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CHAPTER 5

Cognitive Aging

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When people think of growing older, they not only express concerns over losing their abilities to think, reason, and remember as well as they used to, but they increasingly worry that these changes will have a profound impact on all aspects of their lives (Centofanti, 1998). Research suggests that these concerns are not unfounded: decreases in cognitive functioning have been associated with significant increases in depression and can have a great impact on quality of life (Comijs et al., 2004). Individuals experiencing cognitive decline lose relationships even with members of their own family, a change that does not occur with physical decline alone (Aartsen, van Tilburg, Smits, & Knipscheer, 2004). Recent research has established close links among cognitive, physical, social, and emotional health and has shown that they rely on one another to an astonishing degree (Baltes & Lindenberger, 1997; Colcombe & Kramer, 2003; Gallo, Rebok, Tennsted, Wadley, & Horgas, 2003). Findings such as these reinforce the notion that age-related differences in cognitive functioning do not occur in a vacuum: the entire person needs to be considered in order to develop a comprehensive theory of cognitive aging.

As the most recent edition of the *Handbook of Aging and Cognition* (Craik & Salthouse, 2000) illustrates, cognitive aging encompasses a wide

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range of topics, including memory, attention, language, human factors, intelligence, and changes in the brain. One chapter cannot hope to survey all of the topics in cognitive aging. Rather, we situate the field of cognitive aging within gerontology, discuss how cognitive psychologists investigate the fundamental processes underlying the aging of the mind, and identify the most promising theoretical frameworks driving the research. Finally, we briefly touch on some new developments in the area of cognitive neuroscience and aging, and effects of training interventions on retaining or slowing declines in cognitive abilities in older adults.

COGNITION AND GERONTOLOGY

It has been suggested that the field of gerontology has been shifting to a focus on life course analysis that encompasses the entire developmental history of the individual (Ferraro, 1997). In addition, the field has been emphasizing a multidisciplinary approach, including investigating the biological, behavioral, and social structural factors that influence aging and their interactions. To a certain extent, this is also true among researchers interested in cognitive aging. For example, there is an increasing body of research using large-scale cross-sectional and longitudinal methods to examine the psychological, social, health, biological, economic, and other factors that might have an impact on cognitive functioning. These studies include, among others, the Seattle Longitudinal Study (Schaie, 2004), the Berlin Aging Study (Baltes & Meyer, 1999), the Longitudinal Aging Study Amsterdam (Deeg, Knipscheer, & van Tilburg, 1993), and the Victoria Longitudinal Aging study (Hultsch, Hertzog, Dixon, & Small, 1998). All of these studies include multiple measures of each cognitive construct, as well as demographic, health, and other social, economic, and behavioral measures.

These large-scale studies are excellent resources and give an important overview of many aspects of cognitive aging. However, in some senses, these reports are unsatisfying because they are correlational and tend to be rather atheoretical in nature. In addition, the sheer amount of information collected tends to make it difficult to abstract a general message. On the other hand, these studies are valuable in that they can help focus and narrow down the important variables that can then be tested empirically. As such, they can pave the way toward an integration of longitudinal models with experimental tests of the multiple alternative explanations that exist for such data (Hertzog, 2004).

In addition to these large-scale studies, there has been an increasing sensitivity to the importance of considering a broad range of factors in more traditional cognitive aging research. This shift in thinking is illustrated by the contributions in *New Frontiers in Cognitive Aging* (Dixon, Bäckman, & Nilsson, 2004). This edited book includes chapters discussing new theoretical and methodological orientations and sets the field of cognitive aging more firmly in the gerontological arena. In particular, cognition is placed in the context of everyday functioning in familiar environments, something that is often missing from traditional laboratory-based measures of cognition. In contrast to many other compendia on cognition and aging, the book includes an entire section on biological and health effects on cognitive aging.

Thus, it seems that the context of cognitive aging has been broadening considerably, along with the rest of gerontology. These investigations help us determine what empirical effects to search for, the types of dependent variables to be examined, and the methods that will be used to search for explanations. The interplay of theory, method, and the choice of the constructs or underlying effects that are investigated determine, to some extent, the conclusions that are drawn from them (Light, 2004).

METHODOLOGICAL ISSUES

Psychometric (Macro) Versus Experimental (Micro) Approaches

The study of cognitive aging is divided, like many other areas of gerontological inquiry, into researchers who are interested in issues involved with aging in particular and researchers who wish to use the aging population to help develop models of cognition in general. Salthouse (2000) places the psychometric and experimental approaches into two general categories: macro (broad and integrative) and micro (analytical and specific).

The macro approach focuses on a broad range of cognitive processing abilities that differ as a function of age and generally uses correlational or psychometric techniques. In this method, the researcher is interested in identifying commonalities among tasks in terms of the underlying abilities they tap. The ultimate goal is to determine the fundamental cognitive abilities that are different as a function of age. This approach assumes that there are a limited number of general effects of aging that are shared among a variety of tasks. Typically, researchers adopting this method use an individual differences or psychometric design in which each participant is given multiple tasks. The underlying constructs controlling performance in the tasks are identified by using statistical procedures that identify shared variances (see, e.g., Salthouse & Ferrer-Caja, 2003). Using such designs, one can identify the number of age-related influences that operate on the cognitive variables being measured. Mediating variables that interact with the latent variables can also be identified.

