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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).

What is a strategy? Broadly, a strategy is a set of decision processes that determines what sequences of actions to perform. Some strategies that have been extensively studied are rehearsal, recoding, and grouping. As we will see, there are also many subsidiary strategies that a person can adopt for a given situation.

The findings on strategy development have consistently shown that the use of strategies increases with age. It is clear that part of memory and the improvement of metamemory performance must reflect this factor.

Why do we need to go beyond this? Why not simply adopt the view that strategy changes are responsible for all memory (and metamemory) development? There are three reasons: (1) If an adult strategy is taught to children, recall is still generally better in adults (Butterfield, Wambold, & Belmont, 1973); (2) if a strategy is taught to both children and adults, the initial difference in performance is generally maintained (Huttenlocher & Burke, 1976); and (3) if adults are prevented from using certain strategies, their performance remains superior to that of children (Chi, 1977).¹ In general, it is becoming more and more apparent that strategies (at least our traditional notion of strategies) do not account for all the developmental trends or individual differences in memory performance. Hence, it is necessary that we turn to other factors to account for the remaining differences.²

Knowledge

Knowledge affects development through the growth of the knowledge base. By growth I mean simply that there are more concepts, more relations among concepts, and so on in the semantic memory of an adult as compared to a child. Associated with the growth of knowledge is a better structure for that knowledge. A better structure may be one that has, in some sense, a more appropriate or valid set of relations among the concepts as well as a greater number of relations.

No one disputes the assumption that adults have a richer knowledge base than children. However, if one looks at the developmental literature on memory, few researchers emphasize this difference or test directly its effect on memory performance. Researchers often regard knowledge as a catchall for any age

¹The results obtained by Huttenlocher and Burke are also true in adults' individual differences data (Lyon, 1977). That is, the initial individual differences in digit span was not reduced when all the subjects were required to use a certain strategy.

²It is conceivable that for each of the reasons listed above strategy usage could still be an underlying factor in the performance differences. For example, one alternative interpretation for all three points is that adults are using unidentified strategies. Such was precisely the case in Chi's (1977) memory span for faces study. However, I would like to propose that frequently an alternative factor (namely, amount and structure of knowledge) can override the effect of incidental strategy usage.

differences not explained by the experimental variables. No one is certain of the extent to which knowledge influences performance.

This chapter highlights the contribution of amount and structure of knowledge to memory and metamemory performance. The contributions of other components, particularly strategies, have been amply stressed elsewhere. This chapter attempts to place the knowledge factor in a proper perspective.

Capacity

The capacity hypothesis states that the improvement of performance with age can be partially explained by an increase in the capacity of working memory (Baron, in press; Carroll, 1976; Case, 1974). If one examines the developmental data in the area, the hypothesis of capacity increases seems obvious. However, the data may obscure an important issue, namely, that age and knowledge are often confounded.

To define what I mean by *capacity*, one needs to distinguish *performance* capacity from *actual* capacity. Memory capacity can be estimated empirically only by measuring the performance of an individual on a given task. For

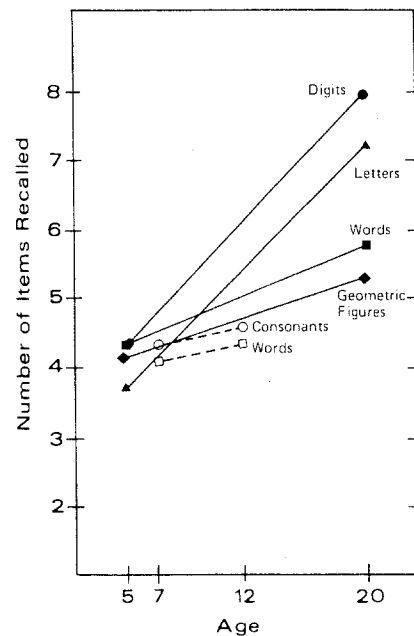


FIG. 3.1 Solid lines summarize results in the literature for memory-span performance for different stimulus materials as a function of age. Dotted lines are Dempster's (1976) results for consonants (open circles) and words (open squares).

example, in a memory-span task, the digit span for college students is about 7.98 units (Brener, 1940), whereas for 5-year-olds it is about 4 units (Starr, 1923; see Table 3.1). Hence, the performance capacity of an adult is superior to that of a child.

Since the introduction of the concept of the chunk (Miller, 1956), researchers have concluded that the actual capacity of working memory for adults is around seven chunks. For any given domain of stimuli, then, adults' performances can vary, as demonstrated in the memory-span estimates, but the theoretical interpretation is that the underlying chunk capacity of working memory is invariant (Simon, 1974). The solid lines in Fig. 3.1 summarize the literature on performance estimates for various stimulus materials.

