

Children's Thi

Developmental Function and Indiv

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examined age differences in the structure of children's language concepts, and these differences will be discussed in Chapters 7 and 9. However, the benchmark of information-processing theories is the idea of limited mental capacity, and it is here that psychologists have searched for age differences that would explain developmental changes in children's thinking. There are apparently no capacity limitations to the long-term store. (Children's ability to store and subsequently retrieve information from the long-term store will be the focus of Chapter 8.) When looking for developmental differences in capacity, most researchers have limited their search to sensory registers and the short-term store of the multistore model described earlier and for differences in speed of processing.

In the sections to follow, I will discuss age differences in the short-term store and speed of processing. In comparison with these two topics, relatively little research has examined developmental differences in the sensory store, and I will summarize the conclusions of this research briefly here. Children from about the age of 5 years can register and hold relatively large amounts of visual information over a brief interval, about as much as older children and adults (Sheingold, 1973). However, young children are less able to get this information to the short-term store where they can make some sense of it. One factor certainly involved in age differences in getting information from the visual sensory store, or *iconic store*, to the short-term store is speed of processing. Research suggests that there are age differences in the speed with which sensory information is transmitted, as well as differences in the speed with which visual information is accumulated and extracted for interpretation from the *iconic store* (LeBlanc, Muise, & Blanchard, 1992). Because younger children process information slower than older children do, younger children lose more information before it can be encoded in memory.

Start here.

The Short-Term Store

Traditionally, the capacity of the short-term store has been assessed by tests of **memory span** that measure the number of (usually) unrelated items that

can be recalled in exact order. Presentation of items is done rapidly (usually one per second), so there is minimal time for the application of strategies to aid recall. A child's memory span is considered a reflection of the size of the short-term store, or the capacity of working memory. Norms from the digit-span subtests of the Stanford-Binet and Wechsler IQ scales show a regular increase with age. Similar findings have been provided by Frank Dempster (1981), who reported, for example, that when digits are used, the memory span of 2-year-olds is about two items; of 5-year-olds, about four items; of 7-year-olds, about five items; and of 9-year-olds, about six items. The average memory span of adults is about seven items. Figure 5-3 shows the highly predictable growth of the memory span for digits (digit span) for children from age 2 years through adulthood (from Dempster, 1981).

Evidence for developmental differences in the capacity of the short-term store comes from a recent study by Nelson Cowan and his colleagues (in press) assessing *span of apprehension*, a term coined by Sperling (1960) to refer to the number of items that people can keep in mind at any one time, or the amount of information that people can attend to at a single time. Sperling found that the span of apprehension for adults was about four items. This is lower than the average adult memory span of seven items because factors such as focused attention, knowledge for the to-be-remembered information, and encoding strategies can affect memory span when items are presented more slowly (see later discussion). Does span of apprehension represent an absolute capacity of the short-term store, and does it increase with age? In the critical condition in the study by Cowan et al. (in press), first-grade and fourth-grade children and adults played a computer game. Over earphones they also heard series of digits that they were to ignore. Occasionally and unexpectedly, however, they were signaled to recall, in exact order, the most recently presented set of digits they had heard. Thus, participants were not explicitly attending to the digits, making it unlikely that they were using any encoding strategies to remember the series of digits. Thus, performance on this task seems to be a fair test of span of apprehension.

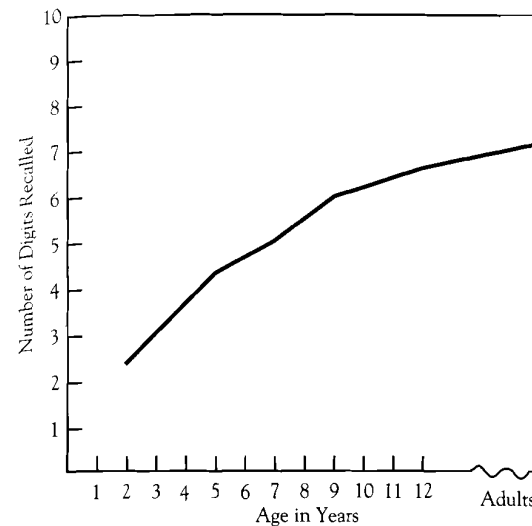


FIGURE 5-3 Children's memory span for digits (digit span) shows regular increases with age. SOURCE: "Memory Span: Sources of Individual and Development Differences," by F. N. Dempster, 1981, *Psychological Bulletin*, 89, 63-100. Copyright © 1981 American Psychological Association. Reprinted with permission.

Average span of apprehension was about 3.5 digits for adults, about 3 digits for fourth graders, and about 2.5 digits for first-grade children. Cowan and his colleagues interpreted these significant age differences as reflecting a true developmental difference in the capacity of the short-term store. According to Cowan et al., there seems to be an underlying difference in capacity, as reflected by differences in the span of apprehension, that serves as the foundation for age differences on memory span tasks.

Despite these impressive and robust findings, research has seriously questioned the idea that the capacity of the short-term is the only (or even most important) source of age differences on memory span tasks. For example, in one often-cited study, a group of graduate students at the University of Pittsburgh were given two simple memory tests. On one, they were read a series of numbers quickly (about one per second) and were asked to recall them immediately in exact order. On a second test, they

were briefly shown chess pieces on a chessboard in game-possible positions (again, about one chess piece per second) and then given the pieces and asked to place them at their previous positions on the board. Their performance on these tasks was compared with that of a group of 10-year-olds. In all fairness, these were not typical 10-year-olds—they were all chess experts, winners of local tournaments or members of chess clubs. When memory for the chess positions was tested, the children outperformed the adults. This finding is probably not surprising, given the expert status of the children. But the critical question is how they did when remembering the numbers. Does being a chess expert cause one's memory capabilities to improve overall, or was the children's remarkable performance limited to what they knew best? The results supported the latter interpretation. The adults, despite being outdone by the children when memory for chess positions was tested, were superior to the children when the test stimuli were numbers. The results of this experiment, conducted by Chi (1978), can be seen in Figure 5-4 (see also Schneider et al., 1993).

These findings indicate that having a detailed knowledge base in a particular domain facilitates memory for information from that domain but not necessarily for information from other areas. But how does being an expert in a subject such as chess result in improved memory span? Some researchers have proposed that age and individual differences in memory span may be caused by developmental differences in the use of *strategies* such as rehearsal (repeating the items to oneself) or chunking (recoding two or more items into a single memory unit). However, Frank Dempster (1981, 1985) and others have questioned both the capacity and strategy hypotheses regarding developmental changes in memory span. Concerning the role of strategies in memory span, Dempster (1981) concluded that "research offers little evidence that strategic variables are a source of span differences, even though several—rehearsal, chunking and retrieval strategies—appear to be sources of performance differences in other tasks" (pp. 78-79). Of ten strategic and non-strategic variables investigated by Dempster, only one—ease of item identification—appeared to be a

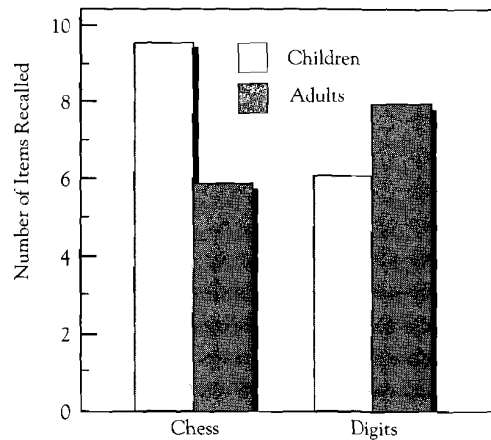


FIGURE 5-4 The average memory span for digits and chess arrays by chess-expert children and college-educated adults. SOURCE: Adapted from "Knowledge Structures and Memory Development," by M. T. H. Chi. In R. Siegler, (Ed.), *Children's Thinking: What Develops?* Copyright © 1978 Lawrence Erlbaum Associates, Inc. Reprinted with permission.

major source of developmental differences in memory span.

Ease of item identification relates to speed of processing: how quickly can a child identify an item? Speed of identification is an indication of processing efficiency; the faster an operation can be completed, the less mental effort it presumably requires for its execution. In work by Chi (1977), 5-year-olds required more time to identify photographs of faces than did adults and showed corresponding differences in memory span for the faces. When the amount of time that adults were permitted to view the faces was limited, however, Chi reported drastic reductions in age differences in memory span. Thus, although maturational differences in the capacity of the short-term store appear to be small (few psychologists would say nonexistent), maturational differences in speed of processing, which in turn affects memory span, are more substantial (Kail, 1993).