In contrast, the micro approach focuses on describing specific tasks and processes that differ as a function of age and generally uses an experimental manipulation of independent variables. This method is a common one in information processing, still the dominant paradigm in cognitive psychology (see, e.g., Fisk & Rogers, 1991; Fisher & Glaser, 1996): A task is decomposed into subtasks, each relatively independent of the others. In terms of aging, the magnitude of the age-related influence on each aspect of a task can be measured. As an example of this type of approach, consider a simple reaction time task in which the subject is asked to respond as quickly as possible to the presentation of a stimulus, perhaps by pressing a key. The time it takes to respond is measured. In a more complex version of the task, the subject may be asked to identify the stimulus and choose among a number of alternative responses. Analytically, the time to complete the second task can be decomposed into the simple task plus the time it takes to identify the stimulus and make a choice. This type of approach lends itself naturally to an experimental design in which the experimenter varies the parameters of a single task to try to determine effects of aging on each aspect of the task.

A relatively recent approach to the study of cognitive aging uses the logic of simulation modeling to investigate very complex interactions among variables. This can be seen as a middle ground between the macro and micro approaches. There are many advantages in using a formal model to help guide interpretation of the data (Neath, 1999). It has become increasingly obvious that the effects of aging on cognition are extremely complex and are caused by multiple interactions among factors. A formal computational model allows for the exploration of higher-order interactions that simply could not be worked through with a less detailed verbal model. In addition, clear and testable predictions can be made from a formal model in which psychologically plausible parameters are mapped on to particular human processes. The drawback to computational modeling, of course, is that it is merely an existence proof; it shows that if we manipulate the parameters in such a way, the proper pattern of data emerges. If the parameters do not map on to real properties of the organism, it can become merely an exercise in fitting data.

Cross-Sectional versus Longitudinal Designs

Much of the research in cognitive aging uses a cross-sectional design. In these investigations, the performance of a group of individuals from one age range is compared to that of a group from another age range. There are numerous difficulties in drawing conclusions about the effects of chronological age per se from such a design. There are a substantial number of uncontrolled covariates, including cohort effects, motivation, and health status, to name just a few (for a review, see Salthouse, 1991). However, these designs can be very informative in identifying specific areas of differences between groups of older and younger adults. There are a number of ways in which researchers overcome or work around the difficulties embodied in cross-sectional designs. For example, many studies use a cross-sectional design but several different kinds of older subject groups (see, e.g., Craik, Byrd, & Swanson, 1987).

In contrast to cross-sectional designs, longitudinal research involves following particular individuals over a period of time and testing them repeatedly (see, e.g., Hultsch et al., 1998; Hertzog, 2004). These designs allow the researcher to estimate individual changes in particular abilities rather than inferring changes based on differences among disparate groups. These sorts of designs control for the covariates that are unconstrained in cross-sectional designs, particularly effects of early experience. However, these designs are costly, and once the study has begun, it is difficult to incorporate new techniques and tasks to test new hypotheses.

Although it may often be argued that the ideal case for studying cognition and aging is a longitudinal design, each approach brings with it difficulties and limitations. As noted nearly 50 years ago (Garner, Hake, & Eriksen, 1956), researchers must be cautious in forming conclusions based on data from just one methodology. Instead, the strategy of looking for converging operations from multiple paradigms results in the most powerful conclusions (e.g., Bromley, 1990; Salthouse, 2000). The idea is that to the extent that one finds a similar pattern of results using a number of different perspectives, the results are less likely to be due to the adoption of one particular method. Hertzog (1996) recommends a three-stage approach. First, one might test participants in an extreme-group cross-sectional study to establish that there is an age-related effect (e.g., young versus older adults). This can then be followed by a larger cross-sectional study involving a continuous range of ages to gain an idea of the magnitude of the effect and at what age it begins to become apparent. Finally, longitudinal studies can be conducted to determine the predictors and other factors that go along with and may be a cause of those changes.

Meta-Analysis

Meta-analysis is a tool for combining results from multiple experiments in order to take advantage of the increased number of observations to determine the true size of an effect. This method can be used to integrate disparate findings and summarize an entire body of research. For example, using such a technique, Light and her colleagues (Light, Prull, La Voie, & Healy, 2000) were able to resolve a long-standing controversy over whether there was a difference in implicit memory performance between older and younger adults.

AGE-RELATED DIFFERENCES IN COGNITIVE FUNCTIONING

The primary question posed by researchers in cognitive aging concerns the specific differences in cognitive functioning between older and younger adults. Is it the case that performance declines only on particular tasks, with some abilities spared, or, as Rabbitt (1993) put it, "Does it all go together when it goes?"

Perceptual Deficits

Both visual and auditory processing abilities decline substantially as a function of increasing age. Age-related hearing loss, or presbycusis, is experienced by as many one-third of adults over the age of 70. In addition, about 14% of individuals from 70 to 75 years old experience trouble seeing even with glasses; that number increases to 32 percent for those over age 85 (Desai, Pratt, Lentzner, & Robinson, 2001). Age-related declines in perceptual abilities are not restricted solely to increases in sensory thresholds: complex processing, including frequency discrimination, temporal processing, gap detection, and sound localization, is also generally affected in older adults. Understanding speech in noise is particularly difficult for older adults, even when they have normal hearing for their age group. This can lead older adults to avoid situations in which conversation will be difficult, thus reducing the number of social activities, for example. Light sensitivity, visual acuity, color vision, and contrast sensitivity are all worse in the older eye. (See Schneider & Pichora-Fuller, 2000, for a comprehensive review of perceptual deterioration as a function of age.) These types of deficits can lead to an unwillingness to drive or travel, again limiting social interaction.

