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**Chapter/Article Author:** Chi, M. T. H.

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*Edited by*

MICHAEL W. EYSENCK

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# CONTENTS

**memory, encoding operations in** *See* ENCODING OPERATIONS IN MEMORY.

**memory, episodic** *See* EPISODIC MEMORY.

**memory, iconic** *See* ICONIC STORE.

**memory, long-term** *See* LONG-TERM MEMORY.

**memory, recognition** *See* RECOGNITION MEMORY.

**memory, semantic** *See* SEMANTIC MEMORY.

**memory, short-term** *See* SHORT-TERM MEMORY.

**memory, state-dependent** *See* STATE-DEPENDENT MEMORY.

**memory, working** *See* WORKING MEMORY.

**memory and aging** *See* AGING AND MEMORY.

**memory development** Memory development refers to the change of performance with age, in all kinds of memory tasks, such as recalling a sequence of digits, reconstructing experienced events such as a birthday party, or remembering to carry out a chore such as what to buy at a grocery store. For all these types of tasks, performance improves with age, in terms of both quantitative measures (the amount of RECALL) as well as qualitative measures (the way it is recalled). For instance, a very robust finding is how well children of different ages recall a sequence of digits in the exact order in which it was presented. The length of this sequence, referred to as the digit span, generally increases from around four digits at the age of 5, to around eight at college age. The qualitative aspect of this recall behavior is that older subjects tend to rehearse the digits prior to the actual recall (that is, repeat the digits over and over again), whereas younger children tend not to exhibit this kind of strategic behavior (see REHEARSAL). Different memory tasks use different quantitative and qualitative measures.

There are four possible explanations for such improvements with age. The two traditional explanations center on the capacity of SHORT-TERM MEMORY and the strategies that children and adults use to carry out such tasks (see, for example, the edited volumes by Kail & Hagen, 1977, and Chi, 1983). Two contemporary explanations center on either the domain-specific or general world knowledge that the child has gained with maturation (Chi & Ceci, 1987), and the metaknowledge that the child has about his or her own mental capacity and capabilities. Metaknowledge refers to what the child knows about his or her own memory (Flavell & Wellman, 1977), as well as his or her theory of mind (Wellman, 1985). Each of these four explanations will be presented below, along with challenges to some of these explanations.

That the capacity of children's memory improves with age seems to be a straightforward interpretation for the age-related improvement in memory performance. One can analogize the mind to a computer, with a given number of slots for the size of short-term memory. There are variants of this view, but this is the most concrete analogy. Suppose we assume that younger children have four hypothetical "slots" for temporarily storing information and that adults have eight slots: that would then easily explain results such as the digit span. The problem arises, however, if we assume that each slot can contain a chunk of information, so that the issue then becomes what constitutes a chunk of information for children versus adults (Chi, 1976) (see CHUNKING). For instance, a single digit may take up one slot of memory capacity for a 5 year old, whereas two digits (such as 9 and 6) can easily make up a double-digit number (96) for the older child and adult, so that 96 can be stored in a single slot. Using this logic, the adults' recall of eight digits may actually be a recall of four two-digit numbers, so that the actual number of slots is exactly equivalent. This line of reasoning makes it essential that we assess children's chunk size for each domain of knowledge. For example, Chi (1978) compared 10 year olds' recall of chess positions with that of adults. The twist in this study is that the 10 year olds are experienced chess players who have participated in chess tournaments, whereas the adults used to play chess when they were 10 years old, but have not pursued the game in adulthood. Thus, the children were actually more knowledgeable than the adults about the game of chess at the time that the study was done. The results showed that children could actually recall a greater number of chess pieces (9.3 pieces) than the adults (5.9 pieces). On the other hand, the same group of children could only recall 6.1 digits whereas the adults could recall 7.8 digits. These spans match exactly those obtained in the literature for these age groups. Hence, this study shows that the normally obtained digit span cannot be interpreted necessarily to reflect a smaller memory capacity per se. An alternative interpretation is that each slot of the capacity can hold a bigger chunk of information. Thus, the issue of the capacity increase becomes a moot point unless one is ready to assess the size of a chunk of information as well.

Closely related to the notion of capacity increase is the second interpretation, namely that young children do not adopt and use sophisticated processing strategies for remembering information, whereas older children and adults do. There is no question that young children do not use processing strategies, and that such use improves with age. Take rehearsal for a simple example. It is easy to demonstrate that children do not use such a strategy: you can look for the existence of labial movements (as measured by electromyographic recordings) during periods of retention, the existence of primacy effect in serial position curves, inter-item pause times during acquisition, or acoustic confusions during recall. It is trivial to point out that the non-use of such sophisticated strategies obviously impairs the amount of recall. However, even when young children do adopt a rehearsal strategy, the characteristic of rehearsal varies with age. Very young children rehearse a string of digits by repeating each digit several times, followed by the next digit (Naus & Ornstein, 1983). So, for instance, in order to rehearse the string of digits 5 9 6 4 7 3, a young child might rehearse 5 5 5, 9 9 9, 6 6 6, and so on, whereas an older child would rehearse 596 473. It is clear that the first method will not facilitate sequential recall since no inter-digit associations have been formed.

