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Developmental Change in a Spatial Task of Attentional Capacity: An Essay Toward an Integration of Two Working Memory Models

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The objective of this paper is to illustrate the complementarity of two lines of studies on Working Memory, the neo-Piagetian models of Pascual-Leone and Case on the one hand, and Baddeley's model, on the other. After a brief summary of each model, their similarities and differences are reviewed. An empirical longitudinal study is then presented as an illustration. Four cohorts of children, aged 5, 6, 8, and 10 years on the first assessment, were examined once a year over five years, with a short-term memory task (Mr Peanut), asking for the recall of the location of coloured spots in a clown figure. Two versions were used: a unicoloured task (Peanut-P) and a multicoloured task (Peanut-C), in which subjects had to recall both positions and colours. Three aspects of the results are emphasised. First, it was found that performances in Peanut-C increased with item complexity up to a certain level, beyond which they tended to remain stable; this stability was interpreted as reflecting the limits in processing resources which are postulated by neo-Piagetian models. Secondly, a drastic diminution in the performances was observed on the fourth year, corresponding to a change in the way of responding: The task was computerised, and subjects had to answer, using a computer mouse. It is argued that the monitoring of the mouse disrupts performances because it draws on the

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same limited resources as the memory task. Finally, results showed that the monitoring of the mouse interferes more with the recall of positions than with the recall of colours, as could be expected if monitoring a computer mouse represents a spatial interference task. Methodological drawbacks of the studies are also discussed, and suggestions for further research indicated.

INTRODUCTION

There are clearly at least two different, independent streams of research on the development of Working Memory (WM), which define it as a system with limited capacity for storing and actively manipulating mental information, for use in cognitive situations. One direction developed from the Baddeley and Hitch (1974) model, according to which short-term memory is not a unitary phenomenon. It was first proposed to account for short-term memory phenomena in adults and was more recently generalised to children. The second perspective is represented by neo-Piagetians who consider the development of WM as a causal factor of cognitive development (e.g. Case, 1974, 1985; Chapman, 1987; Halford, 1982, 1993; Pascual-Leone, 1970, 1987); although different neo-Piagetian formulations of WM have also been proposed, we focus here on Pascual-Leone's and Case's models only. It is striking that there have been so few cross-references from one trend of studies to the other, or external analyses of their similarities and differences.[1]

The objective of this paper is therefore to argue that the theoretical constructs proposed by Baddeley and Pascual-Leone are in fact much closer than it first appears. We came to this conclusion because of the results obtained in the study which is described below. This is a longitudinal study which was designed to test some of Pascual-Leone's and Case's postulates regarding the existence of stages in the development of attentional capacity. Over the course of the study, modifications were introduced in one of the working memory tasks used, and we realised that the unexpectedly large effect on the subjects performances which ensued could be interpreted in the light of Baddeley's model as well as within Pascual-Leone's framework. This paper is an attempt toward this theoretical rapprochement. First, we give a brief summary of both types of models. Secondly, their similarities and differences are discussed. Thirdly, in order to illustrate our arguments, we present the results of our longitudinal study which led us to consider that the two models are compatible.

[1]We thank one of the anonymous reviewers of this paper to have called our attention to Halford's recent book (1993), in which a whole chapter is devoted to a review of different capacity concepts in adult and child cognition.

Brief Summary of Two WM Types of Models

As well documented throughout this issue, *Baddeley and Hitch's* model (1974) suggests a tripartite system, composed of the Central Executive, which is a control mechanism helped by two slave systems: the Articulatory Loop (AL) and the Visuo-Spatial-Sketchpad (VSSP). The two slave systems function independently from each other, as demonstrated by the use of dual task paradigms.

The Articulatory Loop is the most studied part of the system; its role is to hold and manipulate verbal material. It consists of two components: a phonological store, which is relatively passive and to which verbal material presented auditorily has obligatory access; and a rehearsal mechanism which helps to maintain stored items as well as recoding verbal material presented visually. The AL is temporally limited: It contains as many items as can be rehearsed in approximatley 1.5 to 2 seconds. It is therefore closely linked to articulation rate. The functioning of this subsystem accounts for phenomena repeatedly observed in verbal short-term memory studies, such as word length, articulatory suppression, and phonological similarity effects.

The VSSP is responsible for the holding and manipulation of visual and/or spatial information. Experimental studies are less numerous, although their number has greatly increased in the last five years, and results are sometimes difficult to interpret. In particular, the rehearsal mechanism and the limits of the system remain largely unknown. Recent work (Baddeley, 1988; Logie & Baddeley, 1990; Logie & Marchetti, 1991) tends to show that it consists of two distinct components, a visual and a spatial one.

The Central Executive (CE) is an attentional system, with a limited capacity, which can use either slave system in order to free up some of its own resources. It has been relatively little studied, and remains some kind of a "conceptual black box" (e.g. Van der Linden, 1989). Recently, however, experimental studies have directly addressed the CE. For instance, Baddeley (1992) considers that the greater difficulty Alzheimer's patients have in co-ordinating two simple tasks, one calling for the AL system and the other one for the VSSP system, is due to a deficit of the CE. A task of generating random numbers is considered to directly tap the CE; it probably requires the active rehearsal of instructions and the inhibition of automatic routines. Thus, the CE is mainly viewed as a mechanism for monitoring and co-ordinating the processing of information.

Baddeley's model has generated numerous studies. From a developmental perspective, most studies up to now have attempted to determine whether similar effects are found in children. For instance, Hitch et al. (Hitch, Halliday, Schaafstal, & Schraagen, 1988; Hitch, Halliday, Dodd, & Littler, 1989a; Hitch, Halliday, & Littler, 1989b; Hitch, Woodin,

& Baker, 1989c) have shown that the phonological system grows in importance with age, although the ages at which rehearsal has been observed vary with situations. With auditory presentation of verbal stimuli, word length effects are found as early as 4 years of age (see also Hulme, Thomson, Muir, & Lawrence, 1984; Hulme & Tordoff, 1989). By contrast, with visual presentation (drawings of objects), word length effects do not appear before 7 or 8 years of age. Older children (at least from 8 years onwards) spontaneously use articulatory rehearsal, whether presentation is auditory or visual. Incidentally, it is interesting to note that such results converge with Flavell's (e.g. Flavell & Wellman, 1977) and other researchers' work on spontaneous rehearsal in memory tasks. In their recent work, Hitch et al. also suggest that verbal coding does not merely replace visual coding, but that development consists in a multiplication of the number of possible coding systems.

Developmental increase in tasks tapping the AL system has been well documented over the years, in particular through the use of verbal memory span tasks. For Baddeley (1986; see also Case, 1985; Case, Kurland, & Goldberg, 1982; Nicolson, 1981) this increase is accounted for by the development of articulatory speed, rather than by a development of the Central Executive: The faster words or digits can be pronounced, the more can be recalled. It is our position, however, that the increase in articulatory rate does not play a causal role, but depends on a more general developmental mechanism, which influences both rate and span (see also Henry, 1991). Developmental change in VSSP tasks has been less studied, even with respect to the development of spatial span. For instance, Wilson, Scott, and Power (1987) showed that pattern span increases rapidly between the ages of 5 and 11, by which time it is at the adult level; they also found that the memory decay is rapid. Schumann-Hengsteler (e.g. 1989; Schumann-Hengsteler, Demmel, & Seitz, 1992) showed that there is very little qualitative change from 5 to 10 years of age in the ability to perform visuo-spatial memory tasks which do not vary in terms of complexity.

