Is there a general factor of cognitive development?

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The first tests of intellectual development, those imagined by Binet or Wechsler, were not based on very elaborated theories of intelligence. The approach of these pioneers of psychometry was of course inspired by some general ideas on intelligence, but the way in which they searched for tasks likely to measure it was very empirical. Binet, for example, tried various items and retained those that discriminated well between mentally retarded and non retarded children, between older from younger children, good from not so good students. The construction of tests was guided by their empirical validity, in particular relating to criteria like academic performance, more than by their theoretical validity. “ Psychometric ” tests (i.e. intelligence scales or factorial batteries), are the product of this very empirical approach to the measurement of intelligence.

The approach that led to the construction of the so-called “ Piagetian ” tests has been rather different. Piaget’s goal was not to measure individual differences in intelligence, nor to predict academic success, but to verify hypotheses about cognitive development. The experimental situations that he imagined for this purpose were intended to track the stages of construction of operational structures in various fields of knowledge: logic, physics, space, time, causality, etc. The tasks of conservation, of class inclusion, or of coordination of perspectives, to cite only some of them, were directly inspired by his theory of cognitive development and had no equivalent in psychometric intelligence scales. Initially, the idea to use these experimental situations to assess the general level of development of children germinated in the Genevan school itself. The first research on mental retardation using Piagetian tasks was done in Geneva by Bärbel Inhelder (1943). An attempt at standardizing the Piagetian tasks was led by Vinh-Bang (1966), but never published. A quantitative analysis of the results of a large set of Piagetian tasks was also conducted in a thesis defended in Geneva (Nassefat, 1963). Nevertheless, the first attempts that really succeeded in developing Piagetian tests were made outside of Geneva at the end of the Sixties (for example, Kaufman, 1971, Laurendeau and Pinard, 1968, Longeot, 1969, Tuddenham, 1971), one of the reasons

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being probably the disinterest of Piaget for all that could resemble a psychometric, quantitative approach to the development of intelligence.

Piagetian tests had their partisans. One of the arguments most often advanced in favor of these tests was their theoretical basis. This theoretical basis was seen as making possible a kind of exchange, between the data collected with the tests and the theory from which they were drawn ; psychometric tests had no equivalent. Another argument was that Piagetian tests did not characterize subjects by their rank in the population but by their stage of development. This latter form of characterization appeared preferable because of it’s transitory nature and because it seemed more adapted to evaluations made with an educational purpose.

The question which arose immediately was whether Piagetian tests measured the same intelligence as psychometric tests. Was the factorial structure of these tests the same? If so, were the contents of the various factors in which they loaded the same ? If there was a factor common to all Piagetian tasks, was it g?

Only a few empirical studies were undertaken to answer these questions. The first reason is that Piagetian tests generally suppose an individual application. Questions are asked about transformations carried out on objects (pouring of liquids, classification of objects, changing the point of view in a landscape, etc.) and the questioning is often a true discussion, in which the arguments of the child are followed by counter-arguments of the experimenter. This makes it difficult to examine a sufficient number of subjects to be able to carry out a factor analysis. The second reason is that the period during which these studies were conducted was somewhat limited. Research was conducted during the Seventies and the early Eighties, when Piaget’s theory was still dominant in the field of developmental psychology, but ceased when this theory gave way to information processing models of cognition. The same questions, however, arose within neo-piagetian research, which retained certain aspects of the Piagetian framework, in particular the concept of stages, but reinterpreted them within the conceptual framework of information processing. In this trend, developmental stages were no longer explained by the operational structures advocated by Piaget, but by the limits imposed by the processing capacity of the child in a given period of development. The question arose was that of the relationship between this general processing capacity and the general factor of intelligence.

Examination of the various experiments in which the relations between the factorial structure of the psychometric and of the Piagetian tasks were studied, reveals three sets of studies, that tackled this question in a rather different way. The first set includes the studies carried out in the United States to determine if psychometric and Piagetian tests did measure the same intelligence. The second set, which was in fact the first chronologically, includes studies undertaken in France and in French-speaking countries. This set of studies was initiated by the hypotheses advanced by Reuchlin (1964) in a paper trying to articulate the Piagetian and the factorial approach to intelligence. The third, more recent, set of studies raises the same question within the framework of the neo-piagetian approach. First, the results gathered within these three research trends will be reviewed and then their implications concerning the general factor of intelligence will be discussed.

The American approach : Do psychometric and Piagetian tests measure the same intelligence ?

The first studies which included Piagetian, and psychometric tasks in the same factor analysis concluded that these two kinds of tasks did not measure the same form of intelligence.

The first studies

Stephens, Mc Laughlin, Miller, and Glass (1972) administered Piagetian, psychometric and achievement tasks to a sample of 150 subjects. This sample was composed of three age groups with 50 subjects in each group: 6- to 10-year olds, 10- to 14-year olds, 14-18-year olds-. Each of these groups was further divided into 25 mentally retarded subjects (IQ between 50 and 75) and 25 non retarded (IQ between 90 and 110). All subjects completed a battery of 27 piagetian tasks, a Wechsler scale of intelligence (WISC or WAIS according to the age), and a general achievement test, the Wide Range Achievement Test (WRAT) including subtests of Spelling, Arithmetic and Reading.

Among the 27 Piagetian tasks, there were 11 conservation tasks (substance, weight, length, volume, etc), 7 tasks of logical classification (intersection, inclusion, etc), 8 tasks of spatial operations (rotations of beads, rotation of squares, coordination of perspectives, etc.) and a task of assessment of formal operations (combination of liquids). The explanation advanced by the subject for each task was scored on a six-point scale. While the Piagetian tasks were noted in raw scores, the subtests of the Wechsler and the WRAT were noted in standard scores (this point was later criticized).

A factor analysis was carried out on all these variables (principal factor and oblique rotation). Five factors were extracted : The subtests of the Wechsler and the WRAT loaded on the first factor, the conservation tasks on the second factor, the class inclusion tasks on the third and the spatial operations on the fourth factor; loadings on factor 5 were unclear. The correlations between these four factors ranged from .22 to .39, the correlation between the first and the second being .37.

From these results, Stephens et al (1972) drew the following conclusion : " Review of the matrix indicates that Piagetian operativity as determined by measures of reasoning does indeed measure performance distinct from that measured by the Wechsler scales and the Wide Range Achievement Test " (p. 347).

A rather comparable study was undertaken by DeVries (1974). The whole sample of 143 subjects included mentally retarded and non-retarded subjects, but the focus here will be the results obtained with a subsample of 50 non-retarded subjects, 5 to 7 years-old, having completed two tests of intelligence (the Stanford-Binet and the California Test of Mental Maturity (CTMM)), a general achievement test (the Metropolitan Achievement Test (MAT)) and a battery of 15 Piagetian tasks. The factor analysis (orthogonal rotation Varimax) retained three factors. The psychometric tests of intelligence (Stanford-Binet, CTMM) and a few Piagetian tasks (class inclusion, left-right perspective) loaded on the first factor (35% of the communality). The conservation tasks loaded on the second factor (12%), and the achievement test (MAT) loaded on the third factor (7%). An oblique rotation indicated that the first factor, interpreted as corresponding to psychometric intelligence correlated .33 with the second factor (interpreted as Piagetian intelligence), and .34 with the third factor (interpreted as an achievement factor). Factors 2 and 3 did not correlate. DeVries (1974) concluded : “ To a very large extent, Piagetian tasks do appear to measure a different intelligence and a different achievement than do psychometric tests ” (p. 753).

Criticisms and reanalyses of these first studies

The results and the conclusions of these two studies were criticized on two main points. Humphreys and Parsons (1979) stressed that in the study of Stephens et al. (1972), the scores analyzed for the WISC were standard scores (thus independent of age), whereas the scores in the Piagetian tasks were raw scores (thus related to chronological age). This error could explain why these two categories of tests, psychometric and Piagetian, loaded on two different factors. The second criticism made by Humphreys and Parsons was to have stopped the analysis after the extraction of the first order factors, without seeking to see whether an analysis of second order made it possible to extract a general factor, common to Piagetian and psychometric tests.