But the real question is, why? One explanation which is intimately tied to the capacity notion is to postulate that because younger children have less capacity, most of it is taken up for processing, thus less is left for storage. Moreover, even if young children do know what to do in order to apply strategies, their application is so inefficient that such use would tax their capacity excessively. Presumably, older children and adults can use these processing strategies more efficiently, thus leaving more room for storage. Although somewhat circular, these explanations center on the logic that young children might not only have a smaller capacity, but even if they have the same size capacity as older children and adults, they need more capacity to process the complex strategies that adults use, thereby leaving fewer slots for storage. Such a hypothesis would be consistent with the digit span data. No definitive conclusion can be reached about the role of memory capacity, processing strategies, and the tradeoff between the capacity and the efficiency of applying them, in accounting for memory improvement with age. The reason is that it is extremely difficult to discriminate empirically between these differing hypotheses for explaining improving memory performance, both in the quantity of recall and in the use of strategies.

A third explanation for why memory performance improves with age is that knowledge (both general world knowledge as well as specific content domain knowledge) generally improves with age, both from daily experiences and from schooling. Although this hypothesis is intuitively obvious, it is curious that developmental psychologists did not actively explore the effect of this factor until the late 1970s. There are several reasons why the knowledge factor was ignored. First, many researchers implicitly assumed that the contribution of knowledge toward a task's performance is negligible. For a digit span task, for example, the usual assumption has been that having the capability to identify the digits is a sufficient criterion for performing maximally on that task, so that any deficiency in performance cannot be attributed to a knowledge factor. However, one could argue that measuring a child's ability to identify a digit (such as by name) is not a sufficiently sensitive measure of digit knowledge. A more sensitive measure might be how quickly a child can name a digit, so that the children's longer naming latencies (as compared to adults') may be indicative of greater search time, thereby suggesting that the associations surrounding that digit may be more sparse in the child's memory than in the adult's. For example, an adult may know many facts about a digit (i.e. 9 is the square of 3; 9 divides evenly into 18, 27, and 36; 9 is an odd number; and so on). These knowledge facts may be represented as a more intricate and densely related network in the adult's representation of the digit 9. The argument is that with a more densely represented network, the digit 9 may be named and recognized more readily, and their associations would thus be activated. Thus, for an adult, the digit 9 is encoded into a more richly interconnected representation, whereas for a child, 9 may be represented only as a digit with the label "nine" attached to it.

From the foregoing discussion, it is clear that in order to accept the hypothesis that knowledge is a critical factor in accounting for developmental differences, it is necessary to center our efforts on representing the knowledge. For instance, many researchers claim that the presence of knowledge itself is not an issue; rather, the problem is that children do not use or access the knowledge that they do have. They base this conclusion on the fact that they can probe children directly for knowledge relevant to the task, and show that children indeed do have the knowledge. Thus, failure to use that knowledge is attributed to a lack of skill or strategy for using that knowledge. However, consider an alternative hypothesis, that the knowledge that the child has is not represented in a way that is usable, rather than just merely having it or not having it. The following example should illustrate the point. A very robust finding in developmental psychology is the fact that children, when they free recall (irrespective of order) a list of 20 objects (such as dog, ice cream, skirt, paper, cat, gloves, plate, pencil, fur coat, etc.), typically will recall the "cat" and the "fur coat" consecutively, thus representing a kind of retrieval by association, whereas older children and adults recall by taxonomically clustering "cat" and "dog" together. This retrieval pattern is typically accounted for by the failure on the child's part to actively organize the input items into taxonomic categories during encoding, and then recalling them by their category structure. Taxonomic retrieval not only facilitates a more stable pattern of recall (resulting in a high clustering score, meaning that the same set of items is recalled consecutively together), but the taxonomic category will cue all the items that belong to that taxonomic class. The reason that such a result is not interpreted as a lack of knowledge is because when the younger children are probed directly for knowledge of the taxonomic categories, such as by asking them to pick out all the animals among the 20 items, it is shown that they indeed do know that "cat" and "dog" are kinds of animals.