The *neo-Piagetian models* (e.g. Case, 1985; Chapman, 1987; Fischer, 1980; Fischer & Lamborn, 1989; Halford, 1982; Pascual-Leone, 1987) view working memory from a very different perspective. Derived from the Piagetian model, they have in common that they have looked for constructs other than the Piagetian logical structures in order to account for cognitive development in general, and for the existence of general developmental stages. Most theorists assume that general stages should be defined in terms of constraints or upper limits, under which there can be considerable variation across situations and subjects, rather than in terms of the form that behaviour takes across domains. These upper constraints are set by limits in working memory; development of WM is viewed as a causal factor, although not the only one, of cognitive development. Neo-Piagetian models are not all alike, nor do they all explicitly address

working memory (e.g. Case, 1987, 1992; Dasen & de Ribaupierre, 1987). Furthermore, different constructs have been used, such as working memory, attentional capacity, M-space, M-power, mental attention, processing space. We will consider here that these constructs are broadly equivalent, in the sense that they all refer to a limited capacity for storage and manipulation of mental information, for use in cognitive tasks. Thus, the role assigned to WM is the same in these models as in Baddeley's approach. However, the main purpose has not been to determine how working memory functions or whether it is unitary or not, but rather to study whether the developmental increase observed in WM tasks accounts for the developmental differences obtained in cognitive tasks in general. As already mentioned, the focus here is on Pascual-Leone's and Case's models.

Let us first mention that *Pascual-Leone's* model has often been misunderstood as assuming a unitary system to account for the development of working memory. On the contrary, the model is basically multidimensional, whether with respect to working memory or to cognitive development in general. This is in accord with current views of WM (see also Halford, 1993). The multidimensional aspect concerns not only the representational format of items of information but also underlying mechanisms or processes which activate information. Pascual-Leone offers a dynamic view of processing (e.g. Pascual-Leone, 1970, 1984; Pascual-Leone & Ijaz, 1989). Three nested levels of activation are described. First, when an input arrives, a number of schemes (defined as information-carrying functional units or structures) are activated in the repertoire, via their own propensity to be activated and via affective operators; this is referred to as the general *field of activation*, denoted H*. Secondly, affective goals are created which activate relevant executive schemes while a number of silent operators, whose role is to activate schemes, may also be mobilised by patterns of schemes co-activation. This generates a subset of more highly activated schemes, which at times Pascual-Leone himself labels working memory (e.g. Pascual-Leone & Ijaz, 1989).[2] Thirdly, and depending on the type of situations, whether misleading[3] or facilitating, some activated schemes

[2]Note that other authors also define WM as the amount of information for which the activation strength is above a certain threshold (e.g. Engle, Cantor, & Carullo, 1992; Salthouse & Babcock, 1991). For instance, Moscovitch and Umilta (1990, p. 31) consider that there is neither a single working memory system nor multiple systems, but that working memory "reflects or represents whatever processes are currently active and whose outcomes or operations are consciously apprehended".

[3]Misleading situations are those in which different silent operators activate incompatible sets of schemes, one of which is often more highly activated while leading to an incorrect solution; in contrast, in facilitating situations, different sets of schemes are activated which all concur to a correct solution.

must then be actively inhibited, whereas others require supplementary activation. The content of this last subset, that is, the nature and number of the hyperactivated schemes which define the "field of *Mental Attention*" or attentional capacity, depends on at least three mechanisms: (a) mental capacity or M-power, applied to relevant schemes to boost their level of activation; (b) an inhibition mechanism, the I-operator, responsible for actively inhibiting less relevant or irrelevant schemes;[4] and (c) executive schemes, that is, plans of actions and regulatory controls.

It is only with respect to the growth in M-power that precise developmental predictions were made. M-power or M-capacity is considered to be strictly limited, and to increase maturationally with age. It is defined as the maximum number of independent schemes (other than executive schemes and schemes activated directly by the input or other operators) which can be simultaneously activated by M in a single mental operation; it grows from 1 at age 3 to 7 at age 15. M-stages (i.e. the period of time during which the same maximum number of schemes can be activated across different situations) have been empirically determined to last two years. These theoretical assumptions have been validated in a number of empirical studies, using different age samples and different tasks. M-power has also proved to be a good predictor of performance in other cognitive tasks (for details, see Pascual-Leone, 1987; Pascual-Leone & Goodman, 1979; de Ribaupierre, 1983). To our knowledge, Pascual-Leone did not specify the developmental characteristics of the other operators, except for stipulating that the influence of the inhibition and learning operators are stronger in the second than in the first year of an *M* stage. Likewise, he did not indicate whether there are limits to the number of schemes that can be activated in the first two fields of activation.

Case (e.g. 1985) uses the term executive processing space to refer to a construct similar to Pascual-Leone's M-capacity; it is defined as the maximum number of independent schemes that a child can activate at any one time. Case has introduced the distinction between the activity of executing an ongoing operation and the activity of storing and/or retrieving the products of such an operation: Operating space refers to the portion of the executive space devoted to the activation of new schemes (the ongoing operation); short-term storage space (STSS) is devoted to the maintenance and/or retrieval of recently activated schemes. A number of STSS tasks was developed for the different qualitative stages that are distinguished in his general developmental model. Several studies were aimed at demonstrating that the same average values (see later) can be obtained at the

[4]For the importance of inhibitory processes in development, see also Bjorklund and Harnishfeger (1990); Dempster (1992).

same age in different tasks, thus pointing to the existence of stages (lasting approximately two years, as in Pascual-Leone's model) in the development of processing space.

It is difficult to always empirically distinguish between Case's and Pascual-Leone's models. With respect to the growth of working memory, both models predict the same pattern of results, at least within Case's dimensional stage:[5] from 1 to 4 schemes between 3–4 and 10–11 years of age. The two models present, however, a number of important, theoretical divergences. The role assigned to maturation is different. In Pascual-Leone's model, M-power grows with maturation throughout childhood. For Case, although development in general also undergoes maturational influence, the growth of STSS within a general stage is mainly due to a trade-off between processing and storage space: As an operation newly acquired at the beginning of a stage becomes more efficient with practice, the amount of executive space devoted to the operating space diminishes and there is progressively more space left for the storage space. There are other differences between the two models. In particular, Pascual-Leone uses an energy metaphor, probably closer to current connectionist models, whereas Case uses a spatial metaphor, in which processing space consists in a number of slots (Case, 1985). Finally, Pascual-Leone defines several, independent sources of activation of schemes in working memory, whereas Case considers a single source of activation, assigned to different contents. In this sense, working memory can be considered unitary in Case's model but not in Pascual-Leone's. It should be remarked that Case's suggestion of a trade-off between storage and processing, and hence of a general, unitary pool of resources has also been seriously criticised by Halford (1993), who showed that it is contradictory with a number of empirical findings.

Similarities and Differences Between the Two Types of Models

Baddeley's model and the neo-Piagetian models may appear very different. In our opinion, however, they are complementary rather than contradictory.

First, they apply at different scales, "microscopic" versus "macroscopic". Baddeley's experimental approach focuses on the different processes at work within essentially single types of paradigms, and on the predictive power of these paradigms for other cognitive situations. The capacity of each subsystem is considered to be limited; however, Baddeley only

[5]The values predicted by the two models differ across the entire span of childhood, but we will not detail these differences here.

attempted to quantify these limits with regard to the Articulatory Loop. Relationships between WM and cognitive performance have been studied, but without attempting to formulate precise developmental predictions. In contrast, the objective of neo-Piagetian models is to provide hypotheses relative to general processes at work in a whole range of cognitive tasks, in order to predict developmental changes, together with individual differences in the case of Pascual-Leone, as well as to understand the underlying mechanisms responsible for development. As a result, they adopt a rather global point of view. For instance, Pascual-Leone's concept of M-power is meant as a general, content-free mechanism, whose growth accounts for cognitive development at large, and in particular for the existence of general developmental stages. As Halliday and Hitch emphasise (1988), such approaches strive to provide theories about causes of developmental change, whereas developmental studies within the Baddeley tradition tend to contribute a description of developmental differences without looking for explanations of the developmental process. As a result, neo-Piagetian models have focused on a quantitative assessment of limit in information-processing capacity, and on the increase in these limits with age, using tasks in which the influence of other factors is at least controlled to some extent (de Ribaupierre & Pascual-Leone, 1984).

