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Working Memory in Children [and Discussion]

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Phil. Trans. R. Soc. Lond. B 1983 **302**, 325-340
doi: 10.1098/rstb.1983.0058

Phil. Trans. R. Soc. Lond. B **302**, 325–340 (1983)
Printed in Great Britain

Working memory in children

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It is frequently assumed that the development of children's abilities in short-term memory reflects changes in a unitary short-term store. This approach makes only poor contact with recent research on adults, which suggests the idea of a more complex 'working memory' system consisting of a limited-capacity central processor controlling a number of special-purpose stores. Two such stores are (i) the articulatory loop, a subsystem involved in subvocal rehearsal and associated with memory span, and (ii) the visuo-spatial scratch-pad, involved in imagery. This paper considers the applicability of the working memory framework to the study of children's memory. In adults, memory span for words is affected by their length, varying linearly with the rate at which they can be articulated, and thus presumably rehearsed. Studies of the developmental growth of memory span in children show that the same linear relation describes performance, with older children's better memory associated with faster rates of articulation. It appears from this that developmental change corresponds to an increase in the efficiency of subvocal rehearsal, with the decay characteristic of the articulatory loop remaining constant. However, although this simple developmental pattern is observed in memory for sequences of spoken words it is not present when the items are nameable pictures. Further investigation shows that older children use the articulatory loop to remember picture names: their performance is sensitive to phonemic similarity of the names and articulatory interference. However, younger children's performance is not affected by either of these factors but is sensitive to visual similarity. It is suggested that such children may be storing material in the visuo-spatial scratch-pad. An additional aspect of working memory is that separate mechanisms are thought to be involved in memory span and the 'recency effect', the tendency for recent items in a list to be remembered well in unordered recall. A review of evidence obtained with children suggests that age differences in these two phenomena are independent. In general, therefore, it seems difficult to interpret the developmental changes reported here in terms of a unitary short-term store, and it is concluded that working memory provides a more promising approach.

1. INTRODUCTION

Some 10 years ago the dominant theory of adult human memory proposed a structural distinction between the storage systems involved in short-term and long-term retention (Atkinson & Shiffrin 1971). The short-term store was seen as a limited-capacity system responsible for temporary storage and for control processes concerned with the flow of information. It is evident that such a store may play a central role in the many cognitive activities that for various reasons require the temporary storage of information. If so, a larger or more efficient store would be expected to result in more efficient cognitive functioning. Indeed, measurement of short-term memory ability in terms of the memory span was and still is a part of normal IQ assessment, and measures of span tend to correlate reasonably well with general intellectual ability, at least in the course of development. On the other hand, neuropsychological evidence that memory span can be selectively impaired without a corresponding deficit in intellectual performance (Shallice & Warrington 1970) presents a problem for any simple explanation along these lines.

This apparent contradiction might arise from an over-simplistic view of the short-term store itself. In this belief Baddeley & Hitch (1974) decided to explore the functional significance of short-term memory by investigating the effects of performing an irrelevant span-like task designed to place a considerable burden on the short-term store at the same time as engaging in activities such as verbal reasoning, prose comprehension and verbal learning. The results showed some mutual interference between these seemingly disparate activities, but none of them were completely disrupted by the additional short-term memory task. Baddeley & Hitch proposed a working memory system differing from the previous concept of a unitary short-term store to account for their results. Working memory was seen as a set of separate but interacting limited-capacity systems, with the limitation on memory span reflecting only one sub-part of the total system. The components of the working memory system are more fully discussed in Alan Baddeley's paper in this symposium. Briefly, they consist of a central executive, which is mainly involved in control processes and governs two or more slave subsystems. Two of these subsystems, the articulatory loop and the visuo-spatial scratch-pad, have been quite thoroughly investigated.

(i) *The articulatory loop* stores speech-coded information and makes use of a subvocal rehearsal system. Performance in memory span tasks is poorer for words with long spoken durations or words that are phonemically similar, and both these effects disappear when rehearsal is disrupted by requiring irrelevant articulation during presentation of the memory materials (Baddeley *et al.* 1975; Murray 1968). Such results are consistent with the involvement of a speech-based store. In a quantitative analysis of the word-length effect, Baddeley *et al.* showed that people can remember as much as they can articulate in 1–2 s rather than a fixed number of items. Thus the articulatory loop appears to have a limited capacity which is time-based rather than item-based.

(ii) *The visuo-spatial scratch-pad* is a corresponding system for the active maintenance of visuo-spatial information, and is disrupted by concurrent spatial activity (Baddeley & Lieberman 1980).

Baddeley & Hitch also suggested that the recency effect in immediate free recall, a phenomenon that had previously been attributed to the unitary short-term store, was not associated with any of the components of working memory identified at that time. Subsequent research has refined and elaborated some of the details of working memory (Salamé & Baddeley 1982) and has explored the involvement of the system in such important cognitive skills as reading (Baddeley 1979; Baddeley *et al.* 1981) and arithmetic (Hitch 1978*a*, *b*).

