"Children's thinking: What develops?"
Siegler.

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Knowledge Structures and Memory Development

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My research has recently centered on the general question of what determines memory development. Roughly 99.9% of developmental data indicate improvement with age: The question is "why"? My research attempts to answer this question in the domain of memory and also the domains of metamemory and reasoning.

The issues addressed in this chapter are very general ones. In the memory domain, the question is: Why do older children and adults remember more than younger children? In the metamemory domain, the question is: Why are older children and adults more aware of their own memory performance than younger children?

FACTORS IN MEMORY DEVELOPMENT

Three factors influence memory development: strategies, knowledge, and capacity. The influence of each are briefly elaborated.

Strategy

The strategy component is an important factor in memory development because older children are adept at acquiring and using strategies to cope with memory tasks. In metamemory tasks, the strategy component may arise from older children's ability to perceive the useful outcomes of strategic intervention. That is, adults are better predictors of their own memory performance because they can judge the strategic requirements and the usefulness of certain strategies for a task (Brown, in press) the faces so quickly? This is the issue that led to the present research. My hypothesis was that the amount and structure of knowledge children had stored in semantic memory about their peers may not have been sufficient to permit fast access to that information. It is as though the information was so poorly structured that children require a longer period of activation (or search) in order to retrieve it.[4] One could speculate further that the inaccessibility of the names prevents the children from actively using any mnemonic strategies that required name manipulations.

Although this research could not conclusively implicate knowledge and structure of the stimuli as the sources of developmental differences in memory span performance, it did seem to suggest that *above and beyond the usage of strategies*, children do have a more limited knowledge of the stimuli, as indexed here by the naming time.[5] Because this difference in knowledge could be of sufficient magnitude to produce an age effect resembling ones supposedly produced by increased capacity, it seemed as valid to speculate that the remaining age differences showed increased knowledge as well as increased capacity.[6]

MEMORY FOR CHESS POSITIONS

As mentioned previously, in order to converge on the notion of constant capacity, we need to attribute developmental differences in recall performance to alternative factors. Throughout this paper, I have argued that in addition to the role played by strategies, recall performance is further influenced by the amount and structure of knowledge children and adults have about the stimuli. The intention of the following study is to assess the extent to which knowledge can affect memory performance independent of age.

Because knowledge generally increases with age and because there appears to be a relation between developmental differences in recall and knowledge of the stimuli (Dempster, 1976), it seems at least plausible to assume that recall improves with age primarily because adults know more, rather than because adults have a bigger capacity. We already know, for example, that recall varies directly with knowledge for adults. Chase and Simon (1973) found that chess knowledge influenced performance on both a perception and a memory task, and similar results have been found with games such as "Go" (Eisenstadt & Kareev, 1975; Reitman, 1976) and baseball (Chiesi, Spilich, & Voss, 1977). However, such a direct relation between knowledge and recall cannot be inferred from existing developmental studies, even though we normally assume that adults know more than children. This is because, first, the amount of knowledge an age group has about a set of stimuli has seldom been directly measured, and second, too many other variables exist to permit such a simple deduction. On the other hand, a more direct relation between knowledge and developmental changes in recall can be shown if we demonstrate better recall in children who have greater knowledge in a content area than adults. The purpose of the next study is to provide such a demonstration.

The subjects for this study were six children (third through eighth grade) solicited from a local chess tournament. Their mean age was around 10.5 years. The adult subjects were research assistants and graduate students from an educational research center. All could play chess to some degree.

Two tasks were used to test memory for chess positions: immediate recall and repeated recall. In each condition, a chess position was presented for 10 sec, followed by recall. In the immediate recall task, the subject immediately placed the appropriate chess pieces on a blank board. Pieces, colors, and location all had to be reproduced perfectly for an answer to be counted as correct. On the repeated recall task, if the subject did not reproduce the entire board correctly the first time, the trials continued until perfect performance was achieved. The sequence and timing of each reproduction trial were recorded on audiotape. The stimuli were eight middle-game positions (averaging 22 pieces) selected from a chess quiz book (Reinfeld, 1945). Four positions were used for each memory task. At the end of the repeated recall trials, each subject was asked to draw partitions around those pieces that s/he thought formed a chunk.

