Development of attentional capacity in childhood: A longitudinal study

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Development of Attentional Capacity in Childhood: A Longitudinal Study

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Neo-Piagetian models share a number of common postulates (for a review see Case, 1992a), three of which are particularly important for our purpose. First, general stages should be defined in terms of an upper limit at which children of a given age or cognitive level can function. This allows for generality across domains and for considerable variation across situations and subjects. Indeed, the postulate of a general ceiling in performance is entirely compatible with the large situational and individual variability that has been repeatedly reported in the developmental literature.

Second, following the pioneering work of McLaughlin (1963) and Pascual-Leone (1970), a number of neo-Piagetians consider that attentional capacity or working memory plays a strong, if not causal, role in determining this upper limit (e.g., Case, 1974, 1985; Chapman, 1987; Halford, 1987, 1993; Fischer, 1980; Pascual-Leone, 1987, 1989). It should be noted from the start that neo-Piagetian models are of course not all alike, nor do they all explicitly address working memory (e.g., Case, 1987, 1992a, 1992b; Dasen & de Ribaupierre, 1987). Even with respect to working memory, different constructs have been used, such as working memory, attentional capacity, M space, M power, mental attention, and processing space.

For the sake of simplicity, we consider, in this chapter, these constructs equivalent, in the sense that they all refer to a limited capacity for storage and manipulation of mental information for use in cognitive tasks. Growth in attentional capacity, probably due to maturational change, is viewed as one of the causal factors of cognitive development.

\[1\] This general definition is also close to the one commonly adopted in studies on working memory in adults. We argued elsewhere (de Ribaupierre & Bailleux, 1994) that neo-Piagetian models and Baddeley's model are complementary rather than antagonistic.
Third, most neo-Piagetians recognize the importance of situational variability (whether in a narrow sense, referring to experimental situations, or relative to general environmental context), as well as that of individual differences. As a consequence, development is no longer viewed from a unidimensional perspective, but is multidetermined (see, for instance, Fischer & Sielmann, 1985; de Ribaupierre, 1993; de Ribaupierre, Neirynck, & Spira, 1989; de Ribaupierre, Rieben, & Lauteur, 1991; Rieben, de Ribaupierre, & Lauteur, 1990). In such a multidimensional framework, attentional capacity is only one factor of development among others; that is, it is considered necessary, but not sufficient. This has allowed a number of researchers to posit a relation of implication between attentional capacity and performances in cognitive tasks (e.g., Case, 1985; Chapman, 1990; Chapman & Lindenberger, 1989; de Ribaupierre & Pascual-Leone, 1979). The development of attentional capacity is probably responsible for the universal aspects of development, whereas other factors, such as past experience or differential variables, account for the diversity of behaviors within a given general stage. This is the reason why task analysis has taken a great importance in many neo-Piagetian approaches (e.g., Case, 1992a; de Ribaupierre & Pascual-Leone, 1979, 1984). Not all developmental tasks, nor even all short-term memory tasks, provide good estimates of attentional capacity; experimental paradigms have to be developed that ensure that attentional capacity is not confounded with other factors. In particular, tasks of attentional capacity should not allow chunking, nor the use of facilitating strategies that would lower the complexity of the task. They should be simple enough to ensure that performances do not vary across subjects because of individual differences in other factors, such as knowledge base or previous experience; they should, however, require mental effort. Thus perceptual information should not be too salient, or else the complexity of the task would again be lowered.

Pascual-Leone and Case provided suggestions relative not only to the role played by working memory in development, but also to the functioning and the development of attentional capacity. In particular, they proposed that attentional capacity develops in stages, supposed to last for approximately 2 years. Pascual-Leone suggested the existence of an underlying operator, the M-operator, which serves to activate task-relevant schemes or directly activated by the input or by other operators. M-power corresponds to the maximum number of units or schemes that can be activated in a single operation. The limits in M-power increase maturationally with age, growing from 1 at age 3 to 7 at age 15. Growth in M-power is assumed to be continuous; however, enough M-power has to accumulate before a supplementary scheme can be activated. This is supposed to require 2 years. These assumptions were validated in a number of empirical studies, most of which were cross-sectional, using different samples and different tasks (e.g., Pascual-Leone, 1970, 1987). Although we do not go into detail here, Pascual-Leone defined a number of other underlying operators; cognitive developement in general—that is, the increase with age in performances in cognitive tasks—result from the combined influence of these different operators, and not only from the influence of the M-operator.

Case (e.g., 1985) used the term executive processing space to refer to a construct similar to Pascual-Leone's M-power. Processing space is further divided into operating space, which is devoted to the activation of ongoing operations, and short term storage space (STSS), which serves for the maintenance and/or retrieval of recently activated units. Case developed a number of STSS tasks corresponding to the different qualitative stages distinguished in the general developmental model. A number of studies, again most of which were cross-sectional, showed that the increase in STSS is approximately one unit every 2 years.

The main objective of our study was to determine, using a longitudinal design, whether or not the developmental stages postulated by Pascual-Leone and Case could be observed at an intrapersonal level. Indeed, all empirical validations relied only on cross-sectional studies, or on a longitudinal studies, although it is mandatory that developmental change be also studied longitudinally over long periods (see Hoppe-Graff, 1989; Schneider & Weinert, 1989).