A second difference seems to lie in the emphasis placed by Baddeley on the existence and the independence of several subsystems. However, as we have seen, WM is not unitary either in the case of Pascual-Leone's model: Items stored and maintained in WM may not all require M-activation, but can be weighed by other operators, too. This might explain the apparent contradiction between the large variability in performances reported in the experimental studies on working memory (e.g. Dempster, 1985) and the stability described by the neo-Piagetians. In the latter approach, stability is only postulated when the task is a relatively pure M-task; in contrast, in other cognitive tasks which call not only for attentional capacity but also for other processees, variability is the rule more than the exception (e.g. de Ribaupierre, 1993; de Ribaupierre & Pascual-Leone, 1984). We suggest that the mechanism of mental attention described by Pascual-Leone (i.e. M-operator, together with the I-operator and executive schemes) roughly corresponds to Baddeley's Central Executive and that information maintained by the slave subsystems corresponds to the schemes activated by other operators. Pascual-Leone's model not only distinguishes several silent operators, but also different types of schemes (Johnson, 1991; Pascual-Leone, Goodman, Ammon, & Subelman, 1978; Pascual-Leone & Johnson, 1991; de Ribaupierre, 1983), according to their (sensorial) modalities and their modes. The latter distinction refers to the way information is coded, and is not necessarily tied to particular types of content; modes are defined as infralogical or mereological (retaining spatio-temporal and/or causal properties), logological (generic knowledge), and linguistic. Although this distinction is not made by Baddeley, one could regard the schemes maintained in the two subsystems as differing both in terms of modality and mode: Information maintained in the AL might correspond to verbal (modality) and linguistic or logological schemes whereas information stored in the VSSP might constitute visual and mereological schemes.

On the whole, however, for Case and Pascual-Leone, all schemes placed in the field of mental attention or in the processing space are considered functionally equivalent, as long as they are required in a task, are not activated directly by the input or by another operator, and need to be kept separate. Their equivalence results from the fact that they require the same amount of M-activation to apply, regardless of their content, whether verbal or spatial, simple or complex.[6] Measuring M-capacity requires a number of methodological precautions, to ensure that the task does not induce chunking strategies and is not too sensitive to individual differences (see, for instance, Pascual-Leone, 1970, 1978; de Ribaupierre & Pascual-Leone, 1984), that is, is not too sensitive to the influence of silent operators other than M. The main difficulty, in these approaches, consists indeed in assessing the number of schemes necessary in a task and/or used by a subject (e.g. de Ribaupierre, Neirynck, & Spira, 1989). For example, it is often not possible to equate the number of elements recalled with the number of schemes because of chunking strategies.

From an empirical point of view, the difference in focus between the two approaches to working memory influences the type of paradigm used: Typical studies in the Baddeley tradition use dual tasks, and rely on a paradigm of double dissociation to identify the contribution of different components of working memory to performance. In contrast, neo-Piagetians have tended to use a single task, or a battery of tasks (e.g. Morra, 1992, this issue) supposed to address the same underlying processes.

Despite the fact that neo-Piagetian models do not directly address the issue of different working memory subsystems, we believe that they can nevertheless accommodate the kind of empirical findings which led Baddeley to postulate different slave systems. The lack of interference obtained when two different tasks are used conjointly could simply reflect the fact that processing resources are large enough to handle both tasks simultaneously, either because the subjects' M-capacity is sufficient and/or because different silent operators in Pascual-Leone's sense may also contri-

[6]In this regard, schemes are like chunks, that is, they are independent items of information of "arbitrary size, and their status does not depend on their information value" (Halford, 1993, p. 124).

bute to performance. Indeed, the tasks used are generally simple; when they become more complex, interference effects are usually observed.[7] In Pascual-Leone's model, simple tasks often call for schemes which may be activated by other source than M-power and consequently do not compete for the same limited resources. Conversely, one can ask why there is any effect of dual-task interference at all. Pascual-Leone's model would predict interference in two cases: (a) when both tasks are difficult enough to require the contribution of M-operator, and their combined M-demand exceeds the subjects' M-power; (b) when one task is misleading with respect to the other. This is the case when the two tasks call for the same system. It is then necessary to inhibit, in each task, a number of irrelevant schemes which tend to be strongly activated by the concurrent task because they are in the same format. Monitoring both tasks simultaneously and selecting the relevant schemes while inhibiting the irrelevant ones at the proper moment require a particularly efficient I-operator and good executive schemes. It may even be the case that extra M-power is required to activate the relevant schemes.

In summary, there are a number of important differences between Baddeley's and Pascual-Leone's models. Our view is not that all of them can and have to be wiped out. Nevertheless, we contend that correspondences can be established between these two approaches. We have suggested that Baddeley's subsystems of WM, taken together, correspond to Pascual-Leone's second subset of activated schemes sometimes specifically labelled working memory, whereas the CE corresponds to the most restricted subset of highly activated schemes, namely the field of mental attention. We see two reasons for bringing more closely together these two models. First, from a general, epistemological perspective, it seems useful to draw links when it is possible between trends of studies which have largely ignored each other. Secondly, the two models may prove useful when it comes to interpret empirical results. Baddeley's model provides a finer account of the functioning of WM, particularly as regards possible between-task effects of interference; by focusing on general, underlying mechanisms at work in a large number of situations, Pascual-Leone's model contributes to insert WM studies in a more integrated picture of cognitive development.

[7]One of our anonymous reviewers called our attention to Klapp, Marshburn, and Lester's (1983) work, in which no interference effect was observed, even though the tasks were more complex. However, the argument that several operators may work in parallel to activate different sets of schemes applies in this case, too. If there is enough time to encode the memory preload, its content may then be activated by an operator other than M.

AN EMPIRICAL ILLUSTRATION

We will now try to illustrate, using results obtained in a neo-Piagetian task, the way in which these approaches are complementary rather than contradictory. The study presented here is part of a longitudinal project which aimed at studying developmental changes in attentional capacity, using a number of neo-Piagetian tasks. As mentioned in the Introduction, the initial objective was to examine neo-Piagetian developmental hypotheses, it is only in the course of the study that we realised that some results could just as well be accounted for by Baddeley's model.

Four cohorts of children, aged 5, 6, 8, and 10 at the first assessment, were followed over five years; they were examined once a year with attentional capacity tasks adapted from Pascual-Leone and Case, and with Piagetian tasks. In the last two years of the project, other working memory tasks were also introduced (verbal span, articulatory rate tasks). The present paper will focus on the changes observed in two related tasks (visual memory tasks called Peanut-P and Peanut-C), following a modification in the response mode. On Year 4, the Peanut tasks were computerised and subjects had to respond using a computer mouse. Presentation of results proceeds in three parts. First, cross-sectional comparisons of the two forms of the task are presented, which support the neo-Piagetian hypothesis of limits in attentional capacity. Longitudinal results are then described, with a focus on the changes observed following computerisation. It is argued that the task was thereby transformed into a dual paradigm, which was responsible for a severe reduction in performance. Finally, a finer analysis which contrasts two different scores is reported, in order to discuss the possible role played by the VSSP system in our tasks.

METHOD

Subjects

The initial sample consisted of 120 children (30 by age group), aged 5, 6, 8, and 10 at the onset of the study. Each age group is referred to as a cohort. Testing took place within two months of the subjects' birthday, and the interval between the annual testing sessions was approximately one year. The initial sample was representative of the Genevan primary school population with respect to gender, socioeconomic status, and national origin. Results presented here are based on 100 children who were examined each year (i.e. five times) with the task (respectively 27, 22, 28, and 23 for each age group); the overall attrition rate was thus 20% in this task over the five years.

Task

This short-term memory task was adapted from Case (1985) and has been used several times in Case's own research (Case, 1985; Case, Marini, McKeough, Dennis, & Goldberg, 1986). Children were presented with a clown figure (see Fig. 1, left), with a varying number of coloured dots painted on different body parts. The picture was then removed, and replaced with a blank clown figure. Children had to place coloured chips on the parts that were painted in the model. The figure was slightly modified in Year 4 (see Fig. 1, right) so as to increase the number of locations in which painted dots could be placed.

Two forms were constructed, which are considered as two separate tasks: (a) *Mr Peanut Purple (Peanut-P)*: all coloured dots and all chips were purple (red on Years 4 and 5). Children had to recall the position of each dot; (b) *Mr Peanut Coloured (Peanut-C)*: dots were of different colours; children had to recall the position and the colour of each dot.