Humphreys and Parsons (1979) presented a reanalysis of the data of Stephens et al. (1972). The bias coming from the use of raw and standard scores in the same analysis was removed by partialling out chronological age from the correlations. A hierarchical factor analysis was then conducted. After orthogonalization of second and first order factors, a general factor was isolated, in which all the tests had substantial loadings. There were also four first-order factors on which loaded respectively the achievement subtests (WRAT) and the WISC subtests (factor 1), the conservation tasks (factor 2), the class inclusion tasks (factor 3) and, less clearly, the spatial tasks of the Piagetian battery and of the Wechsler tests. In addition, the correlation between the sum of the scores of the 11 subtests of the WISC and the sum of the scores of the 27 Piagetian tasks was .88. Humphreys and Parsons concluded : “ The showing of a substantial communality in function measured by intelligence tests and Piagetian tasks, however, opens the way for their interchangeable use or, better, for their joint use in developmental and educational psychology ”.

Going in the same direction, Humphreys, Rich and Davey (1985), in a later reanalysis of the same data, calculated the correlations between the four following global scores : Wechsler verbal IQ, Wechsler performance IQ, Piagetian tasks, and tests of academic achievement. A hierarchical factor analysis of this table of intercorrelations again showed a general factor which accounted for 94¨% of the variance and two small group factors, one with loadings for verbal IQ and achievement tests, and the other with loadings for performance IQ and scores on the Piagetian battery.

This divergence in the interpretation of the data caused a polemic between the authors (see Humphreys, 1980, Glass and Stephens, 1980, Kohlberg and DeVries, 1980) and a symposium was organized, at the 1981 SRCD Congress, to clarify this confused question. For this occasion, Carroll, Kohlberg and DeVries (1984) reanalyzed the data of DeVries (1974) and of DeVries and Kohlberg (1977) in applying the recommendations of Humphreys and Parsons (1979) : partialling out chronological age from the correlations and carrying out a hierarchical factor analysis. This analysis yielded three first order factors and one second order general factor. The three first order factors concerned respectively the psychometric tests (Stanford-Binet, CTMM and two Piagetian tasks – class inclusion and magic thought), the conservation tasks, and the achievement tasks. This factor structure is similar to that found by Humphreys and Parsons (1999), but the part of variance accounted by the group factor of Piagetian tasks (mainly conservation tasks) was much more important in their results (the loadings of these tasks were stronger for their group factor than for the g factor, whereas the reverse was found in the reanalysis of Humphreys and Parsons). Carroll et al (1984) concluded: “ The net result of the two reanalyses may be said to be, therefore, that Piagetian intelligence, especially as measured by Piagetian tests, is somewhat distinct from psychometric intelligence. Piagetian conservation ability can be likened to a primary factor of intelligence alongside verbal, spatial, and numerical ability. It is entirely possible that Piagetian conservation ability is closely allied with some primary factor of reasoning ability ” (p. 89).

Other studies

Two other studies deserve to be mentioned in this trend of research. First, that of Kaufman, (1971), who administered to 103 kindergartners, (5 and 7 years old), a Piagetian Battery (PB) of 13 tasks, the Gesell School Readiness Test (GSRT), and the group-administered Lorge-Thorndike (L-T). The score on the PB correlated .64 with the score on the GSRT and .62 with the score on the L-T.

The factor analysis of the PB (principal components and orthogonal rotation) yielded three group factors corresponding respectively to the tasks of conservation, classification and seriation. The factor analysis (principal factors) including psychometric, achievement and Piagetian tests yielded a general factor accounting for 70% of the communality, and three bipolar factors. After orthogonal rotation of these four factors, the three subtests of the L-T loaded on factor 1, conservation tasks on factor 2, GSRT subtests on factor 3, and seriation tasks on factor 4.

Inman and Secrest (1981) developed a few years later a revised and extended version of Kaufman’s Piagetian Battery. This new battery, the Cognitive Development Inventory (CDI), is comprised of 35 items corresponding to 6 operations: conservation, seriation, numeration, temporal reasoning, spatial reasoning, classification. The CDI was administered with an achievement test, the General Concept Test (GCT), to a sample of 660 children attending the last year of kindergarten. The hierarchical factor analysis of the 35 items of the CDI yielded, in a first step, five oblique factors, each of them showing loadings for the items corresponding to one of the above mentioned operations (except that the items of classification and numeration loaded on the same factor). The correlations between these five factors ranged from .21 to .49. The second order analysis specified two factors, that were interpreted as corresponding respectively to logico-mathematic and infralogic operations[2]. The first one showed loadings for the primary factors of classification-numeration and

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[2] Piaget used the term ‘logico-mathematic’to refer to operations bearing on the relationships between discrete objects (the logical domain is hence that of discontinuous entities) and the term ‘infralogical’ to refer to operations bearing on relationships between parts of a continuous object (for example space or time, in which subjects must isolate parts from the continuum before operating on them). Nevertheless, Piaget considered that logical and infralogical operations were isomorphic and arose from the same overall structure.

seriation, the second one involved spatial and temporal reasoning. Number conservation had average and approximately equivalent loadings on these two factors. These two second order factors correlate .66, so the third level analysis yields a general factor. After orthogonalization, this general factor accounted for 34% of the communality, the second-order factors, logico-mathematic and infralogic, accounted respectively for 10% and 4%, and each of the five first order factors accounted for approximately 10%.

Inman and Secrest also regressed the total GCT score on these factors in a stepwise analysis. The multiple correlation was R(3) = .665 when entering only the general factor, R (3 + 2) = .666 when the second order factors were added, and R (3 + 2 + 1) = 681 when the first order factors were added. Part of the sample (441 of the 660 subjects) completed other achievement tests 15 months later, at the end of grade 1, (the Primary Reading Inventory (PRI) and the Diagnostic Mathematics Inventory (DMI). Regression of the total score on the achievement tests (PRI + DMI) on the different factor scores described above yielded the following multiple correlations: R(3) = .629, R (3 + 2) = .639, R (3 + 2 + 1) = .652. These results led the authors to conclude that only the general factor of their Piagetian battery was related to the total score on achievement tests.

Discussion

The first studies which concluded that Piagetian and psychometric tasks measured different forms of intelligence had errors and weaknesses that were clearly addressed by Humphreys and Parsons (1979) and Humphreys (1980). When age was controlled in the same way for the two types of tests and when the method of factor analysis allowed a general factor to be extracted, such a factor was found, and the two types of tests had substantial loadings (Carroll et al., 1984, Humphreys and Parsons, 1979, Kaufman, 1971).

When the variance of this general factor was removed, the Piagetian and psychometric tests loaded loaded generally on different group factors. It should be noted that Piagetian tasks are themselves not homogeneous. When the sample of Piagetian tasks was sufficiently varied, they loaded on at least two distinct group factors, one corresponding to tasks involving the logic of classes and relations, the other corresponding to conservation tasks (Humphreys and Parsons, 1979, Kaufman, 1971, Stephens et al., 1972). When there were also tasks of spatial and temporal reasoning in sufficient number, they loaded on a different factor (the second order factor interpreted as infralogic in Inman and Secrest, 1981).