The purpose of this chapter is, therefore, to report on a recently completed cohort sequential study (i.e., a study using both a longitudinal and a cross-sectional design) on the development of attentional capacity. Four groups of children, ages 5, 6, 8, and 10 at the onset of the study, were examined once a year, over 5 years. Each year, four attentional capacity tasks were used, three of which were used throughout the project (two versions of the Mr. Peanut task and the CSVI task), whereas the fourth task varied across years.

A general overview of the study and of the experimental procedures is presented. Then, three types of questions are addressed: First, do the various attentional capacity tasks used in the project measure the same processes? Second, what is the extent and the form of developmental change observed over the 5 years? Longitudinal results are described for each of the three tasks used repeatedly and the results of latent growth curve analyses conducted on the mean performances of the whole sample are reported. These analyses show the importance of situational changes, as well as the difficulty in disentangling development from learning. Third, are there individual differences in developmental change? Individual empirical growth curves are presented to illustrate interindividual differences. Hierarchical linear modeling (HLM) analyses were used to assess whether or not developmental change in each of the three tasks was subject to large individual variability and varied as a function of other variables.
METHOD

Subjects

The initial sample consisted of 4 age groups composed of 30 children each, ages 5, 6, 8, and 10 at the onset of the study. Children were examined within 2 months of their birthday each year; the interval between each assessment was 1 year (± 1 month). The attrition rate over the 5 years was 15% (N = 18). The number of subjects per task varied slightly, because all the tasks could not always be administered to all of the subjects.

Tasks

Three types of tasks were used over the 5 years: attentional capacity tasks, Piagetian tasks, and control or miscellaneous tasks, such as Raven’s Progressive Matrices, the Children’s Embedded Figures Test, and a task of articulatory speed. Only the attentional capacity tasks are described here.

Compound Stimuli Visual Information Task (CSVIT). Developed by Pascual-Leone (e.g., 1970), this task was used each year. It was computerized on Year 2. It consists of three phases:

1. An introduction, during which subjects are shown simple visual stimuli or instances (presented as coded messages) projected onto a screen, to which they learn to associate a simple response. Responses are given by pressing on a nine-key keyboard. For instance, each time children are shown a square figure (other shapes in the test are triangles, circles and crosses and do not constitute messages), they have to press a specific button (e.g., a round, white button); each time a figure is red, they have to press another button (e.g., a diamond-shaped yellow button), and so on. There were nine such pairs (seven for the younger subjects). Simple stimuli, each of which was paired with a different button on the keyboard, were: square, big, red, circle in the middle of the figure, cross in the middle of the figure, dotted outline, frame around the figure, and underlined, purple background. The last two stimuli were used only in the nine-stimuli version.

2. A learning phase, during which subjects are presented with a single message at a time and have to overlearn the association stimulus–response. The criterion was 60 consecutive correct items, allowing for three errors.

3. A testing phase, in which the simple stimuli are nested in a composite stimulus, the task being to respond to all the instances that can be remembered. For instance, subjects saw a red, big square with a cross in the middle and had to press four different keys; or they saw a green small triangle with a circle in the middle, on a purple background. In the latter case, they only had to press two keys, since the particular values of the color, size, and shape variables were not messages. Item complexity was defined on the basis of the number of instances embedded in the complex one (from two to eight for the most difficult version). Items were presented in random order.

Children were instructed to respond to all the messages they saw, and to indicate when they had finished responding, by pressing on an end-button located beside the keyboard.

The task was used as a memory task: The complex stimulus was presented for a limited amount of time, and children could only respond once the stimulus had disappeared from the screen. Response time was free.

The general experimental procedure remained similar over the 5 years. In particular, the same nine instances were used throughout. However, several changes were introduced over the years, some of which induced important differences in the performances. Notable changes were the following: (a) Each year, the position of the specific buttons was changed, although the general layout of the keyboard remained identical; the specific associations between instances and buttons were also changed each year. (b) Exposure time was modified: it was 5 seconds for Years 1–3, and 110 milliseconds on Years 4 and 5. In the tachistoscopic presentation, the stimulus was followed by a mask. This important modification was introduced because the task had to be made more difficult: Ceiling effects had shown in the older age group. Pascual-Leone and collaborators had already used a tachistoscopic presentation. (c) The number of items changed on Year 5. For the first 4 years, the task consisted of 12 items per class; there were 84 items for the more difficult version (Class 2 to 8) and 60 items for the easier one (Class 2 to 6). Until Class 6, items were strictly identical in the two versions and only their order changed; that is, the two supplementary instances incorporated in the more difficult version (i.e., underline and purple background) were used in Class 7 and 8 only. On Year 5, the task was reduced to six items per class (Class 2 to 8 for a total of 42 items, administered to all subjects); on this occasion, new items were constructed and the nine instances were distributed across all classes.

Mr. Peanut Tasks (Peanut–P, Peanut–C). Two versions of this task were used each year. They were adapted from the one-version Cucumber task developed by Case (1985), in turn adapted from the Cucui task (Pascual-Leone, personal communication, July 1987).