Item complexity was defined on the basis of the number of coloured dots: Class 1 items contained one dot, Class 2 items contained two dots, etc. The complexity ranged from 1 to 5 or 6, depending on the version. There were five items for each level of difficulty; items were distributed randomly throughout the task. A number of conditions were met in constructing the task: no item contained two dots in symmetrical locations (e.g. in the two arms) nor two dots of the same colour; obvious patterns were avoided so as to minimise chunking; identical positions were not used on consecutive items.

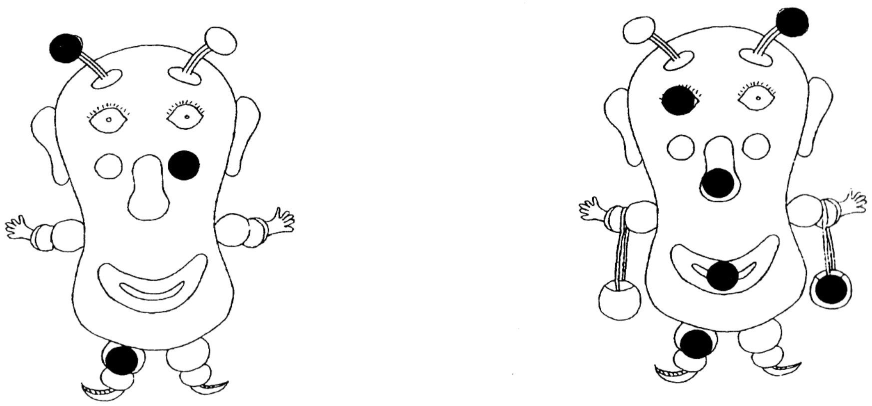

FIG. 1. Peanut figure used in the longitudinal study. Left: figure used in Years 1–3, 14 possible locations; example of a Class 3 item. Right: figure used in Years 4–5, 16 possible locations; example of a Class 6 item.

Scoring. Items were scored as passed when all the correct positions (Peanut-P) or correct colours in the correct positions (for Peanut-C) had been recalled. An overall score was computed by dividing the number of correct items by 5 (i.e. by the number of items in each class of complexity). This score is comparable to a more traditional span measure: For instance, a score close to 1 means that subjects pass Class 1 items, but fail most items of Class 2 or higher. The number of correctly recalled dots, whether the item was passed or failed, was also recorded; it constitutes a finer score than the number of correct items. Finally, for Peanut-C, a colour score (number of correct colours independent of positions) and a position score (number of correct positions independent of colours) were used.

Procedure

Each child was tested individually in a quiet room, each year for 3–5 sessions of approximately 45 minutes, during which the full range of tasks used were administered in no predetermined order. However, the Peanut tasks were given in the same session, and the Peanut-P task was always presented before the Peanut-C task. Each Peanut task lasted from 15 to 30 minutes. Different versions, adapted in terms of the level of difficulty, were constructed for the different age groups and the different years of the project. Table 1 shows the different versions by year and by cohort. All

TABLE 1
Versions of Mr Peanut by Assessment Year and by Cohort

	Cohort 5	*Cohort 6*	*Cohort 8*	*Cohort 10*
Year 1	P1–P4 C1–C3	P1–P4 C1–C3	P1–P5 C1–C4	P1–P5 C1–C5
Year 2	P1–P4 C1–C3	P1–P5 C1–C4	P1–P5 C1–C5	P1–P5 C1–C5
Year 3	P1–P5 C1–C4	P1–P5 C1–C4	P1–P5 C1–C5	P1–P5 C1–C5
Year 4	P2–P5 C2–C5	P2–P5 C2–C5	P2–P6 C2–C6	P2–P6 C2–C6
Year 5	P2–P6 C2–C6	P2–P6 C2–C6	P2–P6 C2–C6	P2–P6 C2–C6

Note. The table reports the classes of complexity administered (5 items per class); P = Peanut-P and C = Peanut-C. P1–P4 means that Classes 1–4 were given in the Peanut-P task.

items of the same complexity level were identical across versions, but followed a different order.

On Years 1–3, presentation was manual: Subjects were shown a Peanut figure on a sheet of paper, and had to recall by placing coloured chips on a blank figure. On Years 4–5, the procedure was computerised. The coloured figure appeared on the screen, followed by a blank figure; children had to move coloured dots on the screen to place them on the Peanut figure, using a computer mouse. In both types of presentation, exposure time was limited (1 second per coloured dot in the figure), but response time was free. New items were constructed for the computerised task, due to the addition of baskets on the arms. A supplementary training phase was also introduced to ensure that children could manipulate the mouse, and to show them how to move the coloured dots to different places and to correct errors.

RESULTS

As mentioned earlier, we focus here on three aspects of the results: (1) the difference between Peanut-P and Peanut-C; (2) the comparison of Years 1–3 versus Years 4–5, that is, the changes consecutive to the computerisa-

TABLE 2
Mean Number of Correct Items

Age	*Peanut-P* *Years*					*Peanut-C* *Years*				
	1	2	3	4	5	1	2	3	4	5
5	1.36 (0.32)					1.09 (0.41)				
6	1.63 (0.41)	1.90 (0.53)				1.38 (0.39)	1.46 (0.39)			
7		2.06 (0.47)	2.27 (0.47)				1.70 (0.37)	1.66 (0.48)		
8	2.61 (0.70)		2.89 (0.59)	2.14 (0.49)		1.94 (0.48)		2.01 (0.57)	1.55 (0.33)	
9		3.34 (0.67)		2.51 (0.52)	2.77 (0.47)		2.54 (0.60)		1.76 (0.32)	1.78 (0.30)
10	3.29 (0.60)		3.77 (0.62)		3.05 (0.63)	2.57 (0.51)		2.84 (0.61)		2.13 (0.49)
11		3.90 (0.67)		3.69 (0.60)			3.16 (0.58)		2.48 (0.50)	
12			4.32 (0.43)		4.14 (0.88)			3.38 (0.62)		2.74 (0.68)
13				4.17 (0.76)					2.90 (0.65)	
14					4.37 (0.87)					3.04 (0.77)

Note. Standard deviations are in parentheses.

tion of the task; (3) the comparison of the colour score and the position score for Peanut-C.

First, overall results are presented. Table 2 reports the mean number of correct items by chronological age and by year of testing, for both Peanut-P and Peanut-C. Recall that four cohorts (5, 6, 8, and 10) were examined. A vertical reading allows a cross-sectional analysis at each assessment point; that is, children were aged 5, 6, 8, and 10 on Year 1, and 6, 7, 9, and 11 on Year 2, and so on. Horizontal reading allows a comparison of results for children of the same age at different assessment years. For instance, three cohorts were examined when they were aged 8: cohort 8 on Year 1, cohort 6 on Year 3, and cohort 5 on Year 4. Longitudinal results, that is the results obtained by a given cohort each consecutive year, can be read in the diagonal (e.g. 5–1, 6–2, 7–3, etc., where the first digit stands for chronological age and the second for the year of assessment).

Two general comments are in order. First, there were clear differences between age groups, each year and for each task. Usually, the difference between cohorts 5 and 6 was smaller than the difference between cohorts 6 and 8, and than between cohorts 8 and 10. This was confirmed through analyses of variance[8] on the results of each year: The main effect of age was significant for each year, and contrast analyses showed that cohorts 5 and 6 either did not differ from each other or differed less than the other cohorts. Likewise, in an overall Age × Task × Year of Testing three-way analysis of variance, the main effect of Age was significant, $F(3,96) = 100.7$, $P < 0.01$. Scheffé tests showed that the difference between cohorts 5 and 6 was only significant for Peanut-C ($F(1,47) = 15.36$, $P < 0.05$), but not for Peanut-P ($F(1,47) = 14.29$). The other effects of this analysis of variance will be discussed later.

