

Action and Thought

From Sensorimotor Schemes to
Symbolic Operations

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Development of Sensorimotor Organization in Young Children: Grasping and Lifting Objects

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Introduction

First, let us outline our position in relation to the theme of this book: the transition from sensorimotor schemes to symbolic operations. According to Piagetian theory, this theme supposes that we first have a logic related to actions succeeded by a logic related to reasoning. The action logic is distinct from reasoning logic in that the former lacks representation. Our purpose here will be to show that the distinction between action and reasoning logic can be found at every developmental stage, including the sensorimotor. Thus, we should not use the action-reasoning distinction to highlight developmental stages or to contrast the sensorimotor and operation stages.

Our hypothesis assumes that children have representations both of reality and of their own bodies at each step of their development (including birth). We shall, however, distinguish several representational levels throughout the course of development (sensorial, perceptual, conceptual, and semiotic levels). We shall also formulate a criticism of the classical methodology used to study cognitive development. If we begin with the idea that cognitive psychology studies the subject's knowledge, it must then be apparent that this knowledge can only be

inferred from the subject's actions, including verbal actions. We shall try to show that verbal actions have traditionally received too much attention in studies of the developmental period, which follows the sensorimotor one. Genetic psychology has too often assimilated and reduced the child's knowledge to its verbal manifestations, often paying too little attention to other actions (movements, for example). Our criticism of the classical approach to cognitive development will therefore include both theoretical and methodological aspects. We shall first present the Piagetian thesis, followed by our criticism of it; we shall then move to our own thesis and its relation to the theme, "action and thought." Finally, we shall illustrate our own viewpoint with a few experimental examples of studies we have made to infer children's knowledge from their action characteristics.

As previously mentioned, the Piagetian description of cognitive development consists mainly of a distinction of two successive periods. The first is called the sensorimotor period and the second is the operative or conceptual period. Two kinds of intelligence correspond to these two periods. Although the second form is functionally considered equivalent to the first, it differs from it structurally.

We see then that thought can neither be a translation nor even a simple continuation of sensori-motor processes in a symbolic form. It is much more than a matter of formulating or following up work already started; it is necessary from the start to reconstruct everything on a new plane. Perception and overt responses by themselves will continue to function in the same way, except for being charged with new meaning and integrated into new systems. But the structures of intelligence have to be entirely rebuilt before they can be completed . . . [Piaget, 1972, pp. 121-122].

It seems to us indispensable to examine the methodological context in which this conception has come about. First note that Piaget's studies did not start from birth and progress through the age scale (Bang, 1966). Indeed, Piaget's first works on psychology cover "Le Langage et la pensée chez l'enfant" (1923), "Le jugement et le raisonnement chez l'enfant" (1924), "La représentation du monde chez l'enfant" (1926), "La causalité physique chez l'enfant" (1927), and "Le jugement moral chez l'enfant" (1932).

We cite these works in agreement with Bang (and we shall have to come back to this hereafter) that in his early works Piaget sought a method to allow him to reach the structures of child thought through its verboconceptual aspects. But Piaget's main methodological options were already in place, and although the methodology has been evolving, its main aspects have never been called into question (Bang, 1966, p. 71).

Thus, Piaget treated the sensorimotor period only later in his career. His studies using the sensorimotor period showed a new methodology,

which is important for us to describe because, as will be seen later, it reveals the theoretical conception Piaget formulated regarding material action and its coordination and regulation, as much more recent works show (Piaget, 1974a, 1974b).

Piaget has studied material action from observations exclusively centered on the “logical” aspect of action, or on the results of actions in the world of objects, and this in the sensorimotor period as well as later on. What we call “logical” aspects are the connection and coordination of the various movements or parts of movements without an accurate attempt of spatiotemporal quantification of such connection and coordination. However, what we call the “physical” or “cinematic” aspect of actions—their duration, amplitude, direction, velocity, and so on—has usually not been considered as an index referring to thought. It has to be stressed that knowledge acquired by the child necessarily requires spatiotemporal organization and the control of his or her actions at the sensorimotor stage as well as at further stages.

The three following groups of works illustrate the convergence of classical studies in cognitive psychology with the verbological aspect and/or the behavior logic: Inhelder, Lézine, Sinclair, and Stamback’s work (1972) “Les débuts de la fonction symbolique”; Piaget’s works “La prise de conscience” (1974a) and “Réussir et comprendre” (1974b); and finally, current works that are Piagetian-oriented and centered on the study of action procedures (Inhelder, Ackermann-Valladao, Blanchet, Karmiloff-Smith, Kilcher-Hagedorn, Montangero, & Robert, 1976; Inhelder & Piaget, 1979).

In the Piagetian works, there are two methods to the analysis of a child’s behavior: Sensorimotor behaviors are studied in relation to their logical characteristics, and conceptual behaviors are studied in relation to their verbal or verbological characteristics. But we must emphasize the fact that Piaget’s theory distinguishes sensorimotor behaviors of the sensorimotor period from sensorimotor behaviors of later periods of development; the latter are dependent on a so-called practical intelligence. Now, beyond the age of 2 years, the child’s sensorimotor behaviors have been conventionally studied in the same way as the sensorimotor period behaviors. The former had comparable status as the latter.

So, in the Piagetian theoretical context, these two methods do not strictly refer to distinct developmental periods, but rather to distinct kinds of intelligence: on the one side, the sensorimotor and practical intelligence; on the other side, the conceptual intelligence. Let us note, however, that Piaget first studied the distinction between the sensorimotor and conceptual intelligences, that is, between the sensorimotor and the conceptual periods. Only recently has he studied the

distinction between the practical and conceptual intelligence in the child beyond the age of 2 years.

Concerning the first of these distinctions, what allows Piaget to distinguish these two forms of intelligence is related to the concept of representation. Roughly, the sensorimotor intelligence consists of perceptions and movements more or less organized in coordinated systems according to the level of development. But for Piaget, this intelligence does not imply the existence of internal representations, as opposed to external objects, likely to have their own dynamic. These differentiating possibilities appear only around the age of 1½–2 years and are collectively termed the “symbolic function”; this function uses representations as a link to reality. The specific means of this second form of intelligence, that is, the operations, would be the result of sensorimotor schemes. This of course does not mean that when the conceptual intelligence arises sensorimotor intelligence disappears, but sensorimotor intelligence at this later stage of development is now called practical intelligence. What connections exist for Piaget, between these two forms of intelligence?

Piaget deals with this question in two works: “La prise de conscience” (1974a) and “Réussir et comprendre” (1974b). The first refers to the study of “the nature and content of the subjects’s conceptualizations (including, but not restricted to, the causal explanations) when these do not concern the typical physical situations that we have already studied (transmission of movements, vectorial compositions, and so on), but the effects of the child’s actions alone and of his ‘practical intelligence’: making use of a sling or an inclined plane, building a sloping path—in other words, easy problems that are solved early in life [Piaget, 1974a, pp. 8–9].”