A distinction is often made between short-term memory and **working memory**, with the former involving only the storage of information held in the short-term system, whereas the latter involves storage capacity and the capacity to transform informa-

tion held in the short-term system (Schneider & Pressley, 1997). Digit-span tasks described earlier assess the capacity of short-term memory. An example of a working-memory task can be found in the research of Siegel and Ryan (1989). They gave children sets of incomplete sentences, requiring them to supply the final word (for example, "In the summer it is very _____"). After being presented with several such sentences, children were asked to recall the final word in each sentence, in order. Such a test requires not only the short-term storage of information, but also some mental work dealing with the to-be-remembered information. Similar to the findings reported for digit span, reliable age differences in working memory are found, although working-memory span is usually about two items less than a child's short-term memory span (Case, 1985).

One popular account of working memory and its development has been presented by Baddeley and Hitch (Baddeley, 1986; Baddeley & Hitch, 1974). According to the Baddeley and Hitch model, age differences in verbal memory span (for example, recall of digits or words) are primarily caused by developmental differences in a phonological subsystem termed the **articulatory loop**. On verbal span tasks, phonological information is stored in the articulatory loop. These verbal representations (or memory traces) decay rapidly but can be maintained in working memory by verbal rehearsal. Although age differences in the rate that information decays in working memory have been reported (see Cowan, 1997), most researchers believe that age differences in rehearsal rate is the primary reason for developmental differences in memory span. The faster one rehearses, the more memory traces one can rehearse, the more information that can be kept active in working memory, the more one can remember. One factor that influences rehearsal rate is word length. Baddeley and Hitch assume that the articulatory loop involves a literal subvocalization process, with people saying the items to themselves. Longer words require more time to say, thus leaving less time to rehearse other words before they decay and are lost from working memory.

There is good evidence from the adult literature that such a process (or one very like it) actually occurs (see Baddeley, 1986, for an extensive review).

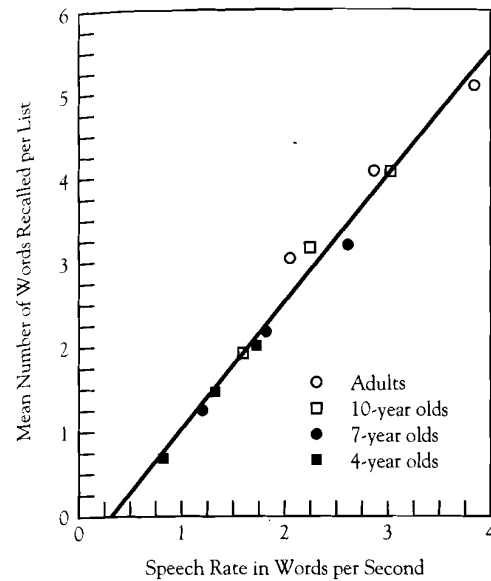


FIGURE 5-5 The relationship between word length, speech rate, and memory span as a function of age. As speech rate increases, more words are recalled, with both speech rate and words recalled increasing with age. SOURCE: "Speech Rate and the Development of Spoken Words: The Role of Rehearsal and Item Identification Processes," by C. Hulme, N. Thomson, C. Muir, and A. Lawrence, 1984, *Journal of Experimental Child Psychology*, 38, 241–253. Copyright © 1984 Academic Press. Reprinted with permission.

In the developmental literature, research has shown a relationship between the speed with which children can say words and memory span. With age, children are able to read or say words at a faster rate, and memory span increases accordingly (Hulme et al., 1984; Kail & Park, 1994). Figure 5-5 presents data from a study by Hulme and his colleagues (1984) showing a very regular, age-related relationship between speech rate (that is, how fast people can say the words) and the number of words recalled on a word-span task. Older children and adults have a faster rate of speech than younger children, and their memory spans vary accordingly.

It is interesting to note that differences in digit span have been found as a function of the language a person speaks. For example, Chinese speakers have considerably longer digit spans than English

speakers do; this difference is apparent as early as age 4 and extends into adulthood (Chen & Stevenson, 1988; Geary et al., 1993). This cultural effect seems to be caused by differences in the rate with which number words (one, two, and so on) in the two languages are spoken. Languages such as Chinese with relatively short number words that can be articulated quickly enable longer digit spans than do languages such as English with relatively long number words that are articulated more slowly (Chen & Stevenson, 1988). In fact, in one study with bilingual children, children had longer digit spans in their second language (English) than their first (Welsh). This counterintuitive finding was because number words can be articulated more rapidly in English than in Welsh (Ellis & Hennessey, 1980). Thus, the greater digit spans of Chinese relative to American children, for example, seem not the result of some inherent cognitive or educational superiority for the Chinese children but, rather, the result of the language they speak.

What seems central to the various accounts of age differences in memory span is **speed of processing**. For example, Dempster's (1981) review of the literature concluded that the only factor influencing memory span is speed of item identification, and the research performed in the Baddeley and Hitch tradition similarly demonstrates that speed of speech articulation plays a central role in children's memory spans. Recent research has shown that both of these factors affect children's memory spans, but that neither factor alone adequately accounts for developmental differences in working memory (Henry & Millar, 1991; Hitch & Towse, 1995). Speed of processing must be considered along with other factors, such as children's familiarity with the to-be-remembered information. Nonetheless, age differences in speed of processing seem to be critically related to age differences in working memory and thus to cognitive development in general.

Speed of Processing

With respect to overall speed of processing, young children require more time, and thus presumably use more of their limited capacity, to execute most cognitive processes than do older children (Dempster,

1981). In a series of studies, Robert Kail (1991, 1997) has reported that the general developmental changes in processing speed are similar across different tasks. In Kail's studies, participants ranging in age from 6 to about 21 years were given a series of reaction-time tasks. For example, in some experiments participants were presented with a pair of letters in different orientations and were to determine as quickly as possible whether the two letters were identical or mirror images of each other. To do this, participants had to mentally rotate one letter into the same orientation as the other. In a name-retrieval task, the participants were shown pairs of pictures and asked to determine whether they were physically identical or had the same name (for instance, different examples of a banana, one peeled and one unpeeled). Patterns of responses over these two, and several other tasks were highly similar, with reaction times becoming faster with age (see also Hale, Fry, & Jessie, 1993; Miller & Vernon, 1997). Figure 5-6 presents the pattern of reaction times across age for a variety of tasks used in Kail's experiments. Note that despite substantial differences in the task requirements, all show essentially the same pattern of changes in reaction time across age. Recent research has even shown a similar (though not identical) age trend in reaction time over the first year of life (Canfield et al., 1997), and between 22- and 32-months of age (Zelazo, Kearsley, & Stack, 1995).

Kail interpreted these findings as reflecting age-related increases in the amount of processing resources available for the execution of cognitive operations. Kail acknowledged that knowledge (such as that possessed by a chess expert) influences speed of processing, and thus levels of performance on cognitive tasks, but he argued that maturationally based factors are primarily responsible for age-related differences in speed, and thus efficiency, of processing (see Kail & Salthouse, 1994).

Developmental and individual differences in knowledge cannot be dismissed as playing only a minor role in differences in speed of processing, though. The relationship between knowledge, speed, and cognitive performance has been demonstrated repeatedly (Chi, 1977). People process fa-

miliar information faster (and thus with less mental effort) than they do less familiar information, and children are relatively unfamiliar with much of what they encounter in their everyday world. With age, they become more experienced and in the process quicken their speed of responding. As Kail and Salthouse (1994) point out, however, although knowledge can substantially affect speed of performance on many tasks, the effects of knowledge appear to operate in a similar way for people of different ages. Thus, underlying individual and developmental differences in knowledge are maturationally based neurological differences, which, in combination, determine speed of processing and availability of mental capacity.