Because only one of the 12 subjects had an official chess rating, some way of assessing the chess knowledge of each age group was needed. This was done in two ways: (1) by how well the subject could predict good moves in a position, and (2) by how quickly subjects could perform the knight's tour task. Following the memory trials and the chunk-partitioning task, subjects were asked to predict the next few moves from the same position. The subject made a move, and if it was correct, the experimenter replied; the subject then predicted the next move, and so on, for two or three moves, depending on the position. When the subject made a wrong move, the experimenter corrected him/her, and the moves were continued from there.[7] The knight's tour task was a modified

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[4] Similar arguments may also be applied to adults with large and small memory spans. Baddeley, Thompson, & Buchanan (1975) found a substantial correlation between adults' memory span and reading speed.

[5] A majority of developmental studies assess children's familiarity with the stimuli by whether they can label (or name) them. In cases where children cannot provide the appropriate labels, the experimenter simply provides them. The differential name-retrieval speed of children and adults in this study clearly highlights the danger of making that assumption.

[6] Remaining age differences will henceforth refer to those not explained by differential strategy usage.

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[7] The correctness of the move was determined by the solution to the chess puzzle in Reinfeld's (1945) book.

version of the one used by Chase and Simon (1973), in which subjects had to move a knight across two rows of the board, with certain constraints, using legal knight moves.[8] The time it takes to complete the moves has been shown to be a gross index of chess knowledge.

As a control, four lists of 10 digits were presented for immediate and repeated recall. The procedure was identical to the chess conditions, except that recall consisted of a written response, and no partitionings were requested from the subjects at the end of the repeated recall task.

Results

The mean knight's tour time for children was around 2.5 min for the two rows, versus 5.5 min for the adults. Hence, the children appeared to have greater knowledge of chess than the adults. On the other indication of chess knowledge, the moves prediction, children's predictions were accurate on about 59% of the moves, whereas adults predicted 44% of the moves correctly. This prediction task did not seem as sensitive as the knight's tour in assessing chess skill, perhaps because the experimenter corrected the wrong moves, which considerably constrained potential subsequent moves.

The most important result of the experiment, though, was that children's immediate recall for chess positions was far superior to adults' (9.3 versus 5.9 pieces), $F(1, 10) = p < 0.05$ (see Fig. 3.3A). In contrast, the children's digit span was lower than that of the adults' (6.1 versus 7.8 digits). Although the digit span differences was not statistically significant, it did replicate the findings in the literature (cf. Table 3.1). The same pattern of results was obtained in the repeated recall task (Fig. 3.3B). It took children an average of 5.6 trials to learn the entire chess position, whereas adults required 8.4 trials, $F(1, 10) = 6.2, p < 0.05$. For the digits, on the other hand, the typical developmental trend was again found – children required 3.2 trials to learn a list of 10 digits, whereas adults required only 2.2 trials – although the difference was not significant.

These results are consistent with Chase and Simon's (1973) findings that subjects with high knowledge recognize many more patterns than do subjects with low knowledge. In conjunction with the previous results on naming time, they suggest that memory performance in developmental studies reflects, to a large extent, the influence of knowledge in a specific content area rather than strategies per se. That is, with the exception of knowledge-specific strategies, the availability of general strategies useful for memory performance should have been comparable in both the digit and chess situations. Hence, general strategies such as rehearsal could not have played a major role in determining developmental differences in recall in this study.

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[8] This modified version was used to save time and simplify the instruction for the children. Basically, the difference was that the knight was permitted to land on the four squares controlled by the two pawns.