The hypothesis Piaget develops in this work is the following. Early successes are actions directed “by mere automatized sensorimotor regulations which are not sufficient to give rise to an adequate grasp of consciousness [Piaget, 1974a, p. 15].” To understand how a grasp of consciousness of one’s own actions comes about, one must, according to Piaget, distinguish mere automatized regulations from active regulations, the latter implying the choice-making abilities that initiate grasps of consciousness. The setting up of these active regulations is linked to the development of reversibility, that is, to the child’s abilities as far as conceptual anticipations and feedbacks are concerned. In this perspective, one sees that the grasp of consciousness is not a simple conceptual “lightning” over the sensorimotor coordinations:

Between the motor and the conceptual coordination there is therefore a fairly fundamental difference (in orientation): On the one side, there is unconscious selection

through trial and error, of the correct release point from all those possible, and on the other side, gradual understanding of all the possibilities of the situation . . . [Piaget, 1974a, p. 44].

For Piaget, however, the conceptual coordination is not completely independent of the motor coordination from which it arises through reflecting abstraction; that is, the “know-how” has to be opposed to the “conception,” but, between the two, different integration levels and different degrees of consciousness have to be admitted.

On the whole, in the case of early successes, the first-level material actions without conceptualization represent a system of schemes already constituted as an elaborate know-how.

This level, with constructions that result in the most fundamental operatory structures (in their capacity of coordination, even though the subject remains unconscious of them), may well appear to the psychologist as a sort of absolute beginning, but this is an illusion. The first level is linked by all the intermediaries to the organic sources from which it derives its material. The second level is that of conceptualization. It derives its elements from the action as a result of cognizance . . . [Piaget, 1974a, p. 349].

The first level therefore realizes a stage of the action initial autonomy: “As far as elementary successes are concerned, the conceptualization always comes with some delay compared to the action, which shows the autonomy of the latter [Piaget, 1974b, p. 232].”

In this line, and even after the coming about of the symbolic function, the development of material action characteristics has always been referred to as a particular and specific form of so-called *sensorimotor intelligence* (practical or situational intelligence), as opposed to another form of so-called *representative intelligence* (discursive or conceptual intelligence). As far as we are concerned, we deny that there is this opposition between action and thought (Hauert, 1980; Mounoud, 1970). We believe that any action is closely dependent on both the representations of the objects toward which the action is aimed and the representations of the subject’s own body; it is through action that the subject builds up representations of his or her environment.

A representation is a realization by way of a code of a translation of objects and their properties. We distinguish several types of codes arising in succession during the course of development. A new code leads to the creation of new representations by a complicated process (Hauert & Mounoud, 1980; Mounoud, 1979; Mounoud & Guyon-Vinter, in press).

We shall synthesize our viewpoint as follows. Intelligence, in all its aspects, and regardless of the child’s age, is manifested as much in the

use of representations and action-logical procedures as in the building and use of defined spatiotemporal action programs. Therefore, to understand how children manage to control the dimensions involved in their environments, it is possible not only to study their verbalizations, their judgments (when possible), or the logic of their actions, but also their action-cinematic characteristics. In the study of cognitive development, therefore, the study of the action cinematic should not be left out. This thesis is the basis of studies we undertook several years ago, some of which will serve as groundwork for the following pages. Note that these works are still in progress; therefore, we cannot answer all the questions we are formulating. In particular, we have an experiment in progress concerning children between the ages of 6 and 9, which aims at integrating the verboconceptual and motor aspects of behavior in a context concerning the notion of weight.

Problem

The study of the action cinematic aspects of the subject's knowledge is unusual in the field of cognitive psychology. It is therefore necessary to formulate carefully the status of this index. This formulation forces us into a rather long detour, the purpose of which is to introduce some concepts specifying on the one hand the connections between the logical and cinematic aspects of behaviors and, on the other hand, the connections between these aspects and the dimensions of reality to which these behaviors apply. Piaget's structuralist approach has for the most part passed over these connections. Our perspective may therefore be qualified as functionalist.

The first concept we shall develop is that of action procedure. We shall call an action procedure the general coordination plans of actions (i.e., transformation classes). This concept corresponds to the Piagetian notion of schemes, or scheme systems. The procedural aspects of behavior determine how movements are organized into the means, necessary but not sufficient, to reach a goal. Such general plans or procedures exist in the baby at birth. At each development stage, new procedures are worked out on the basis of new built-in representations. These general coordination plans or procedures must be specified in relation to each particular situation in which they are used or applied.

It is thus necessary to look for a mechanism that would define the particular application conditions prevailing on a procedure—for example, the intensity or time aspects involved in muscular contractions and relaxations during the execution of a given task. This

mechanism, which we call action program, is therefore responsible for the specification of cinematic characteristics in the movement produced. It is produced from representations of the object's physical characteristics (size, weight, etc.) on which the action applies and from the cinematic characteristics of the action itself. These representations are related to extero- and proprioceptive information. The values of the action program parameters are calculated on the basis of these representations. The working out of both procedures and action programs may be closely linked. Experimentally, however, it is possible to dissociate their study. We shall therefore distinguish two important types of experimental situations:

1. Situations in which the construction of new procedures is being studied: procedures elaboration situations. As an example we shall mention the studies of the various coordination levels in visual and prehension activities in babies between 0 and 5 months, or the studies run by one of us on the construction of simple tools by children between 4 and 9 years (Mounoud, 1968, 1970).

2. Situations in which the specification of action procedures previously elaborated or procedures application situations are studied. We shall here present this type of situation. In such situations the subject already possesses an elaborated action procedure, but its application depends on certain conditions that have to be specified.

Let us illustrate these notions with the example of an object being lifted by a vertical arm movement. This situation involves procedures application. In the context of a study over the size-weight illusion, Claparède (1901) has shown that the more voluminous an object is the more rapidly the adult lifts it, given equal weights. The adult's activity will therefore be analyzed in this situation. The assimilation of the task to a motor scheme determines the choice of an action procedure (movement class), such as lifting movements of the arm, from a starting to an arrival position, or grasping the object by the hand in one way or another. Having made a choice, the subject defines an action program that will accomplish this procedure.

To determine the values of the program parameters, the subjects anticipate the specific characteristics of the situation they are facing, by means of the representations they are able to work out. They will then necessarily take into account (a) the object's properties—its volume as perceived visually as well as an estimation of its density, which will allow them to make a prediction on its expected weight, and (b) their action properties—the time spent over the movement, its velocity, acceleration, and amplitude. These calculations will therefore determine

the moment, the duration, and the intensity of agonist and antagonist muscular contractions necessarily involved in the movement. The movement characteristics thus programmed (course, velocity, acceleration) are the result of the interaction between the application of the action program and the actual weight of the object.

Claparède's experiment (1901) therefore shows that the more voluminous an object is the heavier one anticipates its weight to be. The subject therefore varies the intensity of his or her muscular contractions according to this anticipation. Although certain objects are in fact equal in weight, the velocity with which one lifts them varies.

This conception of the action program notion calls for some comment:

1. The value of a program's parameters (variations of the movement duration, its amplitude, its direction, etc.—in other words, variations in intensity and duration of muscular contractions) can be modulated according to the situation. In this sense the study of movements' cinematic aspects completes the study of movements' logical aspects but also differentiates it: The duration or speed involved in a movement can vary according to the representations worked out by the subject over the properties of the objects he manipulates.

2. If the subjects' representations are incomplete or if some information regarding the situation he is in, are missing, his action procedure will be managed by a maladjusted motor program. In this case, the produced actions can be a supplementary information capture, enabling a redetermination of the program parameter values. As will be seen in our experimental illustrations, actions in such cases show discontinuous characteristics.

