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Motor Development in Children: Aspects of Coordination and Control

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ACTION AND COGNITION

Cognitive and motor skills in a developmental perspective

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We would like to discuss in this chapter the relationships between motor and cognitive skills, usually considered as two separate categories of behaviour. Although it is not usual to speak in terms of "cognitive skills", the idea is not new. Bartlett (1958) already suggested that "thinking is an advanced form of skilled behaviour"; but he made, however, a sharp distinction between "bodily skills" and "thinking skills". Weimer (1977), expanding on the idea, considers that "the processes underlying human knowledge are (pace Bartlett) skilled actions". Similarly, Gelman and Gallistel (1978) speak of counting skills, or classification skills. Fischer (1980) has also adopted the notion of hierarchical skills in his developmental theory. Beilin (1983) considers the actual use of this term as a feature of contemporary functionalism. We will use the "skill" label in this chapter in order to facilitate the comparison between so-called cognitive and motor behaviours or tasks and also to make more explicit the point of view that will be adopted. We shall try to demonstrate, if not the equivalence between motor and cognitive skills, at least that the processes and mechanisms underlying them are the same. This is an important issue, in our view, since for several years now, we have been using motor tasks (skills) to study cognitive development (Hauert, 1980; Mounoud, 1970; Mounoud & Hauert, 1982). In a not too serious strain, we would suggest that this approach may be considered as "cognitivist behaviorism".

The relationships between action and cognition have been widely discussed recently (Arbib, 1980; Prinz & Sanders, 1984; Shaw & Bransford, 1977). Nevertheless little has been written on this topic in relation to development, the only exceptions being the chapters of Hay, Pick and Trevarthen in the book edited by Prinz and Sanders. We shall start this paper by paraphrasing Herb Pick's formula (this volume), according to which "we perceive in order to act and we act in order to perceive", in the following way: "we act by means of our knowledge and we know by means of our actions, by means of what we experience through our actions".

It is perhaps first necessary to specify that our knowledge and cognitive capacities are not necessarily conscious. Our cognitive skills are based mainly upon unconscious processes (in other words, cognition and consciousness do not have any necessary connections) and we are not usually conscious of the rules, relations, operations, schemas and representations (frequently qualified as mental) which determine our cognitive or motor skills.

For the purpose of this chapter, we shall consider cognitive skills and motor skills separately. Then, using our own field of research we shall try to define the links between them. Particular attention will be paid to

"seriation" skills, from both a motor point of view and a cognitive one. A large number of studies have been carried out from the latter point of view in order to discover how children succeed in seriating objects or events according to a given property (size, weight, etc...). Attention is paid both to the final product (the order introduced among objects) and to the procedure, i.e. the strategy used to produce the series. We have studied, from a motor point of view, together with Hauert, Gachoud, Viviani and Corbetta how children manage to seriate certain parameters of their actions (intensity, amplitude, force, etc) in relation to the variations of different properties (aspects) of the objects upon which the action is applied (grasping and lifting of objects of different weight, size, etc) or in relation to the variations in size of objects generated by the action itself (for example drawing circles of different sizes).

It is usual in all these experimental situations to interpret children's performances in terms of plans, programs, strategies that are qualified as more or less local or global (locally or globally defined), more or less integrated, coordinated or juxtaposed or fragmented in a piecemeal way. We shall examine children's skills in different situations - these skills being qualified sometimes as cognitive, sometimes as motor - in order to improve our understanding of children's behaviour as an adaptive tool for interacting with the environment.

The major problem in this kind of study is to know whether these plans (cognitive labels) or programs (motor labels) qualify an unique entity, whether they have the same underlying mechanisms or whether, on the contrary, they are different kinds of seriation skills.

1. COGNITIVE SKILLS

We shall first deal with so-called cognitive skills. We consider these to be the capacity to organise the relationships (spatial, causal, logical) between objects with respect to their different properties, or the capacity to organise the relationships between different parts of an object or yet again the capacity to organise the relationships between the subject and the objects he is confronted with. In our opinion, such a definition of cognitive skills necessarily includes perceptual skills. Cognitive skills can be both concrete material behaviour applied to objects, like sorting or seriating things, and internal or mental behaviour.

We will first consider free *classification or sorting skills* as a prototype of cognitive skills which organise relationships between objects. Sorting skills cannot be considered separately from class inclusion skills. The initial description in three phases given by Inhelder and Piaget (1964) starts with figural collections. These are typical of children aged from 4 to 5 year (objects are organised in spatial configurations as part of a whole). In a second phase (5½ to 7 years), children construct non-figural collections (objects are put together in small groups, based on more or less fluctuating and overlapping criteria). In a third phase (8 to 9 years), children are able to form well-articulated classes which are no longer juxtaposed but hierarchically organised. According to Inhelder and Piaget, children at this level fully grasp class-inclusion relationships, in other words the "all" and "some" relation.