There were nevertheless important variations, between the studies, concerning the relative importance of the general and Piagetian factors. The two studies involving a hierarchical factor analysis that included both Piagetian and psychometric tasks can be compared from this point of view. In Humphreys and Parsons' (1979) study, the contribution of the group factors seems very reduced and the authors considered that the variance specific to Piagetian tests was not important. They did not give the relative parts of variance in the hierarchical factor analysis but one can see that, in the principal components analysis, the eigenvalue of the first factor was 19.86 whereas those of the three following factors ranged between 1 and 2. The part of variance specific to the Piagetian factor –in fact a conservation factor – was more important in Carroll et al.'s (1984) analysis because the loadings of Piagetian tasks were stronger on their own group factor than on the general factor. These variations cannot be explained, in principle, by the difference in the range of ages in the two studies (6 – 18 years in the first and 5-7 years in the second) because age is controlled by partialling it out from correlations. Nevertheless, one can wonder –as do Carrol et al - if Piagetian variables were appropriately scaled to measure growth from 6 to 18 years old. These differences can likely also be explained by differences in the composition of the samples. Half of Stephens et al.'s subjects (reanalyzed by Humphreys and Parsons) were mentally retarded children. This can reinforce the correlations - and thus the part of the general factor - due to increased dispersion of the variables, or due to the fact that intellectual task performance is known to be more homogeneous in mentally-retarded subjects than in non retarded ones.

These studies provide some indications on the relations between IQ or the general factor drawn from psychometric tests and the general factor drawn from the analysis of Piagetian tests. To tell the truth, the correlations were more often calculated between the total scores of the batteries concerned that between factors, but the total score can be considered as an approximation of the score in the general factor. Humphreys and Parsons (1979) found a correlation of .88 between the total score of the Piagetian battery and the total score of Wechsler's tests. In Kaufman (1971), the correlations between the total score of the Piagetian Battery and the total scores of the Gesell and Lorge-Thorndike were respectively .64 and .62. In Inman and Secrest (1981), the correlation between the general factor of the CDI (the Piagetian battery) and the GCT (a general test of achievement) was .66. Here again, the exceptionally strong correlation of .88 in Humphreys and Parsons' study was probably due to the particular composition of their sample. However, the correlations between .60 and .70 found in the other studies are about of the same order of magnitude as those that are usually found between various psychometric scales of intelligence.

It is less easy to establish possible correspondences between the group factors drawn from the factor analysis of Piagetian tests and the group factors generally found with psychometric tests. The psychometric tasks used in these studies are not factorial tests, but intelligence scales, whose factorial structure is less clear. We will come back later to this point. The same can be said about the relations between Piagetian group factors and achievement tests. The results of Inman and Secrest showed that adding these group factors to the general Piagetian factor in the regression analysis did not improve the correlation with a total achievement test score, but the correlations between these specific group factors and achievement in specific fields of knowledge were never calculated.

The French approach: Articulating Piagetian and psychometric concepts.

The French or French-language studies that, in the same period as the American studies, compared the factorial structure of Piagetian and psychometric tests were guided by theoretical considerations on the relations between these two conceptual frameworks.

The hypotheses of Reuchlin

The so-called “ French-connection ” (Larivée, Normandeau, and Parent, 1996) takes its source in the hypotheses formulated by Reuchlin (1964) on the correspondences between the psychometric and the Piagetian conceptual frameworks. The first of these hypotheses was that the Piagetian concept of “ overall structure ” could provide a theoretical explanation of the psychometric concept of a general factor: " In the course of development, reaching a new stage, controlling a new operational structure, constitutes an acquisition of a very general nature. Becoming able to handle formal thought is, for a given child, to ensure a considerable advantage over less advanced children. It ensures especially a general advantage, which certainly appears whatever the nature of the task. For all the period in which chronological decalages exist between children as for these acquisitions, one thus conceives that the most important differentiation between these children is of a general nature, the general superiority of some over others translating simply the fact that some already have powerful and universal intellectual tools which are still lacking for others. To express this fact in factorial language, is to say that, for all the period in which these individual decalages in the chronology of stages exist, the general factor of differentiation will have a great importance compared to other factors ". The second hypothesis formulated by Reuchlin concerned the relations between the psychometric concept of a group factor and the Piagetian concept of horizontal decalage: " … if the factorial approach has much to learn from the genetic epistemological framework with regard to these general processes, and consequently with regard to the general factor which translates them, it does not find the same support with regard to the group factors. There are, admittedly, the horizontal decalages, about which we already spoke. Following a reasoning that we will examine in a moment, they can account for the appearance of group factors during the period of development. But it remains to be understood why these group factors are still here after the period of development. It remains also, especially for the Piagetian approach, to enrich its observations concerning the decalages and to explain them. The basic problem that one can see in this direction is the following: Does there really exist a single pathway to carry out this walk towards equilibrium of the cognitive structures? Or should it be admitted that this walk towards equilibrium constitutes only the most formalized schematization of processes which can, from one individual to another, be carried out preferably in a domain or an other… ".

Empirical studies testing Reuchlin's hypotheses

Longeot (1969, 1978), devoted two sets of studies to test these hypotheses on the relations between the concepts of stage and the general factor on the one hand and the concepts of decalage and group factors on the other hand. To achieve this goal, Longeot constructed several Piagetian tests centered on the period of transition from concrete to formal operations: an individually administered scale, the "Logical Thought Development Scale " (LTDS ; EDPL in French), and group administered tests, the Formal Operations Tests (FOT ; TOF in French), adapted to the examination of the large samples of subjects that are needed to carry out factor analyses. Six FOT were divised, two for each of the three main types of formal operations identified by Piaget: Combinatorial operations, operations of proportionality (supposed to rely on the formal operational structure that Piaget called the INRC group, which is a specific case of the Klein group) and propositional operations (supposed to rely on combinatorial as well as INRC operations). Each one of these tests is composed of a dozen problems whose resolution implies, in principle, the use of the corresponding formal operations.

In a first study (Longeot, 1969, chap V), focused on the relations between group factors and decalages, the six FOT were given to a sample of 200 children in sixth grade. This same sample, in addition, completed factorial tests (numerical ability, spatial ability, verbal ability) and two achievement tests (French and mathematics). The factor analysis of the piagetian tests (principal factors and oblique rotation) yielded two interpretable factors, one on which the two combinatorial tests loaded and one on which the tests of proportionality and propositional operations loaded. Longeot interpreted the first factor as combinatorial and the second as INRC. These two group factors were regarded as confirming the hypothesis of decalages corresponding to differences of pathways in the access to formal operations; some subjects appeared to master first combinatorial operations whereas others appeared to master first the operations corresponding to the INRC group. Factor analysis of the psychometric tests passed by these same subjects (Principal factors and then oblique rotation), also yielded two factors, one on which numerical aptitude and spatial aptitude tests loaded, which Longeot interpreted as a reasoning factor, the other on which the verbal aptitude test and the two achievement tests loaded, interpreted as an academic factor. The Piagetian tests were then projected in the space of the psychometric factors. In this space, the six Piagetian tests had substantial and equivalent loadings on the reasoning factor but not on the achievement factor.

In a second study (Longeot, 1969, chap. VI) focusing on the relations between the general factor of the psychometric tests and stages in Piagetian tests, Longeot used three Piagetian tests of Formal operations (combinatorial operations, proportionality, propositional operations) and six tests of a psychometric battery (two verbal, two numerical and two spatial) with a sample of 250 subjects. In order to maximize the general factor in this study, the dispersion of ages was increased by including subjects from grades 5, 6 and 7 in the sample.

The factor analysis (principal factors, oblique rotation, and hierarchical analysis), yielded a second order general factor accounting for 77% of the commonality and three first order factors, one on which the two verbal tests loaded (10%), one on which the two spatial tests loaded (9%) and one on which the two numerical tests and the three Piagetian tests loaded (4%). Longeot interpreted this third factor as " operational-numerical." The fact that very little variance was left by the general factor for this operational-numerical factor, indicated that in this study, Piagetian tests loaded practically only on the general factor. Returning to the first hypothesis of Reuchlin, Longeot thus concluded " When the general factor is that of a battery in which prevail psychometric tests, this factor is defined by the operational level of the children, i.e. by the general stage of the development that they reached. Subjects being at the formal stage succeed better than the others in all kinds of tests of efficiency of all kinds, whatever the support. Then, on equal operational level, some obtain better results in the verbal tests, some others in the spatial tests or in the numerical tests " (1969, p.149).

