Intraindividual variability in the development of concrete operations: Relations between logical and infralogical operations

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ABSTRACT. Results on Piagetian tasks are not necessarily homogeneous across domains; subjects frequently function at a given operational level in one area and at another level in another area. Such intraindividual variability has most often been considered an anomaly that should be neutralized if not ignored. The present research, on the contrary, focuses on the presence of intraindividual decalages. Four types of decalages are defined and discussed with respect to the Piagetian unidimensional view of development. The primary objective of this paper is to provide a methodological framework for approaching the problem of decalages within a same operational period (i.e., the absence of structural term-to-term correspondences between levels) by studying the relationships between logico-mathematical and infralogical operations as an illustration. The results are presented on the basis of the administration of two logico-mathematical tasks and six infralogical tasks to a sample of 154 children from 6 to 12 years of age.

The study presented in this paper results from an international collaboration supported by grants from both the Fonds National Suisse de la Recherche Scientifique (1.835-0.78) and from the Université de Paris V (Type C). We have also used the resources of the Faculté de Psychologie et des Sciences de l’Education and of the Laboratoire de Psychologie Différentielle (CNRS-ERA 79, Université de Paris V, C.N.A.M., E.P.H.E. 3ème section).

We gratefully acknowledge the assistance of A. Bérbé, O. Hafain, M.A. Khadij, F. Mouhot, U. Rocha da Silva, D. Speezer, and I. de Warenghien in the data collection and scoring.

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THIS RESEARCH FOCUSED on the possibility of using intra- and interindividual differences as a way to study problems encountered in the field of general psychology, particularly in the area of developmental psychology. We argued that the study of individual differences allows investigation of the form of development and permits testing, for instance, of the hypothesis of unidimensionality implied by the Piagetian model. To demonstrate the usefulness of a different approach, we addressed the relation between logicomathematical and infraleralogical operations. The objective is not so much to emphasize the actual findings as to illustrate, through the study of these relations, the methodological approach advocated here.

Piagetian theory presents cognitive development as a progressive construction of new general structures—structures d’ensemble—each of which integrates the preceding one while going beyond it. Structures d’ensemble are not content tied but proceed from general reorganizations that result in a certain synchronism of acquisitions at a given moment of development. Some of Piaget’s writings have presented development as a process recurring similarly in different areas; yet Piaget has as frequently associated synchronism with isomorphism and has said explicitly that the cause of both isomorphism and synchronism resides in the existence of a structure d’ensemble. In numerous writings, operations across domains are thought to derive from the same general operational organization (structure) and are thus supposed to be synchronous (e.g., Fraisse & Piaget, 1963, p. 136; Tanner & Inhelder, 1960, pp. 91, 96, 98). The existence of such structures, and their properties of differentiation and integration, confers a unidimensional trend to development: Steps or stages are reached in the same invariant order by all subjects, and only the rate at which they are reached may vary. This unidimensional model can be considered verified if the notions acquired during the course of development are both synchronous at each step and follow the same invariant order between the steps. The very existence of synchronism, however, raises problems.

Piaget has found support for the concept of structure d’ensemble in that children master at approximately the same age various notions pertaining to a same operational structure. For instance, notions of conservation, inclusion, and transitivity—which supposedly all require the same form of reversibility—appear generally around 7 or 8 years of age. This kind of empirical validation is not, however, sufficient to demonstrate the existence of synchronism because Piaget always studied the various notions using different age groups of children. Piaget’s approach has made it possible to infer the presence of structures for a hypothetical, theoretical subject—the so-called epistemic subject—but not for each individual subject. To determine whether the properties of the epistemic subject are also characteristic of real subjects, it is necessary to verify that the same children have indeed simultaneously acquired notions that are thought to be synchronous. This empirical validation implies that the same subjects be examined on the different notions for which synchronism is postulated.

When this methodological condition is met, correlations between acquisitions based on the same general underlying structure are, in fact, rather low (e.g., Dodwell, 1960; Laurendeau & Pinard, 1968; Lunzer, 1960, 1965; Tuddenham, 1971). As an explanation, Piaget invoked the presence of horizontal decalages that might disturb the synchronism of acquisitions. Certain decalages could result, for instance, from resistances that situational aspects (e.g., figurative aspects) offer to the subject’s structuring activity; the magnitude of these resistances could vary greatly, and in an unpredictable manner, from one situation to the other. The disadvantage of such a position is obvious: If the strength of correlations depends on unpredictable factors—for instance, on the relatively random choice of a given experimental device—the hypothesis of the existence of general structures becomes impossible to disprove. Whether high or low, correlational values can always be attributed to unexpected horizontal decalages, which implies that they are meaningless. Horizontal decalages would not have this impact if the correlations were between continuous variables; however, the operational variables are, in fact, usually dichotomous (e.g., conservers/non-conservers) or trichotomous (e.g., nonconservers/intermediate/conservers). The choice of the experimental material might affect the cut-off points in the distributions, which might in turn greatly affect the correlations. This problem of horizontal decalages is a basic obstacle to any study of the synchronism of operational development, and it is therefore surprising that researchers concerned with the empirical verification of the presence of general structures have generally avoided dealing with it directly.

This obstacle, however serious, is not necessarily unsurmountable. Indeed, horizontal decalages cannot result from all forms of asynchronism; they imply hierarchical relationships between acquisitions. If, for instance, resistances due to situational aspects are more important in Problem B than in Problem A—both problems being isomorphic with regard to the underlying operational structure that their solution requires—certain subjects could solve Problem A while still failing Problem B, others could solve both or fail both, but no subject could solve Problem B while failing Problem A. The presence of such a hierarchy between Problem A and Problem B, due to horizontal decalage, should thus be testable.