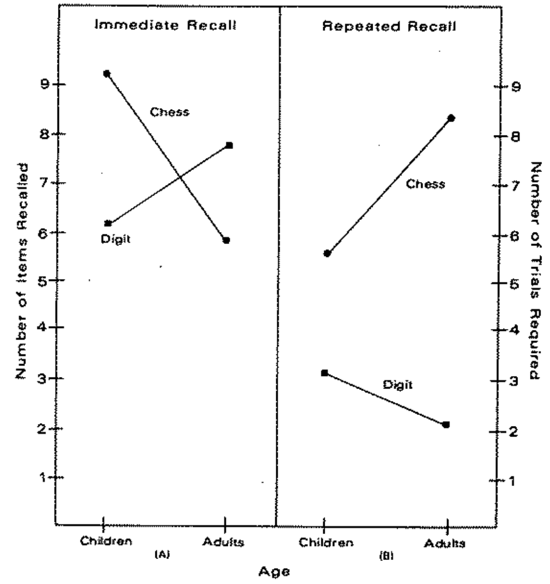

FIG. 3.3 The amount of recall in immediate and repeated recall tasks, for digits and chess stimuli.

Can we similarly rule out the role of capacity in these results? The difference in digit span replicates the standard developmental pattern. Such findings would normally be attributed to a deficient strategy or to a smaller capacity. One way to address the capacity issue is to compare the present results with Chase and Simon's results, in which only adult subjects were tested and in which the adults were assumed to be similar in capacity and strategies. If the results of this study replicate those of Chase and Simon's results in every respect, despite the manipulation of age, then we add support to the hypothesis that capacity is not a very important component.

So far, my results have replicated Chase and Simon's findings in terms of the number of pieces recalled in immediate recall, as well as the number of trials needed to learn the entire board position. It is also important to know how large the memory span is for chess chunks for children and adults. Chase and Simon found that better players recalled more chunks and more pieces per chunk on the first recall trial when chunks were partitioned by an interresponse latency

TABLE 3.1
Digit Span as a Function of Age

Age	*4–5*	*6–8*	*9–12*	*College Students*
Span	4	5	6	7.98

(IRT) of greater than 2 sec. Using a similar technique, the first trial data of the repeated recall task were partitioned into chunks using a 2-sec IRT as boundary. Then the incorrect pieces were eliminated, and the remaining pieces with their existing chunk boundaries were tabulated. From this analysis, we found that children, on the average, retrieved about 4.33 chunks whereas adults retrieved about 2.63 chunks for the first trial, $F(1, 10) = 6.98, p < 0.05$. Hence, children have a larger memory span for chunks, which confirms Chase and Simon's (1973) results. Second, the size of the first and second chunks also tended to be larger for children, although the differences were not statistically significant (see Table 3.2, rows *A*, *B*, and *C*).

In general, these results replicate those of Chase and Simon in showing that better players (here, the children) tend to (1) retrieve more chess pieces from memory in a single recall trial, (2) require fewer trials to memorize the entire chess position, (3) retrieve a larger number of chunks on the first trial, and (4) have larger chunk sizes for the first and second chunks, irrespective of age.

One of the dilemmas these results present is that if the concept of a constant memory capacity is being proposed for children and adults, we should feel as uneasy about obtaining data when children recalled more chunks as when children recalled fewer. Two likely hypotheses have been suggested by Chase and Simon (1973). One is that the better player's chunk structures may have more overlap, so that pieces from one chunk can serve as retrieval cues for pieces from another chunk. The existence of overlapping chunks has since been documented by Reitman (1976) for the game of "Go." By using a pause technique, we can capture what appear to be separate chunks, but these chunks may actually be overlapping and related. A second hypothesis was that a "chunk" is of different sizes and structures for differently skilled players. Suppose we assume that a chunk, such as a rook-queen-rook configuration, is hierarchically organized and that the better player needs only store the "name" of the chunk in a location in working memory. For the poorer player, however, a rook-queen-rook configuration may be composed of two or more chunks, such as rook-queen and queen-rook. (This is the standard explanation used throughout this kind of research to account for greater recall in the better player.) One interpretation of the chunk recall results is that it may take the skilled player more than 2 sec to "unpack" his chunk, so that it looks as if he has many more chunks, even though the number of chunks was limited by the capacity of his working memory.