In addition to the social and health implications of these deficits, there are serious cognitive consequences. Efficient perceptual processing is essential for navigating through the world, following discourse, and integrating information from multiple sources. Speech perception, in particular, relies on the rapid processing of auditory input and may be substantially affected by hearing loss.

Memory

Memory is an area of great concern for many older adults, but the correlation between actual memory ability and self-judged memory ability can be quite low (Hertzog, 2002). For example, Rabbitt and Abson (1991) found that older subjects' estimates of their performance were uncorrelated with their actual performance on recognition, memory span, recall, and cumulative learning tasks. Interestingly, there were significant correlations between estimated memory ability and reports of depression: people who thought their memory abilities were poor or declining were more likely to report feeling depressed.

Older adults generally perform worse than younger adults on memory tests in which there are few environmental cues. Thus, they perform worse on recall tests but equivalently on recognition tests (Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003) and worse on explicit than implicit tasks (La Voie & Light, 1994; Light & La Voie, 1993). In immediate memory, older adults perform worse on tasks that require the active manipulation of information but only slightly worse on measures of simple memory span (Zacks, Hasher, & Li, 2000).

Prospective memory refers to remembering to perform some action at some point in the future. There are two different ways in which prospective memory tasks can be categorized. In a time-based task, the subject must perform some activity at a certain time; in an event-based task, the subject must perform the activity when a certain event occurs. Examples are remembering to take a pill every 8 hours versus remembering to give a neighbor a message when you see her. Comparing young college-age individuals and older adults (age 70 to 78), Einstein, McDaniel, Richardson, Guynn, and Cunfer (1995) found no age-related differences on an event-based prospective memory task, but did find age-related differences on a time-based task. Interestingly, older adults are often better than younger adults in remembering to perform real-life tasks, perhaps due to greater motivation (Rendell & Thomson, 1999). Anderson and Craik (2000) argue that the self-initiated activities that show a large decline with aging in the prospective memory literature are the same as those that show a decline in recall and context; both are sensitive to the amount of environmental support available in the situation.

A burgeoning area of research on memory and aging is often referred to as false memories (although the word *false* is a misnomer; see Neath & Surprenant, 2003, for a discussion). In this type of illusory recollection, individuals "remember" an event that never happened. This phenomenon is common in younger people and surprisingly easy to demonstrate in laboratory conditions (Hyman & Billings, 1998). Older adults seem particularly susceptible to such illusions (Dywan & Jacoby, 1990). This susceptibility has been interpreted as being due to a difficulty in identifying the origin of a memory or source monitoring. For example, older adults have more trouble determining whether an item was earlier seen or imagined (Henkel, Johnson, & De Leonardis, 1998), even when overall recall rates are equivalent to those of young adults. This difference can be eliminated with strategies such as using a distinctiveness heuristic, such as saying the target out loud at encoding. Then, at retrieval, the individual can search for the distinctive information (his or her own voice) in order to identify the source (Dodson & Schacter, 2002).

Intelligence

There are a variety of differences in intellectual functioning between older and younger adults. The typical finding is that older adults score lower on tests designed to tap what is called *fluid intelligence* but perform just as well or even better than younger adults on measures of *crystallized intelligence*. The definitions of these intelligences are not always precise but tasks that involve quick thinking, manipulation of information, and performing multiple activities that require the allocation and reallocation of attention are generally considered to rely mainly on fluid intelligence. Those that tap well-learned skills, language, and retrieval of well-learned material are generally considered to rely more on crystallized intelligence.

Thus, aspects of intelligence such as vocabulary and knowledge are relatively unaffected by increasing age (and, in fact, often increase with age), but tasks such as reasoning, mental calculations, and free recall tend to decrease as a function of age (Salthouse, 1991). In a recent study looking at cognitive performance in over 5,000 20- to 50-year-old adults, Schroeder and Salthouse (2004) reported that scores on composite tests of memory, spatial relations, and reasoning decreased by about 0.02 standard deviation units per year. At the same time, scores on a vocabulary test increased (again, rather steadily) by 0.05 standard deviation units per year. Schroeder and Salthouse speculated that the reason this decline in fluid abilities is not noticeable in our early 40s and 50s is that it is such a very small decline that the cumulative effect is generally not noticed for quite some time. Moreover, these small declines can be offset by increases in knowledge and experience (crystallized intelligence). To a certain extent, one can compensate for decreased abilities in one domain with increased abilities in another.

EXPLANATIONS OF AGE-RELATED DIFFERENCES

There are currently at least four major explanations of the cause of decreases in cognitive abilities as a function of age: (1) slowed speed of processing, (2) lack of inhibitory control, (3) reductions in processing resources or working memory capacity, and (4) reductions in perceptual processing efficiency. The models that are chosen are critical in driving the field toward particular methods, constructs, and dependent variables. The assumptions and premises taken to be given by the researcher determine, to some extent, the questions that will be asked.