This problem will be addressed here by studying the relation between two types of operations distinguished by Piaget: logicomathematical (LM) operations and infraleralogical (IL) operations. In Piagetian theory, these two types of operations are thought to present the same formal mechanisms and to proceed from a common process of structuration; they differ by the type of relations that they introduce. LM operations deal with relations of resemblance and difference between discrete or individual objects, whereas IL operations, particularly in the spatial and physical domains, structure continuous properties and relations of proximity between interdependent parts of a same object. They are, nevertheless, considered equivalent structures with respect to their degree of mobility
and their reversible character and can therefore be expected to present a strictly synchronous development. Nevertheless, Piaget himself, when more thoroughly analyzing differences between these two types of operations, considered the possibility of decalages in their acquisition.

A first difference has to do with the interdependent character of the elements within the infralogical whole. Meaningful configurations must first be broken down before relations between the parts can be brought out. In the LM domain, however, configurations are neither relevant nor stable.

Second, although obviously related to the first difference, IL operations deal with continuous properties and therefore require the introduction of conventional partitioning, whereas elements dealt with by LM operations are already isolated. This difference is, in fact, what Piaget invoked to explain, for instance, the delay presented by measuring operations over numbering operations.

Finally, a third difference is related to the role of imagery, that is, the role of symbolic signifiers on which transformations inherent to operational activity will apply. In the case of IL operations, mental images are much more adequate because they are spatial, as are the objects on which they bear; these IL operations introduce, according to Piaget, a "homogeneity of nature" between operations and images, which does not exist in the case of LM operations.

Given these first two differences (i.e., the influence of configurations and the character of continuity of IL operations), one would expect, if there is a decalage, an advance of LM operations over IL operations. By contrast, the third difference—the greater adequacy of mental imagery in the case of IL operations—could lead to a decalage in the opposite direction, that is, a decalage in favor of IL operations. Such a prediction, however, is only possible if the relation of subordination of figurative aspects to operative aspects, stressed in most of Piaget's writings, is called into question. Indeed, even though Piaget (1974, 1981) modified somewhat his conception of the relations between these two aspects by distinguishing in particular between presentative and procedural schemes, he never explicitly rejected the definition of mental imagery given in 1966. According to this definition, images cannot be more advanced than operations because they are seen as dealing only with states and not with transformations. Therefore, in the classical Piagetian framework, a delay in LM operations over IL operations is not admissible because mental images, even if they are more adequate in the case of IL operations, are seen as evolving under the influence of operations.

Therefore, both the existence of a synchronous development of LM and IL operations and the presence of a decalage in favor of LM operations appear compatible with the Piagetian theory. The presence of an advance in IL operations would, however, be more difficult to interpret. It would presumably require postulating, between figurative and operative aspects, more complex forms of interactions than a univocal relation of subordination (e.g., see Lautrey, 1981). Testing the direction and the form of decalages between LM and IL operations seems, then, of prime importance for Piagetian theory. If their relation is indeed univocal, a decalage in favor of LM operations (or possibly in favor of IL operations) should show up in the form of a predictable asymmetry.

In certain circumstances, asynchronisms between notions implying the same structure do seem to follow an asymmetrical relationship—for example, when the quantity of information to process varies greatly from one situation to the other. Experimental manipulation of this variable has shown that the expected synchronism can exist, for instance, between multiplication of classes and multiplication of relations (Toussaint, 1974) or between seriation of weight and seriation of length (Gilliéron, 1976). Decalages obeying an asymmetrical relation are coherent with a unidimensional model of development: All subjects go through the same stages in the same order (mastery of Task A first and then of Task B, for instance); they differ only in the rate of their development. Following Longeot (1978), we will use the term collective or universal for decalages, whether horizontal or vertical, that are in the same direction for all subjects.

Decalages that are not in the same direction for all subjects (for instance, decalages in the Direction AB for some subjects and BA for others) raise a different question; they will be called individual decalages. When indications are given in the literature not only on the intensity, as is usually the case, but on the form of the relationships between operational tasks belonging to various groupings or various domains, individual decalages appear to be rather frequent (Jamison, 1977; Tuddenham, 1971). Such decalages are hardly imputable to a greater resistance of figurative aspects in either situation or to a difference in the quantity of information to process; it is obviously difficult to explain how the same situation could be both a source of resistance for some subjects and a source of facilitation for others. All subjects do not seem to deal with the same features of a situation, or if they do so, they process them differently. In both cases, individual decalages do not indicate mere variations in rate but variations in the form of development itself. They are therefore inconsistent with a uni-dimensional model of development. The univocity of the relationship between LM and IL operations can thus be tested through the type of decalage they present.

The Difficulty of Direct Comparisons Between Tasks

At first glance, the problem appears simple. It would suffice to determine whether each child has reached the same operational level in the infralogical and in the logico-mathematical domains and, if such is not the case, to compare the form of the intra-individual decalage to those of other subjects. In principle, a structuralist approach should provide the means to undertake such comparisons between domains.
But the presence of certain horizontal decalages, and the unpredictability of their magnitude, raises serious obstacles to between-domain comparisons. If one wants, for instance, to compare the level reached in the construction of notions of inclusion to the level reached in notions of conservation, the results will probably vary greatly depending on both the material chosen to test inclusion—for example, inclusion of flowers or of animals (Piaget & Inhelder, 1959)—and on the shape and size of the containers used to test conservation (Botson & Deliège, 1979). On no theoretical grounds can one or the other of the above-mentioned materials be considered a better indicator of the "true" operational level of the child. Many uncontrollable factors are likely to produce decalages, in addition to the type of operations used. This obstacle prevents any possibility of directly comparing operational levels reached by a child in different domains.

It appears possible, however, to get around this obstacle by trying to infer the form of decalages from indirect comparisons based on the presence of individual differences: (a) The different theoretical forms of decalages between levels reached in logicomathematical and infralogical tasks will first be considered as if the obstacle constituted by horizontal decalages did not exist, that is, in ideal cases; (b) the problem raised by horizontal decalages, that is, the lack of direct correspondences, will be reintroduced and a method to get around them presented.