We have begun to explore developmental changes in the components of working memory in children using memory span and the related task of short-term serial recall. It is well known that there is a developmental increase in memory span, and several hypotheses have been advanced to explain this. Chi (1976) draws attention to two classes of explanation, those that suggest an increase in storage capacity with age and those that propose changes in control processes. But this distinction, although important, is framed in terms of a unidimensional short-term store similar to that proposed by Atkinson & Shiffrin (1971), and this may not be the most effective approach. More generally, much of the debate concerning developmental changes in memory has been conducted, either explicitly or implicitly, within the framework of the Atkinson–Shiffrin model. Case *et al.* (1982) adopt a more complex position in which total processing space is seen as the sum of two separate components, operational space and storage space. Case *et al.* account for developmental changes in span by suggesting that total processing capacity does not change but that operational efficiency increases and so more space is available for storage. This theory is closer to the concept of working memory than that of an undifferentiated system, but does not refer to potentially important distinctions between special-purpose storage systems. Furthermore, in a recent review of the evidence, Dempster (1981) favours the idea of developmental changes in processing efficiency and specifically rejects the idea that the articulatory loop is an important factor. For these reasons it seemed worthwhile to begin a systematic assessment of the applicability of the concept of working memory to the study of children's memory.

Although this paper is principally devoted to the development of children's *memory*, two longer-term aims of our research can also be mentioned here. The first is to use developmental data to test hypotheses about memory in adults. For example, developmental differences may give further evidence about dissociations between subsystems of working memory that may or may not correspond to distinctions based on the study of adults. The study of children may be a particularly fruitful source of evidence if the development of components of working memory proves to proceed at different rates. Just as neuropsychological evidence has proved of great value in testing and developing the working memory model and other models of human memory, so developmental evidence may be able to play an equally useful role. It has the added advantage that it does not depend on very small numbers of subjects nor is it contaminated by the effects of multiple deficits, which often make the neuropsychological work difficult to interpret.

The second longer-term aim is to relate developmental changes in the capacity and use of working memory to more general changes in cognitive abilities. Studies of the involvement of working memory subsystems in the development of cognitive skills such as reading and arithmetic are particularly relevent here. Furthermore, several authors have suggested that attentional and short-term memory limitations may limit the acquisition of general cognitive abilities. For example, Pascual-Leone (1970) has analysed the Piagetian stages of cognitive development in terms of the demands they place on 'M-space', a general capacity for the temporary storage and transformation of information that can be assessed by performance in tasks such as backwards digit span. Pascual-Leone argues that there is a maturational increase in M-space that corresponds closely to values obtained by analysing the improving logical abilities of the child. A related position is taken by Halford & Wilson (1980), who also suggest that much of the development of cognitive ability is contingent upon a maturational increase in short-term memory capacity. As in much of the research on children's memory, however, these approaches tend to assume that what develops is a unitary, general-purpose capacity. As we have already argued, such a view is too simplistic if working memory in children has special-purpose subsystems like those identified in adults. Clearly, a better understanding of working memory in children might contribute to the study of general cognitive development by relating changes in separate subsystems to specific aspects of cognitive abilities. As has been stated, however, the immediate concern of this paper is more modest in scope and examines the applicability of the concept of working memory to age-related differences in children's retention.

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2. Articulatory loop

Evidence about the development of the articulatory loop has been provided by Nicolson (1981), who examined the effect of word length on short-term memory in groups of children aged 8, 10 and 12 years. Sequences of words containing 1, 2, 3 or 4 syllables were presented visually for immediate serial recall by using the procedure adopted by Baddeley *et al.* (1975, expt 6). In addition, speed of articulation was assessed by having the children read aloud printed lists of the four types of material. The results of this study are illustrated in figure 1, which shows recall plotted as a function of articulation rate as the latter varied with age and

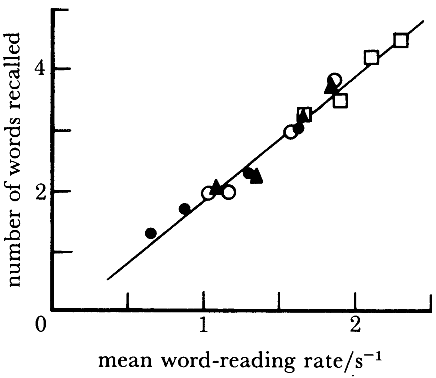

Figure 1. Relation between number of words recalled and rate at which they are read aloud in four age groups: ●, 8 years; ○, 10 years; ▲, 12 years; □, adult. From left to right the data points for each group correspond to words of four, three, two and one syllables. (Data replotted from Nicolson (1981).)

materials. A clear word-length effect was obtained in all the age groups, and recall showed the expected general improvement with age. What is particularly interesting about these data, however, is that the slope of the relation between recall and articulation rate remains constant, suggesting that the capacity of the articulatory loop does not change during this period of development. The graph also shows results previously obtained by Baddeley *et al.* with adult subjects, and perhaps surprisingly these too appear to fit the same linear relation. Nicolson suggests that the improvement in memory with age is not the result of a change in storage capacity but is due to an increase in processing efficiency that is indexed by speed of articulation. Within the working memory framework, it can be suggested that the time-based capacity of the articulatory loop remains constant during development but faster rehearsal increases the rate at which decaying traces can be refreshed, and hence the number of items that can be retained. Although Nicolson's data are strictly correlational, it seems plausible to view the developmental improvement in articulation rate as an example of the well known effects of practice on motor skills, with the change in retention performance consequent upon this increase in verbal fluency.