Slowed Speed of Processing

One of the dominant explanations of cognitive aging is that declines in performance accompanying normal aging are due to a reduced capacity caused by a general slowing of processing speed (Birren, 1965; Salthouse, 1985). Speed of processing has been shown to be a general factor that underlies performance in a wide variety of cognitive tasks, including attention, memory, reasoning, and language (Salthouse & Ferrer-Caja, 2003). On relatively direct measures of processing speed such as reaction times, older adults do perform more slowly than younger adults. These measures share variance with other measures of cognitive functioning such as episodic memory and fluid intelligence scores. In addition, it has frequently been reported that when individual differences in speed of processing are partialed out statistically, age by itself no longer accounts for significant variance (Salthouse, 1996). It has been suggested that speed is a primary ability, and decreases in speed underlie most of the age-related declines in cognitive functioning. This is consistent with the finding that tasks using crystallized intelligence are relatively unaffected by aging: they rely very little on quick processing and more on very well-learned responses.

Although the construct "speed of processing" has been a powerful motivator in a great deal of research, it has not been immune to criticism. The most basic criticism (Collins, 1994; Kramer & Larish, 1996) is that speed may very well play a central role in most cognitive tasks, but that is a description, not an explanation: the mechanisms by which speed may affect performance have not been specified (Craik & Anderson, 1999). Indeed, even if one accepts the conclusion that slowing of processing can account for the majority of the variance in performance, what causes the slowing (Collins, 1994)?

Inhibition and Control

The impaired-inhibition view (Hasher & Zacks, 1988) is in some ways similar to the reduced-speed-of-processing view. Both focus on processing differences between younger and older subjects, and both posit a reduction in one general ability that contributes to performance on a wide variety of tasks. According to the inhibitory view, deficits seen in performance by elderly subjects are due to a difficulty in inhibiting irrelevant information, the consequences of which are increased interference and reduced processing resources.

Hasher, Zacks, and May (1999) have suggested that inhibitory processes could decline at three points: (1) inhibiting access of information to immediate memory, (2) deleting information from immediate memory, and (3) inhibiting output of irrelevant responses. Although separating out these possibilities is difficult, there is some evidence for deficits in each of those functions. The inhibitory view predicts not only worse performance on a variety of memory tasks but also an improvement under certain circumstances. For example, one major prediction is that older adults will have more difficulty eliminating information from working memory when it is activated but is irrelevant. Thus, they should show better memory for irrelevant information than younger adults. Dywan and Murphy (1996) reported that when younger and older adults were given a surprise recognition test on irrelevant information, the younger adults remembered more of the distracting information than the older adults did. One interpretation is that both older and younger adults process irrelevant information, but the younger adults are better at assigning the source of the irrelevant information and can inhibit these responses at output. A summary of this approach is offered by Stoltzfus, Hasher, and Zacks (1996; see also Hasher et al., 1999).

Processing Resources and Environmental Support

One of the great debates in cognitive research during the 1990s concerned whether memory (and cognition in general) is better thought of from a systems view or a processing view (see, e.g., Foster & Jelicic, 1999). Although the dominant view posits multiple systems (Schacter, Wagner, & Buckner, 2000; Tulving, 1999), the processing account (described below) better explains the pattern of data found in research on cognitive aging.

Historically the systems approach grows out of the structuralist tradition in which the purpose of the science of psychology is to analyze and describe the basic elements of cognition and discover how those elements work together (Tichener, 1898; Tulving, 1983). Within this sort of framework, development can be seen as a process of the maturation of those structures in childhood and the deterioration of those systems in older adulthood. This is implicitly (if not explicitly) the viewpoint of researchers who investigate how brain lesions affect performance. Essentially, they assume that a particular function is localized in one area of the brain so that damage in a particular area can be correlated with a particular loss of function. This viewpoint also suggests that specific types of function can be lost without all functioning being compromised. Finally, this system or structural way of partitioning cognition could be interpreted as predicting that the process of aging will be like reverse development: structures that mature latest should be most vulnerable to the detrimental effects of aging and should start to show deterioration first (Tulving, 1983).

A very different view is embodied in what has been called a processing approach to aging, argued by Craik (1986). Although Craik generally restricts himself to discussing memory functioning, his viewpoint can be extended and elaborated to encompass all of cognitive aging (Salthouse, 2001). When Craik looked at the pattern of differences between older and younger adults, he found that the magnitude of the age difference increased in a systematic way—but not in the way that would be predicted by structural theories. Instead, it seemed that the more cues there were available in the environment and the less the individual was forced to rely on self-initiated processing in order to do the task, the smaller the age difference was in the task. But as the amount of environmental support decreased and the more self-initiated processing was necessary in order to perform the task, the larger the age-related difference was. Tasks that were supposedly controlled by one structure or another in the structural theory varied within this taxonomy. In addition, tasks that were supposedly controlled by different structures showed similar patterns.

Craik (1986) argues that memory and cognition are better described in terms of processes rather than in terms of structures or systems. The interaction of the environment at encoding, the environment at retrieval, and the individual is the key to predicting what tasks will show age-related declines. For example, within the systems view, recognition and recall are both explicit memory tasks that rely on the episodic memory system (Tulving, 1983). However, free recall performance is worse for older and younger adults and recognition performance is the same, even when overall difficulty is controlled (Craik & McDowd, 1987).