**Definition of Different Types of Decalages**

For each task, development can be symbolized by an oriented vector. Let us temporarily assume that structural correspondences are indeed possible—that is, that Level 1 of the infralogical (IL) task does correspond to Level 1 of the logicomathematical (LM) task, and so on. To further simplify the presentation, let us also assume that four levels can be defined for each task and that the two tasks (LM and IL) have been administered to two subjects, Sa and Sb. Individual differences refer to the subjects' relative positions in each task, that is, the advance of Sa on Sb or the reverse. When two tasks are compared, the existence of decalages between them and the presence of permutations in the subjects' order constitute two different variables. The combination of these variables (each of which can be present or absent) leads to the description of four possibilities, represented in Figure 1: 1a, absence of permutation between subjects, absence of decalage; 1b, absence of permutation between subjects, presence of decalage between tasks; 1c, presence of permutation between subjects, absence of decalage between tasks; 1d, presence of permutation between subjects, presence of decalage between tasks.

Model 1a of Figure 1 corresponds to an absolute *synchronism* of development; each subject reaches exactly the same level in both tasks. Model 1b describes a decalage in the same direction for both subjects (advance of the LM
task on the IL task for both subjects). Furthermore, the decalage is of the same intensity for Sa and Sb, a difference of two levels. For these reasons, a decalage of this type will be referred to as a homogeneous collective decalage. It respects a less stringent criterion of synchronism than Model 1a: Subjects are not at the same level in both tasks, but they progress concurrently; the lead of Sa on Sb in the LM task is conserved in the IL task.

This weakened model of synchronism is violated by the permutation in Model 1c. By contrast with a collective decalage, the intraindividual decalages of both subjects are in opposite directions: advance of LM on IL for Sb, but advance of IL on LM for Sa. Decalages of this type are called individual decalages.

Model 1d cannot be considered an individual decalage in the sense just defined. There is also a permutation of the subjects' relative positions, yet the decalage between the levels reached in both tasks is in the same direction (advance in the LM task for each subject) but not of the same intensity (three levels of decalage for Sb and only one level for Sa). Thus, such a decalage will be called a heterogeneous collective decalage.

Among the cases violating a model of synchronism, whether strong or weak, only individual decalages (Model 1c) can be thought to disprove the postulated univocity of the relationship between infrafactual and logicomathematical operations. Within a unidimensional model, the intervention of resistances due to situational variables can hardly be considered both a source of task difficulty for some subjects and a factor of facilitation for others. A hypothesis of univocity can, however, be maintained in the case of heterogeneous collective decalages (Model 1d), provided that it is modulated. If the effects of resistances vary greatly in intensity from one subject to another, this variation could be sufficient to explain both the collective decalage and the permutation of subjects. Consequently, the only procedure by which the hypothesis of univocity can effectively be tested consists of trying to reveal the presence of individual decalages.

**Problems Raised by the Lack of Direct Between-Level Correspondences**

The approach just described is, in fact, all the more difficult in a real situation where, unlike the ideal, artificial situation that was considered for purposes of definition, direct correspondences cannot be easily established between tasks (for a discussion, see Lautrey, de Ribaupire, & Rieben, 1981a). Indeed, in the real situation, the probable intervention of uncontrollable variables results in unpredictable horizontal decalages, preventing the establishment of term-to-term correspondences between levels reached in LM and IL tasks. It is as if, for the different models illustrated in Figure 1, the LM and IL scales were subject to all kinds of unpredictable shifts, each with respect to the other; as if each scale could be lengthened or shortened like a rubberband. These variations also explain why such a study has to remain within an ordinal scale, precluding the use of standardized types of data analyses. How, then, can the form of decalages be described under such conditions?

To attempt to answer this question, we adopted a three-step procedure. The first step consisted of determining whether items were scaled within each task (IL or LM tasks); if there was a scale hierarchy, the ordinal characteristics of the data allowed determination of the most probable model. The second step consisted of deciding whether the data supported Models 1a and 1b or Models 1c and 1d. In the latter case, which was the one of interest here, a third step allowed a decision between Model 1c and Model 1d.

Our approach, like that of Wohlwill (1977), assumed four models of decalages. Wohlwill's first three models, however, postulated a term-to-term correspondence (which we assumed cannot be determined a priori) between the tasks' levels, and they appear to constitute finer differentiations of our cases of synchronism and of homogeneous collective decalages; Wohlwill's fourth model, by its probabilistic nature, is closer to our approach. But a main difference remains in that Wohlwill considered temporal relationships between items appropriate for a longitudinal study of a child's cognitive development; furthermore, Wohlwill never mentioned the case of what we termed individual decalages.

**Method**

**Subjects and Procedure**

The tasks were individually administered to 154 children, ranging in age from 6 to 12 years, with 22 subjects per age group (examined at ± 2 months of their birthday). The children were as representative as possible of the Genevan primary school population with respect to the variables of sex, socioeconomic status, and national origin (for more details, see Rieben, de Ribaupire, & Lautrey, 1983).

Subjects were presented, during four or five individual sessions, with eight operational tasks consisting of two logicomathematical (LM) tasks and six infrafactual (IL) tasks. For the purpose of this study, we would have been preferred to use an equal number of LM and IL tasks; however, the study was also geared toward more general objectives about operational intraindividual variability. Guidelines for choosing the tasks, as well as detailed descriptions of the procedures, are presented elsewhere (Rieben et al., 1983). All tasks have been adapted, with some modification, from Piaget and Inhelder's (1941, 1947, 1951, 1959, 1966; Piaget, Inhelder, & Szeminska, 1948) original procedures.