Speed of processing plays an important role not only on tasks where children are required to respond as quickly as they can, but also on tasks that do not demand rapid performance (see Kail, 1993). For example, in studies of memory, young children's performance can be improved merely by increasing the amount of time they have to study the to-be-remembered words (Douglas & Corsale, 1977; Naus, Ornstein, & Aivano, 1977). In one study examining children's use of a rehearsal memory strategy (repeating words to enhance memory), third-grade girls rehearsed more words and remembered more words when they were given more time between the presentation of successive words (from 5 to 10 seconds per word). The different rate of presentation made no difference to sixth-graders, nor to third-grade boys, but the added time apparently allowed the younger girls to compensate for their slower processing time, resulting in increased performance (Naus, Ornstein, & Aivano, 1977). Of course, for some tasks, providing children with all the time in the world will not change their performance. Several studies have given children extra time to study problems, such as determining what factors influence which way a balance scale will tilt (Siegler, 1976), but to no avail. Without explicit instructions or a greater understanding of the nature of the task, increased processing time seems to make no difference. Such patterns of results—with increased time enhancing young children's performance on some tasks but not others—caused Kail (1993) to

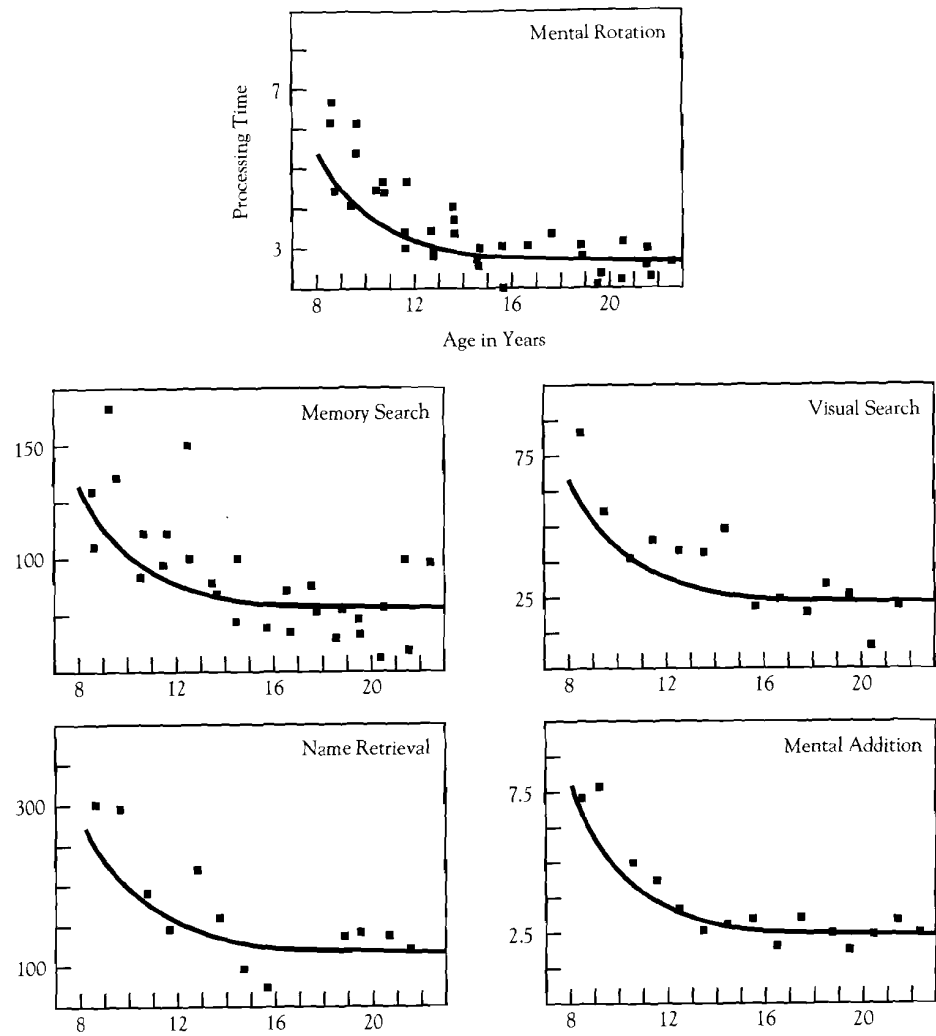


FIGURE 5-6 Developmental patterns of speed of processing for five cognitive tasks. SOURCE: "Development of Processing Speed in Childhood and Adolescence," by R. Kail. In H. W. Reese (Ed.), *Advances in Child Development and Behavior*, 23, 151-187. Copyright © 1991 Academic Press. Reprinted with permission.

conclude that "increased processing time may often be a necessary component of improved performance for younger children but it may not always be sufficient for improved performance" (p. 115).

What is the nature of those maturationally based changes that are proposed to underlie age-related

changes in speed of processing? They might involve the myelination of nerves in the associative ("thinking") area of the brain. As noted in Chapter 2, myelin is a fatty substance that surrounds nerves and facilitates transmission of nerve impulses. Whereas myelination of most sensory and motor areas of the

brain is adultlike within the first several years of life, myelination of the associative area is not complete until the teen years and beyond.

Developmental Differences in the Efficiency of Processing

The findings of Dempster, Kail, and others reporting age-related changes in speed of processing concomitant with age-related changes in cognitive task performance are consistent with theories attributing changes in cognitive development to changes in general information-processing capacity (Halford, 1982; Pascual-Leone, 1970). Early “capacity models” of cognitive development took a neo-Piagetian perspective and essentially proposed that children’s performance on tasks such as conservation could be accounted for by how much information they could hold in mind at a given time (Pascual-Leone, 1970; Stewart & Pascual-Leone, 1992). These theories proposed a domain-general set of cognitive resources that children allocated to various cognitive operations that increase with age. Such domain-general models have a difficult time explaining results such as those reported by Chi (1978), where chess-expert children had a greater memory span for chess positions than did adults, but not when digits served as stimuli. Some cognitive feats seem to be domain specific, with skills in one domain not generalizing to other domains. How can a theory that postulates a domain-general pool of resources account for such findings?

More contemporary theories propose age differences not so much in *absolute* capacity (although such differences may exist), but in the *efficiency* with which children use the mental capacity they have available to them (Bjorklund, Muir-Broaddus, & Schneider, 1990; Case, 1985; Kee, 1994). One influential theory of cognitive development that considers age differences in the efficiency with which information is processed is that of Robbie Case (Case, 1985, 1992a, 1998). (Aspects of Case’s theory were discussed in the previous chapter when we examined neo-Piagetian approaches to cognitive development.) Case proposed age-related declines

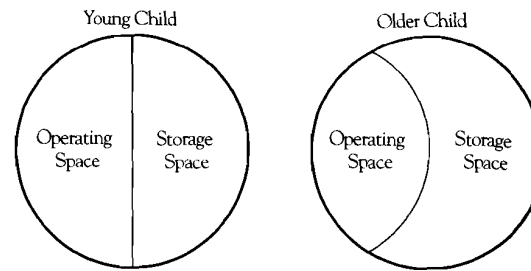


FIGURE 5-7 With age, children process information more efficiently, requiring less operating space and leaving more storage space.

in the amount of mental effort required to execute a cognitive process. Some of this improvement can be attributed to maturation. However, within each maturational stage children become increasingly adept at acquiring information and using strategies. This ability, in turn, fosters greater efficiency, resulting in heightened speed of processing.

Case distinguished between **storage space** and **operating space** when conceptualizing memory processes. Storage space is the mental space that an individual has available for storing information; operating space is the mental space that can be allocated to the execution of intellectual operations. Case also defined **total processing space** as the sum of storage and operating space.

Case proposed that there is a developmental decrease in the amount of operating space required for the execution of cognitive processes with a concomitant increase in operational efficiency. Simply put, as each new developmental skill is mastered and becomes practiced, the increase in processing efficiency frees attention (or processing space) for coordinating new strategies. Developmental changes in operating and storage space are displayed in Figure 5-7. Case’s theory is illustrated in a study by Case and his colleagues (1982), who assessed the independent contributions of storage space and operating efficiency to memory performance. Storage space was measured by counting the number of items that children (ranging in age from 3 to 6 years) recalled

under conditions that minimized the effects of memory strategies (for example, memory-span tasks). Operating efficiency was reflected by the speed with which a set of cognitive operations such as identifying items could be performed. Case and his associates predicted that there would be a relationship between operational efficiency (as reflected by speed of identification) and storage space (as reflected by how much was remembered). Children who were slow in identifying items (thus requiring substantial amounts of operating space) should realize lower levels of memory performance for those items. The data supported this prediction, showing a relationship between storage space and operating efficiency that was also related to age. Furthermore, when the processing speeds of college students were reduced by changing the task so that they no longer benefited from being able to say the words quickly (unfamiliar nonsense words were used), their level of memory performance was comparably reduced. The results of this study are graphically presented in Figure 5-8. As processing efficiency increased (as reflected by speed of processing), memory performance also increased. When adults were given a task reducing their processing efficiency to a level comparable to that of 6-year-olds, their memory performance was similarly modified. These results are similar to those reported by Hulme et al. (1984), who examined the relationship between word length, articulatory speed, and memory span (see Figure 5-5).