For any given domain of stimuli, children consistently exhibit a smaller memory span. The obvious dilemma is whether the results depicted in Figure 3.1 reflect a smaller actual capacity in children or a smaller chunk size. In other words, it could be argued from Figure 3.1 that children are simply unfamiliar with these stimulus materials and that the variability in the adults' data is due to different amounts of experience with (or knowledge about) the stimuli.

Both Chi (1976) and Dempster (1976) used the latter notion to argue that memory capacity is constant, at least beyond the age of 5 years or so. That is, they assumed that children show a smaller memory span in all the materials shown in Figure 3.1 because these materials are less familiar to them. It follows from this argument that if a class of stimulus materials can be found that is equally familiar (or unfamiliar) to both age groups, then children and adults should exhibit the same memory span. Indeed, Dempster found that with consonants and words, span estimates for first graders (4.3 and 4.07) were not significantly different from those for sixth graders (4.6 and 4.3). These data suggest that knowledge of stimuli may be the critical variable in producing differences in memory-span performance among age groups. However, these data are not sufficient to conclude that capacity is invariant with age. Further data are needed to (1) pinpoint knowledge of the stimuli as the critical variable producing age differences in memory-span performances and (2) show better recall in children than in adults when the stimulus materials are more familiar to children. The studies discussed in the following paragraphs attempt to meet these objectives.

MEMORY SPAN FOR FACES

Throughout this paper, the role of strategies has been minimized and the role of knowledge has been emphasized. This orientation was derived from my first research effort, which assessed the extent to which strategies account for developmental differences in memory span and the extent to which remaining age differences are not explained by differential strategy usage (Chi, 1977). A

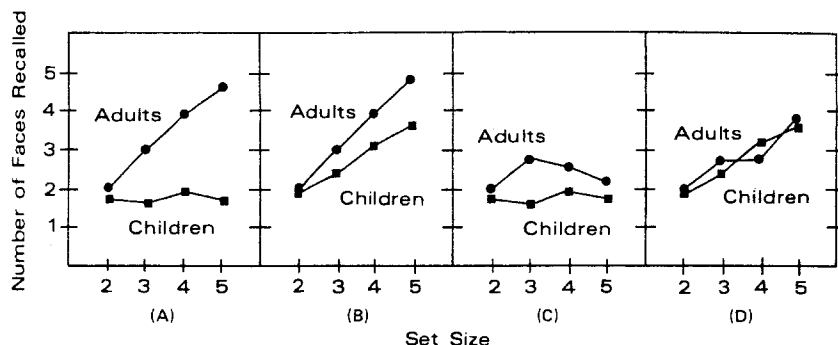


FIG. 3.2 Number of known faces recalled by adults as a function of set size. Panels A and B are 600 msec presentations per face for both adults and children. Panel A used ordered scoring, and Panel B used free scoring. Panels C and D used 300 msec presentation time for adults, replotted with children's data, using ordered (C) or free (D) scoring. In addition, the results of Panel D further prohibited the adults from using a constrained retrieval strategy.

question raised was: If there are age differences not explained by differential strategy usage, can these differences be attributed to differential knowledge of the stimuli?

The study used a reversal of training procedure to identify the specific factors within the knowledge and strategy domains that produce adults' superior memory performance. The usual assumption underlying a training approach is that a specific deficit in the child has already been identified. It is also assumed that the component to be trained is crucial to successful adult performance. These assumptions tend to overemphasize certain components and to overlook other not-so-trainable ones, as well as ignoring how the components interact.

In contrast to the training approach, Chi (1977) attempted systematically to reduce the availability of certain components that are crucial to successful adult performance in order to see whether adults' performance capacity could be brought down to the level of children's. If we can equalize performance capacity (memory span) by manipulating certain variables, then we can ask if these variables are related to actual capacity.

The first goal was to prevent adults from using the major mnemonic strategies that have been well documented in the literature — rehearsal, grouping, and chunking. Both the rehearsal and grouping strategies presumably take time to execute (Lyon, 1977), so we reduced their utility to adults by presenting the stimuli for short durations (600 msec each). Because the set size (number of stimuli in a given presentation array) varied from two to five, the total presentation time varied from 1200 msec to 3000 msec. To reduce the possibility of adults' using a chunking strategy, the stimulus material needed to be equally unchunkable by either age group. At the same time, the stimulus material had

to be equally familiar to all, in order to limit the adults' advantage of greater knowledge. The stimuli chosen were faces of classmates. Faces of peers do not seem to be chunkable unless two or three consecutive faces form a familiar unit. Care was taken not to use twins, siblings, or stable couplets. Faces of peers were also an attractive choice because there was some control over how long (3 years of schooling) the subjects (kindergarteners and graduate students) had been acquainted with them. However, we did not ascertain whether the faces were equally familiar to each age group. Each subject could identify by name all the eight faces used in the experiment.