This is a short-term memory task. Children were presented with a clown figure with colored dots painted on different body parts (eyes, ears, arms, legs, antennas, cheeks, mouth, and nose). The picture was then removed and replaced with a blank figure on which children had to place colored chips on the parts that were painted in the previous picture.

Two versions were constructed: a purple version (Peanut–P), in which all colored dots and all chips were of the same color, and a colored version (Pean-
nut-C), in which children had to remember both the location and the color of the dots. Item complexity, defined by the number of colored dots in the picture, varied from one to six for the most difficult version. Five items per class were used; items were presented in a random order. Exposure time was 1 second per colored dot (e.g., 5 seconds for a Class 5 item).

A number of methodological precautions were taken to minimize the use of facilitating strategies. Colored dots were never placed on symmetrical parts (e.g., on the two eyes), and, as far as possible, figural patterns were avoided (e.g., a straight line across the figure). Seven colors were used so that all colors were never used in a single item; identical positions were not repeated on consecutive items.

Two changes were introduced during the study, both on Year 4. The clown figure was modified (a basket was added on each arm), so as to add two possible locations. As a consequence, new items were constructed. A more important change, which proved to have a significant effect on performances, consisted in computerizing the task. The clown figure was presented on a computer screen and children had to place the colored dots on the blank figure by using a computer mouse.

**Figural Intersections Task (FIT)**. This task was developed by Pascual-Leone (Pascual-Leone & Ballaigenon, 1994; Pascual-Leone & Ijar, 1989) and was used on Years 1 and 3.

This test is composed of geometrical figures. A number of simple geometrical figures is presented separately on the right-hand side of the page and embedded in a composite on the left-hand side. For every item, children were asked to place a dot inside each figure on the right-hand side, and then a single dot on the compound figure on the left side, at the intersection of all of the relevant figures (the relevant figures being those found on the right side).

Classes of complexity, defined on the basis of the number of relevant figures, varied from two to eight for the most difficult version (five items per class); items were presented in random order.

The same version of the task was used on the 2 years in which it was administered; however, figures underwent a 45° clockwise rotation (Pascual-Leone, personal communication, July, 1989).

**Counting Span (CS)**. This task was developed by Case (1985; Case, Kurland, & Goldberg, 1982) and was used on Year 2. Children were presented with a series of cards, each containing green and yellow dots. They were 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 totals.

Digits to be recalled never exceeded nine; series following the natural order of numbers were avoided. Item complexity, defined by the number of sets to count, or totals to report, ranged from one to six in the most difficult version (three items per class); items were presented in random order.

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**Listening Span (LS)**. Adapted from the Reading Span task (Daneman & Carpenter, 1980), LS was used on Year 4. Subjects listened to a sequence of sentences, were required to process each sentence and decide whether or not it was semantically correct, while retaining the last word. At the end of the series, they had to report all the final words. Sentences were presented by means of a tape recorder; the interval between sentences was fixed and long enough for children to respond. The tape recorder was stopped for recall and the children’s responses were manually recorded. The number of correct and false sentences and the length of the last words were controlled across classes of complexity. Sentences were all approximately the same length (from six to eight words).

Classes of complexity, defined by the number of sentences, or final words to retain, varied from two to seven (three items per class). Items were presented in increasing order of complexity, and testing was terminated when children failed all items of a class.

**Reading Span (RS)**. This task was used on Year 5. It was in all points comparable to the Listening task, except that now children had to read sentences on a computer screen and answer yes–no for each sentence by pressing a key on the computer keyboard; as soon as the response was given, the next sentence appeared. The end of an item was signaled on the screen and children had to orally recall all of the last words. The computerization of the task allowed the recording of response times. A preliminary phase was added in which 18 sentences were presented without memory load: Children had only to decide whether the sentence was correct or false. This was meant to measure a base processing time, to be compared with the response time necessary to process the sentence and rehearse the last word.

**Scoring**

For all tasks, several scores were computed based either on passed–failed items, or on response values per item (e.g., how many correct responses in a Class 5 item). Several finer scores were also established, as well as response times whenever possible. For reasons of space, results reported in this chapter are based on passed–failed items only. The task score was the sum of correct items divided by the number of items per class; it is thus comparable to a traditional span score. When no Class 1 items were given (like in CSV1), a one-point credit was given, which may favor the youngest children.

**Procedure**

Children were individually examined each year in their schools with the tasks described. Recall that a number of other tasks were also administered, of which only the Children’s Embedded Figures Test (CEFT; Witkin, Oltman, Raskin, & Karp, 1971) given on Years 1 and 3, and the Raven’s Progressive matrices given
on Year 2 are of interest here. Testing required three to five 45-minute annual testing sessions, grouped over 2 to 3 weeks. Different versions of the tasks were administered to the different age groups, in an attempt to ensure that the difficulty of the task was adapted to the children’s level.

RESULTS

Given the considerable amount of data collected in this research, it is impossible to report in detail results on all the attentional capacity tasks. As mentioned in the introduction, presentation is made according to three questions:

1. Is there a relation between the attentional capacity tasks that were used? Analyses here are cross-sectional, but we also ask whether or not between-task relationships were stable across the 5 years.

2. What was the developmental change observed over the 5 years? This question concerns only the two Peanut tasks and the CSV1 task, each of which is examined separately.

