Do Developmental Changes in Digit Span Result from Acquisition Strategies?

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This study tested the theoretical proposition that the developmental increase in memory span results from a corresponding increase in the use of grouping strategies. With slow presentation, experimenter-provided grouping eliminated the span differences between sixth graders and adults but, while grouping helped first graders more than adults, a sizable difference in digit span remained. With fast presentation, grouping increased the adults' performance more than the childrens'. Another finding was that both groups of children had greater digit spans with fast presentation than with slow. For adults, the reverse was true.

Memory span for digits doubles from age 5 to adulthood (Chi, 1977) Theories differ about whether this results from structural changes (Cavanagh, 1972; Baddeley, Thompson, & Buchannan, 1975; Nicholson, 1981; Huttenlocher & Burke, 1976; Cohen & Sandberg, 1977), or from changes in rehearsal strategies (Flavell, Friedrichs, & Hoyt, 1970; Belmont & Butterfield, 1969) or grouping and organization (Simon, 1974; Olson, 1973). The latter two theories are usually treated as one in the literature (Samuel, 1978) because it is difficult to separately manipulate grouping and rehearsal conditions. The simplest prediction of this theory is that experimenter-provided grouping will aid the performance of younger subjects more than older subjects: An age × grouping interaction. This is based on the assumption that older subjects already use grouping or rehearsal strategies and experimenter-provided grouping should not help them. It is further assumed that younger subjects can make use of grouping if it is provided for them, but that they do not normally group stimuli for themselves.

While four studies have looked for this predicted interaction (Harris & Burke, 1972; Frank & Rabinovitch, 1974; Huttenlocher & Burke, 1976; and Samuel, 1978), all suffer from the same problem to various degrees.

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The problem stems from the difficulty of comparing groups at different stages of development on any given task since a task that is easy for one group may be difficult for another group. Thus it is important that the groups be compared for the effects of some variable at about the same point on their performance curves (cf. Norman & Bobrow, 1975). This criterion is obviously violated when the memory performance of all groups is compared on lists of a fixed length. Frank & Rabinovitch (1974) and Huttenlocher & Burke (1976) tried to circumvent this problem by presenting several list lengths to each age group. This does not eliminate the difficulty, however, because any given list length will be easier for some subjects than for others. Samuel (1978) used a pilot study to determine the length of list which would lead to a performance level of about 60% for subjects of different age levels. In a subsequent experiment, subjects received grouped and ungrouped lists of the length appropriate for their age as determined by the earlier study. The absence of the age × grouping condition interaction led to the conclusion that the developmental increase in memory span is not a result of improved acquisition strategies. The problem with the Samuel study is that appropriate list length is determined for a group of subjects and this estimate is used on another group of subjects. This makes two assumptions. One is that the subjects of a given age group tested in the pilot study would have the same sample characteristics as those tested later. More important is the assumption that deviations from the validity of that estimate of a length that gives 60% performance for subjects within a given age range would have the same consequence for all age groups. For example, an estimated list length that would lead to 60% performance for a group of subjects would presumably lead to worse performance for half the subjects in the group and better performance for the other half. Our concern is with the subjects for whom the group-derived list length is too long, and particularly those subjects for whom it is exceedingly long. Samuel assumes that his deviation from the validity of the estimate will have the same consequence for all age groups. Work from our lab (Engle, Fidler, & Reynolds, 1982) shows, however, that presentation of list lengths markedly beyond the memory span hurts the performance of young subjects much more than it does that of older children and adults. The comparison must, therefore, be at the same point on the performance curve for each subject. Also, it cannot be assumed that the same processes are involved in trying to remember supraspan lists as are involved in remembering lists of span length. Using the memory span itself as a dependent measure will assure the same level of performance for each subject and allow us to observe more directly the phenomenon to which the above theories have been addressed, i.e., the developmental increase in memory span. Thus, this experiment was designed to test the prediction of the acquisition strategies theory of an age × grouping interaction, with the dependent variable being the memory span obtained under the various conditions

Memory span used diagnostically generally involves digit presentation at one item per second (Wechsler, 1974). However, presentation is generally faster in laboratory studies: Huttenlocher and Burke (1976) and Samuel (1978) used approximately 1.5 items per second; Cohen and Sandberg (1977) used 6 items per second. Presentation rate was manipulated in the current study to see to what extent grouping and rate interacted with age of subject. It is possible that the age × grouping interaction would not be found with fast presentation because younger subjects need more time to rehearse the grouped items or more time to make use of the groups in an organizational schema. In that case, the age × grouping interaction might be found with slow but not with fast presentation.