Summarizing the outcome of this serial recall task, we learned that adults remembered more faces in the correct order than did 5-year-olds, even though the use of major strategies was reduced (see Fig. 3.2A). For supporters of a constant capacity hypothesis, this initial outcome was very alarming. It suggested that adults had a larger performance capacity even when (1) mnemonic usage was minimized and (2) children seemed to know the stimuli (could name them) as well as adults. To remain skeptical, we had to probe further to see what produced the age differences. There were three potential factors: ordered recall, naming deficiency, and subsidiary strategy usage.

Ordered Recall

As shown by the data on face recall, children had greater difficulty remembering the faces in their correct order. What processes were responsible for the differences in encoding order information? It seemed that where order was defined in terms of a serial array, adults had multiple and redundant ways of encoding it, such as temporal, spatial, and numerical ordering. Children may not have the abilities to encode serial order in such multiple fashions or to realize that they were all redundant. To eliminate this dimension of developmental differences, we simply scored the data without regard to position errors (free as opposed to ordered scoring). We found that adults were still superior to children, although the differences were reduced (see Fig. 3.2B).

Naming Deficiency

The children's second limitation was their retarded speed of accessing the names of the faces, as measured by vocalization latencies. It took children more than twice as long to retrieve the name of a face (about 1½ sec) as it took adults (about 2/3 sec). This naming-time limitation cannot be ascribed entirely to a perceptual or encoding deficiency, in the sense that the children did not have enough time to scan the stimulus or to extract a sufficient number of relevant features to identify the face. We found this out by presenting the faces in a tachistoscope and measuring the identification thresholds for children and adults. This technique avoids measuring the naming component. The results

showed that although adults were faster at encoding (25 msec versus 138 msec for encoding one face), the magnitude of the difference was not large enough to account for the differences in the vocalization latencies (Chi, 1977).

What is the implication of children's naming deficit for memory performance? The most important implication is that naming can be a very powerful mnemonic device because it provides an "external" memory aid. For adults, the recall task was memory for a serial list of names, because the presentation time (600 msec/face) was sufficiently long to allow them to name each face. For the children, on the other hand, the task was memory for faces only, because the presentation time was only half as long as the time they needed for name retrieval.³

To illustrate this point, we simulated the children's task environment by limiting adults' viewing time so that the task demand for adults also became memory for faces only. Reducing adults' presentation time to half of their naming time (i.e., 300 msec/face) did reduce their recall scores, but their scores remained superior to those of children (using ordered scoring) (see Fig. 3.2C).

Additional Strategy Usage

The adults' third advantage was their spontaneous adoption of various subsidiary strategies that were often not of initial interest to the experimenter. In particular, adults changed their strategies as the task demands changed. When their viewing time was reduced, they altered the task from one of serial recall to one of constrained recall. That is, they reproduced the response in the order that they could retrieve, rather than in the actual order of presentation — for example, first recalling the last two faces, then the first two, then indicating that the first two preceded the last two. The use of such a retrieval strategy can be confirmed by examining the serial position curves. Having identified this strategy, we were able to eliminate it by simply telling the adults not to use it. As shown in Fig. 3.2D, this manipulation, together with the reduced exposure time and use of the free recall measure, yielded equivalent performance in children and adults.

The foregoing discussion centers on three factors — better ordered recall, faster name retrieval, and modified retrieval strategy — that can facilitate adults' recall of serial arrays. We have shown that eliminating any single advantage did not substantially reduce adults' superior recall performance. However, when all possible strategy usage was eliminated and adults' exposure duration limited, we then obtained equivalent recall performance for children and adults. The foregoing findings raise a fundamental issue: How did adults retrieve the names of

³Notice that we cannot equate the task demands simply by increasing children's viewing time, because adults would still have had the additional strategic advantages (such as rehearsal).

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

⁴Similar 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.

⁵A 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.

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

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

⁷The 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.

⁸This 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.