Few theorists today argue that there is a single set of resources that influence all aspects of cognition. Yet the possibility that a general-processing mechanism, in combination with more specific mechanisms, plays a substantial role in cognitive development is supported by much research and many theorists. Although capacity models are frequently expressed in terms of space, energy, or efficiency metaphors, they can also be expressed as a time metaphor. Older children require less time to process information than younger children do. This is reflected by age differences in speed of processing, discussed earlier. If we view speed of processing as a direct indication of capacity, we can avoid some definitional problems associated with resource theories

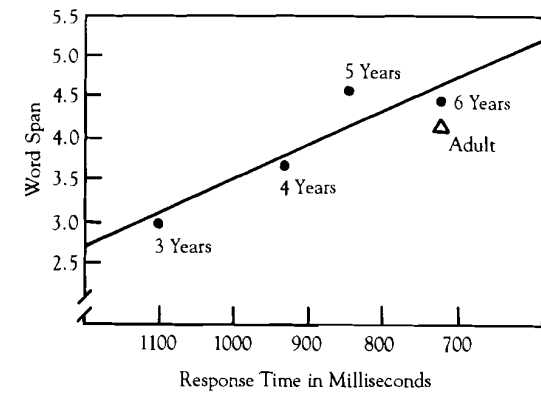


FIGURE 5-8 The relation between word span and speed of word repetition at age levels from 3 to 6 years and adulthood. Younger children were generally slower to identify words and had shorter word spans than older children. When the identification times of adults were slowed to levels comparable to those of 6-year-olds, they showed a corresponding deficit in word span. SOURCE: "Operational Efficiency and the Growth of Short-Term Memory Span," by R. Case, D. M. Kurland, and J. Goldberg, 1982, *Journal of Experimental Child Psychology*, 23, 386-404. Copyright © 1982 Academic Press. Reprinted with permission.

using metaphors of mental space or mental energy. Kail and Salthouse (1994) have proposed such a developmental theory; they suggest that a global processing-speed mechanism influences cognitive performance either directly (faster global processing results in enhanced performance) or indirectly by influencing the speed with which more domain-specific processing mechanisms (such as rehearsal) are executed. Each of these phenomena (global processing speed, specific processing speed, and cognitive performance) can be influenced by other factors associated with age (such as maturational changes in the brain or increased knowledge). Figure 5-9 illustrates the hypothetical relationship between these factors.

Based on evidence of regular age-related changes in speed of processing (discussed earlier), Kail and Salthouse (1994) proposed that speed of processing is a *cognitive primitive*, or a basic aspect of the human

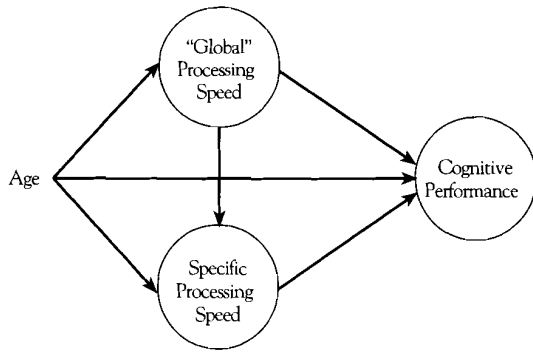


FIGURE 5-9 Model showing the possible relationships among age, global processing speed, specific processing speed, and cognitive performance. SOURCE: Adapted from "Processing Speed as a Mental Capacity," by R. V. Kail and T. A. Salthouse, 1994, *Acta Psychologica*, 86, 199-225. Copyright © 1994 by Elsevier Science Publishers BV. Adapted with permission.

cognitive architecture, much like the central processing unit of a computer is a basic part of the machine's hardware. Differences in this capacity change with age in regular ways and influence much cognitive functioning by limiting how much (or how quickly) information can be handled at any one time. Yet, age differences in speed of processing do not account for all age differences in cognitive performance. As Figure 5-9 shows, factors associated with age may directly influence cognitive functioning independent of processing speed, or age may affect task-specific processing speed. So although speed of processing is not everything, Kail and Salthouse (1994), like other capacity theorists, propose that it is perhaps the most important single factor underlying cognitive development.

Stop here!

The Role of Strategies in Cognitive Development

Given that children have some mental resources available to them, what do they do with these resources to "think"? In other words, from an information-processing perspective, how do they process information? Information must be encoded

or somehow represented in the cognitive system, and once it is in the mind/brain, something must be done with it. Perhaps the information—let's say the word *dog*—must be identified (a meaning must be found in memory for the visual stimulus), classified (as a small, four-legged, domestic mammal), compared with other stimuli or other items in memory (similar to cats; very different from sea slugs), or remembered for later on. Each of these operations (or set of operations) takes time and each requires experience to perform efficiently. Some may be executed automatically and unconsciously, whereas others may be executed only at the individual's discretion, with the mental operations and their results being available for conscious evaluation.

Much of the rest of this book will be concerned with developmental differences in these and other information-processing operations. In the present section, I would like to discuss a broad category of information-processing components—**strategies**. Strategies are goal-directed operations used to aid task performance. Strategies are usually viewed as being deliberately implemented, nonobligatory, and potentially available to consciousness (Harnishfeger & Bjorklund, 1990a; Pressley & Van Meter, 1993). And strategies develop.

Strategies are relevant to most aspects of cognitive development. For example, in memory development, commonly used strategies include rehearsing information or grouping to-be-remembered items by conceptual categories (for example, remembering all the outfielders on a baseball team in one group and all the pitchers in another). In mathematics, simple strategies of addition include counting on one's fingers or mental counting (for instance, for the problem $3 + 2 = ?$, mentally starting with 3 and counting up two to arrive at 5). Strategies can be much more complicated and involve an evaluation component. For example, in reading, one must occasionally determine how well the recently read information is being understood. In all cases, the strategy is used to achieve some cognitive goal (remembering, adding, comprehending).

Although children often discover strategies on their own in the process of performing a task (Siegler & Jenkins, 1989), many important cogni-

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experiment is shown in Figure 5-11. The mental effort associated with having to generate elaborations for relatively unfamiliar pairs of items directly affected how children used the strategy and how much they remembered.

The relationship between knowledge, strategies, and cognitive task performance is a complicated one and an issue of central importance to cognitive development. More will be said of this relationship later in the book, particularly in Chapter 8. What is important to remember is that what and how much one knows influences how and how well one thinks. With age, children acquire more knowledge and, simply as a result of these quantitative increases, process information differently. Because knowledge impacts processing, children (and adults) think differently about topics on which they have detailed knowledge versus those on which they have less knowledge, thus accounting, in part, for the often-observed phenomenon of domain specificity.

Start here.

Attention

One concept closely associated with information-processing approaches to cognition and development is that of attention. In everyday parlance, we use the term interchangeably with concentration. When we tell a child to “pay attention,” we usually want that child to concentrate on the task at hand and not to let his or her mind wander to other things. Attention has been used similarly in the psychological literature. Psychologists who study attention are interested in how and why people attend to some objects and events in the environment and not to others. Developmental psychologists are interested in the development of various aspects of attention.