The processing view suggests that one of the effects of aging is to reduce the resources available to do the memory task (Craik, 1986; Craik & Byrd, 1982; Craik, Anderson, Kerr, & Li, 1995) rather than the selective degradation of one system over another. This is supported by studies showing that dividing attention in younger adults seems to simulate the effects of aging. In addition, aging and divided attention both result in reduced frontal lobe activity when measured by neuropsychological measures such as positron emission tomography or functional magnetic resonance imaging. Attention is needed in order to initiate a strategy and make use of elaborate, deep encoding. Thus, older adults are at a disadvantage in using context or identifying the source of the information. This viewpoint incorporates aspects of the transfer-appropriate processing view in that environmental support provided at retrieval can interact with internal cues to make up for the deficit, which is why cued recall is better than free recall, and recognition is better than cued recall (Craik, 1986; Craik & Anderson, 1999). The processing view suggests that the combination of the person, the task, and the environment are all needed in order to explain age-related changes in memory.

Declining Sensory Abilities as a Function of Age

Recent reports have demonstrated strong relationships between basic sensory/perceptual capabilities and cognitive functioning. For example, (Baltes and Lindenberger 1997; Lindenberger & Baltes, 1994) reported that up to 70% of the variance in measures of intellectual ability for subjects ranging in age from 25 to 101 years could be accounted for by a composite score that included age, vision, and hearing abilities. In a separate study, speed of processing effects on intelligence was entirely mediated by vision and hearing scores (Lindenberger & Baltes, 1994).

The other cognitive explanations described above could be reinterpreted in the light of these results. For example, it is possible that speed of processing slows because basic input processes result in impoverished input that then takes more time to identify and interpret. In addition, difficulties in perceptual processing could take away resources that normally would be devoted to higher-level processing such as rehearsal or elaboration, resulting in reduced abilities to make use of contextual information. Reduced inhibitory control could be an after-effect of reduced perceptual processing: the ability to focus on one stimulus while filtering out irrelevant information is reduced in the auditory system by the upward spread of masking found in hearing loss and in the visual system by loss of contrast information. More recent experiments and reviews have further supported the substantial relations between sensory and cognitive functioning (e.g., Scialfa, 2002; Schneider, Daneman, & Pichora-Fuller, 2002). This sort of direct effect of perceptual difficulties on cognitive processing has been called the information-degradation hypothesis (Schneider & Pichora-Fuller, 2000).

However, given the correlational nature of the previous studies, the direction of causality cannot be conclusively determined. Lindenberger and Baltes (1994), for example, suggested that a third factor, widespread neural degeneration, might cause both perceptual and cognitive deterioration (the common cause hypothesis). Another logical possibility actually reverses the causality and suggests that cognitive declines could cause a depletion of resources at a higher level, which takes away resources that would normally be devoted to the perceptual system (the cognitive load on perception hypothesis). In addition, the effects of perceptual deterioration could act gradually on cognitive processing and result in long-term changes in the cognitive system (the sensory deprivation hypothesis). Based on an extensive review of this literature with these possibilities in mind, Schneider and Pichora-Fuller (2000) concluded that there is likely to be a very complex relationship between perception and cognition because the two systems are highly integrated and interdependent. They proposed an integrated system model of shared resources in which the flexible allocation of resources is a key ingredient. This essentially combines all of the above hypotheses and suggests that each one could play a role at any point in cognitive aging.

Biological Aspects of the Aging Brain

Advances in noninvasive neuro-imaging techniques have provided a window into physical differences in brain structure and function between older and younger brains. Unfortunately, the techniques are not yet precise enough to give more than a relatively gross description of functional and structural aspects of the aging brain. Nonetheless, two major differences have been found between the brains of older adults and those of younger adults: absolute brain volume and frontal lobe functioning. Changes that reduce total brain volume would seem to predict global rather than specific age-related changes in cognitive functioning. As we have seen above, that is not what is found in the behavioral data. However, Raz (2000) suggests that this difficulty can be overcome by positing a threshold model in which age-related cognitive deficits become apparent only after a certain amount of deterioration has occurred. Certain functions that rely on more distributed areas of the brain (such as those involved in combining multiple cues) may thus be differentially affected by a general change in brain volume.

It is clear that although all areas of the brain appear to be smaller in the older brain compared to the younger, the brain does not age uniformly. Aging seems to have a particular effect on the frontal lobe, whereas the primary sensory cortices seem to remain structurally unchanged. In one of the few longitudinal studies using brain imaging, Raz and his colleagues (Raz et al., 2003) reported significant shrinkage in specific areas of the brain, particularly in the frontal lobes, over a five-year period in a sample of healthy adults ranging in age from 26 to 82 years old.

However, relating brain changes to specific cognitive deficits has been difficult. In terms of relating specific functions to brain changes, the clearest case is found by examining the blood flow to different areas of the brain while engaging in a variety of tasks. Although there is age-related shrinking of the frontal lobes, there is an actual increase in prefrontal activation in older as compared to younger adults. There have been speculations (Grady et al., 1994; Raz, 2000) that this may be due to the older adult's making an effort to recruit general resources in order to compensate for reduced processing efficiency at lower levels of processing. This analysis dovetails nicely with the research on the relationship between sensory processing and cognition: the older adult is diverting resources to deciphering the incoming information, which then takes away from more higher-level processing resources. In the younger adult, the initial encoding is generally more effortless and automatic.