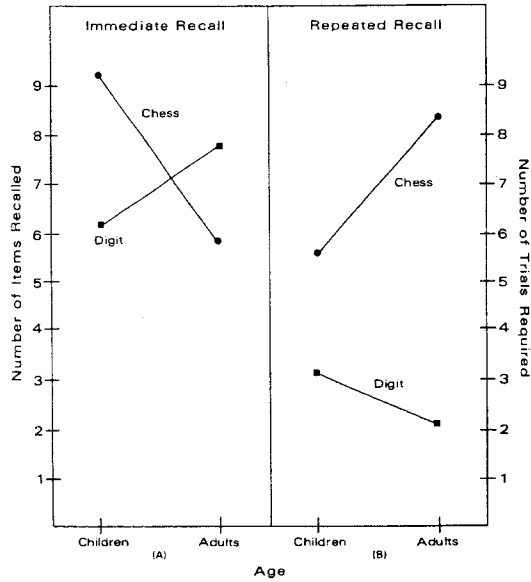


FIG. 3.3 The amount of recall in immediate and repeated recall tasks, for digits and chess stimuli.

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

TABLE 3.2
Chunk Structures

	<i>Children</i>	<i>Adults</i>
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 \pm 1.00	2.71 \pm 1.03
F. IRT within chunks on last trial	1.40 \pm 0.51	1.37 \pm 0.50
G. Number of overlapping chunks on last trial	1.29	1.29

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.

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

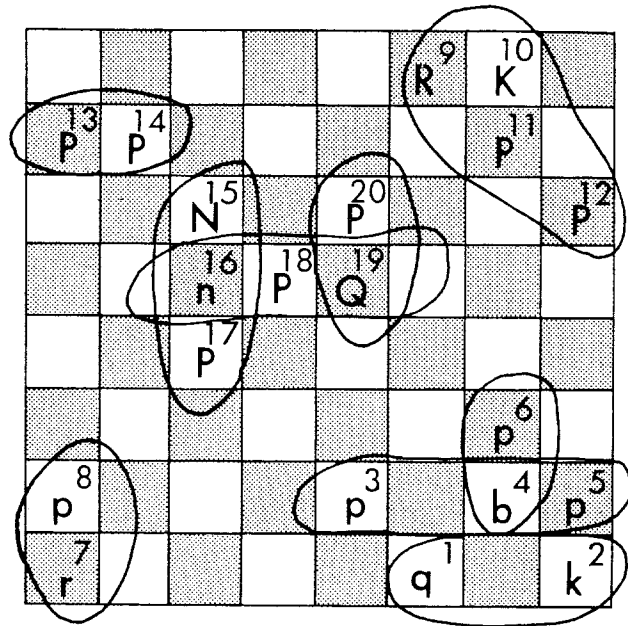


FIG. 3.4 Example of one subject's partitionings. Lower case letters are white pieces and upper case black pieces.

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' partitionings, 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

⁹Table 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 groups.

knowledge of stimuli is an important variable in metamemory performance. One way is to vary the amount of knowledge subjects have about the stimuli. For example, we could vary the chess skill of the subjects. A second way is to use two different kinds of stimuli on the same task and compare a subject's metamemory performance on them. Both of these strategies are discussed in the following paragraphs.

Span and Trials Predictions by Children and Adults

The 12 subjects in the previous study, six children and six adults, were asked to predict their performance on both immediate and repeated recall tasks for both digit and chess stimuli. The immediate recall (memory span) prediction task consisted of showing a subject a chess position (or 10 digits) for 10 sec, followed by a request for a prediction of how many of the chess pieces or digits he thought he could recall. The repeated recall (trials) prediction also consisted of a 10-sec presentation, followed by a prediction of how many such 10-sec looks would be needed to memorize the entire chess position or all 10 digits. These predictions were all made prior to the actual recall phase of the study.

According to the literature (cf. Brown, in press), there should be no significant differences between children and adults in predictions of memory span because the children were fifth graders, on the average. If no differences in accuracy of memory span prediction occurred for either type of stimuli, it would suggest that a metamemory task such as prediction of memory span is not very sensitive to the knowledge factor. On the other hand, it could also be the case that a memory span prediction task does not usually project a developmen-

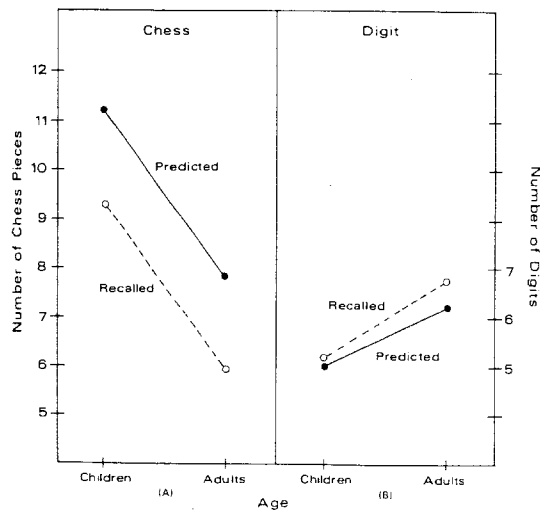


FIG. 3.5 Predictions for immediate recall by children and adults for digits and chess.