Both of these hypotheses, although reasonable, are speculative because the technique of partitioning chunks by a 2-sec interval cannot capture the complete structure of the chunk. What we hoped to do, therefore, was justify the notion of constant capacity, even between 10-year-olds and adults of different skills, by obtaining comparable recall of chunks using a different technique to access the chunk structure. We requested the subjects to partition the board position into chunks at the last (the correct) trial of the repeated recall task. This technique was first used by Reitman (1976) for "Go" positions. Using subjects' own partitionings, we can redefine a chunk as a cluster of pieces that the subject has grouped within one boundary. By this definition, children and adults organized the positions into the same number of chunks, about 6.8 and 7.3, respectively, and the average chunk size was about three pieces.

TABLE 3.2
Chunk Structures

	Children	*Adults*
A. Number of chunks on the first trial	4.33	2.63
B. First chunk size of first trial	2.50	2.25
C. Second chunk size of first trial	1.75	1.21
D. Number of chunks on last trial	6.83	7.33
E. IRT between chunks on last trial	3.03 ±1.00	2.71 ±1.03
F. IRT within chunks on last trial	1.40 ±0.51	1.37 ±0.50
G. Number of overlapping chunks on last trial	1.29	1.29

How do we resolve the apparent discrepancy between the final trial, in which children and adults both represented the chess position in terms of the same number of chunks, and the first trial, in which children seemed to recall more and bigger chunks? The answer may lie in the technique of accessing the chunk structure. Both hypotheses proposed by Chase and Simon (1973) seem reasonable, mainly because partitioning by a 2-sec retrieval interval does not take into consideration either the overlapping nature of the chunk structure or the fact that it may take longer than 2 sec to unpack a chunk. A third possibility is that a better player may not exhaustively retrieve all the pieces from a given chunk and may reenter the same chunk later after seeing it on the board. A fourth interpretation is that first trial performance may be limited mainly by the size and quantity of chunks already stored in memory. As subjects learn a position, they do so in the most economical way: by representing the position with as few chunks as possible and as many pieces as possible per chunk. What took the adults so long to memorize the position (around 8.5 trials) was their slower rate of assembling the pieces into chunks, because they have fewer of these components in memory. That is, if we assume that the adults' memory structure for chess contained smaller patterns, with fewer pieces per pattern, then their slower learning rate can be explained by the longer time required to recode smaller chunks to form larger ones. One simple interpretation, first proposed by Broadbent (1975), is that chunk size is limited by how much capacity of working memory is available for this recoding, because all the elements must be held in working memory while the chunk is being constructed. If adults and children have the same capacity of working memory, then eventually they will both represent the position with the same number of chunks.

Granted that partitioning by a 2-sec interval may not completely capture the chunk structure, can we, on the other hand, rely on the subject's introspections

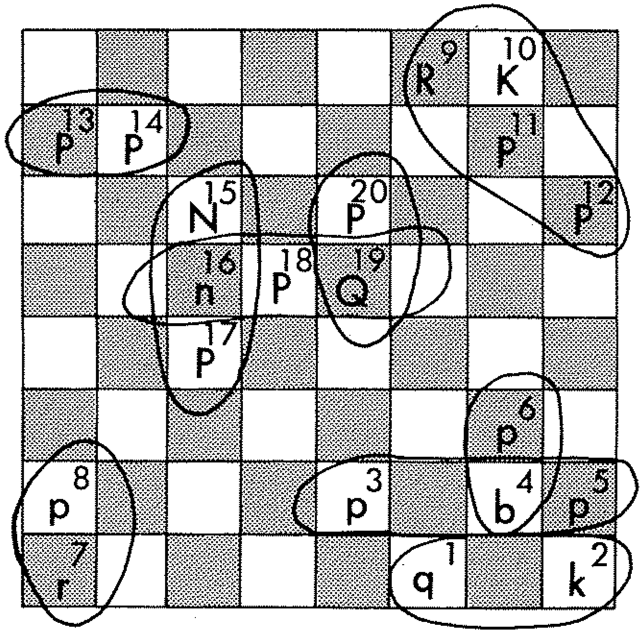

FIG. 3.4 Example of one subject's partitionings. Lower case letters are white pieces and upper case black pieces.