3. If one defines a movement as being the realization of an action procedure, as specified by a motor program, then the movement cinematic characteristics inform us to what extent the subject's representations or knowledge are adequate as to the situation; here is the heart of our thesis.

4. Our conception of the motor program notion therefore implies the existence of several possibilities to control a movement. The first one, of course, refers to the functional properties of the neuromuscular system, which does not depend on the subject's will: As a prototype, one can take the stretch reflex (in this respect a recent article written by Cooke, 1980, can be referred to). In the voluntary control over movement, two kinds of functioning modes have to be distinguished: on the one side, a purely anticipating mode where the values of motor program parameters are specified before the movement itself; on the other side, a functioning mode where these values, or at least some of them, are

(re)specified during the course of movement. This distinction covers the dichotomy existing over central or peripheral control (see for example Brooks, Cooke, & Thomas, 1973) and will be referred to at length in our experimental data processing.

These considerations are at the very basis of our experimental work. They allow a specification of the index status we have established to approach the study of cognitive development. Let us recall that these indices are to be referred to the calculation or processing brought about by the subject on the basis of the representations he already possesses, or those that are being worked out. Let us say again that, in our thinking, the material action—and this is true for the development sensorimotor stages too—must be considered as controlled by representations, according to mechanisms we have just described.

We shall present here two experimental illustrations based on the study of physical action to help us understand certain aspects of cognitive development. The first concerns the child of 6 to 16 months. The second refers to the child between 2 and 5 years. The first illustration will render a detailed criticism of the Piagetian approach to the sensorimotor stages.

Experimental Approach to the Child between 6 and 16 Months

Before we show how the study of action cinematic or physical aspects gives a new way of approach as to the baby's behavior, we would like to examine in more detail how Piaget, about 50 years ago, brought to light the existence of initial forms of intelligence in the baby (Piaget, 1936, 1937).

Critical Examination of the Piagetian Approach

We shall distinguish two main perspectives in Piaget's approach:

1. He has defined the baby's initial forms of intelligence by means of *the organization of its actions*, considering its coordination extent and coordination among the different parts of an action and among several actions. This is what we have previously called the "logical aspects of an action" and corresponds to Piaget's "actions schemes." According to him, schemes determine the structure of actions independently from the objects to which they are applied (in other words, the subject's competences). They are general action coordination plans (nonspecific), which we call action procedures.

Piaget has therefore passed over the whole problem of the specification of these general action coordination plans as far as situation dimensions or particular characteristics are concerned (this is the direct result of his structuralist option, which expressly divides the structures from the contents to which they apply). This specification is effected through a calculation that we believe is made from the representations the subject possesses or builds up over the problem dimensions (of the objects and the situation). This calculation enables the subject to determine a program defining the values of its parameters.

2. Piaget has also defined the baby's initial forms of intelligence from the organization it is able to introduce among objects through its actions. In this respect Piaget has studied the action results (in other words, the subjects' performances as to the results obtained in applying his schemes). Here again Piaget has passed over the cinematic characteristics of the transformations through which the subject manages to get these results.

Now we still have to examine how Piaget has defined the connections between action schemes and the objects to which they are applied. In this respect the connection between action schemes and objects is initially supposed to be direct (no mediatization is being made through representations). The schemes would be directly called into action through contact with the object (its direct perception according to Piaget), without any possibility of delaying execution. It is only progressively, and during the course of the sensorimotor stage, that schemes would stand out clearly from perceived reality and become more independent. The initial integration (strict dependence) between schemes and objects would be followed by a progressive differentiation (more or less total independence) toward objects that are the origin of their transformations. This differentiation is supposed to lead to the complete detachment of schemes.

To define more precisely Piaget's viewpoint, one must recall that, for him, what characterizes the baby at birth is the isolation of schemes connected directly to isolated dimensions of the object (a connection Piaget explains without referring to representation or translation notions). Then development is characterized mainly by the coordination of schemes that determine (progressively) larger action classes (as opposed to more restricted action classes). At the end of this construction, schemes have become coordinated and objects have acquired permanence; that is, they still exist beyond direct perception and the baby masters their visible and invisible removals from sight. At this moment only, Piaget introduces representation, and on this point we deeply disagree with his conception.

Consequently, Piaget has defined the baby's problems during this stage as relative to the object's disappearance (existence = direct perception). But it has been shown that the nature of the baby's problems was not a perceptive one in the Piagetian sense—that is, of nonmediated direct contact with the object. Much research has pointed out that the problems the baby meets in the situations set up to study object permanence were not due to the disappearance of the object (the absence of direct perceptive contact), but to the control the baby has over the relationship objects have to each other (Bower, 1967, 1971; Butterworth, 1974; Wishart, 1979). It has also been pointed out that from a very early age the baby is able to make predictions as to the removals and the object's identity throughout its disappearances (Bower, 1974; Bower, Broughton, & Moore, 1971; Mundi-Castle, 1970).

In conclusion, Piaget's position has led him to separate (too radically) the organization inherent in action schemes (their extent of coordination) from the object's organization as if action schemes could be defined independently from the classes of objects and situations to which they are applied. One can qualify this position as a structuralist one.

In the perspective we have previously described we maintain that actions are organized according to certain dimensions of reality of which the subject possesses representations—the starting point where he chooses a procedure and determines a program. Let us take as an example ocular movements for which the organized character (coordinated) has been pointed out for the baby from birth (Haith, 1978). It is interesting to know how these movements are organized, according to what dimensions of reality, and to specify the present system of representation. It is much more enlightening if the diagram aspect of the action (structures, coordinations) can be pointed out from birth.

The same can be said of the coordinated activities of the arms, the legs, and the head. The relative degree of coordination of the arms, legs, and head is significant only when it is referred to the dimensions of reality of which the subject possesses representations. Information processing capacities can only be applied to representations (translations) of the dimensions of reality. These representations can be of different natures: sensorial, perceptual, conceptual, or formal. They can be either partial or complete.

New Experimental Perspective

From birth, babies show they are able to anticipate. We think that initially these anticipations are not referred to the external world as the

baby would conceive it. Before babies can refer their anticipations or expectations to the external world (thus producing inferences) they will have to (re)translate and (re)work the dimensions of reality from the sensorial code into the perceptual code, thus composing what we call perceptual representations (Mounoud & Guyon-Vinter, in press).

We have studied these inference capacities as they exist in babies between 6 and 16 months of age (Mounoud, 1973, 1974; Mounoud & Bower, 1974). We started off with the idea that during this period the baby was progressively becoming able, thanks to the elaborated perceptual representations, to predict, to infer some dimensions of the object from other dimensions and to define programs more and more adapted to the situation. We especially wondered how the baby would predict the weight variations of homogeneous objects from their difference in sizes in order to program an action over these objects. The remaining problem was to bring these capacities into light.

So we thought we could make use of the characteristics inherent in the actions performed by the baby on the objects (the action cinematic or physical aspects, as we call them).

Our main hypothesis was the following: If the baby effects calculations or information processing, these calculations are meant to organize his actions according to certain procedures, and to program them so that they fit the realities to which they apply. Consequently, the cinematic characteristics of an action performed on an object can give us information as to the nature of these calculations. For example, if we give subjects heavier and heavier objects, they will have to program their muscular activities so that their actions are not affected beyond certain limits by the weight variations of the objects.