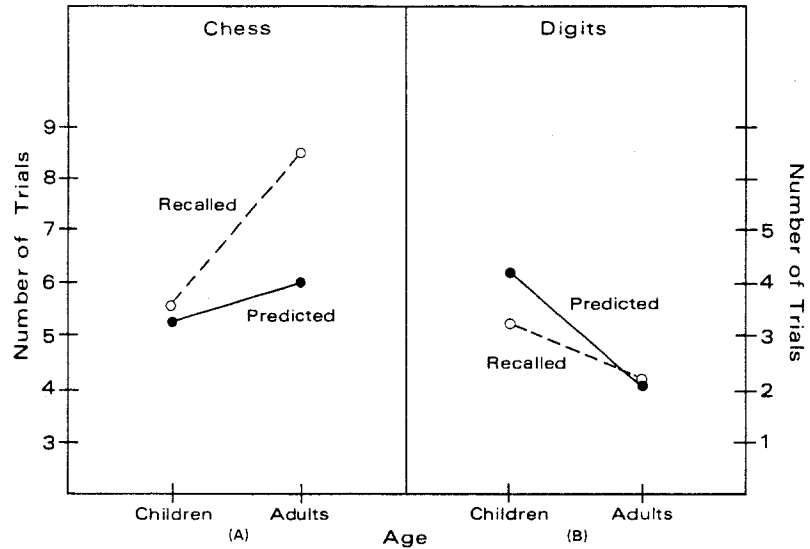


FIG. 3.6 Predictions for repeated recall by children and adults for digits and chess.

tal trend — not because the task is insensitive to the knowledge factor but because the task is too simple. That is, the task may be very conducive to an immediate simulation, so that any child (beyond the third grade) who is aware of a simulation strategy can be an accurate predictor. For a more complex task, in which simulation is not as easily accomplished, however, recall prediction may indeed be sensitive to the knowledge component. Hence, we anticipate that children might be more accurate in the trials prediction.

The immediate recall predictions are shown in Fig. 3.5. Panel *B* shows no developmental differences in either the predictions or the accuracy of the predictions between children and adults for digits. This result replicates the usual findings in the literature, namely, that no developmental differences in prediction accuracy can be observed for children beyond the third grade. For the chess stimuli (panel *A*) there were also no significant differences either in the predictions or the accuracy of the predictions between children and adults.

However, the more important result seems to be that, even though both children and adults were equally accurate in the chess and digit predictions for immediate recall, they both underpredicted their recall for digits and overpredicted their recall for chess pieces. One way to interpret this is to assume that the prediction task itself required identical processes for both types of stimuli, so that the observed performance differences were a function of the type of stimuli. Supposing that this prediction task required a simulation strategy, the results would then suggest that simulating recall in a spatial array (chess) is different from simulating recall in a linear array (digits), if there is any reality to

the simulation strategy. Alternatively, one could interpret this result as suggesting that the demands of the immediate recall prediction task were quite different for the two types of stimuli, with one requiring knowledge of recalling nonverbal location information and the other requiring knowledge of recalling verbal serial lists. In either case, it suggests that a prediction task per se, which is supposed to tap knowledge of person variables, can interact with both the stimuli and the demands of the recall task.

The results on the trials prediction are shown in Fig. 3.6. Again, children did not predict significantly differently from adults for either type of stimuli, although the expected trend occurred. That is, children's accuracy was greater than adults' for chess (because the children had more knowledge of chess), whereas adults' accuracy was greater for digits. It seems to suggest that a more complex task (trials prediction) is more sensitive to the knowledge variable than a simpler task (span prediction).

The results of this study suggest that knowledge of stimuli is an important variable in determining metamemory (prediction) performance, in that different patterns of results were obtained for the chess and digit stimuli. On the other hand, no reliable differences were obtained between children and adults, suggesting that either a prediction task is not very sensitive to the knowledge variable, or else the knowledge differences (about the stimuli) were not large enough to produce an age effect. The next study addressed this latter possibility by using adults with a wider range of knowledge about the stimuli.

Memory Predictions by Adults

The study of memory predictions by adults tested the hypothesis that adults' metamemory predictions may depend on their amount of knowledge about the stimuli. Eighteen adults were divided into three groups according to their knight's tour times. In this case, the knight's tour was identical to the one used by Chase and Simon (1973). The six fastest subjects (two rows in an average of 2.5 min) were classified as the high-knowledge group. Three of the six players in this group also had official chess ratings that averaged around 1600. The medium-knowledge group averaged about 6 min, and the low-knowledge group about 9.5 min. Hence, in this study the high-knowledge group would be classified as Class B players and the low-knowledge group as novices. Thus, the skill range probably spanned about four levels.