From this initial description, it is possible as for the other cognitive skills to distinguish between two lines of research: one centered on early competences, the other on late incompetences (Case, 1985). There are good

reviews on this topic (see in particular Gelman & Baillargeon, 1983; Scholnick, 1983; Sugarman, 1983; Winer, 1980).

Studies done on "early competences" (e.g. Denney, 1972a,b; Fischer & Roberts, 1980; Rosch et al, 1976; C.L. Smith, 1979; L.B. Smith, 1984; Sugarman, 1979, 1981, 1983) all describe a series of steps or phases between 1 and 4 years. According to these authors, three-year-olds for example are able to sort objects according to a stable criterion, without any remainder or overlap. Preschool children can construct consistent and exhaustive classes: they are able to reason about inclusion relations, to embed classes within one another. We fully agree with J.M. Mandler's comment "it is hard to imagine a hierarchically arranged system that did not imply *some* understanding of class inclusion" (1983, p. 469).

Studies done on "late incompetences" (e.g. Bideaud, 1979; Carbonnel, 1978; Lautrey et al, 1981; Markman, 1978; Markman et al, 1980; Ribeaupierre et al, 1985; Rieben et al, 1983; Thornton, 1982) show the limits of 8 and 9-year-olds' classification skills, and in particular the tendency of children up to 11 years to base class inclusion judgments on empirical rather than logical factors.

If we leave aside classification in action, i.e. the sensori-motor or practical form of classification based upon the assimilation mechanism, it would seem that there are two moments when children's classification skills seem to reach some kind of optimal level: a first one at around 3½ or 4 years and a second one at around 9 to 11 years. As far as the transition between these two steps is concerned, we would especially like to mention the systematic research done by Markman (Markman, 1973; Markman & Seibert, 1976; Markman et al, 1980). Her results demonstrate clearly that 6 to 7-year-old children tend to organise objects in terms of collections (collective nouns such as family, forest, etc...) and part-whole relations, rather than in terms of classes or class-inclusion relations. How should one interpret this preference for collections as opposed to classes? Markman considers, for example, that collections have a higher psychological coherence than classes. It is, in fact, true that collective nouns are useful to particularise a class as a whole, to singularise it, to concretise it, to increase its intention. Collective nouns make it easier to keep the whole (the superordinate class) in mind while paying attention to its subparts.

Thornton (1982) studied children from 5 to 10 years in a classification task. She considered the age of 7 years as a transitional phase in which children actively elaborate relations between classes. We prefer to say "re-elaborate" since early competences already presuppose such an elaboration at a much earlier age (between 2 and 3 years). From our point of view, these two successive elaborations are done by means of different types of coding systems (Mounoud, 1976, 1981, 1985).

We now propose to consider another category of cognitive skills: the *seriation skill*. It can be defined as the capacity to order objects or events with respect to one or several of their properties such as height, weight or duration of water flow (Inhelder & Piaget, 1964; Piaget, 1946; Piaget & Szeminska, 1952; Piaget & Inhelder, 1974). This behaviour has been studied not only from the point of view of the final product (how successful the child has been in ordering objects) but also from the point of view of the strategies used by the child to carry out the seriation. In some recent studies on classification skills, sorting strategies have also been

considered (Langer, 1980; Sugarman, 1983). This study of strategies takes us a step in the direction of motor skills. Reid (this volume) includes the study of strategies in the field of motor skills. The task usually evoked is one studied by Piaget. In the size seriation task, children were asked to arrange ten rods differing by .8 cm, from the "shortest" to the "longest" (Piaget & Szeminska, 1941). Although, some 5-year-old children succeeded in correctly ordering the ten rods by a trial-and-error strategy, it is only at around eight years that they were able, according to Piaget and Szeminska to seriate the ten rods in a systematic way, from the smallest to the largest. These children were also successful in subsidiary tasks such as the insertion of additional elements into an already-formed series and the correction of the placement of an additional element that had been incorrectly inserted. For Piaget, the use of a systematic strategy means that the child *anticipates in advance the complete series*. In the same way, as inclusion for classification skills, the operational ability to seriate is formally unseparable from success on transitivity judgments.

Other experiments, some of which are contemporary to that of Piaget and Szeminska, have shown that much younger children can correctly seriate objects with regard to their size, in a systematic way. As for classification skills, *early competences* in three to four-year-old children have also been demonstrated in seriation tasks (Greenfield et al, 1972; Koslowski, 1980; Meyer, 1940; Sugarman, 1983). The same goes for transitive inferences (de Boysson-Bardies & O'Regan, 1973; Bryant & Trabasso, 1971; Harris & Bassett, 1975).