In view of the potential significance of the quantitive developmental relation discovered by Nicolson, we began our own investigations by assessing its generality. There is a large literature on children's short-term memory abilities that suggests that rehearsal strategies are not present in children below the age of 7 or 8 years. Many of these experiments have used nameable pictures of objects or animals rather than printed words, to avoid complications arising from younger children's very limited reading abilities. In a frequently cited study, Flavell *et al.* (1966)

observed children's lip movements in a memory task in which a sequence of pictures was presented for subsequent recall after a few seconds delay. Older children made lip movements throughout the retention interval, suggesting that they were rehearsing the picture names. However, children 5 years old made lip movements only during presentation of the pictures and showed no signs of rehearsal during the retention interval. Subsequent research showed that young children could be trained to rehearse during the delay and that their retention was thereby improved (Keeney *et al.* 1967). Flavell suggested that the younger children were able to create verbal mediators for the pictures while the pictures were physically present but lacked the ability to continue to produce them (rehearse) when the pictures were no longer present. Further evidence is supplied by Conrad (1971) who manipulated the phonemic similarity of the names of pictures in a memory span task. As has been seen, in adult subjects the interfering effects of phonemic similarity have been attributed to the use of the articulatory loop. Conrad found that children over 5 years of age showed poorer memory for sequences of pictures with rhyming names compared with control sequences. Children younger than about 5 years showed no such effect, suggesting that they were not using the articulatory loop. Thus it seemed to us highly probable that the smooth developmental progression demonstrated by Nicolson would break down if slightly younger children were tested on memory for pictures whose names varied in word length. Such a result would supplement Conrad's findings by using an alternative indicator of the articulatory loop.

The findings just discussed used pictures to assess the memory capacities of young children; this is necessary if visual presentation is to be used, because the children cannot read. However, this procedure raises problems of its own. According to one recent suggestion, phonological encoding is an optional process for visual inputs whereas it is obiligatory for auditory inputs (Salamé & Baddeley 1982). Thus the use of picture materials may underestimate young children's capacities to rehearse because they may have difficulty dividing attention between the process of translating the visual input into a verbal code and actively maintaining verbal representations of previously presented items. In this context it is interesting that in adults irrelevant articulation removes the effects of word length and phonemic similarity on memory for *visually* presented sequences of words or letters, but this result is not obtained with *auditory* lists (Baddeley *et al.* 1975; Murray 1968). Such findings are consistent with a distinction between optional and obligatory coding processes on the assumption that irrelevant articulation blocks phonological coding of visual but not auditory inputs. Thus it seemed likely that the asymmetry between modalities in adults might have a developmental counterpart. This is an example of the very way in which developmental evidence may serve to confirm and illuminate our understanding of adult memory processes. We therefore decided to compare spoken and pictorial presentation of the materials in our own investigation of the development of the word-length effect.

In an experiment we carried out together with Alison Dodd (Hitch *et al.* 1983) children 6, 8 and 10 years old were tested for immediate recall of sequences of either spoken words or a corresponding set of pictures presented at the rate of 1 item every 2 s. Their task was to repeat back the items in order of presentation, retention being scored as the number of items recalled in their correct position. Word length was varied by presenting sequences of items with names of one syllable (e.g. *book*, *pig*), two syllables (e.g. *pencil*, *tractor*) or three syllables (e.g. *banana*, *policeman*). In the picture condition, slides of coloured line drawings were presented in succession at a single spatial location by using a back-projector. In the spoken condition, the female experimenter simply recited the names of the items with normal intonation. To ensure that the memory task was neither too easy for the oldest children nor too difficult for the youngest, sequence length was varied among the different age groups. The children aged 10 years were given lists of five items, those aged 8 years lists of four items and those age 6 years lists of either four spoken words or three pictures. These precautions proved successful. However, although they are unimportant in relation to detecting the presence or absence of effects of word length on recall, they tend to minimize age differences in absolute levels of performance. This should be borne in mind in assessing the results of the experiment.

TABLE 1. EFFECTS OF WORD LENGTH (NUMBER OF SYLLABLES) AND METHOD OF PRESENTATION ON NUMBER OF ITEMS RECALLED IN CHILDREN AGED 6, 8 AND 10 YEARS

age / years	presentation	one syllable	two syllables	three syllables
6	pictures	2.33	2.17	2.10
	spoken words	2.85	2.58	1.81
8	pictures	2.29	2.07	1.96
	spoken words	3.13	2.85	2.21
10	pictures	3.00	2.63	2.28
	spoken words	3.11	2.93	2.18

Table 1 summarizes the results obtained. For the oldest children, memory declined with increasing word-length of the materials to an equal extent with both pictorial and spoken presentation. In the youngest children, however, word length had a clear effect on memory for spoken sequences but the differences obtained with pictures were unsystematic and entirely nonsignificant. The middle group gave intermediate results, with the effect of word length on picture recall just failing to reach significance. A further experiment confirmed the differential pattern of word-length effects for pictures and spoken words in children 6 years old, so this result can be accepted with some confidence.