The second research project, carried out some years later by Longeot (1978), aimed at clarifying the relations between group factors and what Piaget called “ horizontal decalages ”. To articulate these two concepts Longeot proposed a model of development in which several routes are possible. In the preparation phase of a stage, several paths can be followed according to whether a child constructs the new cognitive structure in one domain or another.

At the completion phase of the stage, these various routes would converge. This model thus comprised, at the final phase of each stage, nodal points of passage corresponding to the fact that all acquisitions of one stage must be completed before those of another stage can begin. But between these nodal points, in the preparation phases of the stages, this model admits that the order in which a structure generalizes to various domains is not universal. The corresponding decalages are " individual, " meaning that they are not in the same direction for all the subjects. They are distinguished from the "collective" decalages (horizontal or vertical), which are in the same direction for all subjects.

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Figure 1 schematizes this model with a simple example in which the pathways followed by four subjects, (S1 to S4) are represented in the course of mastering the various items of two domains: four items of the logico-mathematic domain (LM1 to LM4) and four items of the infralogic domain (IL1 to IL 4). For each of the two stages represented, stage II and stage III, the figure distinguishes a preparation phase and a completion phase. Two different routes are represented, one (above) in which LM items of a stage are mastered before IL items, the other (below), in which the order of mastering for LM and IL items is reversed. Subjects S1 and S2, who are in the preparation phase of stage II, succeed on items of varied difficulty, but inside only one field (LM for S1, IL for S2). These decalages are " individual " because they are in different directions for the subjects S1 and S2 and, from the factorial point of view, they are at the origin of two group factors in which are respectively loaded tests of the LM and IL domains. The subjects S3 and S4, in contrast, are in the completion phase of stage II, and even if they had previously followed different routes, they master all of the items of stage II and are thus at the origin of a general factor of performance. The hypothesis of Longeot was that the joint presence of a general factor and of group factors in Piagetian tests resulted from the mixture, in the same sample, of subjects being in the preparatory phase and of subjects being in the completion phase of the various stages.

To test this model, Longeot did not rely on factor analytic methods, but on hierarchical analyses. His goal was to show that the expected hierarchical relation between items belonging to different stages is preserved when one admits in the preparation phase of each stage permutations between items belonging to different domains. His data showed however that despite this less-constrained version of the Piagetian concept of stage, it was not possible to order items of different domains in the same hierarchical scale.

Group factors and individual differences in developmental pathways

The distinction between the preparatory and the completion phases of a stage was thus an attempt to make the hypothesis of overall cognitive structure compatible with the existence of individual decalages between domains, provided that these decalages did not exceed one stage (for example, it was not possible that subject S1 of figure 1 responded correctly to item LM3 before having mastered items IL1 and IL2). This model predicted also an increase in intra-individual variability of the developmental stage across domains for the preparation phase of a stage, but a decrease of this variability for the completion phase. These two predictions were tested by Lautrey (1980) by reanalyzing the data collected by Longeot when elaborating his Logical Thought Developmental Scale (EDPL in French).

To develop this Piagetian scale, Longeot (1967) had examined individually 210 subjects from (9 to 16 years old), with 5 subscales whose items made it possible to locate the children at 5 different stages: preoperational, concrete, preformal, formal A, and formal B. The 5 subscales were : (a) 'Conservation' (weight, volume, dissociation heaviness-volume), (b) 'mechanical curves' (tasks requiring the coordination of two distinct systems of reference in the representation of space), (c) 'quantification of probabilities' (problems of proportionality, the more complex ones were supposed to require the INRC group), (d) 'permutations' (combinatorial operations), and (e) 'pendulum' (a task requiring in principle propositional operations to find which of four factors modifies the frequency of pendulum oscillations : weight, length of the string, height of the launching point, force of pushing).

Correspondence Analysis (Benzecri, 1973; Greenacre, 1984), a multidimensional method of analysis for nominal data, was applied to the table having as columns the 20 items of this scale and as lines the 210 subjects aged 9 to 15 (30 by age group). Three factors were found. The first was a general factor of cognitive development, accounting for 21% of the variance and opposing the concrete stage items and the formal stage items. The second factor accounted for 12% of the variance and opposed the items of permutation (combinatorial operations) to those of quantification of probabilities (INRC group). The third factor accounted for 9% of the variance and was interpreted as opposing logical operations (items of permutation and of quantification of probabilities) with infralogical operations (items of conservation and of mechanical curves). The oppositions found on the second and the third factor are the expression of individual decalages, which can be noteworthy for some developmental patterns. Only 16% of the subjects were in fact at the same developmental stage for the 5 subscales. Among the rest of the sample, the maximal amplitude of the observed individual decalages was one stage for 44%, two stages for 33%, three stages for 4%, and four stages for 1% (Lautrey, 1980).

The hypothesis of a reduction of intra-individual variability in the completion phase of a stage, followed by an increase in the preparation phase was also tested. The sample was divided into three age groups: 9-10 years (N = 60), 11-13 (N = 90) and 14-16 (N = 60). These three age groups were selected to correspond respectively to the completion phase of concrete operations, the preparatory phase of formal operations, and the completion phase of this stage. The results did not confirm the alternation predicted by Longeot’s model in terms of phases of decreases and of increases in intra-individual variability with developmental level, but rather showed a regular tendency toward an increase in the frequency and extent of the intra-individual decalages during this period of development.

The study of the relations between the factorial structure of Piagetian tests and the individual differences in developmental pathways continued in a longitudinal research project carried out by Anik de Ribaupierre and Laurence Rieben, of the University of Geneva, and Jacques Lautrey, of the University of ParisV.

The developmental period studied was that of concrete operations. A sample of 154 children representative of the Genevan population was examined twice with a three-years interval. These children were between the ages 6 to 12 on the first evaluation (22 subjects per age group) and thus between 9 to 15 on the second evaluation. Because the tasks described below only discriminate ages 6 to 12, only subjects who were between 9 and 12 at the time of the second evaluation were re-examined with these tasks. Of the 88 subjects aged 6-9 at the first evaluation, 76 were relocated three years later.

Subjects were individually administered eight operational tasks adapted from Piaget and Inhelder. Testing adhered as closely as possible to the ‘critical questioning’ technique developed by Piaget. These eight tasks were selected in order to sample four domains : The logico-mathematical domain (‘class intersection’, ‘quantification of probabilities’), the physics domain (‘conservations’ and ‘Islands’), the spatial domain (‘sectioning of volumes’, ‘intersection of volumes’), and mental imagery (‘folding of lines’, ‘folds and holes’). Each of the eight tasks measured a given operation and was comprised of several items corresponding to different levels of mastery of that operation. For example, the conservation task included four items known to be of increasing difficulty : conservation of substance, conservation of weight, conservation of volumes, and dissociation between heaviness and volume. In total, subjects were tested on 38 items on two occasions. A complete description of the material, instructions and scoring criteria can be found in Rieben, de Ribaupierre and Lautrey (1983) and a more succinct version in Lautrey, de Ribaupierre and Rieben (1986) or de Ribaupierre, Rieben and Lautrey (1985).

Correspondence analysis was applied again (Lautrey & al., 1986). The 154 individuals tested on the first occasion appear in the rows and the 38 items they were administered appear in the columns. For each item, subjects were scored 1 if they succeeded and 0 if they failed (in fact, there are 76 columns, because success and failure are represented as two disjunctive modalities for each item). The correspondence analysis of the first occasion yielded three factors accounting respectively for 30%, 14% and 9% of the variance. The first one can be interpreted as a general factor of complexity (as regards items) and as a general factor of development (as regards subjects). The next factor contrasts logical and infralogical items. The items loading on the logical pole of this factor were those of class intersection and of quantification of probabilities and the items loading the infralogical pole were those of unfolding of volumes, sectioning of volumes, and line foldings. The infralogical items that contributed most to the definition of the second factor were those for which the parts of objects on which the subjects had to perform mental actions were visible. On the contrary, the items contributing most to the third factor were infralogical tasks for which the parts of objects to be manipulated mentally could not be seen. Within this set of infralogical items, axis 3 contrasts items from the physical domain (e.g., conservation of volumes) with some items of mental imagery (e.g., folds ans holes).