The order in which these eight tasks were presented was not fixed, but tasks likely to interfere with each other were not given consecutively. Each item was scored by two independent judges, both in terms of pass/fail scores and,
more qualitatively, in terms of the different levels of correct and incorrect responses according to a dimensional type of analysis (for details, see Rieben et al., 1983). In the present paper, only analyses dealing with pass/fail scores on items will be presented.

**Logicomathematical Tasks**

*Intersections of classes* (Piaget & Inhelder, 1959). The material consisted of 80 small cards, which presented different drawings of objects (a different drawing on each card). There were three situations, differing by the number of classes to intersect (2, 3, and 4) and by the class criteria. There were five different criteria: content (fruit or flower), color (red), number (pairs of objects), objects in something, and size (small). The first situation consisted of an intersection of two classes: Number × Objects Within Something; the subjects had to anticipate the intersection—that is, two objects in something (the actual card, to be given later, presented two birds in a cage). The second situation consisted of an intersection of three classes: Flowers × Number × Size, for example, two small flowers. Finally, the third situation presented an intersection of four classes: Fruit × Color × Number × Objects in Something, for example, two pieces of red fruit in an object (the actual card presented two red apples in a red basket). Testing was conducted in three parts for each of the three situations: (a) discovery by the child of the class criteria by examining the cards placed in plastic boxes; (b) anticipation of the intersection ("what should be placed in the middle"); and (c) distribution of additional cards corresponding, respectively, to each class, partial intersections, and total intersection.

*Quantification of probabilities* (from Piaget & Inhelder, 1951). This task was originally designed to study the child's notions of chance. The material consisted of red and blue chips and of two small cloth bags. In each item, two differently composed collections of red (favorable cases) and blue (unfavorable cases) chips were presented, and the subjects had to indicate in which collection there were more chances to obtain a red chip at the first draw if the chips were hidden and mixed in the bags. There were seven items of increasing difficulty, from an item such as ⅓ versus ⅓ to an item such as ⅝ versus ⅞, where the numerator corresponds to the favorable cases (red chips) and the denominator to the total number of chips in the collection.

**Infrastructural Tasks**

IL tasks covered three domains, with two tasks in each: (a) the physical domain with the conservation of continuous quantities and the islands tasks, (b) the spatial domain with the sectioning of volumes and the unfolding of volumes tasks, and (c) mental imagery with the folding of lines and the folds and holes tasks.

Conservations of substance, weight, and volume (from Piaget & Inhelder, 1941). The material consisted of two differently colored balls of clay, a metal ball of the same size, two identical beakers, and a scale. The task contained six items, two for each type of invariant: four items involved transformation by deformation, one a transformation by cutting up ("crumbs"), and the sixth dealt with dissociation of weight from volume. For both the substance and weight parts, there was first an item of conservation of equality and then an item of conservation of inequality to minimize the possibility of learning sets. The items were administered in the following order: the two weight items, the two substance items, volume, and dissociation weight volume. A set of countersuggestions, adapted to the children's spontaneous answers, was systematically given.

Islands or construction of volumes (from Piaget et al., 1948). In this task, the subjects had to build equivalent volumes ("houses") on different bases ("islands"). The material consisted of 100 small, wooden blocks (units), a wooden model block (containing 36 units), and cardboard forms representing the islands. There were three items: construction of a volume equivalent to the model on a base sharing one dimension with the model, anticipation, and then construction of a volume on a base differing from the model in both length and width.

Sectioning of volumes (from Piaget & Inhelder, 1947). The subjects had to anticipate and then draw on a sheet of paper the surface obtained when different objects were sectioned along different axes. The material consisted of wooden volumes on which the sectioning line had been drawn in light pencil. There were six items, including an example: a round section of a cylinder, square and rectangular sections of a cube, and triangular, elliptic, and parabolic sections of a cone.

Unfolding of volumes (from Piaget & Inhelder, 1947). The children had to anticipate and then draw the development of plane or curvilinear surfaces of different shapes. The material consisted of hollow cardboard volumes on which the glued edges were represented in red (to represent the tape used for assemblage). The procedure involved four items, including an example: unfolding of a "roof," a cylinder, a pyramid with a triangular base, and a cube.

Folding of lines (from Piaget & Inhelder, 1966). The children were presented with geometrical figures made up of different-colored lines drawn on tracing paper and were asked to anticipate and draw with colored pens the figure obtained when the sheet was folded in half. This task required anticipation of the result of a 180° upward rotation of the lower half of the figure. The task consisted of five items of increasing difficulty, including one example.

Folds and holes (from Piaget & Inhelder, 1966). The subjects were shown a square sheet of paper that was first folded and then slightly cut, either in a corner
or in the middle of the fold. They had to anticipate the result if the sheet were unfolded by drawing, on a sheet of paper that was also square, first the folding lines and then the holes. There were five items of increasing difficulty: one folding with a cut in the corner of the folded side (example); two foldings with a cut, respectively, in the corner and in the middle of the folded side; three foldings with a cut, respectively, in the corner and in the middle.

Results

Verification of the Intratask Hierarchy

To establish the existence of an order between the different items within each of the eight tasks, Longeot’s (1969) method of hierarchical analysis was adopted. In this method, a ratio is established between the number of errors observed in the sample—for example, inversions between failures and passes relative to the expected order—and the number of expected errors that would appear if subjects were randomly distributed on the possible patterns of responses. An index of improvement over random (indice d’amélioration sur le hasard) is then computed: $I_a = 1 - \left( \frac{\text{observed errors}}{\text{expected errors}} \right)$. This index varies between 1, when the observed patterns are totally coherent with an ordered structure, and 0, when they present a random distribution. Longeot’s method, which was developed for analyzing operational tasks, allows detection of a possible hierarchy between groups of items without requiring that items be hierarchically ordered within each group (p. 54).