The results are therefore clear: manipulation of word length shows a different developmental pattern in memory for pictures and spoken words. In terms of the working memory system, older children appear to use the articulatory loop to remember both types of item, but younger children do not use the loop to remember picture names, even though it is apparently available for storing spoken inputs. As suggested earlier, the most obvious interpretation is that the extra operation of verbal recoding of the pictures accounts for the developmental disparity between pictures and spoken words. However, children 6 years old could clearly perform this operation because they could all name the pictures aloud during a pretraining session, and the memory task itself required verbal recall. Furthermore, when a subsequent experimental session was run in which the 6 year age group were instructed to whisper the name of each picture subvocally as it was presented there was no sign of the emergence of the word-length effect. The absence of verbal rehearsal despite the availability of a verbal code in the younger children confirms the earlier observations made by Flavell *et al.* (1966) and the previous work of Conrad (1971). However, it would seem quite misleading to adopt Flavell's interpretation of a general production deficiency at this age in view of the radically different results obtained with spoken presentation. A possible explanation of the effect of presentation mode is to suggest that the process of naming pictures is slow in younger children and taxes the central executive

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component of working memory, leaving insufficient spare capacity for the rehearsal of name codes in the articulatory loop. This explanation implies that children 6 years old can rehearse, more slowly but in much the same way as adults, in the absence of executive overload, as in spoken presentation. N. Thompson & C. Hulme (personal communication), using spoken presentation, found reliable word-length effects in children as young as 4 years old, which would appear to extend this conclusion to even younger children. Many developmental psychologists would find the suggestion that such young children are capable of active subvocal rehearsal

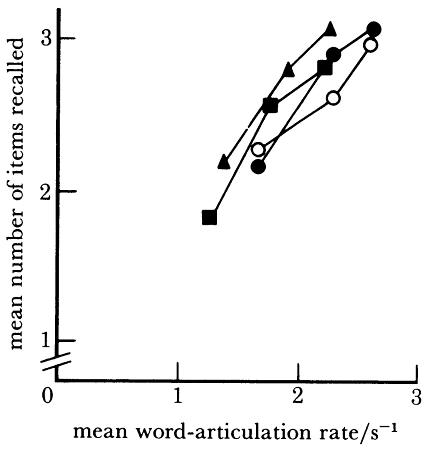

FIGURE 2. Relation between number of spoken words (filled symbols) or picture names (open symbols) recalled and rate at which the items can be spoken aloud in three age groups: ■, 6 years; ▲, 8 years; ●, ○, 10 years. From left to right the data points for each group correspond to words of three, two and one syllables. (Data from Hitch, Halliday & Dodd, unpublished.)

implausible in the extreme and we ourselves tend to share such a suspicion. We are therefore faced with an intriguing choice: either the concept of working memory in adults is suggesting fresh insights into the development of rehearsal processes in children, or our theoretical analysis of the nature of auditory word-length effect needs to be revised. Our current research is tackling this important issue but unfortunately we can take it no further here.

A second aspect of the experimental results is their implications for Nicolson's claim that the time-based capacity of the articulatory loop remains constant during much of development. To assess the capacity of the loop, articulation rates were measured for the various materials used in the present study by showing the children pairs of pictures with names of one, two or three syllables and timing five overt repetitions. Thus for each age group it was possible to calculate the mean articulation rate, expressed in items per second, for each of the three types of material. As expected, articulation rates increased with age and decreased with number of syllables. Figure 2 illustrates the relation between number of items recalled and mean articulation rates in each of the four experimental conditions in which there was a significant effect of word length on recall. When these data were combined in a single analysis the regression was highly significant ($r = 0.91, p < 0.01$) with a gradient of 0.87. Gradients of separate regression lines for each of the four conditions varied between 0.74 and 1.17. Only one of the individual regressions was significant, but the number of data points for each determination was rather small because of the limited attention span of young children. Thus within the rather limited precision allowed by these data it appears that Nicolson's earlier results are confirmed and extended, with the temporal capacity of the articulatory loop remaining constant between the ages of 6 and 10 years. The numerical estimate obtained here is the same order of magnitude but somewhat lower than the values reported by Baddeley *et al.* and Nicolson.†

At this point it should be noted that Case *et al.* (1982) have observed a quantitative relation between auditory memory span and an alternative measure of processing efficiency, the speed with which the memory items can be named. Item identification speed improves with age, and span is linearly related to this variable. Case *et al.* observed this relation in children aged between 2 and 5 years and it is as yet unclear whether it extends through the age range studied here. Such data are not necessarily incompatible with the present argument because naming latencies tend to covary with word length. However, the interpretation by Case *et al.* is rather different and we are currently investigating this issue in greater depth in a parametric study.

