external behaviour (the formula-driven drawings usually produced by non-artist children and adults) and internal representations which, as the present and previous research suggests, undergo developmental changes with respect to accessibility and flexibility. Like language where children go beyond behavioural mastery, that is, beyond communicative adequacy (Karmiloff-Smith, 1979a, b), change in drawing is also endogenously driven and not solely subject to external, communicative influences. It is part of the natural developmental process of representational redescription and progressive explicitation.

This is not to deny that external influences on children's drawing can be effective. I am not of course arguing that change is due *solely* to endogenous causes. Rather, when change is exogenously provoked, subsequent endogenously provoked representational change must still take place. Representational redescription and change is not to be equated with mere representational adjunction (i.e., adding a new representation on the basis of external stimuli). Drawing research successfully inducing change exogenously (Cox, 1985; Davis, 1985; Freeman, 1980; Pemberton & Nelson, 1987; Phillips, Inall & Lauder, 1985) has only demonstrated modest, if any, generalization of the results of such training. Thus, Pemberton and Nelson (1987) trained young children on various draw-a-man skills but only had "modest evidence that some generalization of the new drawing skills carried over to house drawing". Likewise, successful training on draw-a-cube did not transfer to draw-a-pyramid nor vice versa (Phillips et al., 1985). A further example comes from Cox (1985). She successfully trained children to change from object-centred to viewer-centred depictions but, as she herself notes, "the training procedures merely create a new entry in the child's repertoire for producing specific graphic outputs, given specific prompting inputs". Thus, when exogenous training is used, children are not inducing a general solution to a projection problem but merely building a separate structural description (Freeman, 1987). In other words, according to the model developed here, children are adding a new, independently stored procedure which will have to undergo representational redescription and explicitation – an endogenously provoked process – before becoming a data structure available to other parts of the system.

Most developmental work on children's drawing has focused on the progression from inadequate depictions to adult-like competence (e.g., Freeman & Cox, 1985; Goodnow, 1977). For example, to account for how children progressively become able to represent action in their hitherto static drawings of the human figure, Goodnow (1978) has argued that children first change so-called peripheral or accessory parts of the figure. These include, for Goodnow, legs, arms, and facial features. Thus, when asked to draw a man picking up a ball, young subjects draw a rigid, upright trunk to which they attach an elongated arm which can make contact with the ball. Only later in development do children change so-called core parts of the figure, for example draw the trunk of the body bending towards the ball. By peripheral and core, it would seem that Goodnow is referring to spatial distinctions (e.g., she refers to the trunk as "the centre of the figure to which other units are attached") rather than to conceptual distinctions. In the present study, by contrast, trunk, arms, legs and facial features are all taken to be part of the defining core characteristics of manhood, whereas hats, walking sticks, etc., are considered peripheral. The vast majority of children in the present study were all successful at making changes to core characteristics of manhood, househood and animalhood.

It could be that it is those very few subjects who were not successful in drawing an X that doesn't exist that are similar to Goodnow's younger subjects who failed to adequately represent a bending person. However, in the present study subjects were purposefully chosen at an age when in principle they would be successful at the task, and indeed 20 of the 22 younger subjects (as well as all of the older group) made changes to both peripheral and core elements as defined by Goodnow. Goodnow explains developmental change in terms of a movement in external depictions from periphery to core, which may indeed be an appropriate account of early drawing output progressively leading to behavioural mastery, that is, prior to the moment at which my experimental subjects were chosen. The present model goes beyond the observed changes in drawing output and explains general developmental change in terms of a movement from an internal representation specified as a sequentially fixed list of core features (embodying a constraint that was inherent in the procedural representation still available to the system), to an internal representation specified as a structured, yet flexibly ordered set of manipulable core features.

The theoretical framework used here is not only relevant to children's drawings, but has been used to account for aspects of children's theory building in physics (Karmiloff-Smith, 1984, 1988) and of lexico-morphological development in language (Karmiloff-Smith, 1979a, 1986). Some interesting conjectures have been offered in favour of a formal homology between certain syntactic structures in language and the development of action strategies (Goodson & Greenfield, 1975; Greenfield, Nelson & Saltzman, 1972; Huttenlocher, Eisenberg & Straus, 1968; Robert & Sinclair, 1974; Sinclair, 1971). Here I am not suggesting that the acquisition of syntax and the development of skills such as drawing are analogous processes – on the contrary. My view is that the basic syntactic component of language is innately specified and modular. So-called "learning" of sentential syntax is not constrained in my opinion by general cognitive factors. This would explain the data collected from retarded children with very low IQ but who can nonetheless produce fluent, syntactically complex language (Bellugi, 1987; Cromer, in press). And there exist, of course, mentally retarded children and adults whose linguistic capacities are meagre but who are extraordinary artists (Hermelin & O'Connor, 1983; Selfe, 1985). However, innately specified linguistic and non-linguistic procedures, in the idiot-savant and in normal subjects, are not in my view available as data structures to other parts of the system. They are simply run.