Insert table 1 about here

One of the advantages of correspondence analysis is that it is possible to represent simultaneously items and subjects on the same axes. This technique was used to locate, on each pole of each axis, the items and the individuals that contributed most to the part of the chi-square value that this axis contributed. For example, table 1 gives this simultaneous representation for axis 2 (logical / infralogical factor). Reading horizontally this table shows the developmental profiles of the five individuals contributing the most to each pole of this factor ; reading it vertically shows profiles of the items contributing the most to each pole of this factor for these individuals.

The items are presented in the columns. Those contributing the most to the definition of the ‘logical’ pole of axis 2 appear on the left-hand side of the table and are denoted L. These items are tasks of varying difficulty and are about class intersection and quantification of probabilities. The items that contribute the most to the definition of the infralogical pole of axis 2 appear on the right hand side of the table and have been labeled IL. They cover tasks on the sectioning of volumes and mental imagery. The columns were reclassified within each of the two groups of items, according to their order on the first factor. The indices of the items (e.g. L1, L2, …LN) correspond to the order of their coordinates on this factor. The number of subjects N (out of 154) who succeeded on them appears below.

The subjects, identified by sex (M or F) and age (6 to 12) are presented in the rows. The five subjects contributing the most to the logical pole of axis 2 appear at the top and the five subjects who contributed the most to the infralogical pole appear at the bottom. Within each of these groups, the rows were reclassified as a function of the order of their coordinates on axis 2.

For example, reading the developmental profile of subject M7 (a 7 year-old boy) in line 1 , shows that he succeeded coherently at nearly all logical items, including L6 which is an item of quantification of probabilities belonging in principle to the formal stage and passed by only 18 out of the 154 subjects, but that subject M7 failed coherently all the items contributing to the infralogical pole of this factor, including IL1, which is a rather easy item of sectioning of volume, belonging in principle to the concrete stage and passed by 64 subjects. The profile of subject F11 (a 11 year-old girl) is exactly the reverse : she fails at all the items contributing to the logical pole, including L1 which is an easy item of class intersection of the concrete stage, but succeeds coherently at infralogical items. The shape of such developmental patterns is entirely characteristic of what was termed ‘individual decalages’ above. These patterns are of course extreme, the majority of subjects present decalages that are smaller, but the fact that some subjects, who do not suffer of any pathology (all of them attended regular classes), can present such asymmetric patterns of development as well in one sense that in the other, argues for the relative specificity of the developmental mechanisms in these two domains. Such patterns can be seen as different pathways of development in the multidimensional space defined by the three factors revealed by the correspondence analysis.

The profile of each child on the 38 items for the first occasion gives only one point of his/ her developmental pathway in this multidimensional space. The follow-up, three years later, of this sample provided another point in the developmental trajectory of each individual, allowing us to see if there was some stability in the form of this trajectory. As explained above, only children who were 6- to 9-year olds at the first occasion were re-examined with the same tasks when they were 9- to 12-year olds. The method of correspondence analysis gives the possibility of plotting “ supplementary individuals ” into a previously conducted analysis. This possibility was exploited in projecting the 76 subjects examined at the second occasion as “ supplementary individuals ” in the analysis of the first occasion. The sample examined at the first occasion is an appropriate base of reference because it included subjects of 9 to 12, who can be used for purposes of comparison. This procedure has the additional advantage of situating each subject in terms of his / her own coordinate position three years later on an identical system of axes. The stability and change in subjects' relative position has been assessed by computing correlations, for each axis, between coordinates for individuals on the first evaluation (where they appear as main elements) and on the second evaluation (where they appear as supplementary elements). For the first three factors, these correlations were respectively .76, .35, and .34 (Lautrey and Cibois, 1991). It appears thus that during this three-year time period, the order of subjects' coordinates on the first factor, interpreted as a general developmental factor, remained fairly stable. The value of .76 is comparable to that obtained with IQ for the same time period in childhood. The stability on the two other factors, which are group factors, and correspond to differences in developmental pathways, is weaker and suggests that there is an important fluidity in the form of the decalages in the course of development. It is nevertheless possible that this kind of study underestimates the stability in the form of the developmental trajectory. Because subjects who have very asymmetric patterns of development succeed at almost all the items of the domain in which they are in advance, three years later, there is a ceiling effect for them in this domain and, as they generally have progressed in the other domain, their pattern can only become more asymmetric than at the first occasion (this is for example what happened for subject M7 of table 1). This problem could be avoided by using other tasks, more discriminant ones, at the second occasion, but this solution can create another problem because it may be more difficult to retrieve exactly the same factorial structure when using different tasks at different occasions.

In a more recent longitudinal study of the factorial structure of Piagetian tasks, Bradmetz (1996) did not replicate the results concerning the differences in pathways of development. In this study, 104 children were tested five times, once a year, from 4 to 9 years of age, with 25 piagetian tasks. The factorial structure of these 25 tasks on the five occasions was analyzed through structural modeling using LISREL. Bradmetz found for each year a general factor accounting for approximately 30% of the variance and group factors each accounting for approximately 7% of the variance. The correlations between the overall scores (obtained by summing up the scores of the 25 tasks) at two successive occasions were high, approximately .85. The pattern of correlations between the five occasions suggested a simplex model, the amplitude of the correlation decreased as the interval between occasions increased. With an interval of 3 years, between 5;6 and 8;6, the correlation was .72, a value very close of that found with the same interval for the general factor in the above study (.76). Additionally, as in the above study, Bradmetz found an important intra-individual variability, reaching two stages for certain subjects, some of these decalages being individual decalages (i.e ; decalages whose direction is different for different subjects).

But what differs from the above study is that Bradmetz failed to find stable group factors corresponding to a stable distinction between domains, as for example the distinction between logic and infralogic factors in Inman and Secrest (1981) or Lautrey et al (1986). The content of group factors varied from one occasion to another and, as a consequence, there were no stable individual differences in the form of cognitive development. This instability in the content of group factors, from one year to the next, accompanies the fact that the content of the general facor also varied from year to year. For example, At 4 ;6 the highest loadings on factor g were those of numerical tasks ; at 5 ;6 the seriation task had also a high loading ; at 6 ;6, conservation tasks had the highest loadings.

Bradmetz's failure to find stable group factors, and thus to find stable individual differences in the form of cognitive development, seems thus due to the fact that most of the tasks he used were discriminant for only a short period of age. This led to variations on both the content of the general factor and the content of the group factors over occasions. This problem was not present in Lautrey et al's study because each task included items of various level of difficulties. The conservation task, for example, included items of conservation of substance, of weight, of volume, of dissociation between heaviness and volume, so that between 6 and 12 years of age there was always one of the conservation items that was discriminant, and the same was true for the other tasks. This is probably the reason why stable group factors and stable developmental pathways could be found in one study and not in the other.

Discussion

The studies undertaken in what has been called the "French connection", have their origin in the hypotheses formulated by Reuchlin (1964) on the correspondences between the Piagetian and psychometric conceptual frameworks. The first hypothesis was that the Piagetian concepts of overall structure and stage could explain the general factor of cognitive development observed with psychometric tests. By showing that the psychometric and the

Piagetian tests loaded on the same general factor, Longeot thought to have empirically confirmed this assumption.

However, the studies that followed led us to question the concept of general stage itself. The extent of intra-individual variability of developmental level across domains was such that it was difficult to explain the general factor by an overall structure common to different domains of knowledge.