Edith Meyer, in her study of the understanding of spatial relationships between objects in preschool children, studied in 1940 already "the fitting together of forms" (the nesting of boxes). She gave children a set of five triangular boxes. They were asked to take the boxes out of each other and then to put them back again in the correct order. Behaviours were classified by Meyer in three stages.

During a first stage (typical from one-and-a-half to two-and-a-half years), children show *no appreciation of the forms and sizes of the objects* they want to put together. In the second stage (typical from 3 to 3-and-a-half years) children learn from experience to adjust the forms to each other. They succeed in holding the boxes so that their axes fit correctly (in such a way that the axis of one prolongates the axis of the other). They are *"not aware of all the relations beforehand"* but they adjust to them through *experimentation*. They cannot complete the series without making errors. Their planning is limited.

In the third stage (typical from 4 to 4-and-a-half years) children choose the right sizes and adjust the position of the boxes so that they will slide together easily. *They plan their actions beforehand and do not only adjust empirically.*

The description given by Meyer in 1940 still seem relevant today. It could be relabelled in terms of feedback and feedforward mechanisms.

Thirty years later, Greenfield, Nelson and Saltzman (1972) studied the manipulation of different sized cups by 11 to 36-month-old children, drawing a parallel between the development of action-manipulative strategies and grammatical construction. Moreover they establish a parallel between the stages described by Piaget between 4 and 8 years and the stages they

discovered between 1 and 3 years.

In this task, five cups with a circular section were used. Instead of presenting already-nested boxes to the child, the experimenter proceeded to nest the cups. The demonstration started with the smallest cup and proceeded to the next largest, yielding a seriated structure (strategy usually considered as the most advanced). After the demonstration the cups were placed one by one in front of the child. Three distinct strategies were identified.

In the first strategy (typical of one-year-old children) a single cup was placed in or on a second cup and most often immediately withdrawn from this cup. The child constructs one pair or successive pairs of cups. This strategy is compared to the binary division of the sticks into "big" and "little" described by Piaget and Szeminska (1952).

In the second strategy, called the "pot" method (typical at 2 years of age), two or more cups are placed in or on another cup. The child successively holds a number of cups which move into or onto a single stationary cup. The stationary cup functions as a "pot" holding the mobile cups. This strategy is compared to the second stage described by Piaget starting at age six in which series can be constructed by trial and error, but in which an additional intermediate element cannot then be inserted.

In the third strategy typical of the 3 year-old called the subassembly method, a previously constructed structure consisting of two or more cups is moved as a unit into or onto another cup. The critical feature of this strategy is that each cup or cup structure has a double role: it makes the transition from being acted upon to acting; each multicup unit functions as a single moving or acting cup. This strategy is compared with the third and final stage identified by Piaget characterised by the ability to insert a new element in an already formed series.

Between the stages described by Meyer (1940) and those described by Greenfield et al (1972) there is approximatively a one-year decalage. This decalage is partly due to the material and partly to the method. As far as the material is concerned, it is definitely easier to nest cups than boxes with triangular sections. As to the method, it would seem that the demonstration done by Greenfield et al, although it did not determine the use of a specific strategy as the results indicate, probably maximised the child's performance, which was the result the authors had set out to obtain. We particularly mention this decalage in order to relativise the ages mentioned in this presentation. Ages are not and cannot be considered in too strict or rigid a perspective. But it is possible to conclude on the basis of the empirical evidence that children of around 3 to 4-year-old are capable of correct seriation and insertion with a set of nesting cups or boxes, using of a systematic strategy. These preschool children planned beforehand or anticipated the successive actions to be produced in a similar way to the 8 or 9-year-old children in the classical size seriation task.

Early competence has also been demonstrated among 3 and 4-year-old children for transitive inference (de Boyssons-Bardies & O'Regan, 1973; Bryant & Trabasso, 1971; Harris & Bassett, 1975; Riley & Trabasso, 1974). For Halford and Kelly (1984) it is only around 4-and-a-half to 5 years of age that children show a real understanding of transitive inference. There is a strong controversy between the different authors (for an overview of

the topic, see Breslow, 1981; Breslow et al, in press).

As was the case for classification skills, seriation skills and transitive inference have also been considered from the point of view of late incompetences. Researchers have demonstrated the limits of understanding capacities among 8 to 9-year-old children (Bullinger, 1973; Gilliéron, 1976; Retschitzki, 1978). Using ingenious masking techniques to eliminate perceptual indices, some horizontal decalages, e.g. between seriation of length and seriation of weight, were suppressed (for a discussion see also Montangero, 1980). In addition, in certain experimental conditions, the operational strategy (called the choice of the biggest) is not used by children before 11 or 12 years of age. We would like also to mention the paper recently published by Retschitzki (1982) stressing the large variability in the strategies used to solve seriation problems even at a given developmental level.