METHOD

Subjects. There were 12 males and 12 females in each of three groups: First graders (mean age = 6.8, *SD* = .38), sixth graders (mean age = 11.9, *SD* = .28), and college students (mean age = 20.7, *SD* = 3.2). The children were chosen from the public schools in the vicinity of Columbia, South Carolina. The college students came from the university subject pool. The children were average IQ or above and were the appropriate age for their grade. Each subject was tested individually in a quiet room in the school after permission forms had been signed.

Stimuli. The stimuli consisted of 10 sets of 3–9 item lists each chosen from the digits 1–10 excluding the digit 7. The lists were generated by the random number function of a computer with no repetitions. There were five sets of lists arranged in ascending length (from 3–9 items) and five sets arranged in descending length. The lists were recorded in a female voice at 1 digit per second and 2.5 digits per second. A metronome was used to pace the recording. The warning signal "ready" was followed 2 sec later by the first digit.

There were three grouping conditions: ungrouped (grouped by one), grouped by two digits, and grouped by three digits. In the ungrouped condition there was an attempt to present each list in a monotone with no inflection change at the end of the list. In the grouped conditions one space was skipped between each group of digits. It was intended that there be a subtle but distinct inflection change between the groups, with the tone softer and lower on the last digit of each group.

Design and procedure. The design was a 3 × 3 × 2 × 2 factorial with the factors being age of the subjects (1st, 6th, college); grouping size (1, 2, or 3 digits/group); rate of presentation (1 or 2.5 items/sec), and whether the subject started with an ascending or descending set of lists. All factors were between-subjects manipulations.

The memory span was measured by a variant of a procedure introduced by Easby-Grave (1924). The subject was presented the lists in alternating ascending and descending order of length. The *mean* of the longest list

to be recalled perfectly for each of the 10 sets of lists was determined to be the memory span for that subject. Subjects were instructed to write their recall in a strict left-to-right order on answer sheets prepared so that, for each list, the number of blank lines corresponded to the correct number of digits in that list. This was closely monitored by the experimenter. Written recall was used because oral recall has been shown to hinder serial recall of auditorily presented items (Penney, 1979), and unpublished work from our lab (Engle, Note 1) suggested this may be more of a problem for younger subjects.

RESULTS

The mean digit span for each subject was used as the dependent measure in a 3 (Age) × 2 (Rate) × 3 (Grouping condition) factorial analysis of variance. The mean digit span for each group is shown in Fig. 1 (1 digit/second (slow) rate in the left panel; 2.5 digits/second (fast) rate in the right panel.) The most obvious feature of the data is the orderly development of span with age reflected by the Age main effect ($F(2, 54) = 107.6, p < .001$)). While the college students had an overall digit span of 7.5, the sixth graders averaged 6.3 and the first graders 4.1 (just over half that of the adults). The main effect of Grouping ($F(2, 54) = 12.2, p < .001$) showed that performance improved as the size of the group increased, with means of 5.4, 6.0, and 6.6 for group size 1, 2, and 3, respectively. Yet it is obvious that the improvement was not equal for all conditions, and hence the significant Age × Rate × Grouping interaction ($F(4, 54) = 2.9, p < .05$).

Separate 3 × 3 (Age × Grouping) ANOVAs for each of the two rates, and orthogonal comparisons with $df = 54$ and at the .05 level, showed that in the slow (1 item per second) condition, the Age × Grouping interaction only approached significance ($F(4, 27) = 2.05, p > .05$). The mean of the adults' spans showed an increase of only .5 digit going from group size 1 to group size 3 ($t = .9, p > .10$). The first graders went from 3.4 to 4.5 digits (a 31% increase) ($t = 1.85$), and the sixth graders
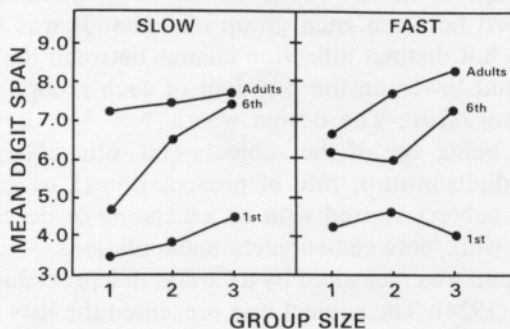

FIG. 1.   Mean digit span as a function of age, grouping condition, and presentation rate.

went from 4.7 to 7.4 digits (a 59% increase) ($t = 4.75$). Grouping by 3's resulted in no significant difference between the adults and the sixth grader's span ($t = .52$, $p > .10$).

Under fast presentation (2.5 digits/sec) the Age × Grouping interaction was significant ($F(4, 27) = 2.78$, $p < .05$). Going from group size 1 to size 3, the first graders showed no effect ($t = .4$, $p > .10$). The sixth graders showed a 19% improvement (from 6.1 to 7.3 items) ($t = 1.99$), and the adults showed a 26% increase (from 6.6 to 8.4 items) ($t = 3.02$). Thus, with the 2.5 digit/second rate there was an Age × Grouping interaction, but the pattern of data was different than that observed with the slower 1 digit/second rate of presentation. Here grouping helped the adults more than the younger subjects, and the youngest subjects showed no improvement as a result of grouping. Grouping actually led to a diverging of performance for the three age groups rather than the elimination of memory span differences.