3. What is the extent of interindividual and intergroup variability in developmental change? This question is explored by looking at empirical individual growth curves, and by means of hierarchical linear modeling.

Relationships Between the Attentional Capacity Tasks: Cross-Sectional Analyses

As mentioned, four attentional capacity tasks were used each year. In order to evaluate whether these tasks covary, confirmatory factor analyses using LISREL were conducted. Given the size of the sample, analyses had to be performed on the four age groups together. If all the tasks tap the same underlying processes, they should all load on the same factor. Therefore, a single-factor model was tested each year. Table 3.1 presents the parameter estimates for each year, and the χ² values obtained. The single-factor model proved satisfactory each year, except for Year 5 (χ²(2, N = 82) = 7.2, p = .03). The parameter estimates varied for the different tasks and were generally higher for the Peanut tasks and for CSV1—except on Year 5, as concerns the latter task—than for the other tasks.

Results show that all tasks tend to measure the same process, as would be expected if they indeed measure attentional capacity. However, the factor may merely reflect a general developmental factor, so much more so because all age groups had to be analyzed together. Therefore, two additional analyses were performed.

First, other developmental variables used in the project on Years 1–3 were included: CEFT on Years 1 and 3, and Progressive Matrices (PM) on Year 2. With these additional variables, single-factor models were insignificant: χ²(2, N = 82) = 10.01, p = .08, χ²(5, N = 82) = 13.34, p = .06 and χ²(5, N = 82) = 13.46, p = .02 for Years 1 to 3, respectively. The difference between these models and those defined on the basis of the four attentional capacity tasks only was significant for Years 1 and 3, and significant for Year 2.

Second, age was defined as a second-order latent variable (a λ variable, totally equated with the observed value of age via a fixed-option), to test whether or not the single-factor models merely reflect the influence of age. Results turned out not to be significantly different from the single-factor solutions obtained with the four attentional capacity tasks alone, provided the parameter γ_1, linking age to attentional capacity (the latent variable η) was left free to vary. Although the estimates of γ_1 were high (ranging from .76 to .91), the model proved inadequate as soon as this parameter was fixed to 1. It can thus be safely concluded that, although age accounts for a good part of the covariance between the four attentional capacity tasks, some of the between-task common variance is not related to age (see also Kliegl & Mayr, 1992, for the use of a similar method).

Because the same factorial structure proved adequate each year, it seemed interesting to test its stability across assessments. One can ask whether or not the latent variable takes the same meaning each year and is stable across years, especially because there was variation in the battery of tasks used each year. Obviously, these two aspects (meaning and stability) are different, but cannot be disentangled at present. Figure 3.1 reports the two simplex models that were

<table>
<thead>
<tr>
<th>Task</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>λ_x</td>
<td>θ_x</td>
<td>λ_x</td>
<td>θ_x</td>
<td>λ_x</td>
</tr>
<tr>
<td>Peanut-Purple</td>
<td>.88</td>
<td>.23</td>
<td>.94</td>
<td>.12</td>
<td>.90</td>
</tr>
<tr>
<td>Peanut-Colored</td>
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<td>.21</td>
<td>.90</td>
<td>.20</td>
<td>.85</td>
</tr>
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<td>CSV1</td>
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<td>.18</td>
<td>.84</td>
<td>.30</td>
<td>.83</td>
</tr>
<tr>
<td>FIT</td>
<td>.74</td>
<td>.45</td>
<td>—</td>
<td>.81</td>
<td>.34</td>
</tr>
<tr>
<td>Counting span</td>
<td>—</td>
<td>—</td>
<td>.82</td>
<td>.33</td>
<td>—</td>
</tr>
<tr>
<td>Listening span</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>.67</td>
</tr>
<tr>
<td>Reading span</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>χ²(5, N = 82)</td>
<td>1.85</td>
<td>4.13</td>
<td>5.34</td>
<td>2.82</td>
<td>7.20</td>
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<tr>
<td>p</td>
<td>.40</td>
<td>.12</td>
<td>.07</td>
<td>.24</td>
<td>.03</td>
</tr>
</tbody>
</table>
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however, not possible to test stability, controlling for age. Nevertheless, individual variability seemed to be the rule. This point is addressed again in a later section.

Extent and Form of Developmental Change

The analyses reported in the preceding section concerned the between-task relationships and their stability over the 5 years. They did not give any information relative to the level of performances. Figure 3.2 presents the group means over the 5 years by cohort and by task, for each of the three tasks used throughout the project.

In summary, the results are congruent with the hypothesis that the different attentional capacity tasks address the same basic underlying process. They also point to a relatively high stability in the covariance structure, most of which can probably be accounted for by age. Given the size of each cohort, it is,
Three points are worth stressing in view of these curves. First, cross-sectional age effects (i.e., developmental differences) were observed each year. Main effects of age were systematically obtained in analyses of variance conducted on the cross-sectional results. Contrast analyses showed that the performances of Cohorts 5 and 6 were systematically lower than Cohort 8, in turn lower than Cohort 10. The difference between Cohorts 5 and 6 was much smaller, and was often nonsignificant.