In a further experiment conducted jointly with Catherine Pettipher we tested further our hypothesis of developmental change in use of the articulatory loop in memory for picture names. We decided to manipulate the phonemic similarity of the materials and the presence of irrelevant articulation because these are converging operations for the articulatory loop in adults. If the same holds true in children, at 10–11 years old they should show poorer retention of pictures with similar-sounding names, but this difference should disappear when they are required to engage in irrelevant articulation during presentation of the pictures. If younger children do not make use of the articulatory loop to store picture names, their retention should be unaffected by phonemic similarity and there should be at most general attentional interference from irrelevant articulation. The first of these results, a developmental change in the phonemic similarity effect for pictures, has already been reported by Conrad (1971). Our concern was therefore to replicate this effect and assess the predicted additional effects of irrelevant articulation.

Two groups of children with average ages of 5 years 0 months and 10 years 8 months were tested, divided roughly equally between boys and girls. The memory materials were taken from those used by Conrad and were simple line drawings with one-syllable names mounted upon cards. There were two sets, one with phonemically similar names (e.g. *cap*, *cat*, *mat*) and one with phonemically dissimilar names (e.g. *horse*, *train*, *clock*). The children either (i) simply watched the items as they were presented at a rate of one per 2 s in a control condition, (ii) said the word *teddybear* (or *butterfly*) as each item was presented in the irrelevant articulation condition, or (iii) simply tapped the table with a small object in a further interference condition. The tapping condition was included because it was thought to make similar attentional demands to irrelevant articulation without providing speech–motor interference. To avoid some of the methodological disadvantages associated with presenting memory sequences of fixed length, a memory span procedure was used. Each child was initially shown two items and asked to recall their names in the correct order. Sequence length was then progressively increased until the child made errors on two consecutive trials, span being taken as one less than the sequence length at which testing terminated. Four determinations of span were made in each of the experimental conditions, which were tested in a counterbalanced order in two separate experimental sessions.

Table 2 summarizes the results. The spans of the 5 year age group were significantly lower than those of the 10 year age group and were completely unaffected by either phonemic similarity or concurrent activity of either type. In contrast, the spans of the older children were

† Both Nicolson and Baddeley *et al.* used oral reading rate as the measure of speed of articulation which differs slightly from the present index.

markedly impaired by phonemic similarity and, to a lesser degree, by concurrent activity. Further analyses showed that there was no significant difference between memory for the two types of materials in the presence of articulatory interference. Tapping was less interfering than irrelevant articulation and resulted in a significant, though somewhat reduced, phonemic similarity effect. These findings confirm the hypothesis of a developmental change in use of the articulatory loop to store the names of pictures and show further that experimental

Table 2. Effects of phonemic similarity and concurrent interference on memory span in children aged 5 and 10–11 years

age / years	materials	control	tapping	articulation
5	phon. dissimilar	2.06	1.92	2.02
	phon. similar	2.15	1.94	2.04
10–11	phon. dissimilar	4.73	3.81	2.88
	phon. similar	3.38	3.00	2.58

manipulations that give converging results in adults also return a convergent pattern in children. The results obtained with the tapping task suggest that rehearsal of picture names draws on general attentional resources in older children. This would be consistent with our earlier suggestion about the possible difficulty of combining picture naming with subvocal rehearsal, and would lead us to predict much more interference from tapping in children with intermediate ages between 5 and 10 years. The total absence of interference form concurrent activity in children 5 years old is, however, perplexing if we assume that picture naming requires attentional capacity. Informal observation suggests that these children found both the interfering tasks difficult, so either we must revise our views about the difficulty of naming or maintain that these children only named the items during the retrieval phase of the task. A corollary of this second possibility is explored in the next section.

3. Visuo-spatial scratch-pad

If pre-school children do not use the articulatory loop to store picture names, their span of about two items must reflect storage in some other component of the memory system. Within the working memory framework a plausible candidate is the visuo-spatial scratch-pad. Indeed, use of visual storage would be consistent with general theories of cognitive development that propose a reliance upon visual–ionic forms of mental representation in the pre-school years with a subsequent change to the use of verbal–symbolic representations in later childhood (Bruner 1964), or a dominance of 'figurative' over 'operative' knowledge in the same period of development (Piaget & Inhelder 1969).

Experiments on adults suggest that the visuo-spatial scratch-pad is used in tasks involving active visuo-spatial imagery and is disrupted by a concurrent spatial activity such as tracking (Baddeley & Lieberman 1980) or voluntary eye movements (Baddeley, this symposium). Another line of research on adults has examined short-term memory for abstract visual patterns, selected so as to be extremely difficult to name and hence store verbally. A series of experiments by Phillips and his coworkers (see also this symposium) has suggested that short-term visual memory is limited to one or perhaps two abstract patterns, is sensitive to visual complexity and is disrupted by a range of concurrent tasks including attention-demanding, non-spatial activity (Phillips 1974; Phillips & Christie 1977). At present it is not clear whether these independent approaches to visual short-term memory in adults converge on a common underlying storage system. Nevertheless they both agree in suggesting the active nature of visual storage and its limited capacity. Is there any evidence that young children rely on this type of storage?