One assumption about attention is that it consumes limited mental resources. Thus, age differences in the ability to attend to, or to focus one’s attention on, a particular stimulus or task have been presumed to reflect differences in the availability of and ability to allocate limited mental resources. Thus, attending to some task has often been seen as equivalent to allocating one’s limited resources to

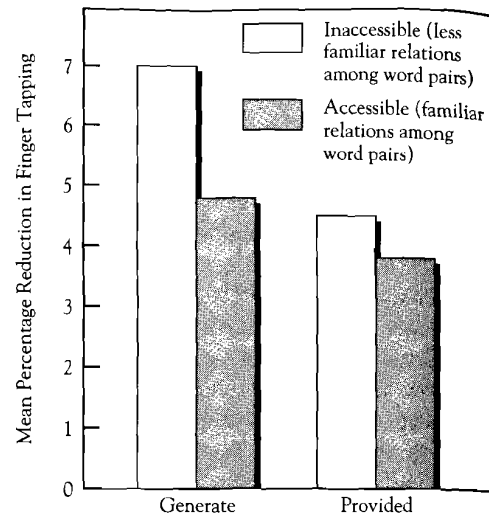


FIGURE 5-11 Mean percentage reduction in finger tapping as a function of accessibility for subjects in the dual-task memory experiment by Kee and Davies. SOURCE: “Mental Effort and Elaboration: Effects of Accessibility and Instruction,” by D. W. Kee and L. Davies, 1990, *Journal of Experimental Child Psychology*, 49, 264–274. Copyright © 1990 Academic Press. Reprinted with permission.

that task. Yet attending means more than merely consuming limited resources. Developmental differences in attention have been examined for a variety of phenomena, including the extent to which children can sustain their focus on tasks, as well as their abilities to switch their focus between competing stimuli, to focus selectively on some stimuli to the exclusion of others, and to apply strategies for selective attention.

Sustaining Attention

One aspect of attention involves sustaining one’s focus on a particular task—that is, paying attention. To some extent, we can measure this even in infancy, with some babies staying “on task” better than others. Some interesting evidence indicates that variations in attention in infants and toddlers (1- and 2-year-olds) are predictive of attention in

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early childhood (3.5 years) (Ruff et al., 1990). Such a finding suggests that some common factor may underlie individual differences in attentiveness, both in infancy and childhood, and might make possible the prediction of attention disorders from measurements in infancy.

The ability to sustain attention becomes increasingly important for children beyond infancy, and ample evidence indicates that children's attention span, the length of time for which they can sustain focused attention, increases with age. For example, Ruff and Lawson (1990) observed children between the ages of 1 and 4.5 years during free play. They noted a regular increase in focused attention during play over this time and attributed such increases, in part, to improved abilities to inhibit extraneous information. In other research, children between the ages of 30 and 54 months were given a series of tests of sustained visual attention, for example, attention during play, while watching television, and during a reaction-time task (Ruff, Capozzoli, & Weisberg, 1998). For each measure, attention increased with age, although it differed among the tasks, with attention during play and for television viewing developing earlier than attention during the reaction-time task. Also, there were only low to moderate correlations among the tasks, indicating that individual differences in attention were relatively domain specific in nature, tied to particular contexts.

One area where issues of sustained attention could have some social and educational implications concerns young children's attention to television shows. It is widely believed that children's comprehension of television is fragmented and passive, promoting a passive attitude toward thinking in general (Singer, 1980). However, there is evidence that young children can and do sustain attention to television shows, although the degree of attention varies with the comprehensibility of the program (Anderson & Lorch, 1983). For example, in a study by Lorch and Castle (1997), 5-year-old children watched special shows of *Sesame Street*. Some of the segments in the shows had been altered to make them less comprehensible by dubbing them in a foreign language, whereas others were intact

(more comprehensible). Children were told to "watch and enjoy" the shows. However, they also were asked to press a button every time a loud buzzer went off, and to do this as fast as they could. This was a *secondary task* (viewing the TV show being the *primary task*), and reaction times to press the buzzer were used as an indication of how much attention they were showing to the TV program. The longer it took them to press the button, the more attention they were presumably paying to the television show.

Lorch and Castle reported that children paid more attention to the television show when more versus less comprehensible segments were showing, and that, when watching the shows, children devoted more attention to the more comprehensible segments. That is, they had slower reaction times to the secondary task when watching the more meaningful shows than the less meaningful shows, or when not looking at the TV at all. Also, the longer children sustained their attention to the meaningful segments (sustaining attention for 15 seconds or longer), the slower were their reaction times on the secondary task, implying that they were devoting more attention to the TV program. In general, children paid substantial attention to meaningful TV programs, implying active, rather than passive processing of the show's content, and they might become more actively involved (cognitively) the longer they continuously attend to the show.

Selective Attention

The term *attention* is frequently used as a synonym for *concentration*. When we concentrate, we focus our attention on some stimulus, ignoring others. **Selective attention** is the ability to concentrate only on chosen stimuli and not to be distracted by other "noise" in the environment. In general, selective-attention abilities increase with age, with young children giving a disproportionate amount of attention to information irrelevant to the task at hand and not enough attention to important information (Lane & Pearson, 1982).

Selective attention in children has been extensively studied using tests of **incidental learning**. In a typical experiment, children are shown pairs of

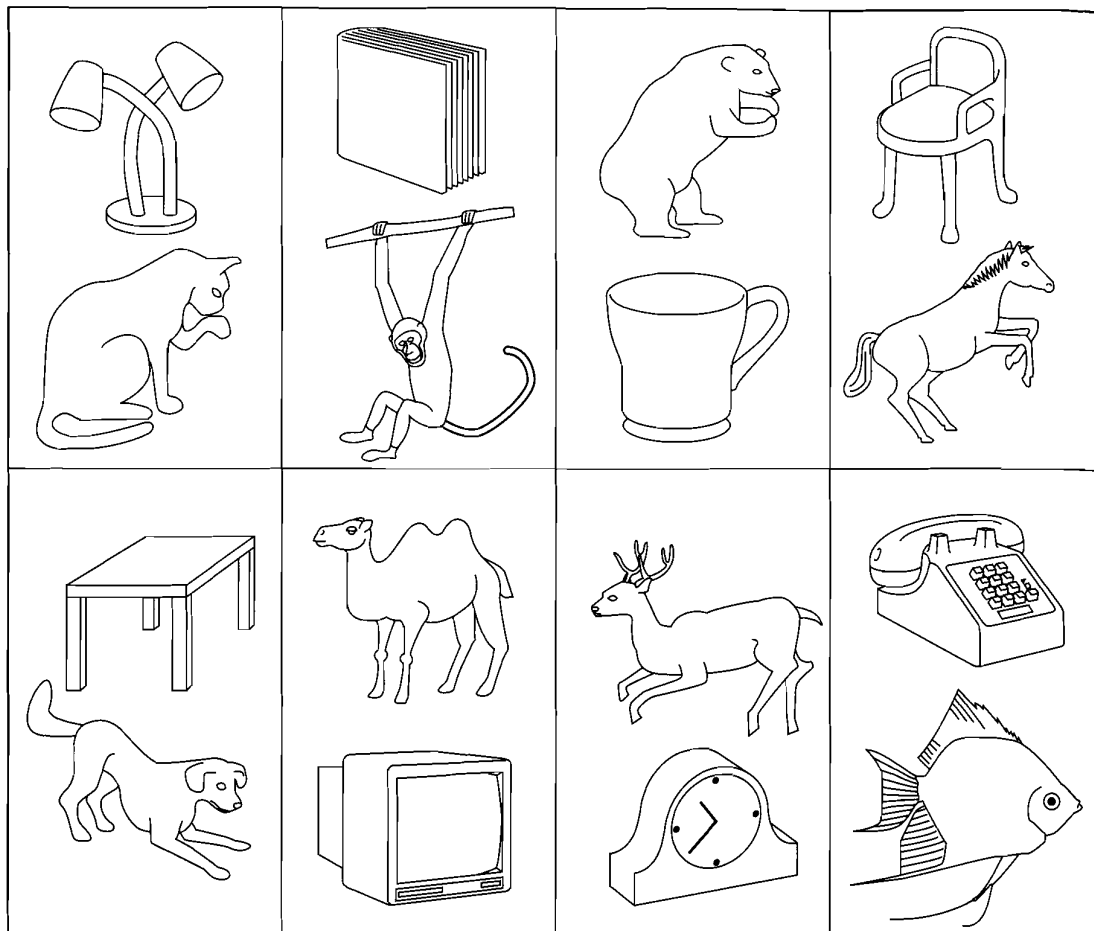


FIGURE 5-12 Stimulus materials used in central-incident memory tasks. Children are instructed to attend to one stimulus class of pictures (the animals, for example) and are later tested for memory of both the central (animals) and incidental (household items) stimuli. SOURCE: "Strategies for Remembering," by J. W. Hagen. In S. Farnham-Diggory (Ed.), *Information Processing in Children*, p. 68. Copyright © 1972 Academic Press. Reprinted with permission.

pictures like those in Figure 5-12. One member of each pair is designated as central, and the children are told to remember it for later on. The other is designated as incidental and the children are told that they can ignore it (Hagen & Stanovich, 1977). Following stimulus presentation, the children are asked to recall the central stimuli, and, as would be expected, the older they are, the more they recall. Then, the children are asked to recall the incidental stimuli—the ones they were supposed to ignore.