Table 1 shows that the index of hierarchy was approximately .70—which is not very satisfactory—for items of the intersection of classes task and for the two spatial tasks and close to .90 for the other tasks, which indicates a strong hierarchy. For the three tasks where the items lacked a strong hierarchical structure, the order was strengthened by considering that subjects succeeding on both of two weakly scaled items were at a higher level than subjects who solved only one or the other. This distinction was also used to equalize the number of levels from task to task and, to a certain extent, the frequencies of the different levels of success. The 154 subjects of the sample were thus distributed among four scaled levels of success in each of the eight tasks (for details, see Rieben et al., 1983, p. 170). Subjects whose patterns of responses did not entirely conform to the hierarchy were eliminated from the subsequent analyses requiring a strong intratask hierarchy. Thus, the number of subjects varies from one contingency table to the other in the Appendix. The frequencies are close to 154 when the tasks compared had good hierarchical indexes but are substantially lower when the three tasks with hierarchical indexes close to .70 are considered.

Deciding Between Models 1a and 1b Versus Models 1c and 1d

The presence of a hierarchy of acquisitions within each task allows inferences, by relying on individual differences, with regard to the form of decalages. In Model 1a, for instance, the advance of $S_b$ on $S_a$ would be conserved whatever the shifts of one scale with respect to the other might be. By using the mere properties of order inherent in each task, we can determine whether the data are coherent with Models 1a and 1b or with Models 1c and 1d. Whenever the subjects’ ordering is identical for the two tasks, the hypothesis of synchronism cannot be rejected, although it is not possible to know whether the synchronism is strong (Model 1a) or weak (Model 1b). On the other hand, any permutation in the order of subjects from one task to the other is contradictory to a hypothesis of synchronism without it being possible to decide whether it is a case of individual decalage (Model 1c) or of heterogeneous collective decalage (Model 1d). The logic underlying such comparisons between pairs of subjects is, in fact, the same as that implied by the computation of Kendall’s tau coefficient. When comparing LM and IL tasks, a value of the tau coefficient close to 1 indicates that there are few permutations in the ordering of the subjects; one can therefore assume the existence either of synchronism in the acquisitions or of a homogeneous collective decalage (compatible with an explanation of asynchronism in terms of greater resistances encountered in the infralogical situation). By contrast, a low value of the tau coefficient implies that the hypothesis of synchronism is invalidated; the data can then be accounted for either by individual decalages or by heterogeneous collective decalages without it being directly possible to decide which.

Table 2 presents the tau coefficients obtained for comparisons of each LM task with each of the IL tasks (Kendall’s tau $b$ with correction for ties). All the values were significant at the .05 level; they ranged from .32 to .51, with a median value of .40. Considering that the children’s ages ranged from 6 to 12 years, the correlations were not very high. When the two LM tasks were compared to each other, the correlation was somewhat higher ($\tau = .50$) than when an LM task was compared to an IL task (except for the pair intersections-

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<thead>
<tr>
<th>Task</th>
<th>$I_a$ Index</th>
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<tbody>
<tr>
<td>Intersections of classes</td>
<td>.71</td>
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<tr>
<td>Quantification of probabilities</td>
<td>.90</td>
</tr>
<tr>
<td>Conservations</td>
<td>.92</td>
</tr>
<tr>
<td>Islands</td>
<td>.89</td>
</tr>
<tr>
<td>Unfolding of volumes</td>
<td>.75</td>
</tr>
<tr>
<td>Sectioning of volumes</td>
<td>.63</td>
</tr>
<tr>
<td>Folding of lines</td>
<td>.82</td>
</tr>
<tr>
<td>Holes</td>
<td>.90</td>
</tr>
</tbody>
</table>
TABLE 2
Kendall's Tau Correlations Between the Two LM Tasks
and the Six IL Tasks

<table>
<thead>
<tr>
<th>IL task</th>
<th>LM task</th>
<th>Probabilities</th>
<th>Intersections</th>
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<tr>
<td>Probabilities</td>
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<tr>
<td>Intersections</td>
<td>.50</td>
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<tr>
<td>Conservations</td>
<td>.44</td>
<td>.51</td>
<td></td>
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<tr>
<td>Lines</td>
<td>.36</td>
<td>.44</td>
<td>.41</td>
</tr>
<tr>
<td>Holes</td>
<td>.40</td>
<td>.42</td>
<td></td>
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<tr>
<td>Unfolding</td>
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<td>Sectioning</td>
<td>.32</td>
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conservations, where \( \tau = .51 \). Nevertheless, the rate of permutations in the
subjects' order was high enough to confirm both the hypotheses of strict and
weakened synchronism (Models 1a and 1b). It remains then to decide whether
the low values of the tau coefficients were generated by individual decalages
(Model 1c) or by heterogeneous collective decalages (Model 1d).

Deciding Between Model 1c and Model 1d

A low value of the tau coefficients thus implies that the different levels of success
in the two tasks being compared were not correlated and also that they were not
subject to a common hierarchy. Errors (i.e., inversions of passes and failures)
with respect to a common hierarchy would not, however, present the same
pattern, depending on whether the low tau values were caused by heterogeneous
collective decalages (Model 1d) or by individual decalages (Model 1c). In Model
1d, the conjoint scaling of levels should be perturbed in a dissymmetrical
manner. The dissymmetry originates in the fact that subjects showing the greatest
decalage passed a difficult level in the LM task and yet failed an easy level in
the IL task (this was the case of subject Sb in Model 1d), whereas the reverse
was not true: The reciprocal pattern (for instance, Level 1 in the LM task and
Level 4 in the IL task) did not occur if the decalage was in the same direction
for all subjects. This type of dissymmetry did not exist in Model 1c, where
decalages were in different directions for different subjects. Given the ordinal
characteristics of both models, they could be differentiated by determining
whether errors with respect to a conjoint hierarchy were symmetrical or not.
Two difficulties remain, however: (a) on what basis should the conjoint hierarchy be defined in the absence of direct between-level correspondences, and
(b) on which inferential grounds can the hypothesis of symmetry in the errors
be rejected?