Unfortunately neither of the above approaches has yet been applied to the study of children's memory. There is some evidence, however, for the importance of visuo-spatial coding in pre-school children's immediate memory for visually presented materials. Conrad (1972) used a matching procedure to assess the memory of children 3–4 years old for a short series of objects differing in colour and shape (e.g. *white square*, *green triangle*) shape alone (e.g. *red square*, *red triangle*) or colour alone (e.g. *green square*, *blue square*). Recall was highest in the condition where the objects differed in both shape and colour. Further tests showed that none of the children could give verbal labels to the shapes, although some were able to name a few of the colours. Retention did not vary as a function of such naming abilities, suggesting that the results were not an artefact of verbal recoding strategies. Further evidence for a visual similarity effect in pre-school children has been obtained by Hayes & Schulze (1977). A matching procedure was used to test memory for sequences of black and white pictures drawn from any of three sets of materials: a phonemically similar set with rhyming names (e.g. *whale*, *nail*, *pail*), a visually similar set in which items were depicted in the same oblique orientation (e.g. *knife*, *arrow*, *bone*) and a control set (e.g. *ring*, *pan*, *bed*). Memory was poorer for the visually similar materials but there was no effect of phonemic similarity. Children had been pretrained to name the pictures and made extremely few errors at this, suggesting that they had no difficulty in discriminating the visually similar items. Using a similar procedure to test pre-school children's memory for visually presented letters, Brown (1977) reported a disruptive effect of the visual similarity of the letters but no effect of their phonemic similarity. The children were able to name the letters in a separate assessment. However, it is not entirely clear that the results of these studies imply the use of a visuo-spatial storage system, because demonstrations of accurate item identification in pretraining are not a guarantee of equally successful identification throughout the memory task, in which several items are presented in succession. Thus it remains possible that the effect of visual similarity may reflect initial encoding processes rather than memory itself. Furthermore, even if pre-school children do rely on visuo-spatial storage, such storage would appear to differ from adult use of the visuo-spatial scratch-pad. Visualization in adults is thought to involve limited-capacity control processes whereas there is no evidence that pre-school children engage in similar activity. Indeed, in our second experiment the memory of children 5 years old for pictures was not disrupted by the attention-demanding activity of concurrent tapping. It may be that the scratch-pad initially develops as a passive storage system taking as its input recently presented visual stimuli. Active control processes for maintaining such information and for transforming visual information that is retrieved from long-term memory may appear only in subsequent development.

To summarize, pre-school children do appear to be relying on visual storage, but the evidence is not incontrovertible and it is not yet clear that such storage can be identified with the scratch-pad. If this can be shown, children of this age may prove to be an interesting subject population because they would provide an opportunity for studying visual memory in the absence of effects due to verbal labelling and rehearsal. The presence of such effects in adults has severely restricted the range of materials that can be used for the study of visual memory in isolation from other systems.

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4. Recency effects

In the modal model of memory (Atkinson & Shiffrin 1971) the limited-capacity short-term store was thought to be responsible for a phenomenon known as the recency effect in free recall in addition to the limited span of immediate memory. Free recall involves the unordered recall of a list of items, and the recency effect is the tendency for the items presented most recently to be remembered better than early items. Interpretation of the recency effect in terms of a short-term store was suggested by the finding that the effect is typically obtained only in immediate recall, being abolished by a short post-list retention interval filled with distracting activity (Glanzer & Cunitz 1966). However, Baddeley & Hitch (1974) found that when their subjects were required to perform a memory span task during presentation of a free recall list, the recency component of free recall was unaffected. If the two phenomena involved a common storage system some disruption should have occurred. Further evidence suggesting that separate mechanisms underlie memory span and the recency effect is reviewed by Hitch (1980). One interesting set of observations is that recency effects can be observed after retention intervals of considerable length in some circumstances, showing that recency is not a uniquely short-term phenomenon (Tzeng 1973; Bjork & Whitten 1974). Baddeley & Hitch (1977) suggested that recency may reflect the use of an ordinal retrieval strategy in which the discriminability of traces is a function of their recency of occurrence. This proposal leaves open the possibility that recency in immediate free recall is a result of applying the strategy to a specifically short-term store. Hitch (1980) proposed that a limited-capacity input buffer, distinct from the articulatory loop and other components of working memory, might be resonsible for the recency effect in immediate but not long-term recall, but this suggestion has yet to receive critical support.

From the developmental perspective, a dissociation between the recency effect and other components of working memory in adults would lead one to expect a similar dissociation in children. The evidence tends to support this view because the recency effect appears to remain relatively invariant during much of development, in contrast to the progressive improvement in memory span. Thus during the pre-school period the recency effect in free recall of lists of pictures or toy objects remains unchanged, developmental change in this task being confined to increased recall of earlier items (Myers & Perlmutter 1978; Thurm & Glanzer 1971). Similarly there are apparently no age differences in the recency effect in free recall of lists of words between the ages of 7 and 14 years, whereas recall of earlier items does show an improvement (Cole *et al.* 1971; Ornstein *et al.* 1975). A corresponding pattern of results has been observed in probed recall where, immediately after being presented with a list of items, the subject is asked to remember the presentation position of a single item drawn from the list (Hagen & Kingsley 1968; Siegel & Allik 1973). Thus, although there appear to have been no direct comparisons of developmental difference in memory span and the recency effect, it seems probable that they have different growth patterns. Further evidence that they reflect separate systems in children is the finding that individual differences in memory span do not correlate with the size of the recency effect (Byrne & Arnold 1981).