For classification and seriation skills, as for inclusion and transitive inference, two levels of success seem to emerge clearly from the empirical findings: a first one around 3 to 4 years of age and a second one around 9 to 11 years of age, with a certain variability due to the experimental conditions. Most of the authors base their explanations upon mental structures. But some of them consider that there is a *structural transformation* between these two levels of performance (this Piagetian explanation is adopted in particular by Breslow, 1981; Breslow et al, in press) whereas for others there is *structural invariance*, and the explanation of change is to be found elsewhere. Authors in favor of the structural invariance consider that children from very early on have the logical competence to solve classification and seriation tasks.

Several hypothesis have been suggested to explain the change between the two levels of performance. For example:

- the ability to apply the logical competence to more and more complex arrays improves in time (Gelman & Baillargeon, 1983)
- the transformation of memory space or of language capacities (Trabasso, 1975; 1977)
- the degree of conscious awareness of categorical relations the tasks require (Mandler, 1983)
- the emergence of new coding capacities (Mounoud, 1981).

We would like to suggest that the first level of success at 3 to 4 years of age could be achieved by means of the perceptual coding system; whereas the second level of success at 9 to 11 years of age depends on (involves) the conceptual coding system. We previously considered perceptual organisation to be achieved around the age of two years. Thus we would be more inclined to consider the success of the 3 to 4 year-olds as a late achievement of the perceptual organisation and not as a first step in the conceptual organisation.

2. MOTOR SKILLS

We shall now discuss the development of motor skills. Motor skills can be considered as based upon the capacity to organise the spatial-temporal and physical aspects of a movement and its different components in relation to - or in correspondence with - the spatial-temporal and physical aspects of a given situation. This type of organisation can be demonstrated by the invariance or systematic variation of the movement parameters involved in

motor skills behaviour. This was basically the method adopted by Piaget for his study of some of the major aspects of cognitive development. In the field of motor skills, many invariants were identified by researchers at the end of the last century already, but these invariants are usually described as laws, principles, tendencies such as the Fitt's law or Isogony Principle and not as resulting from compensatory mechanisms produced by an active organism engaged in an adaptative relationship including action and perception.

As we already mentioned, we shall consider seriation skill from the motor skill point of view. In the experimental situation called weight seriation, the subjects were asked to lift objects of different weight and size. Weight variations can be inferred, at least partly, from variations in size. To accomplish the task in an optimal way, subjects must be able to vary the amount of force in relation to variations in the objects' weight so as to produce more or less similar movements whatever the weight of the object. In other words, the total duration of the lifting movement will be more or less constant and more or less invariant. We carried out various experiments in order to see at what ages children are able to organise their movement in such a way, and which are the different solutions they propose to solve this problem. We are not going to present the initial studies we did with 6 to 16 month-old babies on grasping for objects of different weights (Mounoud, 1973; 1974; Mounoud & Bower, 1974; Mounoud & Hauert, 1982).

We next studied children from 2 to 5 years of age in collaboration with Hauert (Hauert, 1980; Hauert et al, 1980, 1981). Children had to lift each object of a five-objects series three times in two different conditions with and without abutment. We will only mention that the 3 and a half to 4 year-olds were more able than the other children to compensate weight variations by corresponding variations of some parameters of their movements. However, these compensations were relative and partial. In the condition without abutment, they succeeded in keeping the amplitude of their movements roughly constant, the other parameters varying in proportion to the weight variations. In the condition with abutment, i.e. when the amplitude was externally imposed, they kept the movement duration constant. It is also at this age that one finds the highest proportion (80%) of continuous movements, according to Brooks et al's criterion (Brooks, Cooke & Thomas, 1973). Continuous movements are usually interpreted as the sign or the index of an overall planning of action.

Thus, in the motor skill version of the seriation problem, the performances of 3 to 4-year-old children show a peak, an optimum level as was the case for the cognitive version.

We will now present in more detail some of the results obtained in a study done with children from 6 to 9 years of age and adults, in collaboration with Gachoud (Gachoud, 1983; Gachoud, Mounoud, Viviani & Hauert, 1983).

The subjects were forty boys aged from 6 to 9 years and ten young male adults. They were seated in front of an object laying on a table, with their forearm horizontally placed and the half-prone hand grasping the object. The objects to be lifted were parallelepipeds of constant square section (4x4 cm), varying in height from 3 to 19 cm (by steps of 2 cm). The movement required was a simple flexion of the forearm so as to bring the wrist into contact with a fixed abutment; during the whole movement, the elbow stayed in contact with the table. The subjects could choose when to

start, as well as the velocity of the movement. They were asked to perform the movements in what they felt to be the most natural manner. Each object was attached to a rod connected to an angular potentiometer.

Electromyographic activity in the main agonistic and antagonistic muscles (biceps, triceps and deltoid) was recorded.