Age differences are much smaller for the incidental recall. In fact, after about age 11, the amount of incidental information remembered actually decreases (Hagen & Stanovich, 1977). This means that when instructed to remember one set of items and ignore another, younger children have more difficulty with both. From results such as these, researchers have concluded that older children are better able to allocate attention in accordance with task demands and that they can store information

more efficiently than younger children (Schiff & Knopf, 1985). Teachers and parents need to recognize the possibility that young children's seeming inability to learn prescribed lessons might be because they are filling their minds with incidental learning.

Other researchers have emphasized the role that age differences in the ability to exert inhibitory control plays in developmental differences in selective attention. For example, in research with 5- to 12-year-old children and adults (Ridderinkhof & van der Molen, 1995), participants were shown target arrays (central stimuli) with arrows pointing either to the left or the right. In each hand they held a bulb and were to squeeze the bulb in their right hand for a right facing arrow and the bulb in their left hand for a left-facing arrow. The target arrows were surrounded either by (1) incidental arrows (that children were told to ignore) that faced in the same direction as the target arrows, (2) incidental arrows that faced in the opposite direction, or (3) with diamonds, that served as a neutral stimulus. The length of time it took children to squeeze the bulb, depending on whether the distractor arrows were pointing in the same or opposite direction as the target arrows (all relative to the time it took to squeeze the bulb in the neutral "diamond" condition) was measured. The longer it took children to squeeze the bulb, relative to the neutral condition, the greater interference (and the poorer their selective attention) was proposed to be. Children's brain-wave patterns were also recorded. Ridderinkhof and van der Molen reported a reduction in interference effects with age, as measured both by patterns of hand squeezes and brain waves. Based on their findings, they concluded that age-related differences in inhibition account for much of the data and that this is related to developmental differences in the maturation of the frontal cortex (see also Ridderinkhof, van der Molen, & Band, 1997).

Attentional Strategies

When children must inspect something or make comparisons among objects, how do they allocate, or spend, their attention? Do children attend to some parts of a display more than to others? Do they

compare two objects carefully before declaring them the same or different? Are there age differences in what they do? Stated another way, what strategies of attention do children use when they must examine a stimulus or set of stimuli?

Classic work on developmental differences in children's attentional strategies was conducted by Vurpillot (1968; Vurpillot & Ball, 1979). In these studies, children were shown pictures of pairs of houses (see Figure 5-13). The children's task was to tell whether the windows in the two houses were the same or different. While they were making their decisions, their eye movements were recorded by a camera concealed behind the picture. It was found that preschool children rarely looked at all the windows before making a judgment. For example, when there were 12 windows in the two houses, 4- and 5-year-olds, on average, made a decision after looking at only 7 of the 12 windows. Children aged 6 to 8 years old, however, looked at between 10 and 12 of the windows, on average. Not surprisingly, the older children, who used a better strategy, were more apt to be correct in their judgments than the less strategic preschoolers (Vurpillot & Ball, 1979).

Research by Miller and her colleagues, discussed earlier with respect to utilization deficiencies, has similarly shown improved attentional strategies over the course of the preschool years. In this work, children are instructed to study and remember only a subset of items, hidden in clearly marked boxes (for example, they are asked to remember only the animals, which are hidden in boxes with cages marked on them). Most 3-year-olds open all boxes, both relevant (those with cages on them) and irrelevant (those with houses on them). Slightly older children begin to use a systematic strategy, but it is not typically until after 6 years of age that children consistently use a selective strategy on this task (DeMarie-Dreblow & Miller, 1988; Miller et al., 1986).

What Do Children Know about Attention?

Do young children know more about attentional processes than their behavior might indicate? That is, is their **meta-attention** greater than their

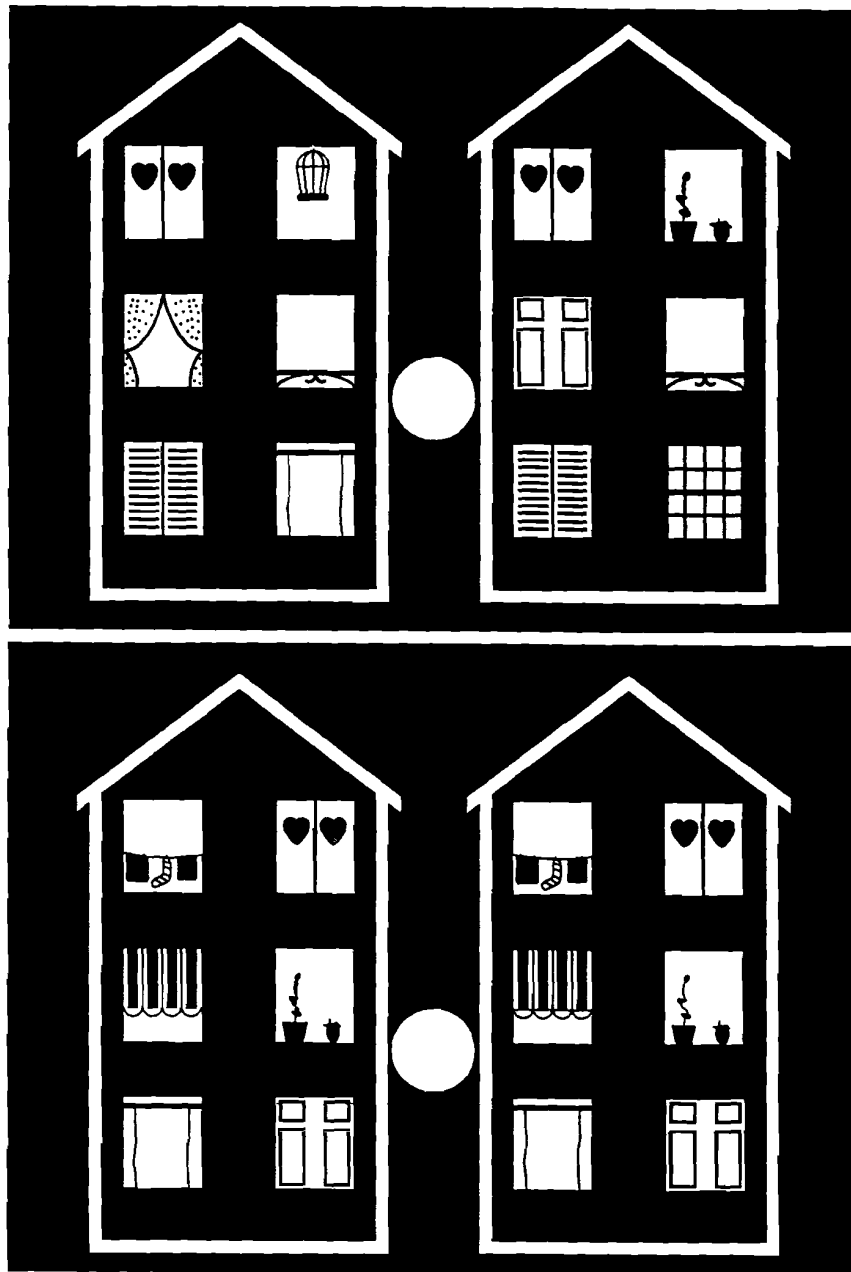


FIGURE 5-13 Stimulus materials used in research on attentional strategies. Children's eye movements are recorded as they determine whether the houses in each pair are the same or different. SOURCE: "The Development of Scanning Strategies and Their Relations to Visual Differentiation," by E. Vurpillot, 1968, *Journal of Experimental Child Psychology*, 6, 632-650. Copyright © 1968 Academic Press. Reprinted with permission.