The evidence suggesting little developmental change in the recency effect is not difficult to reconcile with the view that it results from the relatively automatic entry of material in a passive input store (Hitch 1980) because in this case developmental changes in control processes of the sort relevant to span are unimportant. However, the absence of developmental change is also consistent with the idea that recency reflects a more general ordinal retrieval strategy, because such a strategy is thought to be relatively primitive, being relied upon by adults only when more sophisticated retrieval strategies based on alternative methods of organization cannot be used (Baddeley & Hitch 1977).

5. Discussion

We sum up briefly by assessing the fruitfulness of using the concept of working memory and its associated experimental techniques to study children. Taking the applicablity of the techniques first, it is encouraging that converging operations for investigating the articulatory loop in adults also behave in a convergent fashion when applied to children. Methods for investigating the visuo-spatial scratch-pad have yet to be applied to children, however, leaving an important gap in our present knowledge. Turning to the applicability of the concept of working memory to children, there are two major considerations. First, the evidence discussed here is extremely difficult to reconcile with the idea of a single general-purpose store. The clearest difficulties for this view are (i) separate patterns of development for memory span and the recency component in free recall, and (ii) the apparent developmental shift from visually based to speech-based storage of nameable pictures. Both sets of observations are readily interpretable in terms of the division of working memory into separate subsystems along the lines already established in adults. Secondly, the concept of working memory appears to have generated some new ideas about the nature of developmental changes in children's abilities in memory. For example, it now seems clear that changes in the speed of subvocal rehearsal may be an important contributor to the growth of memory span. A further illustration is the possibility that previous conclusions about the development of rehearsal strategies, based largely on the use of visual materials, may have seriously underestimated young children's abilities.

It also seems likely that developmental data will have an increasing role to play in advancing the concept of working memory, though no strong claims can be based on the evidence discussed here. Nevertheless we have seen that the usual interpretation of the effect of word length on memory for spoken words would have to be seriously modified if it were shown that very young children do not rehearse spoken sequences and yet do show such an effect. We have also seen how differences between the memory processes for nameable pictures and spoken words emerge more clearly when studied developmentally than when investigated solely in adults, where equivalent differences appear only in the presence of irrelevant articulation. In this example the developmental dissociation confirms the adult data, but there may of course be others where developmental differences suggest previously unsuspected dissociations. We are therefore led to the preliminary conclusion that studying working memory in children is both experimentally viable and theoretically promising. Perhaps it can contribute to our understanding not only of children's abilities in memory, an important topic in its own right, but also the structure of such abilities in adults.

Parts of this research were supported by the Social Science Research Council and the University of Manchester. The authors thank S. E. Avons for commenting on an earlier draft.

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Discussion

C. Hulme (*University of York, U.K.*). I should like to comment on the authors' finding that there is less effect of acoustic similarity on the recall of pictures in young children than in older children. I have found in an unpublished experiment using auditory presentation the same pattern of results: acoustic similarity does not affect recall below the age of 5 years and has progressively more effect up to the age of about 10 years. This poses a logical problem in interpreting the effects of acoustic similarity on the recall of pictures. The absence of an acoustic similarity effect in the younger children does not necessarily indicate that they do not use a speech code when remembering the pictures. Instead it may be that even when a speech code is used they are not sensitive to the effects of acoustic similarity.

The idea that the effects of acoustic similarity on recall may be reduced in young children is also relevant to the authors' suggestion that developmental studies may provide a 'test-bed' for theories in this area. It appears that the effects of word length on recall are constant down to the age of 4 years. The effects of both acoustic similarity and word length are traditionally attributed to the operation of the articulatory loop. If there is a discrepancy between the effects of acoustic similarity and word length in young children we may have to revise the idea that both these effects depend on the same mechanism.

G. J. Hitch. Taking the possible 'logical problem' first, our argument that young children are not using a speech code when remembering picture names does not rest solely on the absence of effects of acoustic similarity but includes converging evidence obtained by manipulating word length and articulatory suppression. All three variables affect older children in a consistent manner and none of the three effect younger children. We are reluctant to complicate interpretation of this simple pattern of results because of a problem arising in the case of auditorily presented materials, especially as we wish to argue that the two modalities differ with respect to the entry of materials into the articulatory loop. Indeed, we would suggest that the discrepancy that Dr Hulme finds between acoustic similarity and word length effects may be specific to auditory presentation.

We are much more sympathetic to Dr Hulme's second point, which corresponds with our ideas about the value of developmental data. The developmental discrepancy that he notes is inconsistent with early conceptualizations of the articulatory loop. More recently Salamé & Baddeley have differentiated between sources of acoustic similarity and word-length effects within the loop. However, their position seems to imply that, if anything, sensitivity to acoustic similarity might develop before sensitivity to word length. Since Dr Hulme's results contradict this they provide a good illustration of the potential of developmental data for examining hypotheses about adults.