To become available to cross-domain relationships, the knowledge embedded in procedures has to be redescribed and represented explicitly in central processing (Karmiloff-Smith, 1986). It is this step that I have argued is not available to the linguistic and artistic idiot-savant. The redescribed representations of normally developing children are available to central processing and form part of the basis for their spontaneous theory-building about the physical, social and linguistic environments (Karmiloff-Smith, 1979a, 1984, 1989). Once representations are dealt with centrally, they are constrained by general cognitive processes.

The new results of the present study can also be related to other aspects of language, a link to which my earlier research on more general aspects of representational change did not point. Indeed, the initial sequential constraint on representational redescription suggests a related explanation for data to be found in the literature on phonological awareness. In some interesting developmental work in this area (Bryant & Alegria, 1987), it has been shown that when children are asked to perform tasks involving the deletion of phonemes, they are initially more successful at deleting the final phoneme of a word, rather than the initial one. In the terms developed in this paper, initially children's phonemic representation is specified sequentially; they can put a stop function on the procedure but cannot yet insert anything once the procedure has been called. A similar empirical pattern can be found by comparing illiterate, newly literate, and literate adults. Morais, Alegria, and Content (1987) found that, whereas illiterate adults could not do the phonological awareness task at all, that is, they had not reached behavioural mastery, newly literate adults could only do one aspect of the task: that involving deletion of phonemes at the end of words, but not at the beginning of words. Thus, within the model developed here, it can be argued that once these adults had reached a degree of behavioural mastery in their literacy their initial redescription of the phonemic representations was constrained sequentially. These data are therefore suggestive of the same initial sequential constraint on representational redescription that I have been arguing for in this paper; that is, when adults first become literate they are constrained in the flexibility of their access to phonological knowledge.

Thus, an initial sequential constraint on the first level of redescription holds for both children and adults when knowledge is re-represented; that is, the process involves a phase in a reiterated cycle of representational change, and not a developmental stage only to be found in children.

The theoretical framework used here to account for representational changes underlying drawing output also suggests a link with the acquisition of musical skills. Take playing the piano as an example. Initially, there is a period during which a sequence of notes is laboriously practised; this is followed by a period during which the piece can be played automatically, but the automaticity is constrained by the fact that the learner can neither start in the middle of the piece nor play variations on a theme (Hermelin & O'Connor, in press). The procedure is simply run off in its entirety. Subsequently, however, the learner can interrupt the piece and start at, say, the third bar without having to repeat the entire procedure from the outset. Finally the learner can play variations on a theme, changing various aspects of the sequential order, introducing insertions and so forth. Once again, the end result is representational flexibility and control.

Although not situated within the framework of representational redescription, sequential constraints on output have been documented in studies of seriation and hierarchical constructions (Cromer, 1983; Freeman, 1980; Gilliéron, 1976; Goodson & Greenfield, 1975; Greenfield, 1978; Greenfield et al., 1972; Greenfield & Schneider, 1977; Kilcher & Robert, 1977; Piaget & Inhelder, 1948). For example, in seriation tasks children can first only add elements to the ends of series, subsequently they can add elements to the beginning of series, and only much later can they introduce new elements within an already formed series. This holds both for simple seriation tasks with toddlers (Greenfield et al., 1972) and in more complex seriaton tasks with older children (Gilliéron, 1976; Piaget & Inhelder, 1948). Greenfield has clearly demonstrated that interruption and the insertion of subroutines is a problem that recurs at different moments in development and across a variety of linguistic and construction tasks. Analogous to the principle of interruption that operates at the surface structure level of language (Bever, 1970), Greenfield argues that interruption in action strategies should be considered as a surface structure dimension (Greenfield, 1978).

The present study highlighted two types of sequential constraint. One is that embedded in a rigidly ordered procedure which cannot yet be operated on or changed. This is consonant with Greenfield's arguments that in their initial efforts to master a new domain children follow a chaining strategy that is cognitively less demanding than strategies involving interruption (Greenfield, 1978; see, also, Ninio & Lieblich, 1976). These authors focus on constraints on strategies, without situating them within the broader context of representational redescription. My argument is that mastery in the output activated by such procedural representations constitutes a prerequisite to subsequent representational redescription (Karmiloff-Smith, 1979a, 1986), resulting initially in a second sequential constraint.

The sequential constraint seems to be part of a broader intra-representational rigidity which, when relaxed, constitutes one of several processes leading to inter-representational flexibility. It is this general inter-representational flexibility that was the focus of my earlier work (Karmiloff-Smith, 1979a, 1984, 1986). The present study has specified more clearly the constraints on internal representational change. Development appears to involve reiterated cycles of representational change, from the simple running of automatized procedures, to redescriptions of internal representations specified as a sequentially fixed list, and then to internal representations specified as a structured yet flexibly ordered set of features, that is, a manipulable concept. The sequential specification of a redescribed procedure constitutes a second phase, after behavioural mastery, in a complex cycle of internal redescription and explicitation, ultimately leading in some cases to conscious access and verbal report (Karmiloff-Smith, 1986). In my view, situating sequential constraints within this broader context of multiple representational levels, and linking redescription processes to cognitive flexibility and ultimate conscious access, offers a new, deeper account of developmental change.

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