New Approaches to Developmental Differences in Information Processing

attentional abilities? This often seems to be the case. Even though 4-year-olds generally cannot overcome distractions when performing "selective-attention" tasks, they are apparently aware that distractions are a problem, for they realize that two stories will be harder to understand if the storytellers speak simultaneously rather than taking turns (Pillow, 1988). By contrast, 3-year-olds would just as soon listen to stories told simultaneously as to have the storytellers take turns. In other research, Miller and Weiss (1982) asked 5-, 7-, and 9-year-olds to answer a series of questions about factors known to affect performance on an incidental-learning task (that is, a task like the "animals and objects" test described earlier). Although knowledge about attentional processes generally increased with age, even the 5-year-olds realized that one should at least *look first* at task-relevant stimuli and then *label* these objects as an aid to remembering them. The 7- and 10-year-olds further understood that one must *attend selectively* to task-relevant stimuli and *ignore* irrelevant information to do well on these problems.

However, at other times young children seem unaware that paying attention is something special. John Flavell and his colleagues (Flavell, Green, & Flavell, 1995a), asked 4-, 6-, and 8-year-old children a series of questions about attention. For example, if a woman is examining a set of decorative pins so that she can select one as a gift, what would be on her mind? Would she be focusing just on the pins, or might she have other things on her mind as well? Whereas almost all 8-year-olds and most 6-year-olds were aware that the woman would be thinking primarily about the pins and not likely thinking about other things, few 4-year-olds had this insight. It's as if they do not realize what is involved in selective attention. By 8 years of age, children's understanding of attentional focus was about as good as that of adults.

In sum, the development of attention is apparently a lengthy process in which children first learn to translate what they know into appropriate actions and then gradually come to rely on these strategies as they become more routinized and an effective means of gathering information to achieve their objectives.

I think it would be accurate to say that information-processing models, in one guise or another, remain the dominant perspective in cognitive development today. As with all psychological theories, however, information-processing conceptions of children's thought are constantly being tested, challenged, and modified. Some challenges to information-processing approaches come from the developing field of cognitive science. Psychologists are increasingly concerned with the biological basis of cognition and its development, including both neurological (proximate) and evolutionary (distal) causes. These have not been traditional concerns of information-processing approaches, and critics have argued convincingly that new theories must be developed that take the brain as seriously as the mind when describing and explaining cognition and its development (see Gibson & Petersen, 1991; Tooby & Cosmides, 1992).

But information-processing accounts of cognition and development have been sufficiently flexible to change with the times. Although few researchers today take the "mind as a computer" metaphor too seriously, most still believe that the mind/brain processes information (that is, encodes, represents, categorizes, retrieves). Thinking involves computation, done by bundles of nerve cells and not silicon chips. However, some of the basic assumptions of classical information-processing theory have slowly been eroding, such as the belief in a single set of generic resources or that all processing is serial in nature (that is, that we can only think of one thing at a time).

In the sections that follow, I discuss three new approaches within the general framework of information-processing theory: theories that posit developmental differences in inhibition and resistance to interference as the underlying cause of much of cognitive development; Charles Brainerd and Valerie Reyna's fuzzy-trace theory, which looks at age differences in basic processes, rather than higher-level, conscious processes, as the mechanisms

for cognitive change; and connectionist models of cognitive development, which involve a particular type of computer simulations to achieve a better understanding of development.

Inhibition and Resistance to Interference

Inhibition and interference are old concepts in psychology. With the rise of information-processing theory, however, concepts of inhibition and interference fell out of grace, being seemingly incompatible with the computer metaphor of mind. As gaps in information-processing theory became apparent, theorists looking both at adult cognition and cognitive development re-examined the role that inhibition and **resistance to interference** might play in human thought. Although it is clearly important to activate knowledge or thought processes, it is equally important that we *don't* execute, or that we *inhibit*, processes at other times. A theory of cognition that examines only "activation" is going to have only part of the picture. And the role of inhibition might be especially important, or obvious, in children. Many of children's cognitive errors and their everyday "problem" behaviors come from things they do despite instructions otherwise (for example, "I didn't mean to trip Josh when he walked up the aisle, it just happened"). The basic idea at its simplest is that, with age, children are increasingly able to inhibit prepotent (primary) and often inappropriate mental or behavioral responses or to resist interference from both internal and external sources, and that these improved skills permit the more efficient execution of other cognitive operations.

Neurological Locus

Inhibitory and resistance-to-interference processes are seemingly related to the functioning of the frontal lobes of the neocortex (or the prefrontal cortex—see Chapter 2). The frontal lobes of the neocortex have many projections to other areas of the brain, including the limbic system, the "emotional" part of the brain. The prefrontal cortex is one of the last areas of the brain to reach full matu-

urity in ontogeny. Development of the frontal lobes in humans is rapid between birth and about 2 years of age. Another, less pronounced growth spurt occurs between about 4 and 7 years, with subsequent growth being slow and gradual into young adulthood (Luria, 1973).

Much evidence for the role of frontal lobes in inhibition in humans comes from cases of brain damage. Humans with frontal lobe damage have difficulty with planning and concentration. Frontal lobe dysfunction has been implicated in some psychiatric syndromes, such as obsessive-compulsive disorder (Malloy, 1987). One test that demonstrates the difficulty frontal lobe patients have with interference is the Wisconsin Card Sorting Test (WCST). The WCST consists of cards on which are depicted different objects (such as squares, stars, and circles) that vary in color and number (see Figure 5-14). The participants' task is to sort the cards into specified categories (that is, according to color, number, or shape), which is reinforced by the examiner. Without specifically informing the participant, the examiner then switches reinforcement to another category. For example, the initial category may be number, in which case participants would be reinforced for sorting all the target cards with four items on them under the cue card consisting of four circles, all the cards with three items on them under the cue card with the three crosses, and so on, regardless of the color or shape of the items on the cards. The examiner may then switch from number to shape, so that all target cards are now to be placed with the cue card consisting of the same shape (stars with stars, triangles with triangles, and so on), with color and number being irrelevant. Participants are corrected after a mistake, so they should presumably be able to learn a new classification scheme after only a few trials. Normal people do exactly this. However, patients with lesions in the frontal lobes do poorly on this task, often finding it difficult to make a new response (Milner, 1964). This reflects an inability to inhibit a previously acquired response. Based on these and related findings, it has become clear that the frontal lobes play a central role in the selection and regulation of behavior by

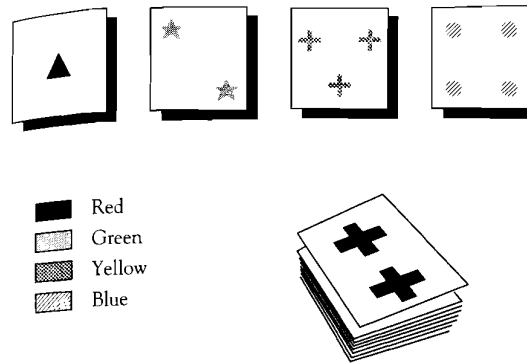


FIGURE 5-14 The Wisconsin Card Sorting Test.
SOURCE: "Some Effects of Frontal Lobotomy in Man,"
by B. Milner. In J. M. Warren & K. Akert (Eds.), *The
Frontal Granular Cortex and Behavior*, McGraw-Hill,
1964.

inhibiting previous responses and fostering resistance to interference from extraneous stimuli (see Dempster, 1993; Diamond, 1991; Luria, 1973).

Developmental Differences in Inhibition and Resistance to Interference

Because we know the frontal lobes develop over infancy and childhood, we should expect corresponding changes in the ability to inhibit irrelevant information and to resist interference, and ample evidence demonstrates just that. Recall, for example, the research by Diamond (1985), discussed in Chapter 2, in which infants' performance on A-not-B object permanence tasks was related to development of the prefrontal lobes (see also Bell & Fox, 1992). Likewise, many of the tasks that adults with frontal lobe damage have difficulty performing also show improvements with development. For example, age differences are found in performance on the WCST, with young children performing much the way adults with frontal lesions perform (Chelune & Baer, 1986).

In a task that is essentially a simplified version of the WCST, children are given a set of cards with

each card depicting one of two objects (a red boat or a blue rabbit, for example). Children first sort the pictures into groups on the basis of one dimension (shape, for example, boats versus rabbits), and then, after several trials, are told that the rules have changed and they must now sort the pictures on the basis of the other dimension (color, red versus blue) (Zelazo, Frye, & Rapus, 1996). Although 3-year-old children can easily sort the pictures into groups on the basis of either color or shape, they almost always fail on the "switch" trials, when the rules change from sorting on the basis of shape to color (or vice versa). Instead, they continue to sort the cards as they had previously, despite being able to articulate the rule. Zelazo and his colleagues attribute this failure to 3-year-olds' inability to reflect on their knowledge, something that develops between the ages of 3 and 5 years (Zelazo et al., 1997) (see further discussion of this and related tasks in Chapter 10). Zelazo might be correct about this, but it also seems clear that one of the difficulties these young children have is inhibiting the activation of the previously correct rule (boats go here, rabbits go there), despite seemingly knowing better.