M. E. Le Voi (*Human Cognition Research Laboratory, The Open University, Milton Keynes, U.K.*). A previous questioner has expressed difficulty at replicating the authors' finding that the memory span of children 6 years old is not affected by the number of syllables when visual presentation is used. Although precautions were taken to ensure that the children correctly named the stimuli, nevertheless even for children at this age, old habits may die hard. Therefore it is possible that the child saw a picture of a pig and said to himself 'piggy piggy piggy', and when looking at a picture of a banana he repeated 'nana nana nana', thereby in fact rehearsing words of a different length from that required by your experimental manipulation. The authors cannot be sure that no children are doing this, and only a few children need to do this to force the within-subject variance so high at to render any trend insignificant. Do the authors think this is a problem?

G. J. HITCH. The general methodological issue that Dr Le Voi raises is an important one, but we do not think that his specific suggestion is a problem in our own experiments. We chose as memory materials pictures that we had previously found to be given the appropriate 'adult' name rapidly and consistently by almost all children. Although we did find that the occasional child had to be prompted during an initial check on naming before the experiment on memory, this was not particularly associated with young children and never involved correcting an inappropriate abbreviation or elaboration. Thus we do not think the possibility of 'old habits dying hard' particularly relevant for the materials we used. In addition, our young children's recall protocols always consisted of the appropriate names, and we think it unlikely that they were adopting the cumbersome strategy of rehearsing one set of names and then translating them at recall. Furthermore, if they were rehearsing they should suffer interference from concurrent articulation and our second experiment suggest that this was not so.

D. A. ROUTH (*Department of Psychology, University of Bristol, U.K.*). One of the points of departure for the authors' interesting developmental work appears to be the presumption that earlier 'pioneering' studies of working memory (Baddeley & Hitch 1974) have secured some of the necessary foundations. However, it seems to me that this view is very much open to question. Originally, they inherited from Atkinson & Shiffrin (1971) a flow diagram and some fairly cosmic claims about the properties of STS as a working memory. Clearly, a proper investigation of their speculations required the adoption of dual-task methodology allied with a fuller specification of the subsystems underlying a range of psychological functions apart from memory. So far as I have seen, a suitably expanded flow-diagram has not been forthcoming from investigators of working memory, with the consequence that simple-minded experimenters like myself have not found it easy to practise our traditional art of functional ablation. At present we have a considerable body of work which is scarcely satisfactory by the best standards of dual-task investigations, for in none of the extant experiments on this topic do we have secure details of trade-off relations within *individual* subjects. Moreover, when it comes to the matter of the association between rate of speaking and memory capacity, it is still unclear in which direction causality runs, or indeed whether there is a causal connection at all (cf. Dempster 1981). Similarly, there is surely an urgent need to move away from analyses at the level of ecological correlations to analyses at the level of individual subjects, otherwise there is a danger of inappropriate inferences being made at one level of analysis on the basis of findings obtained at quite another level.

G. J. HITCH. Working memory was advanced as an alternative to Atkinson & Shiffrin's concept of short-term storage rather than their total model, and its place in a flow diagram that includes other systems such as sensory and long-term memory has yet to be fully specified. An exception to this is Broadbent's 'Maltese cross' model, but his concept of working memory differs slightly from that presented here. More generally, it is not clear that the experimental technique of 'functional ablation' is dependent upon the availability of a fully specified flow diagram: most research on working memory has adopted selective interference techniques to isolate subsystems by using a logic that does not make assumptions about information flow.

Concerning Dr Routh's second point, we accept that detailed and thorough investigations of trade-off relations within individual subjects need to be performed in dual-task studies. However, our own attempts to do this have met with a number of methodological problems that are not easy to resolve and that hinder progress in this direction.

As regards Dr Routh's third point, we have been careful to acknowledge that a causal interpretation of the relation between rate of speaking and memory capacity is not justified from correlational data alone. Our suggestion that there may be a causal connection has the status of a hypothesis that has yet to be subjected to critical test.

Finally, we are aware of the need to examine relations between variables in individual subjects as well as across groups. After doing this for our first experiment we are confident that the qualitative relation between recall and word-length typically obtains within individuals whenever it is present in group data. However, we have been unable to demonstrate that the linear, quantitative relation between recall and articulation rate holds within individuals as it does for the group. At present we are inclined to attribute this to the small amounts of data collected from individuals, and we are reassessing this question in a current study.

A. Conway (*Department of Psychology, University of Bristol, U.K.*). Would the authors care to comment on possible relations between components (such as the articulatory loop) of the system described by them and by Baddeley and the suggestions of the 'verbal regulation of behaviour' as presented by Vygotsky, Luria and others?

G. J. Hitch. Verbal regulation of behaviour via the 'second signalling system' is essentially a control function, whereas the articulatory loop is conceived as a slave subsystem under the control of a central executive. As such, Vygotsky's and Luria's ideas fall outside the scope of our immediate area of concern. However, they are potentially interesting in that they may be relevant to the question of how children learn to use the articulatory loop during the course of development.

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