MATERIAL AND TECHNIQUE

In the first trial we performed (Mounoud, 1973), we handed objects to the babies for them to grasp, and we measured the amplitude of the arm drop. This drop is considered as an index of the baby's preparation for or adaptation toward the weight of the objects. The experiment was recorded with a videotape camera, the baby posed sideways to it, and the measurements of the arm drops were taken on the screen. The part of the act of grasping that interests us here is what we call the "grasp" or "capture." In spite of its limits, this technique did prove satisfactory for the initial research we conducted. The technique we used was the following: First we had the baby grasp the same object several times. It was heavier than the objects the baby usually handled, and we examined how the baby adapted its handling of each given object. We used

objects of various weights for this experiment, namely, 190 gm, 290 gm, and 330 gm.

In a second trial we again gave the baby the same object several times, and after we obtained a more or less constant grasp, we replaced the object with one identical in appearance, but this time much lighter in weight. We call this trial "substitution." Several pairs of objects have been used: cylinders of 165 and 20 gm, 330 and 40 gm, 330 and 110 gm; spheres of 180 and 10 gm, 250 and 50 gm. This experiment allowed us to see if the baby would show any surprise at this sudden change of weight; this would tell us if the object could be identified through its weight. Moreover, the motor disturbance occurring after this substitution will inform us of the nature of the baby's motor program.

In a third trial the baby was to grasp each metal cylinder of a series three times according to an increasing and decreasing order. Different series of cylinders were used: 110, 220, 330, 440, and 165, 330, 495 gm. Through this experiment the researcher can see if the baby can anticipate his muscular contractions following the change in size of the cylinder; if he can make determinations or local anticipations; or if he only adjusts his grasp to the object's registered weight. In other words, we tried to determine when the baby becomes able to infer the weight of an object from its size or one of its dimensions (height).

Finally, in a fourth trial, we used the classical conservation situation but in a behavioral version, as we call it. After the baby had grasped the same object several times, we changed it in front of him and we gave him this altered object to grasp again. We then saw if the adaptation realized with the initial shape was maintained when the altered object was grasped. Two types of objects were used. One of them was a metal cylinder (550 gm), the top half of which could be folded over the lower half. To the extent that we could verify it, the baby should take the object's dimensions into account to infer its weight. This trial should show at what age the baby can compose the object's dimensions (height, width, thickness) and deduce its weight conservation.

In our initial research we did not follow a particularly strict procedure as we first wanted to clear the rather complex problems this study brings up.

RESULTS

Let us try briefly to characterize the main results of this first experiment, in which 30 babies from 6 to 16 months were seen. For the purpose of this chapter, we have roughly divided the examined population into four groups according to their reactions: a first group of nine babies between 6 and 8 months, a second group of six babies between 9

and 10 months, a third group of nine babies between 11 and 13 months, and a fourth group of six babies between 14 and 16 months.

As to the repeated grasp of the same object (Trial 1), the prehension adaptation is expressed by a reduction of the subject's arm drop amplitude, this for the group of youngest babies (6–8 months) as well as for the oldest (14–16 months). The two intermediary groups have clearly different reactions. The Group 2 babies (9 and 10 months) show an opposite reaction: The drop amplitude tends to increase along with the successive grasps. One could say it is a supple or loose type of adaptation. As to Group 3 babies, they do not present a grasp distinct from the carrying phase. The object is grasped and immediately involved in a movement that seems to be the typical mode of adaptation for babies at this age. One would talk about a cinematic type of adaptation.

The substitution trial (Trial 2), in which we replace the very heavy object with a very light one without the baby noticing, allows us to better characterize the nature of prehension adaptation toward the objects' weights. The youngest babies have no considerable reaction after the substitution of the heavy object by the light one. This allows us to qualify such a prehension as *rigid*. The Group 2 babies (9–10 months), however, have a very striking reaction: The baby's arm suddenly rises when the heavy object is replaced by the light one. This attests the presence of a motor program well adapted to a given object and confirms the supple and loose character of their prehension. For the Group 3 babies (11–13 months), this substitution considerably affects the speed, which increases while the arm course is deviated; the cinematic character of their grasp is also confirmed. In Group 4 (14–16 months), the arm also rises but this quickly compensated by the baby and allows us to qualify Group 4 prehension as *adapted* if compared to the three other groups.

It is to be noted that Group 1 babies do not seem surprised at all after the substitution (nor do we see any difference in their prehension), whereas the babies between 9 and 10 months (Group 2) are very much disturbed by the change, and they generally start shaking and looking at the object, as if they wanted to determine its weight. From this difference in behavior we think it is possible to infer that the object is identified through its weight only from the age of approximately 9 months, whereas the previous rigid adaptation type does not enable a baby to identify an object by its weight.

We now understand that the subjects in Group 1 do not show significant variations in their prehension when handed the series of different

objects (Trial 3). Reactions in Groups 2 and 3 are quite different. The series of objects led Group 2 (9–10 months) to have arm drops proportional to the object's weight, and for Group 3 (11–13 months) the speed of the arm movements is also proportional to the object's weight. We may therefore conclude that these subjects distinguish the objects of the series as such, as we note the significance of their arm drop or the acceleration they produce. It is probably during this period between 9 and 13 months that the differences registered during the action and based on proprioception are progressively related to the different sizes of the objects visually perceived at the elaborated perceptual representation level.

In Group 4 (14–16 months), babies manage to grasp the different objects of the series in a similar manner. As they increase their contractions before grasping the object, they obviously infer the object's weight from its size. It is therefore possible to conclude that the perceptual representations constructed by the subjects are complete.

We shall not present here the results obtained in the conservation item, which raises a series of different problems.

We can say that on the perceptual motor level, babies between 14 and 16 months are able to refer their proprioceptions to an object's weight and to infer objects' weight variations from their size variations, as a result of the perceptual representations they have elaborated.

To conclude, babies between 6 and 16 months can be characterized by three successive main motor program modes, as follows:

1. The youngest babies' (6–8 months) program mode has been qualified as *rigid* (global nonspecific preprogram). The subjects have a rigid style of prehension (jointed contractions of antagonistic muscles), which is functionally adapted to grasp objects of different weights but hides these differences.
2. Among older babies (9–13 months) we have a program mode which we call *respondant* (partial preprogram). Subjects in this program mode do not make specific calculations as to the weight of the objects to grasp. In such conditions the executed actions are modulated by the weight variations.
3. The oldest of our subjects (14–16 months) show a program mode we describe as *operant* (specific preprogram). In this case, the subjects make a calculation (a prediction of the weight variations) and, to grasp the objects, they develop strength proportional to their calculations. Here we have an adaptation form made possible by the perceptual representations worked out during this

period. We shall now examine the further evolution of this type of behavior in the child between 2 and 5 years when new representations which we call conceptual, are built up.

Experimental Approach to the Child of 2 to 5 Years¹

Introduction

We have seen how we conceive of the connection between the representations worked out by children regarding objects and actions and children's movement characteristics. An illustration has been given regarding the child between 6 and 16 months. During this period, babies work out perceptual representations of reality which enable them at around 16–18 months to control the relationship among object properties and those relationships to his action characteristics.