The first difficulty can be overcome by considering the frequencies of
success in both tasks. The contingency table (see the Appendix) of the four
scaled levels of probabilities (LM task) by the four scaled levels of lines (IL
task) illustrates the approach. Frequencies of passes for each level were com-
puted by cumulating the marginal frequencies from Level 1 up (because the
subjects who passed Level 4 could also be considered to have passed Levels 3,
2, and 1). In Table 3, the levels of probabilities (P) and lines (L) were ordered
on a conjoint scale according to their cumulated frequencies of passes. Because
of the cumulative feature, Level 1 is not reported; by construction, all subjects
passed it, and therefore it was of no interest for testing the hypothesis of a
conjoint hierarchy.

If the two tasks, P and L, were subjected to a common hierarchy, all
subjects passing an item of the scale should also have passed all the preceding
items. Because the intratask hierarchy was verified for each task separately (Step
1), errors could only be caused by intertask ordering, that is, by the manner in
which passes and failures were ordered between P and L. They could be due
either to subjects passing difficult P items while still failing easy L items (the
difficulty being again defined on the basis of rate of passes) or to subjects
presenting an inverse pattern. The hypothesis of symmetry can then be tested
by analyzing separately these two sources of errors.

The two sources of errors allow different predictions, distinguished in Table
4: (a) a success on a P item implies success on those L items that were easier
\( (P_i \rightarrow L_j) \); (b) success on an L item implies success on those P items
that were easier \( (L_j \rightarrow P_i) \). Applying Prediction \( \alpha \) to Table 3 leads to specific predictions:
P4 \( \rightarrow \) L4, P4 \( \rightarrow \) L3, P4 \( \rightarrow \) L2, and so on. To avoid interpreting random
fluctuations as due to systematic sources of decalages, Table 4 reports only the
cases where the cumulative frequencies differed significantly at the .05 level.
Moreover, each error was weighted according to its importance; an error was
considered all the more serious for a prediction as the difference between the
frequencies increased. Thus, an inversion in the expected order of L3 and P3—
where frequencies of success differed by 69/135 - 25/135 = .33—was less
serious than an inversion between L2 and P4, whose frequencies differed by
94/135 - 25/135 = .51. This difference was taken into account by assigning
a weight of .33 to the first error and a weight of .51 to the second. The necessity

TABLE 3
Conjoint Scaling of Probabilities Levels (P)
and Lines Levels (L)

<table>
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<td>P2</td>
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<tr>
<td>Rate of success ( (n) )</td>
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</tr>
</tbody>
</table>
of this weighting comes from the varying degrees of difficulty of the items, which can be very unequal for Predictions α and β—particularly when the LM task of intersection of classes, which is clearly much easier than the others, is compared to the IL tasks.

The first column of Table 4 reads as follows: According to Prediction α, we hypothesized that success on P4 implies success on L3 (P4 → L3). Errors relative to this prediction were due to subjects who passed P4 while failing L3 (P4 ∧ L3); they passed only L2 (or L1, but this is considered in the next column). In the contingency table, these subjects figure in cell P4-L2; the observed frequency of cell (4, 2) is 3, and its theoretical frequency is 4.6; the ponderation weight of the cell is .33. This cell, as well as all other error cells, has been hatched in the contingency tables (see the Appendix). The number of observed errors relative to Predictions α and β, as indicated in Table 4, is 9 and 13, respectively. The problem is now to draw inferences about the symmetrical aspect of these errors. Defining the cells of errors on the basis of conjoint scaling presents an advantage over previous methods used by the authors, such as relying only on the corner cells (Lautey, de Ribauiperre, & Rieben, 1981b), in that it uses the totality of the data.

Regarding the second difficulty, a method to evaluate the importance of errors with respect to a prediction made on ordinal data has recently been developed by Hildebrand, Laing, and Rosenthal (1977a, 1977b). This method appears particularly interesting for the present problem because it provides a "custom-designed measure for specific predictions," without requiring that a prediction deal with the totality of the table. It presents a clear superiority, recently stressed again by Hofmann (1983), over goodness-of-fit tests such as that proposed by Thomas (1977) and used by Jamison (1977; Jamison & Dansky, 1979) to test Wohlfwill's models. Hildebrand et al. have suggested that the observed errors in the predicted cells of errors be related to those that would be expected without knowledge of the independent variable's states (Pj's state to predict Lj in α and Lj's state to predict Pj in β in Table 4). Relying on marginal frequencies for defining the item difficulty constitutes what Hildebrand et al. (1977b) referred to as an ex priori case, which they nevertheless considered treatable like a priori cases, as contrasted with ex posti cases. Furthermore, even if the use of marginal frequencies constituted a bias, it was neutralized in the present case: The method here consisted of balancing two del indexes, one against the other, both of which were submitted to the same bias, and not in testing the significance of a single del against chance. For a contingency table of \( i \times j \) cells, the adequacy of a prediction to the data is expressed by the following index:

\[
V = 1 - \left( \frac{\sum \sum \omega_{ij} p_{ij}}{\sum \sum \omega_{ij} p_i p_j} \right),
\]

where \( \omega_{ij} \) is the weight assigned to errors when cell \( ij \) is an error cell and is set
to 0 for the other cells, and where \( P_{ij} \) and \( P_{i'} \) \( P_{j'} \) respectively, represent the observed and the expected frequency of each cell \( ij \). The del index varied between \(-\infty\) and \(+1\); a del equal to 0 indicated that the prediction was not better (and a negative value that it was even worse) than the prediction that would be possible without knowledge of the independent variable’s state. Applying the above formula to the two predictions, \( \alpha \) and \( \beta \), in Table 4 leads to

\[
\nabla_u = 1 - \frac{[(3 \times .33) + (1 \times .51) + (1 \times .14) + (4 \times .33)]}{[4.6 \times .33] + (4.6 \times .51) + (7.6 \times .14) + (7.6 \times .33)]} = .65
\]

\[
\nabla_\beta = 1 - \frac{[(5 \times .52) + (1 \times .29) + (7 \times .10)]}{[(7.6 \times .52) + (6.2 \times .29) + (5 \times .10)]} = .42.
\]