Each subject was presented with two coherent and two random chess positions; both the coherent and the random positions contained a middle game (23 pieces) and an end game (15 pieces). The subject viewed each position for 5 sec and then gave two predictions: the number of pieces he thought he could recall immediately and the number of trials he thought he would need for complete recall. Following the predictions, the subjects were given a repeated

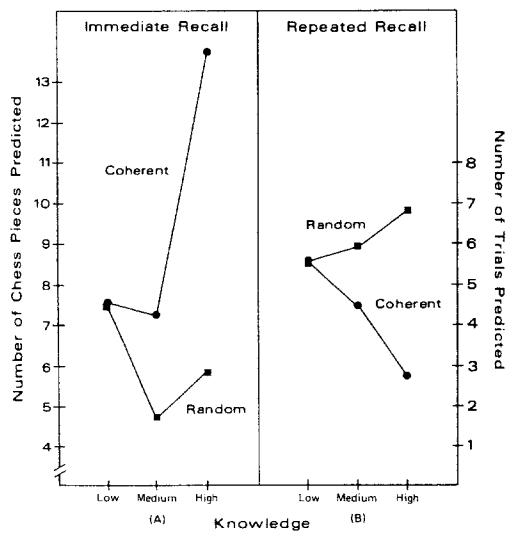


FIG. 3.7 Predictions by adults of high, medium, and low knowledge for coherent and random positions. Panel A is immediate recall predictions, and Panel B is repeated recall predictions.

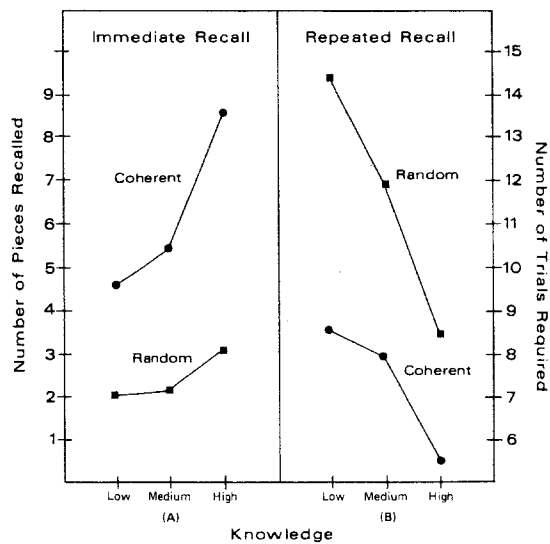


FIG. 3.8 Actual recall for high, medium, and low-knowledge subjects in immediate and repeated recall tasks.

recall task, using a different set of four positions – two coherent and two random – each containing a middle and an end game.

The results are straightforward and for the most part provide good support for the hypothesis. Figure 3.7A illustrates the prediction data for immediate recall (number of pieces) and Fig. 3.7B shows the predictions for repeated recall (number of trials to learn the position). In both cases, as the skill level increases, there is a systematic increase in the ability of subjects to discriminate the coherent from the random positions ($p < 0.01$). In other words, better chess players predicted that they would remember coherent positions much better than random ones whereas the differentiation for less good players was less dramatic.¹⁰

How do the metamemory predictions compare with actual performance? Figure 3.8 shows the recall performance on the repeated recall task. In this case, the first trial data are used as an indication of immediate recall performance (panel A). Panel B shows the number of trials needed to recall the entire position. The data are consistent with those in the literature.

Figure 3.9 shows the accuracy data (i.e., the differences between predicted and actual performance). There are two things to notice about these data. First, subjects consistently overestimate their memory abilities: They tend to predict more pieces than they will actually recall, and they tend to predict fewer trials than they will actually need. Second, with one exception, the prediction accuracy tends to improve with skill level (Fig. 3.9). The one reversal is due to three high-knowledge subjects who insisted that they could remember all the pieces of the coherent positions.

To summarize, these data taken together provide good support for the hypothesis that people with more knowledge about chess assess their ability to remember chess material more accurately. This is mainly shown by the better players' ability to predict the relative difficulty of coherent versus random positions. There is also a tendency for the better players to make more accurate absolute predictions.

Discussion of Metamemory Research

The metamemory studies discussed here have shown that metamemory performance can vary as a function of knowledge about the stimuli, in addition to knowledge about the task, strategies, and person variables. The lack of significant differences between children's and adults' metamemory performances, coupled with significant differences in memory performance, suggest that memory performance is more sensitive to knowledge (stimuli-relevant) than is metamemory

¹⁰Subjects were not told in advance that they would see random versus coherent positions.