Second, retest effects were observed over the first 3 years. Keeping chronological age constant, performances were higher for children having had more encounters with the tasks. For instance, Cohort 5 had higher scores on Years 2 and 3 than Cohort 6 on Years 1 and 2 (both cohorts being then ages 6 and 7). Likewise, Cohort 6 had higher scores on Year 3 when it was age 8, than Cohort 8 on Year 1. Retest effects were stronger for the CSV1 task than for the Peanut tasks, and for Peanut-P than for Peanut-C. Retest effects also showed in an independent, parallel study in which 6-, 8-, and 10-year-olds were examined twice with the CSV1 and the Peanut tasks over an interval of 1 month (de Ribaupierre & Spira, 1991; Spira & Keizer, 1991). They are probably due to the intervention of more elaborate encoding and processing strategies resulting in larger chunks, which children can develop when they know the task better and may be due to other processes (learning factors, executive schemes) than attentional capacity (see also de Ribaupierre & Bailleux, 1993). The developmental curves observed over the first 3 years thus clearly point to the difficulty of dissociating learning and developmental changes.

Third, on Year 4, performances dropped drastically on all three tasks as a result of the important changes introduced in the experimental procedures. Recall that there was a change in the mode of response in the Peanut tasks due to their computerization, and in the time of exposure in the CSV1 task. That these changes would have an effect on the level of performance was to be expected, particularly as regards the CSV1 task: A drastic reduction in time of presentation certainly modifies the number of simple stimuli that can be attended, and perhaps even the type of processes used at encoding. With respect to the Peanut tasks, our current hypothesis is that responding by means of a computer mouse not only represents an additional attentional load, but also constitutes a concurrent spatial task interfering with the rehearsal and retrieval of positions. This result was used elsewhere to illustrate the complementarity of Baddeley's model and neo-Piagetian models of working memory (see de Ribaupierre & Bailleux, 1992, 1994). In the line of Baddeley's model (e.g., Baddeley, 1986), the Peanut task and the monitoring of the mouse are both likely to draw upon the resources of the same slave system (the VSSP system); therefore, one can expect an effect of interference. In terms of Pascual-Leone’s model, monitoring the mouse requires good executive schemes. In addition, there might be an incompatibility between the displacement of the mouse on the table and the displacement of the dot on the screen, particularly with respect to the up-and-down movement (on a horizontal versus a vertical plane).

This probably transforms the monitoring of the mouse in a misleading task, which requires the intervention of the 1-operator, independent from the M-operator. It may even necessitate additional activation by M.

Performances increased again on Year 5 for the Peanut tasks, showing renewed developmental progression, possibly confounded with retest effects. In contrast, performances decreased again significantly on the CSV1 task. Our explanation is that the construction of new items and the redistribution of all instances across classes that ensued, further prevented the use of chunking strategies.

Latent growth curve analyses were used to estimate the developmental trends obtained in each task over the 5 years (e.g., McArdle & Epstein, 1987; Rudinger, Andres, & Rietz, 1991). The variables y correspond to the observed variables of each successive year. Three latent variables were introduced: η1 for the means, related both to the observed variables and to the observed means (the variable x to which η1 is equated through a fixed-options corresponds to the observed means), η2 for the variances, and η3 for the increase in means on Years 2 to 5. The addition of η1, η2, and η3 parameters for each year, respectively, should allow the reconstruction of the observed scores. Figure 3.3 presents, as an ex-

![Figure 3.3](image-url)


### TABLE 3.2

<table>
<thead>
<tr>
<th></th>
<th>Free Model</th>
<th>Linear Model</th>
<th>Post Hoc Model</th>
<th>Staged Model (6-10 only)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\eta_1$</td>
<td>$\eta_2$</td>
<td>$\eta_3$</td>
<td>$\eta_1$</td>
</tr>
<tr>
<td>Peanut-P</td>
<td>2.21</td>
<td>0.19</td>
<td>0.00</td>
<td>2.37</td>
</tr>
<tr>
<td>(N = 100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peanut-C</td>
<td>1.73</td>
<td>0.20</td>
<td>0.00</td>
<td>1.54</td>
</tr>
<tr>
<td>(N = 100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSVLI</td>
<td>2.5</td>
<td>0.20</td>
<td>0.00</td>
<td>1.39</td>
</tr>
<tr>
<td>(N = 89)</td>
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</tbody>
</table>

Note: $y_1$ to $y_5$ stand for observed variables on Years 1 to 5. Latent variables $\eta_1$, $\eta_2$, and $\eta_3$ stand for the means (set equal), the variances (left free), and the increase in means (left free in free model and set to fixed values in the other models), respectively.

*The coefficients correspond to the values of the fixed parameters; for instance, the coefficient 2 for Year 3 in the linear model means that the model assumes that increase from Year 2 to Year 3 is twice the increase from Year 1 to Year 2.

*These parameters were left free, but equalized for Years 2 and 3, and Years 4 and 5, respectively.
tested in Model 4, can only hold if the task does not undergo changes and, more importantly, if attentional capacity is singled out. As soon as learning effects come into play (e.g., during the first 3 years), a linear change is more likely. Therefore, we did not expect the staged model to present a good fit.