Besides, at the age of 16–18 months there also appear new coding possibilities, classically termed the "symbolic function" or "semiotic function." Several years are then needed for the (re)elaboration of the objects' properties on the verboconceptual level. But let us recall once more how Piaget studied this (re)elaboration through a methodology in which verbal and sometimes logical indices of behaviors are privileged and without consideration for the physical or cinematic aspects of actions. Consequently, surveys of the child between 2 and 5 are very few in the Piagetian approach. Piaget's works (1974a, 1974b) we mentioned in our introduction clearly illustrate this point and, referring to early practical successes, they go as far as asserting the *complete* independence of material actions from the representations the child possesses or works out.

Our hypothesis led us to continue the study of the cinematic characteristics in the child's actions beyond the development sensorimotor stages, when new representations (conceptual) are being developed. In this perspective we are induced into considering that the "early complex successes" mentioned by Piaget are controlled by perceptual representations previously elaborated, and by new conceptual representations built up by the child. But the conceptual elaboration of reality is more or less complete relative to the child's age. Its function in the control of actions will be the cause of their more or less preprogrammed character.

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Our hypothesis therefore sees the action cinematic characteristics as indices to the extent of the subject's conceptual elaboration, indices that change during development between ages 2 and 5. So do the action characteristics change between 6 and 18 months, owing to the development of the perceptual representations controlling them. This conception therefore implies the rejection of the Piagetian hypothesis regarding the action autonomy. Indeed, the Piagetian hypothesis does not expect changes, owing to the growing conceptualization in the cinematic characteristics of early successes between ages 2 and 5.

We have chosen to study actions similar to those examined with the baby between 6 and 16 months as presented above. We have considered object grasping and lifting actions, and we have studied in particular the lifting phase from the cinematic viewpoint. It has to be stressed that, in our initial research, the action cinematic aspects had been examined in a relatively elementary way. This was partly due to the fact that, at that time, we were not sufficiently aware of the existing specialized literature in the field of cinematic movement. The critical analysis of our first research as well as bibliographical work has allowed us to set up a new experimental situation (object grasping and lifting) as well as various analytic techniques. Besides, we are still developing these study tools and we plan to extend them to further experimental variables (such as the uni- and bidirectional visuomanual tracking).

Analysis over Voluntary Movement Cinematic Aspects in the Literature

What are the analysis instruments we dispose of to carry out a study on movement cinematic? A survey of the literature reveals that the authors studying human or animal voluntary movements come to some agreement in spite of the variety of the experimental situations. The usual classifications are made around one (or several) of the following criteria:

1. Global description of the movement, no acute registration or measurements: rapid and direct movements as opposed to slow and controlled movements
2. Movement execution conditions: presence or absence of peripheral feedback possibilities
3. Movement velocity characteristics
4. Movement acceleration characteristics
5. Type of subjacent muscular organization

Differences sometimes appear among certain authors but these seem to come about mainly because most of the authors have taken into account only some of the above criteria to define the movements they intended to study and because they have selected criteria according to their specific interests.

What therefore appears, especially in works giving only a global description of movements, is the first wide dichotomy in opposing movements described as "rapid," "acute," "regular," "ballistic," etc., to those described as "controlled," "slow," "irregular," "step-by-step," etc. (White, Castle, & Held, 1964). According to some authors this dichotomy overlaps another one: Rapid movements would take place without peripheral feedbacks, whereas slow movements would not.

In considering the works where the motor performance has been registered accurately, three main types of voluntary movements are described. These are ballistic, ramp, and stairway types of movements.

Ballistic movements are considered to be entirely preprogrammed inasmuch as no correction is made during the movement itself (Bizzi, 1974; Brooks, Cooke, & Thomas, 1973; DeLong & Strick, 1974; Paillard & Brouchon, 1974). In other words, the ballistic movement's characteristics are determined once and for all before the movement starts. All the authors agree on the absence of peripheral feedback in ballistic movements. Evarts (1974), however, stands as an exception when he stresses that the saccadic eye movements, which are above all considered ballistic movements, are almost continuously dependent on vestibular feedbacks.

Besides, the ballistic movement is described as brief (its duration is less than or equal to about 140 or 200 msec according to the authors [DeLong & Strick, 1974; Klein & Posner, 1974; Kornhüber, 1971; etc.]) and of high velocity. As far as its acceleration characteristics are concerned, the ballistic movement starts with an acceleration phase followed by a deceleration phase. Therefore, its acceleration curve occurs only once between the beginning zero value and the end of the movement: The ballistic movement has only one maximum of velocity.

Experimental situations involving ramp or step movements are mostly tracking tasks. Ramp-type movements have the following characteristics. They go most probably with almost continuous peripheral feedbacks; they are slow (400 to 700 msec according to DeLong & Strick, 1974, and Kornhüber, 1971, among others); their acceleration fluctuates around a zero value with small amplitude (Stark, 1968); their speed is relatively constant.

Step-type movements go with discontinuous peripheral feedbacks and can be compared to a series of ballistic movements whose duration

and amplitude are weak (Brooks et al., 1973). Their acceleration curve goes several times through the zero values horizontal axis. There are therefore several maxima of velocity.

It is also to be noted that most authors interested in voluntary movements, whether they have treated the motor program notion or not, have worked most of the time on unloaded movements that have been practiced. We, however, have worked on "spontaneous" movements; that is, no special training has preceded the experiment. We shall see how striking the variety of their morphology is.

We shall now present the experiment conducted with children between the ages of 2 and 5 who have been asked to lift a series of objects with a vertical movement of the arm. Results will first be considered according to the mechanical morphology of movements as an index of the action program's extent. This analysis will then be completed by the study of some notable values of these movements, specifying the parameter values of the particular action program used by the child.

Experiment

The subjects were 62 children from 2:0 to 4:11. The purpose was to describe the evolution, according to the child's age, of object grasping and lifting actions during the first part of the preoperative period in development. With babies, the emphasis had been put on the object grasping; with children from 2 to 5, we shall be more interested in the lifting.

We proposed to the subjects three types of items equivalent to those used with babies. In the first, the same object has to be lifted several times repeatedly. This type of experiment should allow us to characterize the child's performance when the object's properties to which he reacts do not change. In a second type of experiment, the child lifts a series of objects whose volume and weight are growing. This experiment helps us to appreciate the adjustment modalities of the action to a linear and predictable variation in reaction to the objects' weights. Finally, in a third experiment, we ask the child to lift an object whose weight varies suddenly with no forewarning and whose other properties remain the same. We shall not go further into this third experiment here (in this respect see Hauert, Mounoud, Mayer, & Erkothen, 1980).

To the experimental variable relative to the subjects' ages, we have added a variable regarding movement amplitude. In an experimental condition we call "with abutment," we have limited this amplitude

with an abutment, whereas, in another condition called "without abutment," this amplitude is determined by the subjects themselves. In varying the degree of freedom in the experimental situation, we are interested in the children's control possibilities over their movements' spatial characteristics within their action programs. We shall not study this aspect in detail here.