Anderson et al. (2000) measured brain activity in both younger and older adults when they were performing a paired-associate task under conditions of full or divided attention. They found reduced activity in the left frontal lobe during encoding in older adults as well as in the younger adults, but only when they were performing the primary task while doing a secondary task. They suggest that older adults might be essentially operating with reduced attentional resources all the time, which would affect memory processing. This fits in with the hypothesis that the frontal lobes are involved in strategic, self-initiated aspects of memory (Kapur et al., 1995) and that the difficulty of older adults to retrieve context may be due to a difficulty in the encoding and retrieval of associative information, which is known as the *associative deficit hypothesis* (Naveh-Benjamin, 2000).

IMPROVING COGNITIVE ABILITIES IN OLDER ADULTS

Is there anything to be done to reduce or slow the progress of age-related declines in cognition? The findings on this point have been mixed and are often difficult to interpret, partly because some studies suffer from basic methodological flaws. However, there are at least three areas in which interpretable research can be summarized: experience, cognitive training, and improving vascular fitness through fitness training. A brief review follows (for a more in-depth review, see Kramer & Willis, 2004).

Expertise

It is possible that individuals who are very experienced in a task or are experts in a particular domain might show little or no age-related decline in those consolidated abilities. The available research on this question is quite mixed. In particular, it has been found that some well-learned skills (typing, complex game playing, piloting) can be maintained at very high levels even in very old adults. However, the abilities that are spared are specific to the area of expertise and do not generalize to other tasks or domains. In addition, the maintenance of such skills is probably due to a variety of compensatory strategies that the individual uses (Bosman, 1993, 1994). However, along with studies showing spared abilities, there are numerous studies that have shown that age differences can be found among experts in complex domains such as music-related tasks (Halpern, Bartlett, & Dowling, 1995). The discrepancies between such findings and the ones on typing might be due to differences in the demands of the task or the components of each task (Kramer & Willis, 2004). Thus, although it seems that some age-related declines can be reduced or at least compensated for with experience or expertise, the effects are very domain specific and may not generalize to very complex tasks.

Cognitive Training

What is the effect of deliberate training in cognitive skills? As in the preceding section, the available data show variable results. It is clear that older adults can benefit from practice on specific tasks (such as visual search, recognition, and recall) and that they show approximately the same amount of gain as younger adults. However, as in the expertise literature, the training effects are quite specific to the task that is trained and tend not to generalize to other tasks. Thus, if an individual is trained in using a particular mnemonic technique, memory and cognitive performance in general do not improve as well (Verhaeghen & Marcoen, 1996). As a result, the usefulness of such training in everyday life is somewhat open to question. Because it is clear that older adults can benefit from cognitive training on specific tasks, if not overall, there should be some benefit to developing training programs and targeting them at important domains of performance.

Fitness Training

Due to the numerous studies showing a positive link between fitness and cognitive abilities (e.g., Colcombe & Kramer, 2003), an obvious question is whether increasing an older adult's level of fitness will increase that person's cognitive functioning. As with the other possibilities considered in this section, the answer is a qualified yes. Colcombe and Kramer (2003) carried out a meta-analysis including a great many studies on whether fitness training has an effect on cognitive functioning. They found that, overall, improving fitness has a significant effect on cognitive functioning and, moreover, the effects were largest on tasks that entailed executive control processes such as planning, task coordination, and working memory. In other studies Colcombe and colleagues (Colcombe et al., 2003; Kramer et al., 2003) suggested that the effects of fitness training on cognition were due mainly to increases in cardiovascular fitness. They suggested that older adults with good cardiovascular fitness lost less brain tissue than those with poor cardiovascular fitness.

SUMMARY AND CONCLUSIONS

Age-related changes are slight in measures of crystallized intelligence such as vocabulary or knowledge tests. In contrast, age-related losses are sizable when measured by tasks tapping fluid intelligence such as reasoning and divided-attention tasks. The latter tasks generally require the manipulation of information or the coordination of multiple tasks. Performance on tasks that offer sufficient retrieval cues and performance on indirect tasks frequently show no age-related impairment. That is, to the extent that self-initiated processes are important, there will probably be age-related differences; to the extent that the task provides sufficient cues or relies on well-learned behaviors, there will probably be few or no age-related differences.

Explanations of age-related differences in cognitive processing as a function of age have focused on speed of processing, increased inhibition, reduced processing resources, and self-initiated processing and reduced sensory capabilities. In the end, most or all of these explanations will be needed to a certain extent, depending on the particular task at hand. New research using noninvasive imaging technology is still in its infancy but shows the promise of providing converging evidence to the behavioral data.

Decline in cognitive abilities has been shown to have wide social and emotional consequences and has been linked to reductions in effective social functioning, diminished psychological well-being, difficulties in personal relationships, lower self-esteem, and a reduction in general quality of life. Declines in physical health also have a significant impact on cognitive processing. Even worrying about declines in cognitive functioning can have a negative effect on health and relationships. Some declines may be ameliorated with cognitive and fitness training, although the generality of such training is limited. Cognitive aging researchers have only just begun to incorporate such social and biological effects into their theories, and much work is yet to be done in this area.