The inequality of indexes \( \nabla_u \) and \( \nabla_\beta \) indicated that errors infirming Predictions \( \alpha \) and \( \beta \) were not symmetrical without it being yet possible to know whether the dissymmetry was due to random fluctuations of del in the sample. Because \( \nabla_u \) and \( \nabla_\beta \) were computed on the same contingency table, the statistical test of their difference required an estimation of variance for the case of matched samples. Statistical procedures for estimating this variance can be found in Hildebrand et al. (1977b, Chapter 6, Appendix 6.4). When applied to the contingency table of Probabilities \( \times \) Lines, they yielded an estimate of the standard deviation of the \( \nabla_u - \nabla_\beta \) distribution of .16. A z score was then computed:

\[
\frac{\text{\( z_{\alpha - \beta} \)}}{\text{\( z_{\alpha - \beta} \)}} = \frac{(.65 - .42)}{.16} = 1.43.
\]

This \( z \) value was not high enough to reject the hypothesis of symmetry in the errors at the .05 level and consequently led us to consider Model 1c (individual decalages) as accounting better than Model 1d (heterogeneous decalages) for decalages perturbing the synchronism of acquisitions in the probabilities and lines tasks.

Table 5 presents the \( \nabla_u \) and \( \nabla_\beta \) indexes obtained for each IL-LM pair. The corresponding contingency tables are reported in the Appendix. In each contingency table, the hatched cells of the lower-left corner are error cells for Prediction \( \alpha \) (LM \( \rightarrow \) IL), and the hatched cells of the upper-right corner are error cells for Prediction \( \beta \) (IL \( \rightarrow \) LM). No \( \text{\( z_{\alpha - \beta} \)} \) value was significant at the .05 level. Therefore, the null hypothesis of symmetry in the errors with respect to both predictions cannot be rejected at this level. Model 1c appears, consequently, more probable than Model 1d to account for decalages between LM and IL tasks.

Although the \( z \) values were not significant at the adopted level, certain \( z \) values were higher than others, particularly when the probabilities task was compared to the lines and unfoldings task, \( \nabla_u \) being higher than \( \nabla_\beta \). The difference was smaller and in the other direction when the probabilities task was compared to the other four IL tasks. The unfoldings and lines task differed from the other IL tasks with respect to the role of perception. In both tasks, elements on which subjects had to act to anticipate the transformation (colored lines whose positions had to be represented after rotation or surfaces of volumes that had to be located after unfolding) were directly accessible to perception. By contrast, the four other IL tasks required that subjects act on the inside of the objects or at least on elements that were not directly perceived.

The structure of the \( \nabla_u - \nabla_\beta \) relation was not completely identical for the analyses concerning intersections of classes. Nevertheless, the contingency tables show that the results were less reliable for this task. Indeed, intersections of classes proved to be much easier (in terms of passing rates) than four IL tasks (unfoldings, sectionings, islands, and holes), so much so that the most difficult level of intersections was barely more difficult than the easiest level of these tasks. In these four cases, the prediction LM \( \rightarrow \) IL could only be inferred by a single cell (two cells in the case of sectionings), whereas at least four cells could infer the reciprocal prediction, which rendered the results very shaky. In the two other cases (lines and conservation), where the number of error cells presented about the same balance as for probabilities, the structure of the \( \nabla_u - \nabla_\beta \) relation was coherent with what was observed for probabilities.

**TABLE 5**

<table>
<thead>
<tr>
<th>Index</th>
<th>Lines</th>
<th>Unfolding</th>
<th>Conservations</th>
<th>Sectioning</th>
<th>Islands</th>
<th>Holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probabilities ( \nabla_u )</td>
<td>.65</td>
<td>.63</td>
<td>.60</td>
<td>.51</td>
<td>.55</td>
<td>.49</td>
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<tr>
<td>( \nabla_\beta )</td>
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<td>.42</td>
<td>.68</td>
<td>.54</td>
<td>.59</td>
<td>.55</td>
</tr>
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<td>( \tau_{u - \beta} )</td>
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<td>1.51</td>
<td>-.62</td>
<td>-.14</td>
<td>-.42</td>
<td>-.53</td>
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<tr>
<td>Intersections ( \nabla_u )</td>
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<td>.69</td>
<td>.70</td>
<td>.68</td>
<td>.73</td>
<td>.66</td>
</tr>
<tr>
<td>( \nabla_\beta )</td>
<td>.51</td>
<td>.49</td>
<td>.69</td>
<td>.49</td>
<td>.58</td>
<td>.62</td>
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<tr>
<td>( \tau_{u - \beta} )</td>
<td>1.72</td>
<td>1.49</td>
<td>.08</td>
<td>1.14</td>
<td>1.15</td>
<td>.40</td>
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</tbody>
</table>

*Note.* Significant values of \( z \) at the .05 level (two-tailed) is 1.96.