The free model should provide the most adequate solution; this is trivial, because it consists in merely reconstructing a 1-factor confirmatory model while decomposing means and variances. The second best model should be the post hoc model. Once again, this is trivial because it was modeled after the empirical curves; nevertheless, it allowed us to assess the extent of developmental change. Finally, we assumed that the staged model should provide a better fit than the linear one. A direct comparison of the staged model with the other models is difficult on the basis of the values provided in Table 3.2, because the size of the sample is not the same. Nevertheless, a global comparison in terms of fit is possible; further, the first three models were also run on the reduced 6–10-year-old sample and results were similar. Results (see Table 3.2) show that the hypothesized order holds for the three tasks. The post hoc models are satisfactory, and equivalent or even better when considering the level of significance, than is the free model, despite stricter constraints. Of course, the post hoc model was also significantly better than the linear model. The staged model did not provide a good fit; however, it generally led to lower $\chi^2$ values than the linear model, except for the Peanut–P task.

In summary, one can conclude that the developmental trends in these three tasks do not support a strong stage hypothesis, but are more likely to reflect a combination of developmental and learning effects. In addition, they are sensitive to changes in situations. A last methodological remark is in order: These analyses were run on an insensitive score—the number of passed items. As a replication, they should also be performed on the number of correct responses, retaining more information than the average number of passed items. In both cases, it may be preferable to attempt to estimate a latent ability using the techniques of item response theory. This is planned as a further step in the study.

Are There Individual Differences in Developmental Change?

The analyses reported in the preceding section were conducted on the whole sample. This proved necessary because of the requirements that LISREL sets on the number of subjects. It is nevertheless interesting to determine whether there is interindividual variability not only in performances, but in developmental change. On simple visual inspection, this seems to be the case. Figure 3.4 presents a sample of the empirical, individual growth curves observed in the different age groups. Not only is progression more or less steep across children, but the direction of the change also varies: Although the mean level of performance regressed on Year 4, some children did progress from Year 3 to Year 4. Likewise, some children did not progress, but even regressed, from Year 1 to Year 2 or from Year 2 to Year 3.

In order to estimate the importance and reliability of this interindividual variability, we used Hierarchical Linear Modeling (HLM; Bryk & Raudenbush, 1987, 1992; Willrett, 1994), based on regression analysis. This technique allows one to dissociate within- and person-variables and to assess the effect of the between-person (Level 2) variables on the within-subject (Level 1) ones.

In the present case, the Level 1 variables were the number of passed items (means) and the slope over the 5 years. In view of the results reported in the last section, it seemed meaningless to compute individual, linear regression lines over the 5 years. Therefore, we decided to break up the growth trajectories into two components: the trajectory from Year 1 to Year 3, and the trajectory from Year 3 to Year 5. In the second case, the empirical curve was not linear either, except for CSV. Nevertheless, we thought it important to retain at least three points of measurement. Applying a linear model to the second portion of the curve has as a probable result to flatten the curves and to lower the reliability of the parameter estimates.

As a second step, we asked whether the slopes of the developmental curves vary as a function of age (cohort), field-dependence–independence (FDI), gender,

*Although, theoretically, HLM allows one to model quadratic or even cubic growth curves, we could not figure out how to do it in the version of the program we have.
or socioeconomic status (SES). Preliminary analyses showed that gender and SES had no effect, either on the intercept or on the slope in any of the three tasks. Therefore, only Age and FDI were retained. With respect to the latter variable, recall that the CEFT was administered twice. To control for the effect of age, t scores were computed by age and averaged over the two administrations. We also decided to enter the progression observed from Year 1 to Year 3 (the difference between Years 1 and 3) as a Level 2 variable for the second component of the curve. That is, we asked whether the change taking place during the first 3 years accounts for the intercept and/or the slope of the change observed in the last 3 years. As mentioned with respect to retest effects, a strong progression may be indicative of the fact that subjects use facilitating strategies. Because strategies were harder to apply in the modified tasks, subjects using them in the first 3 years should be penalized more by the changes introduced in the tasks than subjects who progressed less to start with. Therefore, we expected that the subjects who progressed most during the first 3 years were also those who regressed most on Year 4 for the three tasks, and on Year 5 for CSVI. For reasons that cannot be developed here, it was hypothesized that such developmental patterns of a stronger progression over the first 3 years coupled with a stronger regression on Year 4 were more likely to be found in older children and in field-independent children.

Six analyses were conducted, two series per task, on the longitudinal subjects who received the three tasks (N = 87). Table 3.3 presents, as an example, the results obtained for the models used on the second part of the curve (Year 3 to Year 5) in the CSVI. They are commented upon in some detail because of the novelty of this type of technique (see also Al Akker, 1992; Bryk & Raudenbush, 1992; Schneider, 1993). The first panel of Table 3.3 reports the results of an unconditional model, that is, a model in which no Level 2 variable was introduced, interpreted as an ANOVA with fixed and random effects. The estimated mean intercept (initial status) and the mean growth rate were 5.97 with a standard error of .29* and -.71, respectively. This indicates that the regression was approximately .7 item per year. The significant t ratios show that both parameters are necessary to account for the mean growth trajectory. The estimates for the variances of the individual parameters (random effects) are .62 and .14, respectively; both are significant, meaning that there was large interindividual variability. The reliabilities of the growth parameters that the estimation of the unconditional model also allowed us to investigate were .70 and .50; although not high, they indicate there is true individual variability.