Secondly, there were effects of retest or practice on Years 2 and 3. Table 2 shows that, keeping age constant, performances were higher for children having had more encounters with the tasks. For instance, children aged 6 years on Year 2 had higher scores than children aged 6 on Year 1 (mean scores of respectively 1.9 vs. 1.63 for Peanut-P and 1.46 vs. 1.38 for Peanut-C); the same was true at Ages 7 (only for Peanut-P) and 8. Retest effects were stronger for Peanut-P. These differences were not all tested or did not all prove significant. Nevertheless, such retest effects were also observed in a parallel study in which 6-, 8-, and 10-year-olds were examined twice with the Peanut tasks over an interval of one month (for more

[8]Given the different versions administered to the different cohorts and over the course of the study, the design of analyses of variance was not always the same. For instance, when all age groups were considered together, only Class 1 to Class 3 items could be analysed on Years 1 and 2, even though the older subjects had items up to Class 5. Therefore, different analyses of variance were conducted each year on cross-sectional data, and for reasons of space only a few will be reported in some detail.

details, see de Ribaupierre & Spira, 1991; Spira & Keizer, 1991). They are probably due to more elaborate encoding and processing strategies (e.g. spatial chunks) which children can develop when they know the task better, this reflecting other processes besides attentional capacity *per se*.

Cross-sectional Comparison of Peanut-P and Peanut-C

A number of differences were hypothesised between the two tasks (see also de Ribaupierre et al., 1989). First, Peanut-P should be easier than Peanut-C, because of a lower informational load. Secondly, the use of spatial patterns or chunks is more likely in Peanut-P due to a greater homogeneity in the information to be encoded; if two or more purple dots can be encoded as a single chunk, the difficulty of the task is lowered further. In Peanut-C, it is necessary to recall positions and colours and to match them correctly; this requires the co-ordination of visuo-spatial and verbal encoding and is therefore hypothesised to draw on the resources of the Central Executive. In terms of Pascual-Leone's model, the necessity to match colours and positions demands probably an additional activation by M, monitored by executive schemes. Thirdly, although being nonverbal in nature, both tasks are assumed to require a visuo-spatial and a verbal encoding (the colours as well as the positions are nameable), particularly with respect to positions. The different positions can be named and they are spatially located; in addition, as already mentioned, there is a certain likelihood that subjects chunk several positions by creating spatial patterns. However, the relative importance of each type of encoding differs between the two tasks. Incidentally, it probably also varies among different types of subjects, but individual differences will not be analysed further in the present paper. With respect to Peanut-C, in which subjects had to retain not only positions but also colours, it is suggested that the relative weight of verbal encoding is greater for the encoding of colours than for positions. Reciprocally, the relative weight of spatial encoding is larger in encoding positions than colours. This point will be analysed more in detail in a later section.

We had a fourth hypothesis with respect to the difference between the two tasks, which had to do with the maximal performances possible. Neo-Piagetian models predict that performances are severely constrained by limits in the amount of information that can be processed. This should result in a relative invariance of performance across items of different complexity, once the processing limits are reached. In the Peanut tasks, this implies that subjects should recall approximately the same number of dots independently of class complexity. For instance, a subject whose upper limit corresponds to two units of information should pass items Class 1 and Class 2, and should not recall more than two correct dots on the more difficult items, regardless of whether items are of Class 3, 4 or 5. We assumed that this would apply to Peanut-C only; in this task, the number of correctly recalled dots should remain stable across classes, beyond a certain level of difficulty corresponding to the child's processing limits. In contrast, in Peanut-P, stability in performance was not expected, for the two reasons stated above, that is, the lower informational load and the greater facility to encode spatial patterns. Moreover, the opportunity for chunking increases with the number of dots. Consequently, the number of correctly recalled dots should no longer be invariant across classes, but should increase with complexity.

Results were consistent with these hypotheses. Table 2 shows that the number of correct items was higher for Peanut-P, attesting to its greater facility. All analyses of variance conducted on cross-sectional data showed a main effect of the task. In the Age × Task × Year of Testing three-way analysis of variance which was described earlier, the main effect of Task was significant, $F(1,96) = 791.02$, $P < 0.01$, as well as the Age × Task interaction, $F(3,96) = 16.15$, $P < 0.01$. Scheffé tests showed the Task effect to be significant for each age group and the Age effect significant in each task; however, the Task effect was larger for the older age groups, which was to be expected if older children apply more readily facilitating strategies. The difference between the two tasks is not due to an order effect: Indeed, the Peanut-C task was always administered after the Peanut-P one, and, given the effects of retest which were observed, it is likely that the difference would have been even larger had the two tasks been administered in a different order.

Figure 2 reports the mean number of *correctly recalled dots* by cohort, class complexity (C2–C6), and year (Years 1–5). It can be observed that performance increased steadily with class complexity in Peanut-P (top panel), this being replicated for each age and assessment. In contrast, performance tended to be stable in Peanut-C (bottom panel), or even to slightly diminish. When the overall difficulty of the task was relatively low, as for instance on Year 3 or Year 5 for cohorts 8 and 10 (these subjects were then respectively aged 10 and 12, and 12 and 14), performance increased up to Class 4, after which it remained stable. This was confirmed by analyses of variance conducted on the cross-sectional data obtained each year. For instance, on Year 5, the Age (4) × Task (2) × Class (5) three-way analysis of variance performed on the number of dots recalled per class (Class 2–6) showed a main effect of Age ($F(3,96) = 42.1$, $P < 0.01$), Task ($F(1,96) = 790.7$, $P < 0.01$), and Class ($F(4,384) = 188.3$, $P < 0.01$), as well as the following interactions: Class × Task ($F(4,384) = 153.6$, $P < 0.01$), Class ×Age ($F(12,384) = 12.3$, $P < 0.01$) and Age × Task × Class ($F(12,384) = 2.54$, $P < 0.01$). Of particular interest here is

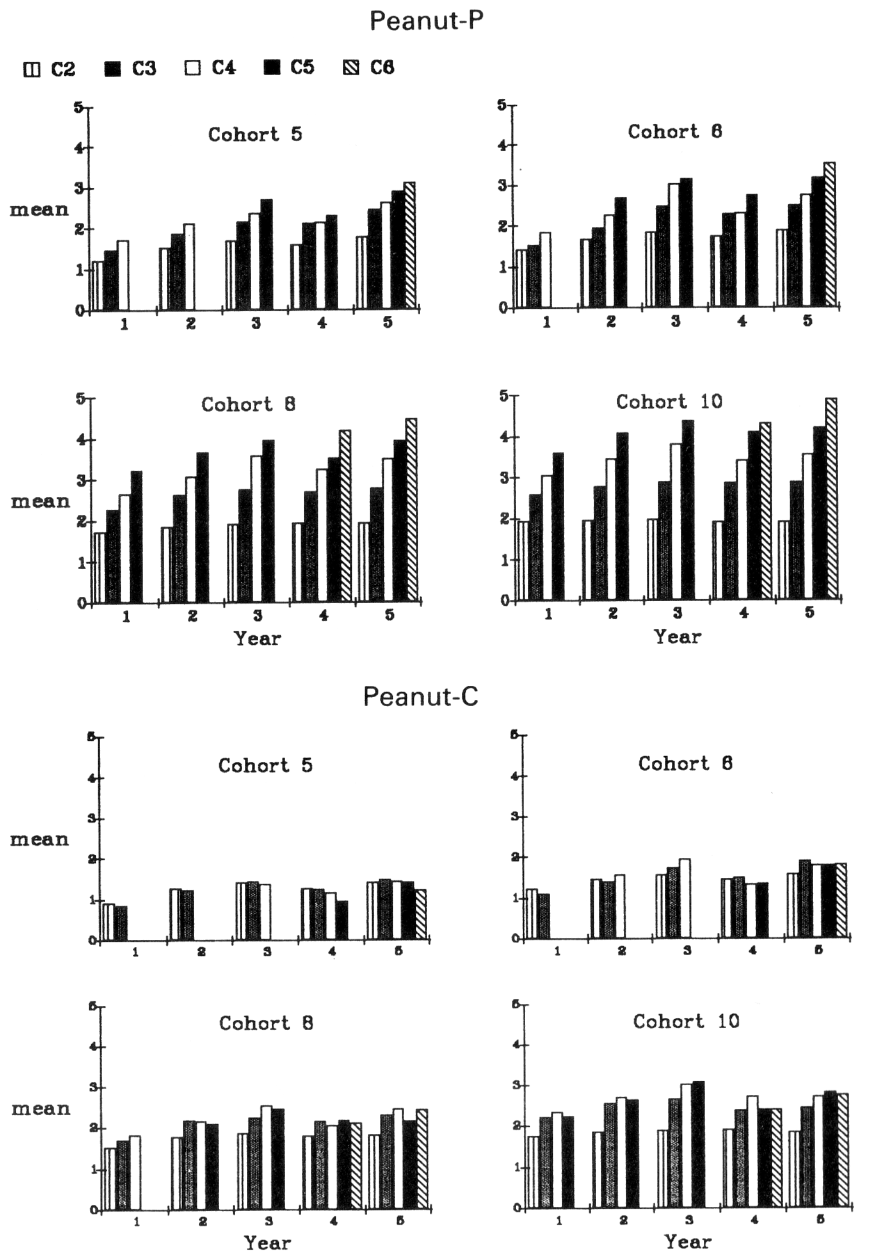

FIG. 2. Mean number of correctly recalled spots by Cohort, Class, and Year (C2–C6: Class 2 to Class 6 items). Top panel: Peanut-P. Bottom panel: Peanut-C.