The analysis focused primarily on the interaction of age and grouping conditions, but the rate variable itself gives rise to an interesting effect. Since most studies of digit span and of serial recall of short lists of items involve ungrouped presentation; and since monotonic nongrouped presentation is suggested in the psychometric use of digit span (Wechsler, 1974), we show a graph of the mean digit span for just the ungrouped condition (size 1) in Fig. 2. A separate analysis of these data showed the Age × Rate interaction to be significant ($F(2, 18) = 3.62$, $p < .05$). Speeding up the rate of presentation hurt the performance of adult subjects, who showed a 6% drop from slow to fast presentation. By contrast, the sixth graders and first graders showed markedly better performance at the fast rate, with the sixth graders being 30% better and the first graders being 23% better. These findings, for both children and adults, support earlier findings from our lab (Engle et al., 1982) that adults do better with slow presentation of short auditory lists while children do better with fast presentation.
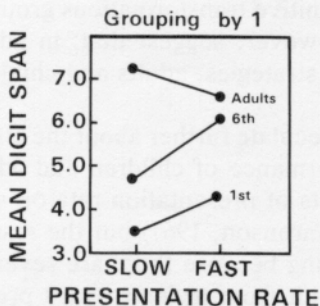

FIG. 2. Mean digit span for the group size 1 condition as a function of age and presentation rate.

DISCUSSION

The question that motivated this study was whether the children s failure to use grouping strategies accounts for the fact that their digit span is only about half that of adults. A seemingly straightforward assumption for any such theory is that experimenter-provided grouping should greatly reduce the developmental difference in span. At the 1 digit/second presentation rate, a rate presumably slow enough for rehearsal to occur, grouping did nearly eliminate the difference between adults and sixth graders. We interpret this to mean that adults already use grouping of the digits and thus external grouping benefits them little. The sixth graders, however, do not impose and use grouping, even though they do use it if is provided. The fact that first graders do not benefit from imposed grouping as much as do sixth graders suggests that a certain level of cognitive maturity is necessary before subjects will make use of imposed grouping. Thus, the difference between adults and children may not simply be that children do not use grouping strategies while adults do. It may be that children as old as the sixth graders can use an organization that is provided for them but for some reason do not group stimuli themselves during acquisition and rehearsal. On the other hand, children as young as the first graders may not be able to use a grouping organization even if it is provided for them.

At 2.5 digits/second, a rate which presumably makes rehearsal difficult, the pattern of results was considerably different. The adults were helped most and the first graders helped least by imposed grouping which is just the opposite of the age $\times$ grouping interaction predicted by a simple acquisition theory of memory span differences. We would simply conclude that memory span differences are probably not the result of a single factor like use of acquisition strategies. The results with the slow presentation rate suggest that the failure to use acquisition strategies does play some role in memory span differences, at least for children like sixth graders who are capable of using grouping once it is provided for them and at presentation rates slow enough for them to rehearse and perform whatever cognitive transformations grouping allows. The results with the fast rate, however, suggest that, in addition to differences in the use of acquisition strategies, adults and children differ in other ways that affect digit span.

We would like to speculate further about the effects of the presentation rate variable on performance of children and adults. There is a sizable literature on the effects of presentation rate on short-term memory performance of adults (Aaronson, 1967) but the results are frequently contradictory and confusing because there are several potential differences in the stimuli that result from trying to vary presentation rate. Thus, a main effect of presentation rate for a given age group is suspect. In both the present study with the ungrouped conditions and in an earlier study

(Engle et al., 1982) we found that presentation rate interacted with the age of our subjects such that adults performed better at slower presentation rates while children (both first and sixth graders) performed better at faster presentation rates. This is an important interaction because it was found twice using the same stimuli with different groups of subjects. And, indeed, since the two different studies used different speakers and the fast rate was different in the two (2.5 and 4/second), the finding is even more secure.

Our interpretation of this finding is that adults can and do actively use acquisition and retention strategies when the presentation rate is sufficiently slow, but the younger subjects do not. In addition to this differential use of strategies we would argue that there is a gradual decay of the echoic memory traces resulting from auditory presentation and that there is echoic information about more items with faster presentation rates since there is less time for decay between items. At the fast rate of presentation the adults have difficulty using acquisition and retention strategies in the short time between items which leads to a decrement in their performance. The children, on the other hand, find themselves better off with the fast rate since there are more of the traces on which their recall is based.

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