Children's ability to regulate their behavior (which involves inhibiting undesired behavior as well as executing desired behavior) improves with age (see Kochanska et al., 1996; Luria, 1961). This includes using language to guide their behavior (see Luria, 1961; Vygotsky, 1962), with young children often displaying the same problems shown by adults with frontal lesions. For example, preschool children show the same difficulty in performing tasks in which verbal instructions contradict a more salient routine as do frontal lesion patients, such as the task in which participants are to tap once each time the examiner taps twice, and tap twice each time the examiner taps once (Diamond & Taylor, 1996). Young children's difficulties inhibiting their behavior to language can be seen even in simple games such as "Simon Says." Preschool and early school-age children make many inhibitory errors in this game, making responses to verbal commands even though Simon didn't say so; simplifying the game helps, but young children still make many more

inhibitory errors than older children (LaVoie et al., 1981; Reed, Pien, & Rothbart, 1984).

Children also have a difficult time inhibiting their speech. For example, in research in which children were to name out loud only certain pictures on a page (for example, animals) but not say the names of distractor items (for example, people), kindergarten children showed no evidence of inhibiting their responses. They mentioned the distractor items as frequently on trials when they were told not to mention the distractor pictures as on trials when they were told to mention them (Kipp & Pope, 1997). (This reminds me of a verbally precocious 4-year-old who was telling a story to his parents about his day at school and then, in the middle of the story, suddenly started talking about a TV show he had recently seen. The child paused briefly and then said, "Oops, I just interrupted myself." He couldn't keep the distracting thought about the TV show from intruding on his story about his day at school.)

Changes in inhibitory processes over childhood have been related to a number of cognitive tasks. For example, children's ability to selectively forget information is affected by their ability to keep the to-be-forgotten information out of mind. Older children are better able to execute these inhibitory processes than younger children are (Harnishfeger & Pope, 1996; Lehman et al., 1997; see Wilson and Kipp, 1998). Age differences in selective attention (discussed earlier in this chapter) can be explained by young children's inability to ignore task-irrelevant stimuli. Although task instructions make it clear that they are to attend only to the central stimuli and ignore peripheral stimuli, they have a difficult time doing so (see Ridderinkhof et al., 1997). And young children's difficulty in inhibiting some behaviors (such as pointing to where an object is hidden) might impede their ability to deceive others in some situations (Carlson, Moses, & Hix, 1998).

Katherine Kipp Harnishfeger and I (Bjorklund & Harnishfeger, 1990; Harnishfeger, 1995; Harnishfeger & Bjorklund, 1994) proposed a model of inefficient inhibition in working memory to account for the influence of inhibition mechanisms on cognitive development. The central idea in this model is that

differences in the ability to keep task-inappropriate information out of working memory influences task performance. Harnishfeger and Bjorklund suggested that young children not only have difficulty ignoring task-irrelevant stimuli in their environment, but they also have a difficult time keeping task-irrelevant "thoughts" out of working memory. They proposed that the greater amount of task-irrelevant information in working memory for young children results in greater "cognitive clutter," which effectively reduces functional working-memory space (see Lorscheid & Reimer, 1997).

Evidence for this comes from a study by Lorscheid, Katz, and Cupak (1998). They modified a procedure initially used to assess inhibition mechanisms during text processing in younger and older adults (Hamm & Hasher, 1992). Basically, third-grade, sixth-grade, and college students heard passages that initially led to a particular interpretation (for example, Mike and his mom were watching butterflies). During the second half of the passage, the story either continued as expected or the interpretation switched (they were actually watching birds). Participants were given memory tests to determine whether or not they still had the idea of butterflies (now disconfirmed) in their minds at the end of the story. Adults were able to "forget" about the initial, now disconfirmed, interpretation (that is, butterflies), keeping this irrelevant information out of working memory. Third- and sixth-grade-children were much less likely to do this. In other words, whereas adults were able to inhibit the irrelevant interpretation (butterflies) and focus only on the relevant interpretation (birds), the children had a more difficult time inhibiting the irrelevant information, resulting in cognitive clutter in their working memory.

Frank Dempster (1992, 1993) has focused on age differences in resistance to interference, such as reflected by children's performance on selective-attention tasks and the Wisconsin Card Sorting Test, both described earlier. Dempster sees resistance to interference as a basic-level process that is central to understanding cognitive development. However, this resistance to interference is not a unitary construct. Although Dempster believes that the frontal lobes are involved in most cases of resistance

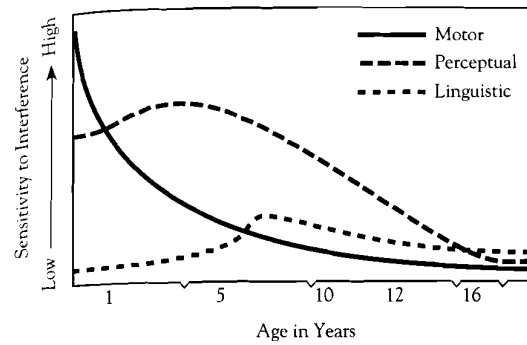


Figure 5-15 The hypothesized relationship between age and sensitivity to motor, perceptual, and linguistic interference. SOURCE: "Resistance to Interference: Developmental Changes in Basic Processing Mechanisms," by F. N. Dempster. In M. L. Howe & R. Pasnak (Eds.), *Emerging Themes in Cognitive Development, Vol. 1: Foundations*, p. 19. Copyright ©1993 Springer-Verlag, New York, Inc. Reprinted with permission.

to interference, he contends that there are at least three separate types of interference phenomena, each with its own developmental course. The hypothesized relation between age and sensitivity to interference is shown in Figure 5-15 for the motor, perceptual, and verbal domains.

As can be seen from the figure, sensitivity to motor interference is greatest early in life. Such high sensitivity to motor interference would account for infants' behaviors on A-not-B object-permanence tasks (Diamond, 1985; see Chapter 2). Infants might know that an object was hidden at location B, but they cannot prevent themselves from reaching toward location A. Children's ability to inhibit responses increases over infancy and childhood, as reflected by the greater motor control children acquire during the elementary school years (which can be seen in playing a game of "Simon says," for example).

Sensitivity to perceptual interference shows a more gradual decline over late childhood and early adolescence. This, Dempster proposes, is reflected by young children's perception being stimulus bound, or, following Piaget, being perceptually centered. For example, in the conservation-of-liquid

task, preschool children cannot ignore the differences in height of the two containers. Their perception is centered on the most salient aspect of the perceptual array and they make their decisions on this aspect. According to Dempster, children during Piaget's preoperational period cannot easily resist perceptual sources of interference.

Dempster suggests that sensitivity to verbal interference remains relatively constant over development, peaking during early childhood, when language begins to play an increasingly important role in guiding problem solving (Vygotsky, 1962). This increase in sensitivity to verbal interference corresponds with the decrease seen in sensitivity to perceptual interference, suggesting a change in the underlying representational system.

Acknowledging that inhibitory processes play an important role in cognitive development seems to be an important step forward in helping us arrive at a better understanding of children's thinking. But such a perspective should be seen as supplementing information-processing views of development and not replacing them. Age changes in inhibition may permit certain other abilities to be expressed, but they do not seemingly cause them to develop. Improvements in inhibitory control may thus play a permissive role in cognitive development, with a certain level of inhibitory control being necessary before other specific abilities can develop.

Stop here!

Fuzzy-Trace Theory

Charles Brainerd and Valerie Reyna have suggested a new metaphor for cognitive development, proposing that the logical, structuralist approach of Piaget and the symbol-manipulation, "mind-like-a-computer" approach of information processing have each run their course. In their place, they suggest the metaphor of **intuitionism**, in which people prefer to think, reason, and remember by processing inexact, "fuzzy" memory representations rather than working logically from exact, verbatim representations. In a nutshell, according to Brainerd and Reyna, most cognition is intuitive, in that it is based on "fuzzy representations (senses, patterns, gists) in