MATERIAL, ITEMS, AND PROCEDURE

The objects used were cylinders covered with adhesive opaque plastic:

1. One object lifted 10 times repeatedly, diameter 30 mm, height 60 mm, weight 330 gm, used as the heavy object repeatedly lifted.
2. One object lifted 10 times repeatedly, diameter 30 mm, height 60 mm, weight 40 gm, used as the light object repeatedly lifted.
3. A series of five objects each being lifted three times repeatedly according to its weight; diameter (all of them) 27 mm; height 30, 50, 70, 90, and 110 mm, respectively; weight 140, 230, 320, 410, and 500 gm, respectively, used for the seriation trial used with the youngest subjects.
4. A series of five objects each being lifted three times repeatedly according to its weight; diameter (all of them) 30 mm; height 30, 60, 90, 120, and 150 mm, respectively; weight 170, 340, 510, 680, and 850 gm, respectively, used for the seriation trial used with the oldest subjects.

The following protocol has been proposed for each subject: (a) repeated lifting of the heavy object, (b) repeated lifting of the light object, and (c) seriation. All subjects go through these three items in the experimental conditions with and without abutment; half of them, age by age, start with the abutment condition and half without. The abutment is fixed 30 cm above the support on which the objects are placed. Note that the experimenter changes the abutment position in the seriation trial with abutment so that the movement amplitude is equivalent to each object of the series.

Each object to be lifted has its bottom covered with an adhesive material so that it may be fixed onto a light metallic support covered with the same material. When the object is lifted, it draws the support with it. The support is joined to an aluminum stem that activates, through a rubber roller, the axis of a rotating potentiometer. The lifted object produces the rotation of the potentiometer axis proportionally to the moving of the object. The signal collected from the potentiometer outlet is stored and numerically processed (filtering, derivation).

The subject is sitting in front of the support on which the experimenter places the objects one by one. The height of the subject's chair is adjustable so that the forearm is horizontal when he or she grasps the object, forming a 90° angle with the arm in a sagittal plane. The subject is requested to grasp each object with the thumb and opposite fingers and lift it. Before the experiment, the subject is shown what type of movement is expected: Each object has to be lifted by a forearm flexion onto the arm.

RESULTS

Mechanical Morphology Analysis. Before we go into a genetic perspective, we shall note that our subjects present quite a variety of actions in the mechanical morphology of their movements. As already mentioned, all the actions we have noticed can be considered as "successful" but what interests us is the way in which they may be more or less completely specified.

A detailed study on the morphological diversity of the curves we have collected is the object of another article (Hauert, Mounoud, & Mayer, 1981). Our purpose here is to show what use we have made, in the experimental data processing, of the movement classification model proposed by Brooks *et al.* (1973).

Continuous and Discontinuous Movements. Considering the classification criterion proposed by Brooks *et al.* (1973), the movements we have collected can be categorized into two classes. Indeed, in studies carried out on the animal (horizontal to-and-fro movements between two targets involving Cebus monkeys), the authors distinguish continuous and discontinuous movements. The criterion used is the acceleration curve of these movements. When the acceleration curve goes through the horizontal axis once only, the movement is considered continuous. When the acceleration curve takes several times the zero value between the beginning and the end of the movement, then it is considered discontinuous.

Brooks *et al.* (1973) believe that the difference between the two types of movement is mostly due to the fact that discontinuous movements are more dependent on peripheral feedbacks than continuous movements. Also, speed variations occurring during the course of discontinuous movements are indices to these feedback interferences. In our theoretical context, these two types of movement correspond to different program degrees.

To analyze the behavior development we studied, we worked out a general classification of the collected movements into two categories made according to Brooks's criterion.

The Genetic Perspective. Our subjects have been distributed into six age groups, each with a 6-month range:

- Group I: 11 subjects from 2:0 to 2:5
- Group II: 10 subjects from 2:6 to 2:11
- Group III: 10 subjects from 3:0 to 3:5
- Group IV: 11 subjects from 3:6 to 3:11
- Group V: 10 subjects from 4:0 to 4:5
- Group VI: 10 subjects from 4:6 to 4:11

Age by age and according to the experimental conditions (with or without abutment), we have calculated the relative frequency of continuous movements as an index of the extent to which the action is programmed. For the three items presented here (repeated lifting of the light and heavy objects and seriation), Figure 1.1 gives the evolution of this index according to age.

The following points are to be noted:

1. On average, the subjects produce more continuous movements in the condition without abutment; this difference is statistically significant for Group III (for all trials), for Group IV (repeated lifting of the light object and seriation), and for Group V (seriation).
2. Regarding interitem comparisons in the experimental condition without abutment, only Group IV shows significant differences. In the experimental condition with abutment, there are more significant differences: Group II shows two differences (one between the repeated lifting of light and heavy objects, and one between the repeated lifting of the light object and seriation). Group IV also shows two differences (one between the repeated lifting of light and heavy objects, and one between the repeated lifting of the light object and seriation).
3. The value of the index under study is not constant over the six age groups. The lowest value is 27.7% for Group I (heavy object with abutment), and the highest value is 85.4% for Group IV (seriation without abutment).

The general pattern of this development is as follows: increase in the index value from Group I to Group IV, then decrease in its value from Group IV to Group VI. This last statement (the center of our concern) has been tested by means of a polynomial adjustment of the results throughout the age groups. The degrees 1, 2, and 3 of the adjusted polynomial have proved significant. Referring to Figure 1.1, one can make the following interpretation:

1. The linear trend is an indication of the global increase of the continuous movements occurrence throughout the groups.