All three predictors introduced in the Level 2 model (second panel in Table 3.3) related significantly to the initial status or intercept. This is rather trivial

3The outcome variable was not centered; therefore, the intercept corresponds to an estimate for Year 2. Because scores decreased from Year 3 to Year 5, the estimate for Year 2 is higher than the estimate for Year 3, and therefore much higher than the actual Year 2 score.

### Table 3.3

#### Linear Model of Growth in CSVI, Year 3 to Year 5

<table>
<thead>
<tr>
<th>Fixed Effect</th>
<th>Coefficient</th>
<th>se</th>
<th>t Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial status</td>
<td>5.97</td>
<td>.29</td>
<td>20.41**</td>
</tr>
<tr>
<td>Growth rate</td>
<td>-.71</td>
<td>.06</td>
<td>-12.69**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Random Effect</th>
<th>Variance Component</th>
<th>df</th>
<th>X²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial status</td>
<td>5.21</td>
<td>86</td>
<td>286.3**</td>
</tr>
<tr>
<td>Growth rate</td>
<td>.14</td>
<td>86</td>
<td>173.53**</td>
</tr>
</tbody>
</table>

#### Reliability of OLS Regression Coefficient Estimate

| Initial status | .70 |
| Growth rate    | .50 |

#### (b) Effects of Age, CEFT, and P3 – P1 (Level 2 model)

<table>
<thead>
<tr>
<th>Fixed Effect</th>
<th>Coefficient</th>
<th>se</th>
<th>t Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>-.190</td>
<td>1.10</td>
<td>-1.73</td>
</tr>
<tr>
<td>Age</td>
<td>.76</td>
<td>.09</td>
<td>8.95**</td>
</tr>
<tr>
<td>CEFT</td>
<td>.43</td>
<td>.20</td>
<td>2.20*</td>
</tr>
<tr>
<td>Diff P3 – P1</td>
<td>1.93</td>
<td>.22</td>
<td>8.97**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model for growth rate</th>
<th>Coefficient</th>
<th>se</th>
<th>t Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>.50</td>
<td>.27</td>
<td>1.88</td>
</tr>
<tr>
<td>Age</td>
<td>-.11</td>
<td>.02</td>
<td>-5.25**</td>
</tr>
<tr>
<td>CEFT</td>
<td>-.07</td>
<td>.05</td>
<td>-1.47</td>
</tr>
<tr>
<td>Diff P3 – P1</td>
<td>-.38</td>
<td>.05</td>
<td>-7.28**</td>
</tr>
</tbody>
</table>

#### (c) Variance Explained in Initial Status and Growth Rate as a Result of Age, CEFT, and P3 – P1

<table>
<thead>
<tr>
<th>Model</th>
<th>Initial Status</th>
<th>Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconditional</td>
<td>5.21**</td>
<td>14**</td>
</tr>
<tr>
<td>Conditional on Age and CEFT</td>
<td>.06</td>
<td>.003</td>
</tr>
<tr>
<td>Proportion of variance explained</td>
<td>98%</td>
<td>97%</td>
</tr>
</tbody>
</table>

*p < .05. **p < .01.
CONCLUSION

The objective of this chapter is to give a general overview of the results obtained in administering a number of attentional capacity tasks at yearly intervals to children ages 5 to 10 at the onset of the study. Three series of questions were asked, concerning the between-task relationship of the tasks, the development of change observed, and the extent of individual differences. Confirmatory factor analyses were performed on each of the tasks because a single factor was not sufficient to account for the variance observed. Of course, the age difference and the variance accounted for a good part of the variance, which reflects the underlying processes because a single factor was not sufficient to account for the variance observed. Of course, the age difference and the variance accounted for a good part of the variance.

When other developmental tasks such as CFT or the Raven Progressive Matrices were considered, however, the single factor analysis showed that despite changes in the tasks, they all seemed to address the same underlying processes. The extent of individual differences varied, but not significantly. The single factor analysis showed that the single factor was not sufficient to account for the variance observed. Of course, the age difference and the variance accounted for a good part of the variance.

Finally, as expected, the rate of change between Year 1 and Year 3 was a strong predictor of the rate of change between Year 1 and Year 5 in all three tasks. It was not surprising that age was a significant predictor of the rate of change for this long period. The rate of change between Year 1 and Year 3 was a strong predictor of the rate of change between Year 1 and Year 5 in all three tasks. It was not surprising that age was a significant predictor of the rate of change for this long period.

The results are summarized in Table 3.4, together with the five other analyses. The results are theoretically consistent with the findings presented in earlier reports. The results are theoretically consistent with the findings presented in earlier reports.

When combined, the three predictions accounted for the small reduction of the initial variance (99% and 79% for the first and second predictions, respectively).

The estimated variances for both models (third and fourth) can be compared.

When compared, the three predictions accounted for the small reduction of the initial variance (99% and 79% for the first and second predictions, respectively).

The estimated variances for both models (third and fourth) can be compared.

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tasks constitute good developmental tasks. Results are also in accord with other studies that showed, in adults, the existence of a general memory factor (e.g., Kyllonen & Christal, 1990).