**Discussion**

According to Piaget, asynchronisms between acquisitions pertaining to a same underlying general structure are due to horizontal decalages, the origin of which lies either in the degree of resistance that situations oppose to the subjects’ structuring activity or in the intervention of figurative aspects of knowledge. Horizontal decalages, as defined by Piaget, are largely unpredictable with respect to their presence and magnitude; consequently, a hypothesis of synchronism in acquisitions is difficult to test, especially because term-to-term correspondences cannot be established between levels of two different notions.
Indeed, Piagetian theory does not provide means for postulating, on theoretical grounds, structural correspondences between tasks within a stage, and we argue here that contrary to what is often done in Piagetian-type research, it is not possible to test a hypothesis of synchronism by directly comparing levels reached in different notions. The main goal of the present study was, therefore, to suggest a methodological approach, based on individual differences, to overcome this obstacle. The method rests on the following principle: If asynchronisms between notions are due to the fact that resistances raised by situational contents are more important, or that figurative aspects play a greater role, in one task than in another, the resulting decalage may or may not vary in magnitude, but it has to be in the same direction for all subjects. When the direction of a decalage between two tasks, A and B, is not the same for different subjects (i.e., in the Direction AB for some subjects and in the Direction BA for others), another explanation must be offered. Individual decalages of this type are not compatible with a unidimensional view of development and indicate that there might exist different paths of development. The problem is then to be able to distinguish between asynchronisms resulting from collective decalages and asynchronisms resulting from individual decalages in cases where a priori correspondences between tasks cannot be assumed.

We have suggested and illustrated through a study of the relationships between infralogical and logico-mathematical operations that an interesting methodological approach of the problem consists of three steps. First, it is necessary to verify that an internal order or a hierarchy of items exists within each task. Second, these ordinal characteristics can serve to estimate, through Kendall’s tau coefficient, the frequency of permutations in the relative positions of subjects when two tasks are compared. This step enables one to test a weakened form of synchronism and to know whether the progression in the two tasks is more or less concordant (synchronism or homogeneous collective decalage). Frequent permutations in the positions of subjects do not allow, however, to infer the existence of individual decalages directly; such permutations can also result from collective decalages that are not of the same magnitude for all subjects. A third step is therefore necessary to determine whether the decalage is collective or individual. The model developed by Hildebrand et al. (1977b) for testing predictions about cross-classification tables was judged most appropriate for this step. The error cells, relative to the predictions based on the two possible directions of collective decalages, were defined in function of the relative difficulties of the levels, in turn expressed by the frequencies of success.

The results do not permit rejection of the hypothesis of individual decalages between IL and LM operations. The data are therefore compatible with the existence of several possible paths of development, although they are not sufficient to demonstrate it. Indeed, the fact that, for some subjects, IL operations are further developed than LM operations, but the reverse is true for other subjects, can result from different causes:

1. Random fluctuations in developmental processes, showing that the form of the relation between IL and LM operations is not a stable characteristic of subjects;
2. Interactions between these two types of operations during the course of development. Periods during which LM operations precede IL operations could alternate with periods where IL operations precede LM operations; this alternation would correspond to Wohlwill’s (1973) model of reciprocal interactions (Model 3). In this case, like in the first, the form of intraindividual decalages would not constitute a stable characteristic of subjects, but it would represent a period of their development;
3. Finally, modes of functioning that in fact represent stable characteristics of subjects and result in the existence of several paths of development.

The most plausible of the above explanations cannot be determined through a cross-sectional study such as that presented here; these alternatives can be tested only through a longitudinal study. Such a study is currently being undertaken: The same subjects whose results were presented here are now being examined a second time, with the same tasks, 3 years after the first examination.

Another interesting result is the finding that the difference between $\nabla_a$ and $\nabla_b$ is positive and greater than a standard deviation precisely when LM tasks are compared to those IL tasks where all elements on which subjects have to operate are accessible to perception. In those cases, the prediction LM $\rightarrow$ IL (i.e., solving IL items is a necessary condition for solving more difficult LM items) fits the data more closely than the reciprocal prediction IL $\rightarrow$ LM (solving LM items is a necessary condition for solving more difficult IL items). When all elements are perceptible, the most frequent decalages are due to subjects who solve difficult IL items and yet fail easier LM items. For these subjects, figurative aspects apparently do not play a role of resistance but constitute a source of facilitation. These tasks do not call for a simple exploration of static configurations but require the subjects to anticipate the result of complex transformations that are not actually performed. This finding is therefore not compatible with the Piagetian hypothesis according to which figurative aspects of knowledge entertain a univocal relation of subordination with respect to operative aspects; it leads to the assumption of more complex forms of interaction between these two aspects of knowledge.

These results are only tentative; the purpose of this paper was to address a methodological issue that has frequently been overlooked by researchers interested in the comparison of Piagetian substages. We argued that the main obstacle to a study of the form of decalages, namely the lack of structural correspondences between Piagetian substages, can be turned around when relying on individual differences. This research thus belongs along with that of Jamison (1977), after Wohlwill (1973), in that it tries to define and offer means of experimentally studying different types of decalages. It presents advantages over
Jamison's work by avoiding two main pitfalls: the implicit hypothesis that structural correspondences can be directly established between substages (and the explicit use of such correspondences) and the necessity of assumptions with regard to certain cells of the contingency tables (Jamison, 1977; Thomas, 1977).

The first difficulty was overcome by relying on the subjects' relative positions, as assessed by Kendall's tau coefficients, to distinguish two broad types of decalages. This approach makes it possible to remain, in accordance with the nature of the data, within a strictly ordinal scale. A common hierarchy was then determined for a pair of tasks on the basis of the levels' frequencies of passes, and those cells that did not conform to this empirical scaling were considered the critical cells to be tested. We then suggested that the second difficulty could be overcome by using a statistical method, the del method, that allows specific predictions about certain cells of only the contingency table. We have elsewhere been looking for different ways of testing the form of decalages, namely by attempting to devise a structurally based scoring system (i.e., a system based on fine-grain structures, applicable within a same general stage) that should allow the definition of structural correspondences between levels (e.g., Lautrey et al., 1981a; Rieben et al., 1983).

**APPENDIX**

Contingency Tables for the Two LM Tasks × the Six IL Tasks

<table>
<thead>
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<th>Lines</th>
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<th>Conservations</th>
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Received January 2, 1985