the Class × Task interaction. Scheffé tests showed that all between-class differences were significant in Peanut-P. In contrast, only the difference between the two easiest classes were significant in Peanut-C. This is, of course, due to the ceiling effect in Classes 2 and 3, particularly for the older cohorts: Subjects cannot obtain a score higher than 2 in Class 2 or higher than 3 in Class 3, even though they are capable of retaining more dots; therefore, they obtain higher scores in Class 4 items than in either of these two classes. Between-class differences were, however, not significant from Class 4 on. Similar effects were obtained each year: The Class × Task interaction was always significant (F ratios were $F(2,192) = 32.09$, $F(1,192) = 47.65$, $F(3,288) = 129.46$ and $F(3,288) = 97.04$ for Years 1, 2, 3, and 4 respectively) and Scheffé tests showed that only the easiest classes (up to Class 3) were different in Peanut-C, while all between-class differences were significant in Peanut-P.

The greater difficulty and stability obtained in Peanut-C is due to the necessity to match colours and positions. This was confirmed by means of a different score: the sum of correct colours and correct positions recalled (Co + Po), independent of whether they were correctly matched. This sum was further *divided by two*, to make it directly comparable to the number of dots in the stimulus. Results turned out somewhat differently in the three-way analyses of variance comparing this score for Peanut-C with the number of correctly recalled dots in Peanut-P. On Year 5 again, the Age × Task × Class three-way analysis of variance also showed a main effect of Age ($F(3,96) = 44.3$, $P < 0.01$), Task ($F(1,96) = 95.6$, $P < 0.01$), and Class ($F(4,384) = 526$, $P < 0.01$). All interactions proved significant, too. However, the analysis of the three-way interaction ($F(12,384) = 2.54$, $P < 0.01$) by means of Tukey tests showed that the two tasks no longer differed, except for the two older age groups in the more difficult classes (in Classes 4–6 for Cohort 8 and in Classes 5 and 6 for Cohort 10). All classes differed significantly from each other, in both tasks, in contrast with the analyses conducted on the number of correctly recalled dots. Similar effects were obtained on the first four years: on Years 3 and 4, a three-way interaction was also obtained ($F(9,288)$ were respectively 4.28, $P < 0.01$ and 3.06, $P < 0.01$), showing an effect of Task only in the older cohorts and the more difficult classes, whereas the Class effect was significant in both tasks. In Years 1 and 2, the three-way interaction was not significant; however, analyses of the two-way interactions obtained (Age × Task, Age × Class and Version × Class) showed that again the effect of Task showed only in the more difficult classes (it was not more pronounced in the older subjects), whereas the Class effect remained significant in both tasks. This means that subjects now retain as much information, if not even more, in Peanut-C than in Peanut-P; because it has been divided by two, the Co + Po score in Peanut-C has a higher information value than the number of correct positions in Peanut-P. Furthermore, the effect of Class observed with this score in Peanut-C shows that the ceiling in performance observed with the previous score originates in the necessity to match two heterogenous types of information (colours and positions).

It is argued that Pascual-Leone's model can better account for this difference in results than Baddeley's model. Positions and colours alone are probably activated not only by M-operator but also by other operators which allow for a less effortful encoding, resulting in an increase in performance across classes. However, the matching of colours and positions can only be handled by an M-activation, together with the executive schemes. Given the limits in M-power, the number of correctly recalled dots is invariant once the ceiling is reached. In reference to Baddeley's model, it can be suggested that the matching of colours and positions is handled by the Central Executive, whereas the retention of colours and positions alone could be managed by the Articulatory Loop system and/or the VSSP system. However, stability across classes could probably not be predicted.

LONGITUDINAL ANALYSIS: YEARS 1–3 VS. YEARS 4–5

For reasons of space, the results which are reported in this section are based on the number of passed items only. Analyses conducted on the number of correctly recalled dots led to similar results. The overall proportion of passed items by task, cohort, and year of assessment is displayed in Fig. 3 (see also Table 2). It can be observed that the increase was relatively linear over the first three years, for the four cohorts. This linear increase is not congruent with the neo-Piagetian postulate of developmental stages lasting for two years. In view of the M-stages defined by Pascual-Leone for instance, Cohorts 6, 8, and 10 should have progressed from Year 1 to Year 2, but not from Year 2 to Year 3; Cohort 5 should have progressed from Year 2 to Year 3, but not from Year 1 to Year 2. We cannot claim, however, that the results invalidate the neo-Piagetian models because of the retest or practice effects which were mentioned above. The developmental curves observed over the first three years must therefore be understood as pointing to the difficulty of unconfounding learning and developmental changes.

With respect to the comparison of Baddeley's and neo-Piagetian models, results obtained on Year 4 are particularly interesting. Recall that on Year 4, the task was computerised. The consequence was a drastic change in performances, which were considerably lower on Year 4 than on Year 3 despite the interval of one year; for instance, for Cohort 10, performances on Peanut-C "regressed" by more than two years. An Age (4) × Year of Testing (2) × Task (2) three-way analysis of variance comparing Years 3

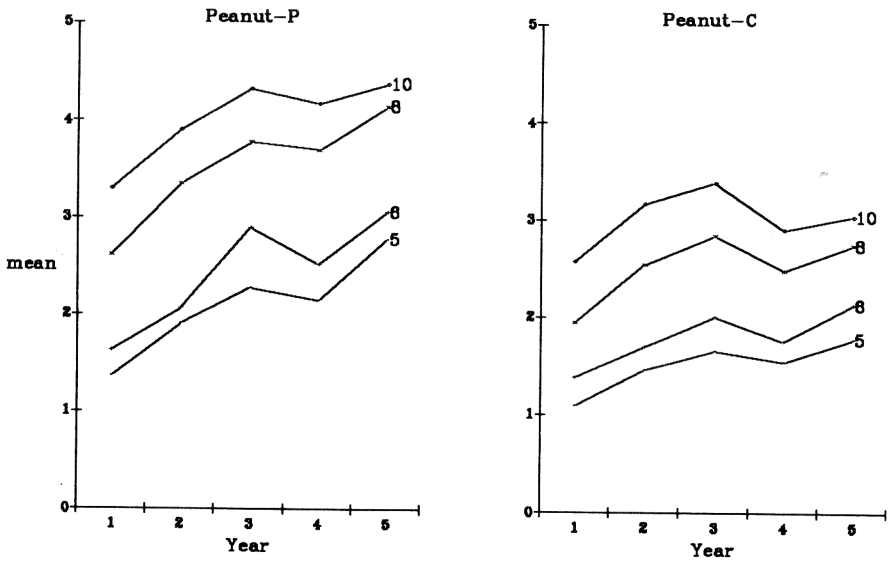

FIG. 3. Mean number of passed items by Cohort and by Year. Left: Peanut-P; Right: Peanut-C.

and 4 only showed a main effect of Age ($F(3,96) = 93.4$, $P < 0.01$), Task ($F(1,96) = 526.6$, $P < 0.01$), and Assessment ($F(1,96) = 27.6$, $P < 0.01$); there was also a significant Age × Task interaction, ($F(3,96) = 9.60$, $P < 0.01$).