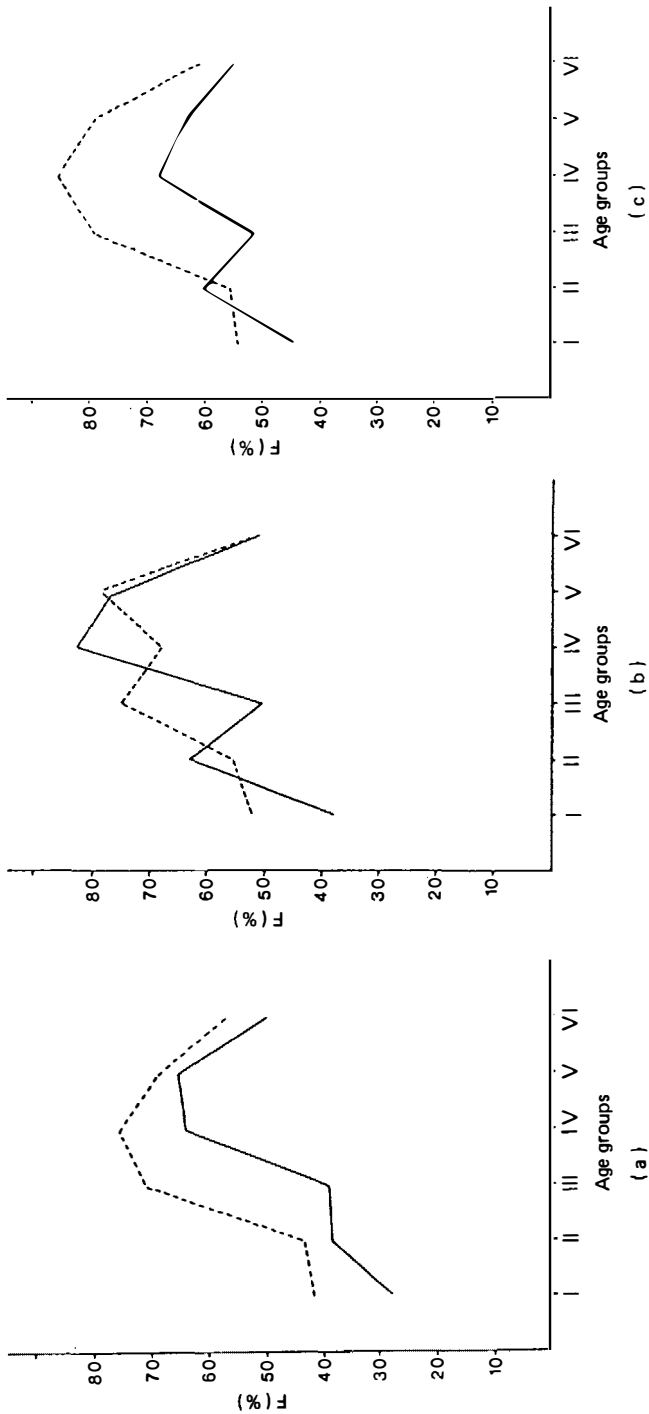


Figure 1.1. Relative frequencies [F(%)] of continuous movements for each age group in the following trials (—) experimental condition "with abutment"; (---) experimental condition "without abutment." (a) Repeated liftings of the heavy object (N of movements = 996). (b) Repeated liftings of the light object (N of movements = 1084). (c) Serialiations (N of movements = 1630).

2. The quadratic trend is the expression of a modulation of the linear tendency produced by the decrease in the index value between Groups IV and VI.
3. The cubic trend is the manifestation of the quick increase of the index value from Group II to Group IV.

Discussion. The relative frequency of occurrence of the continuous movements produced in each age group is, in our theoretical context, an index of the subjects' capacity to preprogram their movements. In this developmental period it is therefore an index of the working out of the experimental situation's conceptual representations. Within an age group, a significant variation of the continuous movements' occurrence frequency means that a property in the experimental situation is (or is no more) a problem for the subjects. If there is a problem, this means the subjects cannot, from their representative elaborations of this property, deal with it in anticipation and integrate it into their action programs. This property either is parasitizing the child's action, or it introduces an uncertainty in the course of the action. In either case, the subject's movement will more likely be discontinuous as it is only partially programmed.

Inversely, how can we explain a stable performance? If the subjects produce continuous movements in the same proportion in situations both with and without abutment and with whatever item is being considered, this means they meet no particular problem facing the experimental variations.

Then one has to admit that either the subject is not aware of this variation introduced into the experimental situation and does not integrate these data into his action program (in this case, for example, the subject's movement will not reach the abutment, or, in the seriation trials, his movements will be less and less ample as the object's weight increases); or this variation is integrated to his action program in anticipation (in this case, for example in the seriations, the subject compensates for the simultaneous increase in the object's size and weight in advance and produces movements of equal amplitudes). It is clear that this first analysis does not allow us to choose as yet one of the other explanations.

In brief, there are two age groups both presenting great stability in performance. These are the youngest and the oldest subjects (Groups I and VI). Through further analysis we shall try to see if they reach such results because they are not aware of some of the variables in the experimental situation or if they reach them in another way. The other groups show performance variations in various degrees and in response to the experimental situation involved.

Besides, it appears that between 3:6 and 3:11 an important phase of development takes place. At this age, various preprogrammed movements cover the majority of subjects even if the properties of the experimental situation introduce significant performance variations. Because of that, each object offered to the subjects between 3:6 and 3:11 makes the subject initiate a global preprogrammed movement which is partly specified during the performance as the result of some properties of the current situation that had not been sufficiently anticipated at the conceptual level.

Before this age and after, the experimental situation properties do not interfere in this way. Subjects in Groups I and II (2:0–2:11) produce a higher proportion of partially programmed movements. At this age, the experimental situation's properties are probably not much differentiated at the conceptual elaboration level. Variations in physical dimension in the experimental situation are not processed in an anticipatory way at these age levels. Discontinuous movements are therefore numerous in all trials.

The oldest subjects (Groups V and VI) would, however, have partially worked out these properties and their variations at the conceptual level. These partial elaborations are the basis for the oldest subjects' program possibilities; they make it possible to give an account of their performance stability. We talk about elaboration in process because Group VI subjects on average produce only a small majority of continuous movements (54, 13%) compared to adults (Mounoud, Mayer, & Hauert, 1979). This partial elaboration builds up through a continuous control over the action and through a test of the experimental situation's properties and their connections to each other. In this sense, we think the discontinuous movements produced in a rather large number around 4:6 and 4:11 do not have the same meaning as those produced, also in great number, by children around 2:0 and 2:5. We shall return to this point in the following analysis.

Complementary Analysis of Movement Velocity. We have seen how the mechanical morphology of movements could be a program index. But the latter is somewhat limited in regard to the questions that interest us. Indeed, if a movement can be preprogrammed, this does not mean that the object's physical properties are entirely and correctly anticipated. Some movements may well show morphological analogies and at the same time differ in duration, amplitude, or velocity. This limitation is evident in the seriation trials as well as in all intertrial comparisons.

We have therefore carried out a second analysis on these data, processing this time the duration, amplitude, and/or average velocity pa-

rameters of the classified movements. We shall first refer to analyses concerning the three tasks, then a specific analysis of the seriation task.

We first analyzed the average lifting velocity for each trial. As pre-programmed movements are by definition faster than discontinuous movements, we found a similar parabolic development as that given by the morphological index. The reader who is interested in the details of this analysis may refer to Hauert (1980).

But we still have two problems to discuss that are closer to our present purpose. The first refers to the way children deal with an object's weight variations in the seriation trial. A survey of this trial's data will help us to solve the second problem: the apparent similarity of the children's behaviors in Groups I and VI.

Seriation Trials. How do subjects deal in their actions with an object's weight variations? In order to produce a constant movement with each seriation object, the child must actively compensate for the increase in the object's weight, which is deductible and can be anticipated from the size or volume variations visually perceived. But if, for the baby between 6 and 16 months, these anticipations are realized through a perceptual elaboration of data (*perceptual representations*), we suppose children between 2 and 5 years of age deal with the task through a *conceptual elaboration of data*.

The question we pose now refers to these compensatory inferences: How, according to the subjects' ages and the experimental conditions, do our subjects produce these compensations? The following data have been considered to describe our subjects' performances in these seriation items: In the seriation trials with abutment, we calculated for each age group the average lifting duration (i.e., from the beginning of the movement to its maximum amplitude) for each object; the regression line slope of this duration in the object series; the average lifting velocity for each object; and the regression line slope of the lifting velocity in the object series. In the seriation trial *without* abutment, in addition to the above data, we calculated the average lifting amplitude for each object and the amplitude regression line slope in the object series.

We then explained the subjects' performances as follows: If they fully anticipate the object's weight in their action programs, all the regression line slopes thus calculated should be near zero. If the slope value goes away from zero, this should inform us of its meaning: Either we have "overcompensations" (positive slope of velocity and amplitude, negative for duration), or we have partial compensations (negative slope for velocity and amplitude, positive for duration).

Global results are the following (for a detailed presentation see Hauert, 1980): When the abutment is there, the lifting durations in-

crease a great deal as the object's weight increases, this for Groups I, II, III, and V; they increase only a little for Groups IV and VI. Consequently, the average lifting velocities drop a great deal in Groups I, II, III, and V, and little in Groups IV and VI. When the abutment is not there, the amplitude lessens in Groups I, II, III, and V, and is nearly stable in Groups IV and VI. The lifting durations and consequently the average velocities decrease, although in various degrees depending on the groups.