Adults lifted the entire series of nine objects from the lightest to the heaviest six times. Children only lifted the seven lightest objects in the series in the same order as the adults.

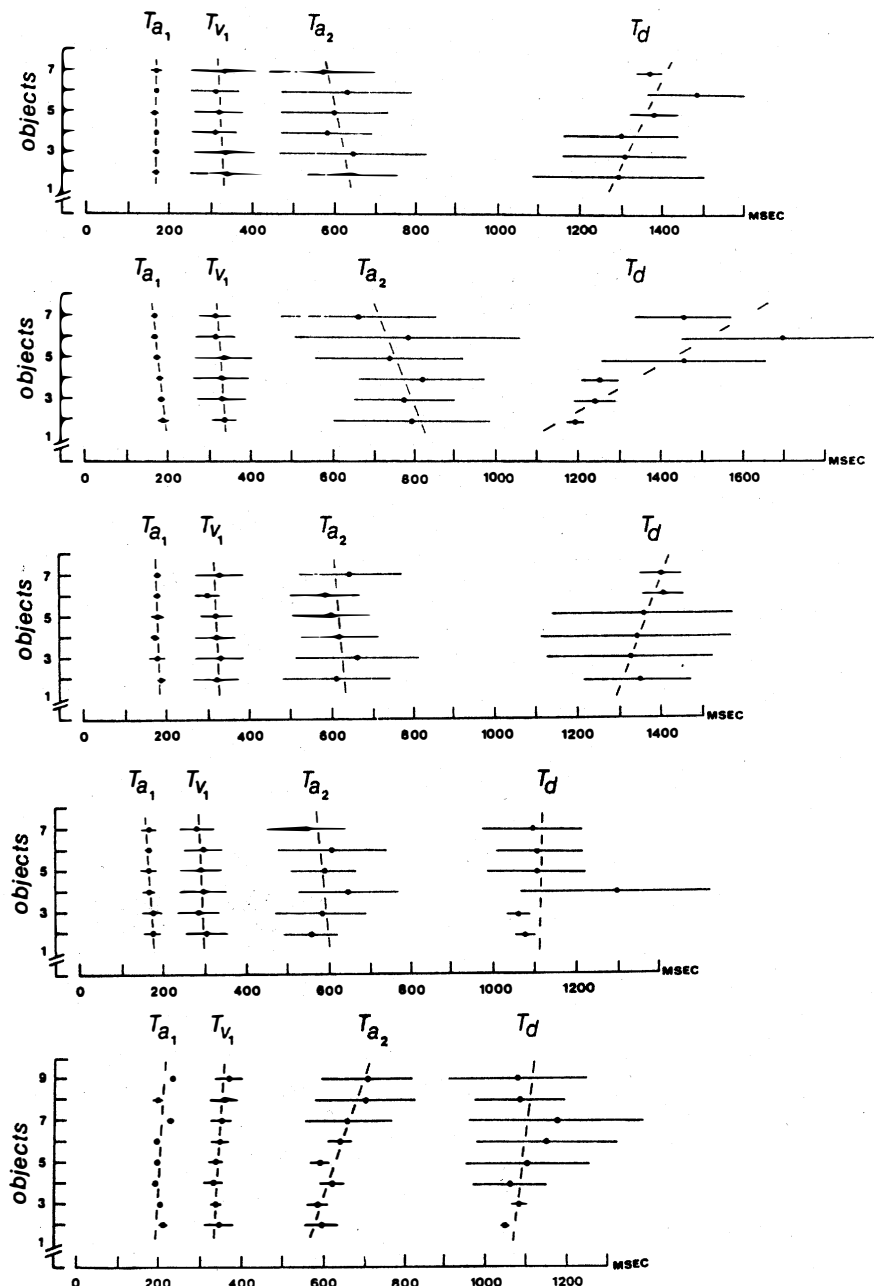


Fig. 1. Times of occurrence of the velocity and acceleration peak values (see text) in an object lifting seriation task. From the top: 6, 7, 8, 9 year-old children and adult subjects. Bars indicate the standard deviations.

We shall briefly summarise the results. Firstly, adult performance is characterised by a clear tendency to invariance with respect to the considerable changes in the external conditions. Figure 1 illustrates this tendency. It shows the time of occurrence of the first two peaks of acceleration (Ta_1 , Ta_2), of the first peak of velocity (Tv_1), and the total duration of the movement (Td), as a function of the object rank order in the series. Note that the value Ta_1 , Tv_1 and Td do not vary with the weight of the object.