The analysis of the form of this intra-individual variability, and in particular of the decalages that we called 'individual,' has shown that, as suggested by the second hypothesis of Reuchlin, the group factors correspond to individual differences in the pathway of development. The extent of these individual decalages in the developmental pattern of some individuals suggests a relative autonomy in the development of the various cognitive domains. All these domains are certainly under the influence of a set of common maturational and environmental factors that give rise to a general factor of development, but they do not seem interrelated by a general cognitive structure that would lead to a common and single form to cognitive development. These reflections were extended in a pluralist model of development, in which the plurality of the processes likely to fulfill the same cognitive function account for variations in the trajectories of development (Lautrey, 1990, Lautrey and Caroff, 1996).

General developmental factor and processing capacity : The neo-Piagetian approach

The difficulties encountered with the Piagetian concept of overall structure led some of the disciples of Piaget to search in information processing models for another explanation of the sequential order of acquisitions in the course of cognitive development. There are different neo-Piagetian theories in this trend (see for example Case, 1987; Fischer and Farrar, 1987; Pascual-Leone, 1987) but all of them share some fundamental postulates (Case, 1992). All of them keep the stage model of cognitive development advocated by Piaget. Nevertheless, the developmental stages are no longer explained by the construction of an operational structure that is common to different domains of knowledge. These theories rather explain the relative synchronism of development by the existence of an upper limit in the processing capacity of children, and they explain the sequence of developmental stages by the increase of this processing capacity with age. This increase is conceived as a necessary condition to reach the following stage of development but is not considered as sufficient. Optimal environmental conditions of familiarity, training and exercise are necessary to reach the optimal level of performance allowed by the upper limit of the processing capacity

(Fischer and Farrar, 1987). This model of a general ceiling in performance has the advantage of being compatible with both the relative synchronicity and the important situational and individual variability reported above.

The models of processing capacity differ among neo-piagetian theories, but all of them can be related to one or the other of two conceptions of working memory. The first one, mainly advocated by Pascual-Leone, is a model of attentional capacity. The metaphor used is that of "Mental Power." The capacity of this Mental Power, named M capacity, is defined as the number of schemes that can be simultaneously activated in a single operation. The range varies from one scheme at age 3 to seven schemes at age 15, in principle at the rate of one more scheme every two years. According to Pascual-Leone, this increase relies essentially on brain maturation. In the second conception, mainly advocated by Case (1985), the processing capacity is defined by storage space in working memory. The metaphor used here is that of mental space. Working memory is conceived as a limited space, in which there is a trade off between the space used for processing (Operating Space, OS) and the space used for momentary storage of the products of processing (Short Term Storage Space, STSS). The complexity of the problems that can be solved depends thus of the number of goals and subgoals that can be kept simultaneously activated (i.e ; momentary stored in STSS) while processing a mental operation (in OS). According to Case (1985), the increase of STSS with age is probably not due to the growth of the whole working memory space, but to the increase of processing speed. Due to exercise, automatization, reorganization, as well as maturational factors, this acceleration of processing decreases the size of operating space and so doing, increases STSS.

As noted by de Ribaupierre (1995), the first kind of model is close to those general models of cognition viewing working memory as a strongly activated subset of long term memory (for example Cantor and Engle, 1993 ; Cowan, 1993), whereas the second kind of model is close to those models viewing working memory as a system with its own specific processes (for example, Baddeley, 1986). But despite their differences in the interpretation of working memory development, all the researchers of the neo-Piagetian trend define developmental stages by the upper limit in the number of schemes that can be simultaneously activated and use the same set of tasks in order to measure this upper limit. In the following, this upper limit will be named ‘processing capacity’, whatever the theoretical background of the sudies considered (working memory span or attentional capacity or M capacity)

Tasks measuring processing capacity

Some examples of tasks that have been developed in the neo-Piagetian framework will be briefly presented below.

Compound Stimuli Visual Information Task (CSVI). This task was developed by Pascual-Leone (for ex. 1970). In a learning phase, the subject learns to associate some attributes of a set of simple stimuli (such as square, red, circle, etc.) to a specific button of a keyboard (for example, associate the square with the round, white button). In the test phase, once these associations are overlearned, the simple stimuli are nested in a composite stimulus and the task of the subject is to respond to all the elements that can be remembered (for example, press the four appropriate keys when the compound stimulus is a red big square with a cross in the middle). Item complexity is defined by the number of simple elements embedded in the complex stimulus.

Figural Intersection Task (FIT). This task was also developed by Pascual-Leone (see Pascual-Leone and Baillargeon, 1994). Each item consists of two to eight simple figures on the right-hand side of the page and one compound figure on the left-hand side of the page. The participant's task for each item consists of two subtasks. First, he / she is required to place a dot inside each simple figure. Second, he / she is asked to search successively for each simple figure in the compound figure and to place a dot at the point where the simple figures intersect. The factors intervening in the M demand of an item are the number of task relevant simple figures and the presence of task-irrelevant simple figures in the compound figure.

Mr Peanut Task. This task was developed by Case (1985) and adapted again by de Ribaupierre and Bayeux (1994). Children are presented with a clown figure with colored dots painted on different body parts. The picture is then removed and replaced by a blank figure on which children had to place colored chips on the parts that were painted in the previous picture. Item complexity is defined by the number of colored dot.

Counting span. This task was developed by Case (1985). Children are presented with a series of cards, each containing green and yellow dots. They are instructed to count the green dots and retain that total while counting the number of green dots on subsequent cards, the preceding ones being removed. At the end of each series, subjects had to report the total. Item complexity is defined by the number of sets to count or totals to report.

Reading span. This task was developed by Daneman and Carpenter (1980). Subjects are presented with a series of sentences. They are instructed to read each sentence, decide whether it is semantically correct, and to retain the last word while reading the subsequent sentence. At the end of the series, they had to report all the final words.

The *listening span task* has been adapted from this task for children who do not master reading. The principle is the same except that they have to listen the series of sentences rather than to read them.

If these different tasks all measure the same general processing capacity they should load on a common factor. If, in addition, the upper limit of processing capacity underlies the general factor observed in developmental studies, this common factor of processing capacity should be the same as the general developmental factor. As for Piagetian tasks, there are few studies having performed factor analyses on neo-Piagetian tasks. Some of them conclude that these tasks measure effectively the same capacity and others that they do not.

Studies pointing to the unity of processing capacity

The first published factor analytic study of processing capacity tasks was conducted by Case and Globerson (1974). In this study, 43 children aged 7 ½ to 8 ½ years were administered 7 tasks. Four of them were considered as measuring Field Independence-Dependence (FID) - Rod and Frame Test, Children Embedded Test, Block design subtest of the WISC, Colored version of Raven’s Progressive Matrices - and the three others were considered as measuring Processing Capacity (PC) - CSVI, Digit placement, and Backward Digit span. Different methods of factor analysis were used on the intercorrelation matrix of these seven tasks, all of them resulting in two factors, one loading the four FID tasks and the other loading the three PC tasks. With a principal factor analysis followed by an orthoblique rotation, for example, the FID factor accounted for 34% of the variance and the PC factor for 17% ; these two factors correlated .61. This result was interpreted as demonstrating that the three PC tasks loaded on a common factor corresponding to M capacity.

In an unpublished study cited by Case (1985), Collis and Romberg observed a similar result. In their study 139 children aged 5 to 8 years were administered four PC tasks (Mr Peanut, Digit Placement, Counting Span, Backward Digit Span). According to Case, the factor analysis yielded only one factor in which the four PC tasks had substantial loadings.