The field of cognitive aging is not a cohesive one. There are clear disagreements in the methodology, theoretical constructs, and even what questions are the important ones. However, the debates are healthy and vigorous and have resulted in an increasing amount of imaginative research that may not have been possible without these types of challenges.

REFERENCES

Aartsen, M. J., van Tilburg, T. G., Smits, C. H. M., & Knipscheer, C. P. M. (2004). A longitudinal study on the impact of physical and cognitive decline on the personal network in old age. *Journal of Social and Personal Relationships, 21*, 249–266.

Anderson, N. D., & Craik, F. I. M. (2000). Memory in the aging brain. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 411–425). New York: Oxford University Press.

Anderson, N. D., Iidaka, T., Cabeza, R., Kapur, S., McIntosh, A. R., & Craik, F. I. M. (2000). The effects of divided attention on encoding- and retrieval-related brain activity: A PET study of younger and older adults. *Journal of Cognitive Neuroscience, 12*, 775–792.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12*, 12–21.

Baltes, P. B., & Mayer, K. U. (Eds.). (1999). *The Berlin Aging Study: Aging from 70 to 100*. New York: Cambridge University Press.

Birren, J. E. (1965). Age changes in speed of behavior: Its central nature and physiological correlates. In A. T. Welford & J. E. Birren (Eds.), *Behavior, aging and the nervous system* (pp. 191–216). Springfield, IL: Charles C. Thomas.

Bosman, A. A. (1993). Age-related difference in the motoric aspects of transcription typing skills. *Psychology and Aging, 8*, 87–102.

Bosman, A. A. (1994). Age and skill differences in typing related and unrelated reaction time tasks. *Aging and Cognition, 1*, 310–322.

Bromley, D. B. (1990). *Behavioural gerontology: Central issues in the psychology of ageing*. New York: Wiley.

Centofanti, M. (1998). Fear of Alzheimer's undermines health of elderly patients. *APA Monitor, 29*, 33.

Colcombe, S. J., Erickson, K. I., Raz, N., Webb, A. G., Cohen, N. J., McAuley, E., et al. (2003). Aerobic fitness reduced brain tissue loss in aging humans. *Journal of Gerontology: Medical Sciences, 58*, 176–180.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14*, 125–130.

Collins, L. M. (1994). Comment on "How many causes are there of aging-related decrements in cognitive functioning?" *Developmental Review, 14*, 438–443.

Comijs, H. C., van Tilburg, T., Geerlings, S. W., Jonker, C., Deeg, D. J. H., van Tilburg, W., et al. (2004). Do severity and duration of depressive symptoms predict cognitive decline in older persons? Results of the Longitudinal Aging Study Amsterdam. *Aging, Clinical and Experimental Research, 16*, 226–232.

Craik, F. I. M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.), *Human memory and cognitive capabilities* (pp. 409–422). Amsterdam: Elsevier.

Craik, F. I. M., & Anderson, N. D. (1999). Applying cognitive research to problems of aging. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII* (pp. 583–615). Cambridge, MA: MIT Press.

Craik, F. I. M., Anderson, N. D., Kerr, S. A., & Li, K. Z. H. (1995). Memory changes in normal ageing. In A. D. Baddeley, B. A. Wilson, & F. N. Watts (Eds.), *Handbook of memory disorders* (pp. 211–241). New York: Wiley.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum.

Craik, F. I. M., Byrd, M., & Swanson, J. M. (1987). Patterns of memory loss in three elderly samples. *Psychology and Aging, 2*, 79–86.

Craik, F. I. M., & McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 474–479.

Craik, F. I. M., & Salthouse, T. A. (Eds.). (2000). *The handbook of aging and cognition.* Mahwah, NJ: Erlbaum.

Deeg, D. J. H., Knipscheer, C. P. M., & van Tilburg, W. (Eds.). (1993). *Autonomy and well-being in the aging population: Concepts and design of the Longitudinal Aging Study Amsterdam.* Bunnik, Netherlands: Netherlands Institute of Gerontology.

Desai, M., Pratt, L. A., Lentzner, H., & Robinson, K. N. (2001). Trends in vision and hearing among older Americans. In *Aging trends, No. 2* (pp. 1–8). Hyattsville, MD: National Center for Health Statistics.

Dixon, R. A., Bäckman, L., & Nilsson, L. G. (Eds.). (2004). *New frontiers in cognitive aging.* New York: Oxford University Press.

Dodson, C. S., & Schacter, D. L. (2002). Aging and strategic retrieval processes: Reducing false memories with a distinctiveness heuristic. *Psychology and Aging, 17,* 405–415.

Dywan, J., & Jacoby, L. L. (1990). Effects of aging on source monitoring: Differences in susceptibility to false fame. *Psychology and Aging, 5,* 379–387.

Dywan, J., & Murphy, W. E. (1996). Aging and inhibitory control in text comprehension. *Psychology and Aging, 11,* 199–206.

Einstein, G. O., McDaniel, M. A., Richardson, S. L., Guynn, M. J., & Cunfer, A. R. (1995). Aging and prospective memory: Examining the influences of self-initiated retrieval processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 996–1007.

Ferraro, K. F. (1997). The gerontological imagination. In K. F. Ferraro (Ed.), *Gerontology: Perspectives and issues* (pp. 3–18). New York: Springer Publishing.