It is clear that if all age groups in the seriation trials without abutment were characterized on the whole by their performances in terms of average velocity, they will show comparable tendencies. However, this is not the case. Indeed, subjects of Groups I, II, III, and V show performances that vary systematically with the object's weight as to their velocities, amplitudes, and durations. They bring into their actions only partial compensations. Subjects of Groups IV and VI, however, realize more or less complete compensations over one of the task dimensions (see example in Figure 1.2). The amplitude corresponding to their lifting of the five objects in the seriation trial without abutment is about constant. This result can be compared to those collected with a population of adults (Mounoud, Mayer, & Hauert, 1979).

The data shed new light on the children's performances in the seriation trial with abutment. We see that in this situation the subjects in groups IV and VI produce an average movement velocity more or less stable for all the objects. But their movement amplitude, which they keep constant when the abutment is not there, is now fixed by an external restraint. A steadiness thus externally determined, subjects in Groups IV and VI specially control their movement duration, which therefore appears to be rather stable.

As a result, the average movement velocity is also about constant when the object's weight varies. When the amplitude is not determined by the abutment, however, the subjects in these age groups retain the stability of their movement amplitude to the detriment of their duration and thus of their average velocity.

For all the other age groups, all the performance characteristics vary with the increase in the object's weight. In this respect, the explanation of age Group V's behaviors remains a problem for us.

These results more than those of the previous analysis allow us to distinguish the functioning types of Group I and VI subjects. If they are partly comparable in the frequency of continuous movements produced, they clearly differ as to the compensations brought about in the seriation trials. It is therefore possible to say that conceptual representations of the youngest subjects are poor, thus leading them to an

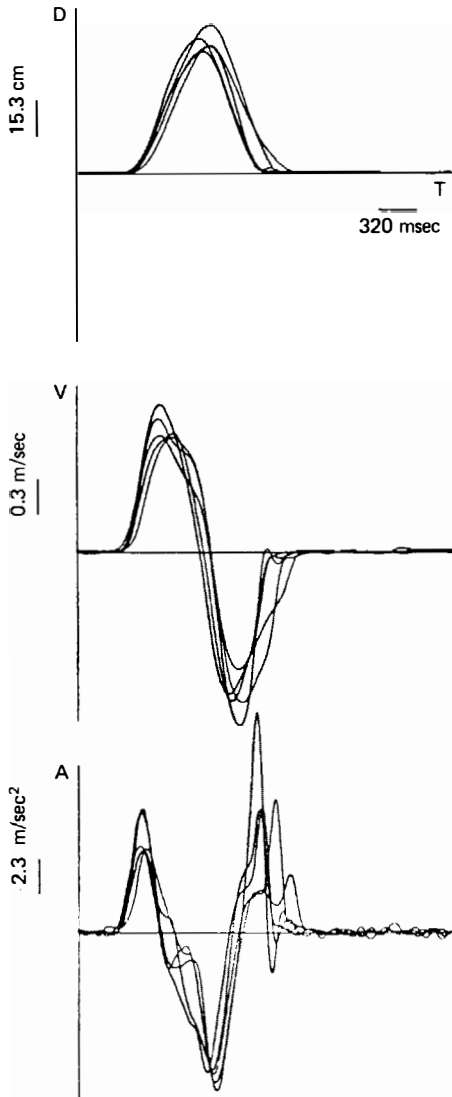


Figure 1.2. Example of movements in a seriation trial without abutment (first lifting and lowering of each object) in a Group IV subject; D is displacement, V is velocity, A is acceleration.

essentially reactive functioning type. Conceptual representation of the oldest subjects, however, are more complete, and enable them to improve their action programming, preparing for the object's weight variations in advance. Finally, let us note that these preparations are different in Group IV from those in Group VI. Subjects in group IV are purely *anticipant*, whereas those in Group VI compare their expectations to the actual consequences of their movements during the course of the action through a functioning type we qualify as mixed.

Thus, we have characterized the conceptual representation elaboration of objects' properties between the ages of 2 and 5 after the perceptual elaboration under process around 16 and 18 months.

Conclusion

We shall focus our conclusion on the transition from the sensorimotor stages to the (pre)operative stages, covered elsewhere in this book. It is clear that intelligence does not progress from a level without representation to a level with representation. This point has been sufficiently developed here and does not need to be brought up again. We would, however, insist on the methodological aspect of our approach in saying again how indices of the action's physical or cinematic aspects are transformed in behavioral development, not only from the angle of their general or formal characteristics, but also considering their application conditions in various contexts and taking into account a given situation's particularities.

Indeed, as we have already stressed several times, if we consider only the action's logical aspects, we only get information on the procedures used by the baby or the child. The study of the action's cinematic aspects, however, informs us of the child's specific adaptation (program) to the object's characteristics.

To what developmental process can this evolution in turn be assigned? It is clear that a maturational mechanism could not account for this type of evolution. In our thinking it is rather the development of the child's representative capabilities that is implied. From birth to the age 2, the child works out the dimensions of reality through perceptual representations. For example, in the experimental situation mentioned above, the child can anticipate the object's weight increase as its size increases in order to program his or her actions accordingly. The sensorimotor stage's last step can therefore be characterized as a complete perceptual motor organization relative to behaviors (specific prepro-

gram). Only then do new conceptual representation possibilities appear, which progressively take over the control of actions.

The initially elementary state of these new representations induces a momentary inability to anticipate the increase in the object's weight. This ability will appear again only around 3½–4 years, the age when seriation calls for anticipatory compensations. Besides, we have seen how children of 3½ and 4 years differ from those of 4½ and 5 years as to some of their actions' cinematic characteristics (morphology). Let us note that, at 5 years, this developmental process is of course not yet finished.

The development we have described between 6 months and 5 years is that of the child's interactions with the objects that enable him to figure out their physical properties. First, the elaboration appears at a perceptual or perceptual–motor representation level; then the child starts reworking them on a conceptual or conceptual–motor representation level.

The model we propose to account for this development is as follows (Mounoud, 1979; Mounoud & Hauert, in press). Generally speaking, the relationship children develop can be of three types: If they possess *elementary representations* of objects' properties, their actions aim at taking information (responding–functioning type or local preprogram). If they possess *global representations* of these properties, they will apply their own organization to the objects to which they are adapted in a nonspecific way; then their actions have only an execution function (operant functioning type or nonspecific preprogram). Finally, if the children possess *complete and differentiated representations* of the object's properties, this will enable them to program their actions specifically, and to modulate their programs in case of disturbances or according to the information gathered during the course of the action (specific preprogram).

The development could then be characterized by the transition, at each representational level, from a stage of local preprogramming to a stage of specific preprogramming, through periods of nonspecific preprogramming. In other words, there exist states during which the child's interactions with reality are preprogrammed, automatized, that is, based on either global or specific well-elaborated representations. Between these stages, transition periods allow the construction of the new representations. During these transition periods, the child's interactions with the environment change—they become partially preprogrammed, and the representations that control them are fragmentary.

As psychologists, we will of course have to go further into our research, extending it to all of the considered stages, so as to reach a

more satisfactory and differentiated representation of what development is.

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