Additional analyses using structural equations modelling were conducted on the data for the whole sample, to test further the difference between the two tasks, and to assess the extent of developmental change. They will only be briefly summarised here (for details, see de Ribaupierre & Bailleux, 1992, 1993). In our case, structural equations modelling makes it possible not only to work at the level of latent variables instead of observed means, but also to overcome the difficulties introduced by the changes in the versions administered over the years; recall that the versions differed across age groups in terms of the number of classes used. First, confirmatory factor analyses were used to test the hypothesis that different processes were tapped in the manual task on Years 1–3 on the one hand, and in the computerised task on Years 4–5 on the other. Two models were contrasted: a one-factor model for the five years; and a two-factor model opposing Years 1–3 and Years 4–5. Note that the hypothesis that all years load on a single factor not only implies that the same processes are tapped, but also that a very high stability exists from year to year. Results indicated that a one-factor model was satisfactory for Peanut-P: Although it was not very good ($\chi^2(5) = 11.67$, $P = 0.04$), it was not significantly different from the two-factor model ($\chi^2(4) = 10.30$, $P = 0.036$). For Peanut-C, however, a two-factor model ($\chi^2(4) = 3.96$, $P = 0.41$) was both very good and significantly better than the one-factor model ($\chi^2(5) = 11.67$, $P = 0.04$). The difference observed between the two tasks is consistent with the suggestion that the computerisation introduced more changes in Peanut-C than in Peanut-P. Secondly, latent growth curve analyses were used to estimate the developmental trends in the number of passed items on each task (e.g. McArdle & Epstein, 1987; Rudinger, Andres, & Rietz, 1991). Again, differences were found between the two tasks. The slope of the change was steeper in Peanut-P than in Peanut-C whether in the first three years or from Year 4 to Year 5; it was also more linear in Peanut-P from Year 1 to Year 3. The absolute decrease in performance from Year 3 to Year 4 was larger for Peanut-P; however, when compared to the level in performance observed in previous years, subjects "regressed" relatively more in Peanut-C and did not "recover" as well. In the latter task, their performances on Years 4 and 5 were identical to those of Years 2 and 3, respectively; in Peanut-P, despite the drop on Year 4, the level on Year 5 was the highest of the five years.

Our current hypothesis is that underlying processes are altered by the change in the response mode. In Baddeley's terms, the concurrent monitoring of a computer mouse can be considered to draw heavily on the VSSP system, just like the Peanut task itself; as a consequence, less processing resources are left for retrieving information. In addition, the Central Executive is probably also called for, to co-ordinate the two tasks. In Pascual-Leone's terms, the monitoring of the mouse calls for an activation by M, unless it is completely automatised. In addition, there might be an incompatibility between the displacement of the mouse and the displacement of the dot, particularly with respect to the up and down movement (on a horizontal vs. a vertical plane). This renders the monitoring of the mouse a misleading task, requiring the intervention of the I-operator. The difference in slope in the two Peanut tasks may be due to the relatively higher involvement of M-power in the Peanut-C task, which was discussed earlier.

Colours vs. Positions

If the monitoring of a mouse is considered not only to require supplementary resources, but also to constitute a spatial concurrent task, interfering with the placement of the dots on the screen, the interference should be stronger for the position score. To investigate this, partial scores were compared for Peanut-C: correct colours independent of positions and correct positions independent of colours.

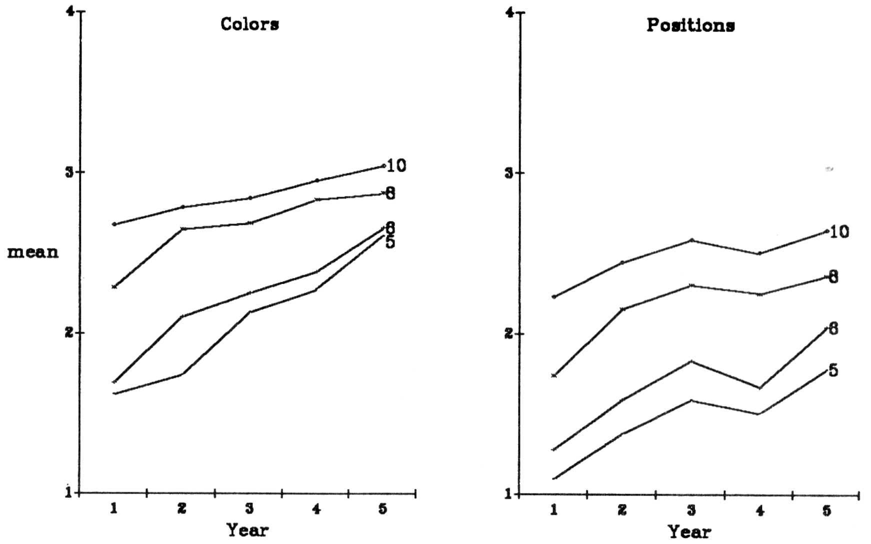

FIG. 4. Peanut-C: Mean number of correct colours (left) and positions (right) by Year and by Cohort.

Figure 4 reports the mean number of colours and of positions recalled, by Year and by Cohort. As expected, the drop from Year 3 to Year 4 was greater for the Position score.

In order to compare the developmental changes in both scores over the five years, an Age (4) × Year of Testing (5) × Type (2, Position vs. Colour) three-way analysis of variance was made. All effects were significant, including the three-way interaction, $F(12,384) = 3.99$, $P < 0.01$. Because effect of assessment may be confounded with changes in version over the years, four separate analyses of variance, in which the number of classes was kept constant, were also conducted on each pair of consecutive assessments. The focus being here on the change from Year 3 to Year 4, detailed results are given for these two years only. The four-way analysis of variance (4 Age groups × 2 Years of testing × 2 Types × 3 Classes, for Class 2 to 4) showed a main effect of Age ($F(3,96) = 55.1$, $P < 0.01$), Assessment ($F(1,96) = 6.74$, $P < 0.01$), Type ($F(1,96) = 343.2$, $P < 0.01$), and Class ($F(2,192) = 652$, $P < 0.01$). Of interest here is the Type × Year interaction ($F(1,96) = 12.7$, $P < 0.01$). Further analysis of this interaction by means of Scheffé tests showed that the effect of Type was significant each year, more colours being recalled than positions, and the effect of Year significant for both types of responses, but more marked for the position score. Also, the Year effect was opposite: Progression for colours versus regression for positions. A Type × Year of testing interaction was also obtained in the other analyses, except when comparing Years 2 and 3: $Fs(1,96)$ were 10.8, $P < 0.01$ when comparing Years 1–2 and 9.65, $P < 0.01$ for Years 4–5, but only 1.96 for Years 2–3. This shows that the change from year to year was usually less important, although still significant, for colours than for positions. The other interactions obtained in these four analyses were: Age × Type, Age × Class, and Class × Type; they are all due to a ceiling effect in the lower classes and/or the colour score. The difference between the two scores remained, nevertheless, significant for all age groups.

These analyses are congruent with the hypothesis that computerisation has a more disruptive effect on positions than on colours recalled. Even if subjects continue to encode positions in the form of patterns in the computerised task, they probably cannot retrieve them as easily nor rehearse them once they start responding, because of the spatial interference created by the monitoring of the mouse. A further argument in favour of the importance of encoding strategies for positions is found in analyses on individual curves: It was observed that the subjects who "regressed" most from Year 3 to Year 4 showed, on average, a higher rate of progression from Year 1 to Year 3. This seems true for the number of correctly placed dots in Peanut-P and the number of positions in Peanut-C, but not for the number of colours (de Ribaupierre & Bailleux, 1993).

DISCUSSION

The main objective of this paper was to argue that it is theoretically interesting to combine two approaches to Working Memory which have developed within radically different perspectives, namely, neo-Piagetian models such as Pascual-Leone's and Case's on the one hand, and Baddeley's model, on the other. It was not to discriminate between these models. Results obtained in a neo-Piagetian task, Mr Peanut, used in a longitudinal study of attentional capacity in children aged 5 to 14, were presented as empirical evidence. The original intent of our longitudinal study was to study developmental changes in attentional capacity from a neo-Piagetian perspective; it is only midway in the project that we realised that our data could be interpreted within Baddeley's model as well. Therefore, the results reported here were essentially meant as an illustration of the argument, rather than as a decisive, empirical demonstration. The latter requires further experimentation (see later); until then, some of our conclusions remain necessarily speculative.