If we now look at children's performances on the timing of the kinematic parameters, we see that for the 6, 8 and 9 year-olds, the times of occurrence are constant for all parameters. Although the trends are not statistically significant, the duration parameter (Td) increases more for the 6 and 8 year-olds as a function of the object weight than it does for the 9 year-olds. For the 7 year-olds, the times of occurrence of Tv_1 and Ta_2 are constant. The time of occurrence of the first peak of acceleration (Ta_1) decreases linearly with weight. In contrast, the duration parameter (Td) increases linearly with the objects weight. The different phases of the movement (acceleration and deceleration) are not completely coordinated. Taking into consideration other parameters such as the amplitude of the kinematic parameters and the emg data, it appears that the 9 year-olds children master the task in an optimal way: they fully compensate the variations of weight throughout the movement, including the deceleration phase.

We are not going to discuss the differences between children and adults. This has been done in detail in a recent paper (Gachoud et al, 1983). It is sufficient for our purpose to note that the 7 year-olds show simultaneously an overcompensation in relation to the increase in the weight of the objects in the first phase of acceleration, followed by a partial compensation in the deceleration phase. Such data are very illustrative of the nature of regulations and relations which are established at this age between the spatial-temporal characteristics of the movements and the object's properties. These regulations can be considered as analogous to those which appear in classification skills (elaboration of relations between hierarchical classes).

As for cognitive skills, motor skills seem to reach an optimum level at the age of 9. However, this achievement is probably dependent on the nature of the situation. Indeed, if the task were to consist of lifting objects in a random order of weight, we would probably have to study older children to get similar compensations in action.

We will now briefly outline the main results of an ongoing research on graphomotor activities in the developmental perspective (a study in collaboration with Viviani, Corbetta & Hauert). This research also involves a "motor seriation" task: subjects are asked to draw circles with various perimeters from the largest to the smallest. As early as 1893, Binet and Courtier presented evidence of invariants in the organisation of graphic movements. In particular, they suggested a direct relationship between the amplitude of the movement and the average speed of execution which, they noted, implies the relative invariance of the total execution time. More recently, Viviani and Terzuolo (1982) have demonstrated that the figural parameter that relates directly to the tangential velocity is the total linear extent of the trajectory, irrespectively of the overall size and shape of the trajectory. They also showed that total execution time is relatively insensitive to total linear extent (Isochrony Principle). A striking feature of this compensatory regulation of speed in adults, as noted by Binet and Courtier,

is the independence of visual feedback and its apparently involuntary nature. One could assume that this principle is an intrinsic characteristic of the neuromuscular system and that it is independent of development and active experience. In order to study this problem, we asked children aged from 5 to 9 years to draw circles of different perimeters. They used an Edison pen which burns a sensitive paper at a constant rate, in order to characterise the spatio-temporal parameters of their productions. Subjects were shown four circles (perimeter: 24, 18, 12, 6 cm) presented side by side on a board. They were asked to reproduce the four models in order of decreasing size. The models were not visible during the execution phase. In one experimental condition, subjects could monitor their movements visually. In a second condition they were blindfolded. Conditions were counterbalanced across subjects. Let us first examine the data collected concerning the amplitude of the movement, i.e. concerning the seriation of the perimeters.

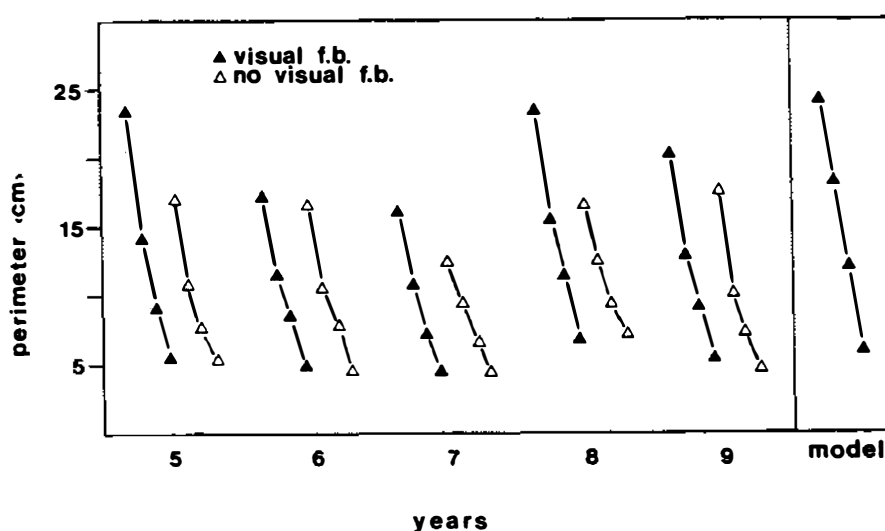


Fig. 2. Relation between theoretical (model) and experimental mean values of the perimeter in each condition.