Morra (1994), examined 191 children aged 6- to 10-year olds with 17 tasks including M capacity tests as well as psychometric tests. There were 5 PC tasks(FIT, Mr Peanut, Counting span, Backward Digit Span, Backward Word Span) and 10 psychometric tasks some of them considered as spatial tests (for example Block design, Googenough Draw-A-Man, Corsi's tests, Raven's Matrices, etc.) and the others as verbal tests (Vocabulary, Word Span, verbal fluency, etc.). A factor analysis of these 17 tasks (principal components with orthogonal rotation) yielded three factors that accounted for 44% of the total variance, respectively 20%, 14% and 10%. Spatial tasks loaded on the first factor, verbal tasks on the the second, and PC tasks on the third (except the FIT test which had stronger loadings on the spatial factor). The correlations among the five measures of PC when age was partialled out were significant, but rather weak (ranging from .21 to .33). Morra's conclusion was that despite their specificities, these five tasks measure the same processing capacity.

The above studies have been criticized by Pulos (1997). The point is that these studies suggest that there is convergent validity of the PC measures but do not establish the divergent validity of these measures. In other words, it is not clear how measures of PC are related to other cognitive constructs and one can not to dismiss the hypothesis that the common factor of PC measures corresponds in fact to one of these other cognitive constructs. This hypothesis could be dismissed if it could be shown that there is no relation between the PC factor and the others, but othogonal rotations are not appropriate to give an answer to this question.

Reanalyzing the data with a promax rotation, Pulos found that the PC factor and the other factor (that he interprets as a Gv / Gf factor) correlated at .46 in Case and Globerson's study , and at .42 in Morra's study. According to Pulos, this result suggests a hierarchical factorial structure with a second order factor relating PC and Gv/Gf. This point is reminiscent to that made by Humphreys concerning factor analysis including psychometric and Piagetian tasks (but see Morra, 1997 and Pascual-Leone, 1997 for replies).

Finally, a single factor loading all the PC tasks was also found in a longitudinal study conducted by de Ribaupierre and Bayeux (1995). Four age groups composed of 30 subjects each, aged 5, 6, 8, and 10 years old at the onset of the study, were examined once a year over 5 years with 4 PC tasks. Three of the tasks were administered each year (CSVI, Mr Peanut-P, Mr Peanut-C), the fourth task being different each year (FIT, Counting Span, Listening Span, Reading span). In the confirmatory factor analysis (LISREL) performed on these data, a single factor model proved satisfactory each year, except for age 5. In addition, a simplex model was able to account for the correlation between the five occasions on this factor.

However, as de Ribaupierre and Bailleux themselves acknowledge, the size of the sample constrained them to put the four age groups together in their analyses of each occasion. Given the extent of these ages (from 5 to 10 years), it is possible that this single factor reflects mainly the influence of age (the correlations between age and this single factor ranges from .76 to .91).

Studies supporting a plurality of processing capacities.

Some studies on Working Memory (WM) in adult samples have yielded results that have also been interpreted as consistent with the unitary resource position (Engle et al., 1992, Kyllonen and Christal, 1990). According to Shah and Miyake, this interpretation is debatable because the working memory tasks used in these studies have contents that, although different (words or numbers), are verbally coded.

The aim of the study carried out by Shah and Miyake (1996) was to show that working memory ressources for verbal and non-verbal processing is separable. Thus, they developed a spatial analog of the Reading Span task inspired by the experimental paradigm of mental rotation. Series of capital letters and of mirror-images of these letters were presented on a computer, one at a time, rotated in various orientations. For each letter, the participants had to say if it was ‘normal’ or ‘mirror-imaged’ (component of treatment), while keeping track of the orientation of the previously presented letters (component of storage). At the end of each set , they were asked to recall the letter’s orientations in the correct serial order. The participants (54 undergraduate students) were administered this task and Reading Span as a verbal WM task. In addition they were administered three visuo-spatial tests, for which was computed a composite score of spatial ability, and verbal SAT. The results show that the Spatial Span task correlated significantly with the Spatial Composite score (.66), but not with Verbal SAT (.07). Reciprocally, the Reading Span task correlated significantly with Verbal SAT (.45), but not with the Spatial Composite score (.12). In addition, the correlation between the Spatial Span task and the Reading Span task was weak (23). According to Shah and Miyake, these results suggest the separability of the cognitive resources for verbal and spatial processing at the central executive level.

The same criticism can be made with the PC tasks used in the developmental studies reviewed above. In general, these tasks privilege a verbal content (numbers or words), and even when their material is spatial they lend themselves to verbal coding strategies. In addition, some of them are short-term memory tasks rather than working-memory tasks, because they do not require simultaneously storage and processing. In the Mr. Peanut task, for example, the material is spatial but nothing prevents the child from making a verbal coding of the positions of the dots; secondly this task requires mainly the storage of the dots' positions on the clown's body, but no real concurrent processing.

On the basis of these considerations, Bardon and Lautrey (in preparation) adapted two PC tasks so that they required simultaneously storage and processing. In the Mr. Peanut task, the requirement for processing was increased by presenting sequentially, one at a time, the figures of the clown, each having one painted dot placed on one part of the figure. On each drawing, there were in fact two pink dots playing the role of distracters and one non-pink dot (the color of which varied on each drawing). The children's task was to point their finger, for each drawing, to the non-pink point (processing component) while retaining the position and the color of the dots in the preceding figures (storage component). At the end of each set of drawings (whose size varied from 2 to 5), children were asked to recall the position and the color of dots by putting chips of the appropriate color at the appropriate positions on a blank figure of the clown.

The second task of spatial working memory, the Spatial Span task, was adapted from Oakhill, Yuill and Parkin (1986) and from Seigneuric (1998). Children were presented series of cards, each having a grid of 3x3 cells. Each grid contained two dots of the same color and the task of the children is to point with their finger to the box in which it would be necessary to add a third point so that these three points form a straight line (as in the game of tic tac toe). Children must store the orientation of this line and its color while processing the following card. At the end of each set of cards they are asked to position these lines on a blank grid (they had colored strips of cardboard at their disposal).

To prevent strategies of verbal coding and subvocal rehearsal, these two WM tasks were administered under the condition of articulatory suppression. The children had to count aloud from 1 to 5, in a repetitive way, as quickly as possible, while carrying out the task.

Insert table 2 about here

In the framework of a study on the relations between reading and working memory, 48 fourth-grade children were administered these two tasks with two verbal WM tasks, the Reading Span task and the Counting span task. The intercorrelations of these four WM measures are presented in table 1. In a confirmatory factor analysis (LISREL), a good fit ($Khi2_{(1)} = .85$, $p = .36$; GFI = .99; AGFI = .91, RMR = .01) was obtained with a hierarchical model comprising two first order factors, one loading the two verbal WM tasks and the other the two spatial WM tasks, and a second order general factor loading the four WM tasks. This result needs to be replicated given the small size of the sample, but it goes in the same direction as that obtained by Shah and Miyake with adult subjects (1996).

Discussion

The assumption that the various PC tasks measure the same general cognitive resource has probably to be reconsidered. It seems that when the PC tasks imply both storage and processing, and when the nature of both processing and storage required is systematically varied, the structure of their intercorrelations is compatible with a hierarchical model. In such a model, the first-order factors should correspond to domain-specific cognitive resources, and the second-order factor, to general purpose resources that can be assimilated to the central executive capacity.

This hierarchical structure appears so close to the factorial structure of intelligence that - as for the Piagetian tests - one can wonder whether the factors found with the two sets of tasks do not correspond to the same constructs. This similarity raises, in particular, the question of the identity between the general factor of PC tasks and the general factor that has been observed with psychometric tests. There are not yet sufficient empirical data to give a firm answer to this question but the reanalyzes of Pulos (1997), showing that psychometric tasks and PC tasks loaded on the same second-order factor, are compatible with this hypothesis. The results of Pennings and Hessels (1996), who found that the processing capacity (here, M capacity) evaluated with the FIT correlated at .72 with the M capacity evaluated in Raven's Progressive Matrices, also goes in this direction.

Conclusion

Is there a general factor of cognitive development? In a certain sense, yes, and in an other sense, no.