Neo-Piagetian models, in particular Pascual-Leone's model, provided a number of predictions for the present study. The stability in scores which was observed in Peanut-C across different classes of complexity, beyond a certain level, is totally congruent with the hypothesis that limits in M-

power exert constraints on cognitive performance. These limits were, however, lower than those observed by Case: In the manually presented task, they ranged from around 1 unit (defined here as the number of correctly recalled dots) at 5–6 years of age to 3 units at 12 years of age, rather than 4 around 10 years of age as predicted by Case. Incidentally, there is also a rather large variability among the results reported in the different studies conducted by Case and collaborators in which this task was used (Case, 1985; Case et al., 1986; Dennis, 1991). This is probably due to differences in the experimental procedure and demonstrates the difficulty to define what is a unit or chunk from the subject's point of view (see also Flavell, 1984; de Ribaupierre et al., 1989). In the Peanut tasks, a chunk does not coincide with a dot and does not contain the same information value in Peanut-P and in Peanut-C. Pascual-Leone's very elaborated method of task analysis is an attempt to take into account the difference between a situational unit and a subjective chunk (for details on task analysis, see for instance, Alp, 1992; Case, 1992; Pascual-Leone et al., 1978; de Ribaupierre & Pascual-Leone, 1979). It was, however, not applied in the present case.

The developmental curves did not show the existence of stages lasting for two years. Indeed, the increase was relatively linear from year to year for the first three years, that is, before the task was computerised. We argued, however, that our results are not sufficient to refute the neo-Piagetian postulate of the existence of stages, but rather that they attest to a combination of learning and developmental aspects. This is almost unavoidable in longitudinal studies in which the same tasks are used repeatedly; *a contrario*, if different tasks are used, it is difficult to claim that the very same processes are studied (de Ribaupierre, 1993). Pascual-Leone's model can indeed account for such effects: In his model, learning operators come into play mostly during the even year of a stage, enabling, in particular, the acquisition and consolidation of more sophisticated executive schemes (Pascual-Leone & Goodman, 1979). In consequence, changes with age may be linear when they result from a combination of the growth in M-power and of effects of learning. It should also be noted that, contrary to Case's hypothesis (Case, 1985), performances did not tend to an asymptote around the age of 10–11: The difference between the older cohorts was always significant, whether they were aged 8 and 10 (Year 1), 10 and 12 (Year 3), or 12 and 14 (Year 5).

Other results were probably less directly predictable albeit explainable from a neo-Piagetian perspective, namely the drop in performance when subjects had to respond using a computer mouse. This is not a developmental effect. There is indeed no reason to think that developmental changes in this task should undergo regression, as has been sometimes observed in other developmental tasks yielding U-shape curves. On the basis of our theoretical analyses, it was argued that a double encoding, verbal and spatial, is at work in the Peanut tasks. The monitoring of the mouse presumably calls for spatial processes, interfering with the spatial aspects of the Peanut task itself. One could of course claim that the interference is due to poor skills in manipulating a computer mouse; if individual differences were certainly important in this respect—some children had a computer at home, others not—it is sufficient to observe a child using a mouse for the very first time to realise that this is probably not the main factor at work. On the basis of Pascual-Leone's perspective, we suggested that the use of a mouse requires additional activation by M unless thoroughly automatised, and also constitutes a misleading task which calls for better executive schemes and the intervention of the I-operator.

The diminution in performance on Year 4 was also, and perhaps more directly, explainable in terms of Baddeley's model. The Peanut tasks draw upon the resources of both the Articulatory Loop and the VSSP system whereas the Central Executive is probably needed for co-ordinating the verbal, visual, and spatial information. Baddeley and other researchers within the same line of studies provided numerous experimental demonstrations of interference effects when two concurrent tasks rely on the same subsystem. Their results can thus directly be used to understand the change in performance following the computerisation of the task. The use of the mouse is assumed to rely on the VSSP system, like, in part, the Peanut task itself. It is therefore not surprising that performing simultaneously two VSSP tasks lowers the scores despite the one year interval.[9] The finding that the diminution was more marked for the number of positions than the number of colours recalled was a supplementary argument in favour of the mouse task being a concurrent spatial task. Although both types of information can be named, verbal encoding is indeed likely to play a relatively larger role in encoding colours than positions whereas spatial encoding is more important for positions. Thus, if the monitoring of the mouse constitutes a spatial interference, its impact should be higher on the positions score than on the colours score. This is precisely what was found.

It should be underscored that the results presented here do not provide a conclusive, empirical picture of the processes at work in the Peanut tasks, but serve to illustrate our thesis that the two types of models are

[9]Note that, in our study, the concurrent task was performed during the retrieval phase. In most studies, the concurrent task is introduced during the encoding phase and continued or not into the rehearsal phase; in some studies it is even extended to the retrieval phase. Morris (1987) claimed that VSSP is only disrupted by a concurrent task introduced during the encoding phase, and not during the rehearsal phase. Results are, however, still unclear as to when an interfering task is most effective (e.g. Hue & Erickson, 1988).

complementary rather than contradictory. The computerised task was originally introduced for reasons of convenience (stricter conditions of presentation, automatic recording of response, etc.), and was not necessarily meant to be contrasted with the manual task. It is therefore very difficult, in the present study, to assess the extent of interference created by the use of the mouse. A number of additional experiments and converging operations are necessary.

First, the comparison was longitudinal; it is likely that the interference was somewhat compensated by a developmental change. One could argue that the results reported in the present paper are artefactual, hence our conclusions unwarranted, due to a confound between age and method. Note, however, that these two effects work in opposite directions: Whereas the modification in the response mode leads to a regression in performance, changes with age should be accompanied by enhanced peformances. Performance increased in the first three years of the study; an increase was again observed from Year 4 to Year 5. One can therefore be rather confident that the drop in performance observed on the fourth year is a reliable result. A cross-sectional study is nevertheless needed, comparing two groups of children, one with a manual presentation, the other with a computerised presentation using a computer mouse as a mode of response.

Secondly, a much more direct test of the role of verbal and spatial encoding is needed, by systematically introducing selectively interfering tasks. Tasks such as articulatory suppression and easy spatial tasks (e.g. drawing circles or eight-like shapes on a sheet of paper) should be given concurrently with the Peanut tasks. Our hypothesis is that both types of concurrent tasks should produce disruption in performance. Combining two types of concurrent tasks with different modes of response should allow a comparison of interference effects, at the time of encoding and/or retrieval. We also intend to compare a sequential presentation with the simultaneous one; presenting the coloured dots sequentially should prevent subjects from creating spatial patterns and reinforce the role of verbal encoding. A number of these additional experiences are presently in progress in our group.

To sum up, despite its drawbacks, this study illustrated that a same set of empirical findings are compatible with two very different models of working memory, showing that these models might be complementary rather than contradictory. Pascual-Leone's neo-Piagetian model, and to some extent Case's model, provided the ground for the longitudinal study itself; it could also account for the drop in performance observed on the fourth year, by means of general mechanisms such as the M- and I-operators. Baddeley's model of WM, and perhaps still more the numerous empirical studies conducted in this direction, provided more specific explanations of the interference effect; it has been shown repeatedly that two tasks calling on a same subsystem, as we assumed was the case for the Peanut task and for the monitoring of the mouse task, should indeed lead to a diminution in performance. Our propositions of similarities between the two types of models, however, remain still highly speculative and we do not want to convey the idea that Baddeley's and neo-Piagetian approaches are totally superposable. There remain a number of important divergences between them, both at an epistemological and an empirical level. Finally, we would like to point out that we deliberately restricted ourselves to the comparison of two theoretical models, albeit two predominant ones, whereas there exist a number of other approaches to working memory. There will undoubtedly pass some time before the field of working memory, which is in full expansion, can be considered unified.

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