Figure 2 shows the mean value (10 subjects in each age group) of the perimeters of the circles drawn in both experimental conditions. In all cases, the movement amplitudes clearly correlate with model size. But, in terms of *error* (quadratic error between model sequence and movement sequence), the analysis shows that the best performance is produced by the 8 year-old children in the experimental condition with visual feedback, followed by the 5 year-olds. The 7 year-old children present the greatest error in their reproduction of the models. However, if one considers the *regularity* of the differences in movement amplitude - i.e. the regularity of the seriation per se -, the 7 year-old children present the best performances in the experimental condition in which visual feedback is unavailable. They tend to keep the difference between successive circles almost invariant, as in the template. It is also at this age that the circles are restituted most regularly with respect to their curvature.

If we now look at the isochrony principle, it can be seen from Figure 3 that at all ages and in both experimental conditions a linear correlation exists between perimeter and duration. The slope of the regression, however,

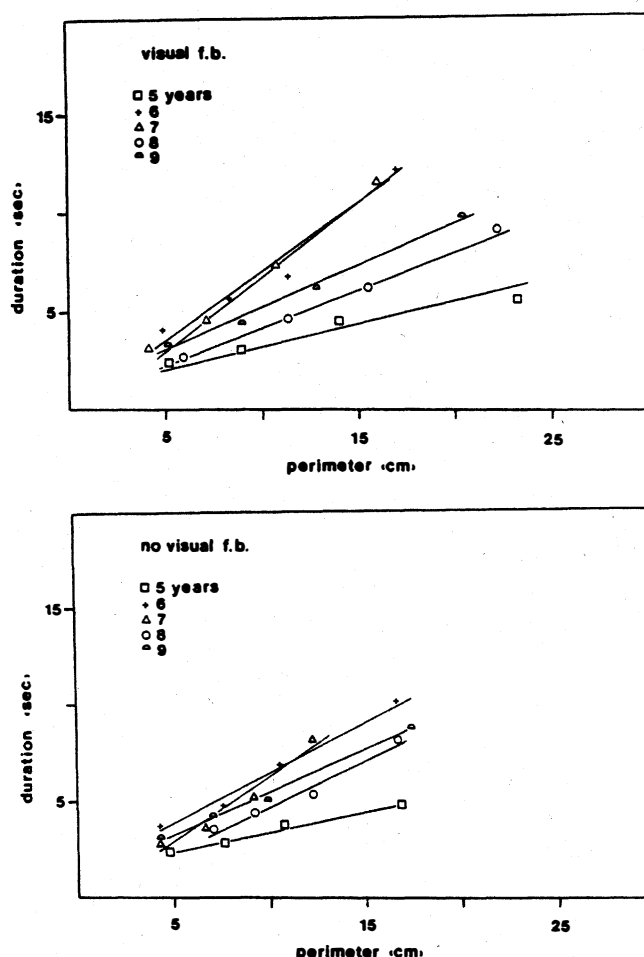


Fig. 3. Relation (regression) between perimeter and duration.

varies with age. When the slope is shallow, as at 5 years, the velocity compensation - the isochrony - is quite good. At 6 and 7 years, the slope is much steeper: duration increases almost linearly with the perimeter. At these ages, isochrony is practically absent: the subjects move their hand at a relatively constant and low velocity. At 8 and 9 years of age, isochrony tends to reappear. Let us note finally that similar results can be obtained in a circle cutting situation (Corbetta & Mounoud, 1985).

The ease with which such a figure as a circle for example can be produced under different biomechanical conditions is well-known. This fact is often advanced as evidence that the motor programs or engrams underlying the movements are to be considered as abstract. In this context, it is interesting to note that the performance of the 5 year-old children in the circle seriation clearly shows the existence of such an abstract representation of the movement, allowing the subject to control, in particular, the temporal aspects of the movements. The representation of the 6 to 7 year-old children differs from the previous one in that it allows the control of the spatial aspects of the seriation movements via a constant velocity strategy.

The age-related evolution of behaviours in the situation of motor seriation we have studied is very close to that Hay obtained in several of her experiments (1978, 1979, 1984), particularly in a manual pointing task without visual feedback. While children of 5 years present rapid and direct pointing movements, with a very low error, children of 6 and 7 years demonstrate slow and discontinuous movements with high error rates (under-

shoots). Error decreases afterwards, between 8 and 11 years of age.

The modifications that appear with age in the development of motor skills seem to concern the control modalities of the movements. These modifications increase the adaptation of the actions to the various characteristics and constraints of the environment. In the object-lifting task, for example, the child becomes progressively more able to adjust the acceleration and deceleration phases of his movements accurately. In the data Hay presents in this volume, she insists on the fact that 7 year-old children try to master the interruption of the action (a particular phase of their movements).