In developmental studies, the general factor expresses the relative synchronicity of the acquisitions observed in various aspects of cognition. The greater the dispersion of ages in the sample considered, the more commonplace is this factor (because greater is the contrast between the performances of the younger and of the older subjects of the sample on all the tasks of the battery). A common factor of development is however found also when the dispersion of ages is narrower and even when the effect of age is removed, either by studying children having the same age (for ex. Inman and Secrest, 1984), or by partialling out the correlation with age (for ex. Humphreys and Parsons, 1979). This common factor then reveals a less commonplace synchronicity in cognitive development.

Such a common factor of development was found both within batteries of Piagetian tasks and within batteries of psychometric tasks. As mentioned at the beginning of this chapter, these two kinds of tests were developed in very different theoretical frameworks. The existence of strong correlations between the common factors of these two kinds of tests (or between the total scores of these two kinds of batteries) thus suggests that they measure the the same latent variable and widens its “ general ” nature. The common factor observed in these two kinds of developmental tests can be considered relatively “ general ” in this precise sense.

Furthermore, the group factors that are observed with Piagetian tests do not seem different from those found with psychometric ones (cf Carroll, 1993). The Infralogic factor, frequently found when Piagetian batteries include tasks requiring spatial and temporal operations, seems to correspond to the Gv factor (visuo-spatial representation) and the Logico-mathematic factor seems to correspond to the Reasoning factor and thus to the Gf (fluid intelligence) factor (cf. Gustaffson, 1984). The batteries of Piagetian tests thus assess a more restricted subset of factors than the psychometric batteries or scales ; they do not include, in particular, verbal or achievement tests corresponding to the Gc factor (crystallized intelligence). Their specificity is to assess the development of logical reasoning in a much more detailed way.

The relative importance of these group factors, compared to the general factor, depends of course on the sampling of the subjects (in particular from the point of view of the dispersion of chronological or mental ages) and of the sampling of the tasks. When these two aspects of sampling are satisfactory, the group factors account for substantial parts of variance. In developmental studies, these group factors express differences in developmental pathways, which correspond to asynchronisms of development. The extent of the these asynchonisms, in the developmental pattern of some subjects, suggests that cognitive development is in part domain specific.

How then can the relative synchronicity that underlies the general factor of development be explained? Given the asynchronisms observed, this general factor cannot be explained by the construction, at certain stages of development, of a general purpose structure, which would be common to the various fields of knowledge. The notion of an upper limit in the processing capacity fits better with the observations. It should not however be inferred that this processing capacity corresponds to an unitary cognitive mechanism. Many assumptions, which are not exclusive, have been advanced to explain the development of the working memory capacity with age (see Dempster, 1981; Cowan, 1997). There are of course explanations that depend on the maturation of the central nervous system, for example the myelinization (Case, 1985) or the periodical waves of dendritic connections, in particular those relating the frontal lobes to the other areas of the brain (Thatcher, 1992, Fischer and Rose, 1994). Other explanations have emphasized the effects of environmental factors like the automatization of information processing with exercise, the discovery of metacognitive strategies, and the influence of instruction which increases knowledge simultaneously in various fields.

All these factors, maturational and environmental covary with age and there are interactions between some of them, for example, via pruning , between the waves of dendritic connections and exercise . It is thus illusory to search for a single, general purpose, elementary process, that would account for the upper limit of processing capacity and thus for the existence of a general factor of development. The increase in processing speed, sometimes advanced as an elementary mechanism susceptible to play this role (cf. Kail and Salthouse, 1994) results from changes in the complete set of these factors and is thus only one global indicator of development, as global as mental age. Explaining the general factor of development by an increase in processing speed adds little more than explaining it by an increase in mental age.

Whether psychometric, Piagetian or neo-Piagetian, all the tasks included in the factor analyses reviewed above concern the understanding of the relations between objects or between more or less abstract symbols. These factor analyses did not include tasks assessing, for example, the development of the competence to communicate with other people, or the practical intelligence developed in everyday life (Sternberg and al, 1995). We do not have results of factor analyses including all these various aspects of cognitive development. If such a study could be conducted, would there be a general factor of development ? When asked in this sense, the only answer that can be given to the question raised in the title of this chapter is that we don’t know.

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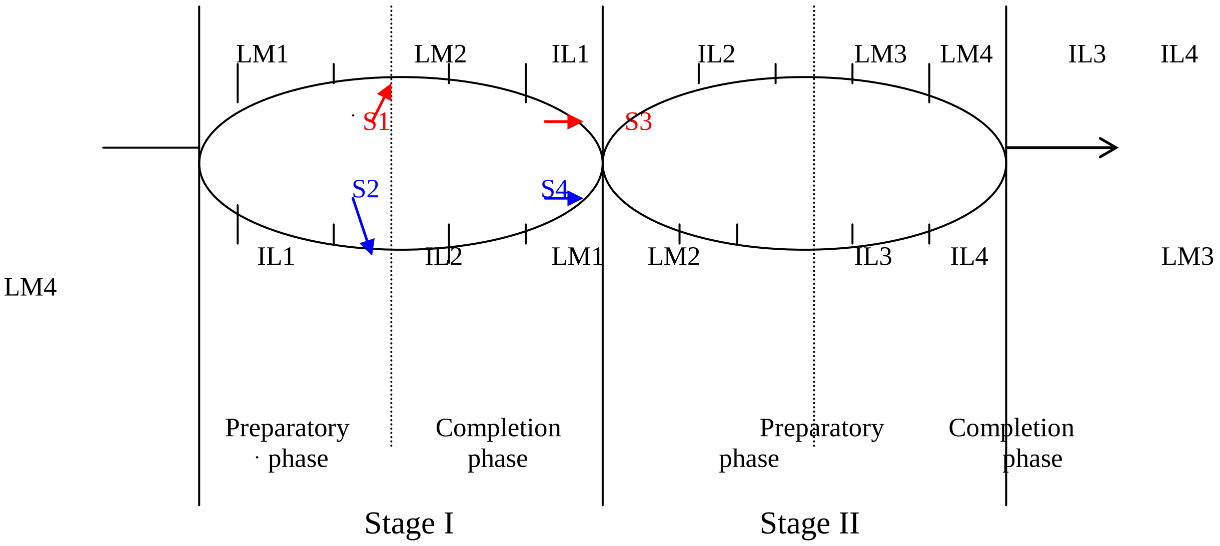

Figure 1.Schematic representation of Longeot's model of cognitive development.

Table 1. Success patterns of the five subjects contributing the most to each pole of factor 2

Subjects			Logical items							Infralogical items					
Sex	Age		L1	L2	L3	L4	L5	L6	L7	IL1	IL2	IL3	IL4	IL5	IL6
		N	100	76	68	44	40	18	18	64	45	39	32	24	19
M	7		1	1	1	1	1	0	0	0	0	0	0	0	0
M	9		1	1	1	1	1	1	1	0	0	1	0	0	0
M	9		1	1	0	1	1	0	1	1	0	0	0	0	0
F	12		1	1	1	1	1	1	0	0	0	0	0	0	0
M	10		1	1	1	1	1	1	0	0	0	0	0	0	0
F	11		0	0	0	0	0	0	0	1	1	1	1	0	0
M	12		1	0	0	0	0	0	0	1	1	1	1	0	1
F	10		0	0	0	0	0	0	0	1	1	0	0	0	0
G	12		1	1	0	0	1	0	0	1	1	1	1	1	1
F	6		0	0	0	0	0	0	0	1	0	0	1	0	0

Table 2 : Intercorrelations between the four working memory tasks in Bardon & Lautrey 's study : RS = Reading Span, CS = Counting Span, SS = Spatial Span, MP = Mr Peanut.

	RS	**CS**	**SS**	**MP**
RS		**.67**	.41	.35
CS			.43	.46
SS				**.65**
MP				