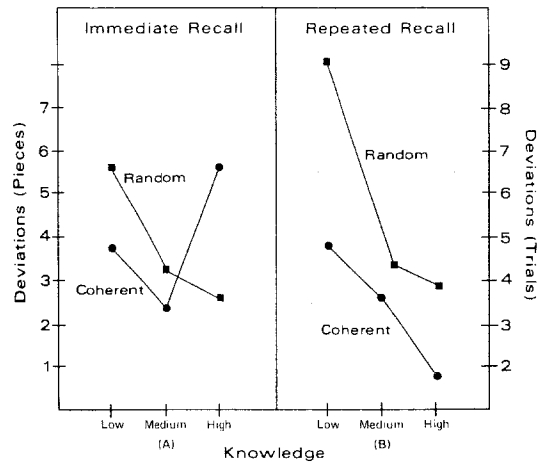


FIG. 3.9 Accuracy of subjects' predictions, as determined by absolute difference between number predicted and number recalled for each position.

performance. Metamemory performance, however, can also be sensitive to the knowledge factor if subjects vary widely in what they know.

What does this tell us about the metamemory process? Since the present studies were designed to demonstrate the importance of knowledge about the stimuli, the data are not specific enough to support any detailed theory. However, one can speculate that the underlying processes responsible for recall prediction performance can be separated into at least two general components. The first component is the amount of stimuli-relevant knowledge activated; the second is a decision process that evaluates the activated knowledge. In the case of chess positions, we assume that coherent positions will activate many more chess patterns in the memory of high-knowledge persons because they have many more patterns stored. The decision process, then, could be as simple as counting the number of activated patterns. Such a simple mechanism is sufficient to account for the immediate recall predictions. The theory would have to be expanded to account for the complexities of the number-of-trials predictions.

It should also be apparent that there are complexities in the decision processes. Suppose the decision does involve some quantification processes. For the high-knowledge persons, a 5-sec look will activate a large quantity of information, which may necessitate reliance on estimation rather than on counting. Because estimation processes are less accurate, the prediction accuracy of high-knowledge subjects using estimation may also be less accurate. Recall that three of the six high-knowledge subjects insisted that they could remember all the pieces in the coherent positions (23 and 15 pieces). Such an erroneous decision could have been based on some gross quantification process such as estimation.

Other subjects, by contrast, counted on their fingers before making an immediate recall prediction. The experimenter recollected that one of these "counting" subjects was a low-knowledge player. Clearly, the exact nature of metamemory mechanisms must await further research.

GENERAL DISCUSSION

This paper has attempted to show that the amount of knowledge a person possesses about a specific content area can determine to a large extent how well he or she can perform in both memory and metamemory tasks. The implication is that the sources of some of the age differences we often observe in developmental studies must be attributable to knowledge about the stimuli rather than to capacity and strategic factors alone. Notice that this knowledge is about the stimuli only, not about the task (i.e., we tested memory and metamemory performances, not chess playing).

In the introduction of this paper, both the knowledge and strategy factors were discussed in very gross terms, and they were treated as separated entities. Clearly, there is a need to remark on the distinction or lack of distinction between the two components, because strategies are obviously part of our knowledge system. Perhaps a better distinction would be to classify them as procedural versus declarative types of knowledge. However, without reiterating the distinction between data and process, let me stress the distinction that needs to be made concerning strategies.

Most of the developmental research has centered on what can be called "general strategies," such as rehearsal and grouping. These strategies can be applied to a wide variety of tasks. It may be misleading, however, to think of adults' superiority in terms of these few, limited mnemonics. As we saw in the first set of studies on memory span for faces, adults usually perform better than children, even without the use of these general strategies. This may be due, in part, to the fact that adults have a general scheme for adopting or inventing new mnemonics to cope with a task. (This scheme, I believe, is what Flavell referred to as knowledge about the strategy variables.) Hence, it may be necessary to introduce a subclass of general strategies, which we shall call task-specific strategies. For example, we may want to classify the following behavior as a task-specific strategy: One adult subject in the chess study always looked at the remaining chess pieces during recall to see whether any of the pieces could cue her in further recall. In fact, this particular adult subject did as well as the children, even though her chess knowledge was inferior to theirs. She seemed to have sophisticated task-specific strategies. However, overall, the adults' task-specific strategies did not overcome the children's greater advantage from years of accumulated knowledge in chess.

Another obvious subclass of strategies is knowledge-specific strategies, which can be defined as strategies applicable only to a specific body of knowledge.

The following behavior might be classified as a knowledge-specific strategy: Two of the subjects in the chess study continually memorized the chess board in mirror images. For example, if they found a rook in the left-hand corner, they would then check to see if there were also rooks in the other three corners, so that they could code all the rooks together. This is nothing more than a chunking strategy, but it is knowledge-specific. It requires some minimum knowledge of chess to predict that given a rook in one corner, there is a high probability that a rook will also be in the other corners.