This does not mean that interindividual differences are not important. On the contrary, HLM analyses showed that individual variability is important, not only in initial status, but also in the developmental growth curves. In the latter case, individual differences were not always significant, but this may have been due to a relative lack of reliability of our measures. Combining the results of the longitudinal structural equations model and of the HLM analyses, it can be concluded that age accounts for a good part of the variance, but is not sufficient.

The number of variables that could serve as predictors of individual differences was limited in the study; it is therefore difficult to explore further sources. Neither gender nor socioeconomic status, traditionally used when raising the issue of interindividual differences, had any effect.

The initial objective of the study was to test the neo-Piagetian hypothesis that there are developmental stages of a 2-year duration. Results did not support this hypothesis; in particular the latent growth curve analyses showed that a staged model provided a poor fit, even when tested on only the 6-10-year-olds, who should have progressed in a similar manner. However, it is only fair to the neo-Piagetian models to say that the experimental procedure adopted in the present study does not provide a clear test. There are at least two reasons for that, namely learning effects and the situational changes introduced after 3 years. The repeated administration of the tasks induced evident practice effects, already apparent on the second year; incidentally, this is one of the reasons why modifications were made, because there was a risk of ceiling effects after Year 3.

Pascual-Leone (e.g., Pascual-Leone & Goodman, 1979) warned that step functions cannot be observed when learning effects are combined with strictly developmental change. Indeed, his theory postulates that the first (odd) year of a stage corresponds to an increase in M-power, whereas the second (even) year consists in a consolidation made possible by the greater importance taken by a learning operator. In particular, subjects are then better able to assemble better, more efficient executive schemes. Thus, the combination of M-power and learning leads to a hypothesis of the linear developmental curve observed in the first 3 years of our study. Attentional capacity tasks should not be used more than once if they are to provide a good measure of M-capacity. In a longitudinal study, different, equivalent tasks should be used. However, truly equivalent tasks are scarce, as is well demonstrated in the literature. This makes an assessment of developmental change extremely difficult, when the objective of the study is to assess the extent and form of intraindividual developmental change, and not only the stability of individual differences.

The importance of situational variability was also clearly shown in the present project: The modifications introduced in the tasks caused important inflexion points in the growth curves. They did not only counteract the effects of learning by preventing the subjects to continue using the facilitating strategies elaborated over the previous years, but probably raised the intrinsic difficulty level of the tasks. Three modifications proved disruptive: the reduction in exposure time and the construction of new items in the CSVI task, and the computerization of the Peanut tasks. Although explanations can be found within the framework of neo-Piagetian theories, they are mainly post hoc, particularly as regards the Peanut tasks. Each of the three effects requires a different explanation. Obviously, the easiest one to account for is the regression caused by a tachistoscopic presentation in the CSVI task; this effect was predictable within Pascual-Leone's theory. In this case, we deliberately resorted to this mode of presentation to limit the ceiling effects that were appearing in the oldest cohort. Yet, it complicates the comparison of levels of performances across years, although the theoretical type of scoring (K estimates) proposed by Pascual-Leone (1970) allows us to bridge the two types of tasks. The further regression brought about on Year 5 by the reduction in the number of items in the CSVI task was less predictable. It is not due to a mere reduction in the length of the task, but probably to the fact that the construction of new items led to a redistribution of all instances across classes. This modification is likely to have further prevented chunking strategies that subjects might still use despite the brief presentation time. Learning effects may no longer be effective on Year 5, which in turn could explain why results for this year are different in the confirmatory factor analyses. As support for this hypothesis, it is only for Year 5 and for Year 1 that the theoretical scores predicted by Pascual-Leone in terms of K estimates on the basis of age found empirical support; for the 3 other years, they were too high.

Finally, the importance of the change caused by the computerization of the Peanut tasks was the least predictable. Again, it is probably not the computerization that was responsible for the regression in performance, but rather the change in the response mode. In the manual version, children had to place chips on a sheet of paper by a simple motor movement. In the computerized task, they had to use a computer mouse. Of course, some children probably lacked practice. However, monitoring a mouse requires processing resources that are no longer available for handling the Peanut task. An explanation was previously offered that drew on Pascual-Leone's model and on Baddeley's model. A series of experiments is currently in progress to investigate this hypothesis further and more systematically.

ACKNOWLEDGMENTS

This research was supported by grants from the Fonds National Suisse de la Recherche Scientifique (grants 1.437–0.86 and 11.2767.89). We thank Professors J. Pascual-Leone and R. Case for permission and advice in using their tasks, and R. Kail for useful comments on a first version of this chapter. We would also like to thank Professor G. Rudinger for his help in conducting confirmatory factor
analyses and latent growth curve analyses both in Geneva and in Bonn where he agreed to host C. Bailleux while she was holding an ESF fellowship. We are grateful to Sylvain Dionnet, Ineke Keizer, Thierry Lecerf, Santino Livoti, Caroline Moutia, Francisco Pons, Ana Sancho, Anne Spira, and Laurence Thomas who were actively involved in the collection and analysis of the data. Finally, we also want to thank the children who willingly participated in the study, despite its length and, at times, repetitive aspects.

REFERENCES