of the chunk structures? It seems necessary to compare subjects' partitionings directly with their recall latencies. If there is any reality to the 2-sec chunk boundary, then we hope to find that the IRTs within a chunk are less than 2 sec and that the IRTs between chunks are greater than 2 sec. To test this, the IRTs between pieces for the last trial of each subject were divided into two categories: between- and within-chunk IRTs, where chunks were defined by the subjects' partitionings. For example, Fig. 3.4 illustrates the partitioning of one subject. The letters represent pieces on the board, the encircled areas are the subjects' partitioning, and the numbers by each piece indicate the order of recall on the last trial. This recall sequence started at the lower right corner, with two pieces, the king and queen, constituting the first chunk; the IRT between these two pieces was considered to be a within-chunk time. Likewise, the IRTs for the next three pieces, pawn, bishop, and pawn, were also considered to be within-chunk times. However, the IRTs between the king and the pawn (the second and third pieces), or between the next two pawns (the fifth and sixth pieces) were considered to be between-chunk times because neither pair was enclosed within the same boundary.

If there is any reality to partitionings, between-chunk times should be longer than within-chunk times. Averaging across subjects and positions, the amount of time it took subjects to cross a chunk boundary was longer (around 3 sec) than the amount of time it took to place pieces within a chunk (around 1.5 sec) for both adults and children, even though sometimes there were overlapping chunks.[9] (See Table 3.2, rows E and F.) This analysis supports Chase and Simon's assumption that retrieval time between chunks is greater than 2 sec, whereas retrieval time within chunks is less than 2 sec.

To summarize the results: Children and adults exhibit typical developmental trends for digits in two memory tasks, immediate recall and repeated recall. However, when chess materials are used and children have greater knowledge of chess, children exhibit better recall on both tasks. Furthermore, children also have a larger span for chess chunks in immediate recall (and the first trial of the repeated recall task) but represented the board position in terms of the same number of chunks as adults on the last trial, suggesting that the capacity of working memory limits the number of chunks into which a board position can be organized.

KNOWLEDGE AND METAMEMORY

Metamemory refers to the knowledge people have about memory storage and retrieval rather than to memory performance itself. We can summarize Flavell's (1977) review of metamemory research by saying that memory-relevant knowledge is acquired throughout development. Certain types of knowledge about memory tasks (task variables) and memory strategies (strategy variables) are acquired at an earlier age than others. For example, even kindergarteners know that a memory task is harder if it has a large number of items, whereas only older children know that a recall task is harder if one has to learn two sets of words that are easily confusable (Kreutzer, Leonard, & Flavell, 1975).

Another important variable in metamemory, according to Flavell (1977), is a person's knowledge about intrinsic and stable characteristics of self and others as a memorizer (person variable). The data have consistently showed that younger children are less aware (or have less knowledge) of their recall potential than are older children. To be more specific, metamemory about person variables has been investigated in a span estimation paradigm in which the subjects are asked to predict their own recall potential. The findings have consistently showed that (1) young children are not realistic in predicting their own span performance, and (2) this inaccuracy seems to disappear beyond the third grade (Brown, Campione, & Murphy, 1977; Flavell, Friedrichs, & Hoyt, 1970; Markman, 1973; Yussen & Levy, 1975).

The intention of this research is to suggest another factor influencing metamemory: subjects' knowledge of stimuli. There are two ways to test whether

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[9] Table 2, row G shows the number of overlapping chunks represented by subject's partitioning of the last trial. There were no significant differences between the two age