The problem with such a conclusion is that no analyses have been made of the representation the child has of the knowledge probed. Directly probing for knowledge facts does not imply that the knowledge is organized in such a way as to make it usable in the task. The following example should illustrate the point. Suppose a 5-year-old child is asked to retrieve the names of his or her classmates (from an open-classroom type of environment which included first- and second-grade racially mixed boys and girls). Several retrieval patterns are possible, such as by age, gender, grade, race, or even alphabetical order. The child used none of these retrieval patterns. However, if one directly probed the child, he or she clearly knew the age, gender, grade, and race of each child, and even the letter of the alphabet with which the classmate's name began. If the study stopped at this point, then the conventional interpretation is that the child has the knowledge about each child's age, gender, grade, and race, but did not use such information to taxonomically organize the classmates so that retrieval could be more consistent, and perhaps also more complete. Thus, the interpretation is one of a deficiency in skill. Somehow the child is viewed as not actively noticing a taxonomic organization that is present, and thus not taking advantage of it. However, through various means of assessing the representation the child had of his or her classmates, it turned out that the child was using the spatial seating arrangement to organize his or her recall because this is how the child had represented his or her classmates in memory. Using this organization to analyze the retrieval pattern showed complete consistency in that clusters of children's names were retrieved in a consistent order, depending on the seating locations (Chi, 1985). In conclusion, the point to be gained by this example is that direct probing for isolated factual knowledge in a piecemeal way does not mean that the child has that knowledge represented in an integrated and usable way. Thus, the inability to access that knowledge may not be due to a deficiency in an accessing skill, but rather, the knowledge is not represented in a way that it can be accessed for use in a specific task.

The foregoing discussion basically makes the point that what is often hypothesized as a processing or strategy deficiency in the younger children can really be attributed to the way that the younger children's knowledge is represented. Understanding how they organize and represent their knowledge would shed light on understanding why they perform the way they do in memory tasks. Viewed this way, the kind of research questions that should subsequently be asked should focus on the representation of children's knowledge, and how that representation changes with age. For instance, does it undergo gradual restructuring or radical restructuring (Chi & Ceci, 1987)? How do the changes affect all kinds of cognitive performance, memory and otherwise?

The fourth explanation for what produces memory improvements with age is that children develop more sophisticated knowledge about themselves as a memorizer, their own capabilities and limitations, and knowledge about how their mind works (Wellman, 1985) (see METACOGNITION). Early work along these lines failed to show a direct correlation between knowledge about memory and actual memory performance. However, a more interesting approach is to attempt to improve children's memory by making them more aware of their failure to use mnemonic strategies (Brown, 1978). At this point, it is too early to evaluate the outcome of this line of research, although the results are promising.

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M. T. H. CHI

**memory systems** This term denotes putative brain/behavior and brain/cognition systems concerned with different forms of learning and memory. "Memory" is a general label for different forms of acquisition, retention, and utilization of information, skills, and knowledge. These different forms of learning and memory constitute a hierarchy in which forms that emerged early in evolution represent the lower levels, and forms evolving later represent the higher levels. Because evidence exists showing that the operations of different forms are related to different neuroanatomical substrates, the different forms of learning and memory have been increasingly thought of as constituting different memory *systems* (Weiskrantz, 1987). All systems have in common the ability to retain, and to make available for use in ongoing behavior and cognitive functioning, effects of earlier behavior and experiences. They differ in the kind of information they handle, and in the nature of their operations.

Separate neural systems are believed to underlie simple forms of learning, such as sensitization and habituation. Some evidence also exists for separable neural bases for SHORT-TERM MEMORY and LONG-TERM MEMORY. However, most of the research concerned with the classification of forms of learning and memory has revolved around three hypothetical systems: EPISODIC MEMORY, SEMANTIC MEMORY, and procedural memory (*see* DECLARATIVE AND PROCEDURAL KNOWLEDGE) (Tulving, 1985). These systems are considered here.

Episodic memory is the memory system that makes it possible for a person to remember concrete personal episodes or events dated in the subjective past – that is, to remember that he or she did or witnessed something on a particular occasion at a particular time. This ability to remember personal experiences is possessed by all normal individuals, but it is absent in very young children, and absent or less well developed in lower organisms. Episodic remembering is, in its essence, a *mental* phenomenon. It entails a conscious experience of a unique kind, one that every normal human can readily tell apart from other kinds of mental experiences, such as perceiving, imagining, dreaming, daydreaming, and hallucinating. The nature of the conscious experience of remembering a past event also differs qualitatively from the nature of the conscious experience resulting from the actualization of general knowledge about the world. The hallmark of episodic-memory capability is the rememberer's strong belief that the remembered event did in fact occur and that he or she was present when it occurred. JAMES (WILLIAM) (1890) described the difference between "remembering" one's own past states and experiences, and "conceiving" someone else's as follows: "Remembrance is like direct feeling; its object is suffused with a warmth and intimacy to which no object of mere conception ever attains."

At the next level of the classificatory scheme is semantic memory. It is concerned with what William James called "conception," or what today can be described as "general knowledge of the world." The term was introduced into the literature by Quillian in 1966, and the distinction between episodic and semantic memory, as "two parallel and partially overlapping information processing systems," was proposed by Tulving in 1972. Semantic memory was initially defined in close reference to knowledge expressible in language, but is now conceptualized much more broadly, consisting of a number of hypothetical subdivisions. The information that the semantic system handles need not have any personal relevance to the individual. Neither need it refer to the past, or any other particular time in the individual's existence. The semantic-memory system allows the individual to construct mental models of both concrete and abstract parts and aspects of the world. It makes possible the cognitive representation of stimuli, objects, situations, facts, and events, and the utilization of information thus represented in the absence of original stimuli and events.