Adults seemed capable of using all these strategies — general, task-specific, and knowledge-specific. There is no evidence at this time about children's proficiency with them. It appears as if the children performed better in the memory task by virtue of their sheer volume of knowledge. Clearly, more research is needed to identify whether or not children's inefficient use of strategies is intimately related to their lack of knowledge.

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REFERENCES

- Baddeley, A. D., Thompson, N., & Buchanan, M. The word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behavior*, 1975, 14, 575–589.
- Baron, J. Intelligence and general strategies. In G. Underwood (Ed.), *Strategies in information processing*. New York: Academic Press, in press.
- Brener, R. An experimental investigation of memory span. *Journal of Experimental Psychology*, 1940, 26, 467–482.
- Broadbent, D. E. The magic number seven after fifteen years. In A. Kennedy & A. Wilkes (Eds.), *Studies in long term memory*. New York: Wiley, 1975.
- Brown, A. L. Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), *Advances in instructional psychology*. Hillsdale, N.J.: Lawrence Erlbaum Associates, in press.
- Brown, A. L., Campione, J. C., & Murphy, M. D. Maintenance and generalization of trained metamnemonic awareness in educable retarded children. *Journal of Experimental Child Psychology*, 1977, 24, 191–211.

- Butterfield, E. C., Wambold, C., & Belmont, J. On the theory and practice of improving short-term memory. *American Journal of Mental Deficiency*, 1973, 77, 654-669.
- Carroll, J. B. Psychometric tests as cognitive tasks: A new "structure of intellect." In L. B. Resnick (Ed.), *The nature of intelligence*. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1976.
- Case, R. Structure and strictures: Some functional limitations on the course of cognitive growth. *Cognitive Psychology*, 1974, 6, 544-573.
- Chase, W. G., & Simon, H. A. The mind's eye in chess. In W. G. Chase (Ed.), *Visual information processing*. New York: Academic Press, 1973.
- Chi, M. T. H. Short-term memory limitations in children: Capacity or processing deficits? *Memory and Cognition*, 1976, 4, 559-572.
- Chi, M. T. H. Age differences in memory span. *Journal of Experimental Child Psychology*, 1977, 23, 266-281.
- Chiesi, H. L., Spilich, G., & Voss, J. F. *Cognitive processes and structure in individuals with high and low baseball knowledge: The first inning*. Unpublished manuscript, University of Pittsburgh, 1977.
- Dempster, F. N. *Short-term storage capacity and chunking: A developmental study*. Unpublished doctoral dissertation, University of California, 1977.
- Eisenstadt, M., & Kareev, Y. Aspects of human problem solving: The use of internal representation. In D. A. Norman & D. E. Rumelhardt (Eds.), *Exploration in cognition*. San Francisco: Freeman, 1975.
- Flavell, J. H. *Metacognitive development*. Paper presented at the NATO Advanced Study Institute on Structural/Process Theories of Complex Human Behavior, Banff, Alberta, Canada, June, 1977.
- Flavell, J. H., Friedrichs, A. G., & Hoyt, J. D. Developmental changes in memorization processes. *Cognitive Psychology*, 1970, 1, 324-340.
- Huttenlocher, J., & Burke, D. Why does memory span increase with age? *Cognitive Psychology*, 1976, 8, 1-31.
- Kreutzer, M. A., Leonard, S., & Flavell, J. H. An interview study of children's knowledge about memory. *Monographs of the Society for Research in Child Development*, 1975, 40 (1, Serial No. 159).
- Lyon, D. Individual differences in immediate serial recall: A matter of mnemonics? *Cognitive Psychology*, 1977, 9, 403-411.
- Markman, E. M. *Factors affecting the young child's ability to monitor his memory*. Unpublished doctoral dissertation, University of Pennsylvania, 1973.
- Miller, G. A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 1956, 63, 81-97.
- Reitman, J. S. Skilled perception in Go: Deducing memory structures from inter-response times. *Cognitive Psychology*, 1976, 8, 336-356.
- Reinfeld, F. *Win at chess*. New York: Dover, 1945.
- Simon, H. A. How big is a chunk? *Science*, 1974, 183, 482-488.
- Starr, A. S. The diagnostic value of the audio-vocal digit memory span. *Psychological Clinic*, 1923, 15, 61-84.
- Yussen, S. R., & Levy, V. M. Jr. Developmental changes in predicting one's own span of short-term memory. *Journal of Experimental Child Psychology*, 1975, 19, 502-508.