Jeannerod (1984, and this volume) claims that adults are able to plan the transport and grasping phases of their manual prehensile behaviours in a fully organised and anticipatory way. Prehension is organised as a whole by means of representations or abstract schemas, which Jeannerod calls "visual maps" and "proprioceptive maps". The movement can therefore be successfully produced with or without visual feedback. Isochrony appears to be one of the most important characteristics of these organisation: Jeannerod's experimental subjects compensate the amplitude variations of the movement by variations of the movements' velocity. Such a compensation results, in our opinion, from an anticipatory processing of the characteristics of the situation and of the movement. However, at certain stages of ontogenetic development, the transport and grasping phases of prehensile movements are not coordinated. During these stages, one can consider that the child is actively processing the spatial, temporal, cinematic, etc., information relative to his action and to the situation (Mounoud, 1983, in press; Mounoud & Vinter, 1981; Mounoud, Vinter & Hauert, 1985).

3. RELATIONSHIPS BETWEEN COGNITIVE AND MOTOR SKILLS

We have tried, in this survey, to show the synchrony of the stages characterising the development of a set of cognitive and motor skills, and the similarity between the problems the child has to solve to master these skills. In our theoretical perspective, this synchrony and this similarity are evidence of a common underlying process, consisting of the *ability to establish relationships between the different properties of the objects (or situations) and actions*. These relationships can be established, partially or wholly, before the onset of the movement and, in this case, we speak of a *beforehand planification* (anticipatory planning) of action by means of central abstract representations (feedforward). But, these relationships can also be built up during the movement. In this case, we can speak of *adjustments* via retroactive loops, combined with a partial planning of the movement. These two modes of functioning tend to confirm the proposition we made at the beginning of this chapter: "we act by means of our knowledge (beforehand planification or anticipatory planning) and we know by means of our actions, by means of what we experience through our actions (empirical adjustments)". However, it is important to consider that these planning abilities depend to a critical degree on developmental and learning processes. In this sense, it is no longer possible to distinguish between different kinds of abilities. There is a general *Cognitive Ability* underlying all types of behavioural abilities. It can be considered the equivalent of Weiner's "skilled actions", considered as processes underlying local knowledge. However, we would like to emphasise that new knowledge does not simply consist of sampling information from the environment: it involves

the *adjustment* of this information to previously existing schemas. In all cases, it is the initial knowledge which allows the planning of action, followed or not by adjustments. We have seen that such a process concerns both so-called cognitive and motor skills, and their acquisition.

The question now is: do motor skills necessitate less "skilled actions", less general processing abilities than cognitive skills? Our answer is no. The objection could be raised that we have chosen, for our demonstration, motor skills which particularly need cognitive activities to be performed. But, do motor activities exist - such as professional, musical or sporting activities - which do not involve mediation by cognitive activities? Let us take as an example the highly-regulated run-up in long jumping (Laurent, 1981; Lee, Lishman & Thomson, 1982). The strides can be considered as seriated backwards from the last one. As in a cognitive task such as the seriation, it is always necessary for the subject to master some parameters of his/her action (amplitudes, durations, etc...) in an orderly manner, in correlation with the increase or decrease of certain dimensions of the situation involved.

In this connection, we would like to stress again the unconscious nature of these activities. At the beginning of this chapter, we clearly rejected the equation "cognitive activities=conscious activities". The human subject is unconscious of a very large part of the internal processing that is involved in all his/her cognitive, motor and affective behaviours.

An other objection could be that, when a behaviour becomes a skill, cognitive activities are no longer necessary. In other words, cognitive activities play a role only during the acquisition phases of a skill. Once the skill is acquired, the behaviour becomes irreflective. This question - the automatisisation of behaviours - is one of the greatest challenges put to contemporary psychology. It should be remarked in this connection that, if it is usual to speak of a irreflective behaviour in the case of a skill, it is curiously unusual to speak in terms of thoughtful behaviour during the acquisition phases of a skill. Authors say then that the behaviour is actively controlled or corrected. However, it remains evident that when a behaviour is being acquired, it is slow and awkward, and that a fully-achieved behaviour is rapid and elegant.

Now, for years, psychologists have associated the time of response to the complexity of the processing involved. It is clear that in such a perspective, a sports' champion or a musical virtuoso is a irreflective person. Psychologists have imperatively to change some of their points of view if they wish to avoid being qualified as ...mindless.

Motor development and cognitive development have been considered during this century as based mainly on the capacity to coordinate elementary behaviours called sub-routines or elementary and partial representations in a broader organisation (see Bernstein, Piaget & Bruner). These coordination or chunking operations involve mainly a gain of time and memory, and they can be considered as being at the root of the automatisisation of behaviours. Such automatisisation does not reduce the importance of the computations the subject has to do but makes them simpler and faster. In this sense, "thought" increases rather than decreases. Without underestimating the importance of this mechanism, we have personally placed the accent, in our works, on the complementary process of dissociation and segmentation of complex, highly organised behaviours into elementary behaviours. Indeed, this process is

often neglected by theories of development.

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