Fisk, A. D., & Rogers, W. (1991). Toward an understanding of age-related memory and visual search effects. *Journal of Experimental Psychology: General, 120,* 131–149.

Fisher, D. L., & Glaser, R. A. (1996). Molar and latent models of cognitive slowing: Implications for aging, dementia, depression, development, and intelligence. *Psychonomic Bulletin and Review, 3,* 458–480.

Foster, J. K., & Jelicic, M. (1999). *Memory: Systems, process, or function?* New York: Oxford University Press.

Gallo, J. J., Rebok, G. W., Tennsted, S., Wadley, V. G., & Horgas, A. (2003). Linking depressive symptoms and functional disability in late life. *Aging and Mental Health, 7,* 469–480.

Garner, W. R., Hake, H. W., & Eriksen, C. W. (1956). Operationism and the concept of perception. *Psychological Review, 63,* 149–158.

Grady, C. L., Maisog, J. M., Horwitz, B., Ungerleider, L. G., Mentis, M. J., Salerno, J. A., et al. (1994). Age-related changes in cortical blood flow activation during visual processing of faces and location. *Journal of Neuroscience, 14,* 1450–1462.

Halpern, A. R., Bartlett, J. C., & Dowling, W. J. (1995). Aging and experience in the recognition of musical transpositions. *Psychology and Aging, 10,* 325–342.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193–225). San Diego, CA: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII* (pp. 653–675). Cambridge, MA: MIT Press.

Henkel, L. A., Johnson, M. K., & De Leonardis, D. M. (1998). Aging and source monitoring: Cognitive processes and neuropsychological correlates. *Journal of Experimental Psychology: General, 127,* 251–268.

Hertzog, C. (1996). Research design in studies of aging and cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (4th ed., pp. 24–37). San Diego: Academic Press.

Hertzog, C. (2002). Metacognition in older adults: Implications for application. In T. J. Perfect & B. L. Schwartz (Eds.), *Applied metacognition* (pp. 169–196). New York: Cambridge University Press.

Hertzog, C. (2004). Does longitudinal evidence confirm theories of cognitive aging derived from cross-sectional data? In R. A. Dixon, L. Bäckman, & L-G. Nilsson (Eds.), *New frontiers in cognitive aging* (pp. 40–64). New York: Oxford University Press.

Hultsch, D. F., Hertzog, C., Dixon, R. A., & Small, B. J. (1998). *Memory change in the aged.* New York: Cambridge University Press.

Hyman, I. E., Jr., & Billings, F. J. (1998). Individual differences and the creation of false childhood memories. *Memory, 6,* 1–20.

Kapur, S., Craik, F. I. M., Jones, C., Brown, G. M., Houle, S., & Tulving, E. (1995). Functional role of the prefrontal cortex in retrieval of memories: A PET study. *Neuroreport, 6,* 1880–1884.

Kramer, A., Colcombe, S., McAuley, E., Eriksen, K., Scalf, P., Jerome, G., et al. (2003). Enhancing brain and cognitive function of older adults through fitness training. *Journal of Molecular Neuroscience, 20,* 213–222.

Kramer, A. F., & Larish, J. L. (1996). Aging and dual-task performance. In W. A. Rogers, A. D. Fisk, N. Walker (Eds.), *Aging and skilled performance: Advances in theory and applications* (pp. 83–112). Mahwah, NJ: Erlbaum.

Kramer, A. F., & Willis, S. L. (2004). Cognitive plasticity and aging. *Psychology of Learning and Motivation, 43,* 267–302.

La Voie, D. J., & Light, L. L. (1994). Adult age differences in repetition priming: A meta-analysis. *Psychology and Aging, 9,* 539–553.

Light, L. L. (2004). Commentary: Measures, constructs, models, and inferences about aging. In R. A. Dixon, L. Bäckman, & L-G. Nilsson (Eds.), *New frontiers in cognitive aging* (pp. 89–112). New York: Oxford University Press.

Light, L. L., & La Voie, D. (1993). Direct and indirect measures of memory in old age. In P. Graf (Ed.), *Implicit memory: New directions in cognition, development, and neuropsychology* (pp. 207–230). Hillsdale, NJ: Erlbaum,

Light, L. L., Prull, M. W., La Voie, D. J., & Healy, M. R. (2000). Dual-process theories of memory in old age. In T. J. Perfect & E. A. Maylor (Eds.), *Models of cognitive aging: Debates in psychology* (pp. 238–300). New York: Oxford University Press.

Lindenberger, U., & Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging, 9,* 339–355.

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187.

Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 826–837.

Neath, I. (1999). Computer simulations of global memory models. *Behavior Research Methods, Instruments, and Computers, 31,* 74–80.

Neath, I., & Surprenant, A. M. (2003). *Human memory: An introduction to research, data, and theory* (2nd ed.). Belmont, CA: Wadsworth.

Rabbitt, P. M. A. (1993). Does it all go together when it goes? The Nineteenth Bartlett Memorial Lecture. *Quarterly Journal of Experimental Psychology, 46A,* 385–434.

Rabbitt, P. M. A., & Abson, V. (1991). Do older people know how good they are? *British Journal of Psychology, 82,* 137–151.

Raz, N. (2000). Aging of the brain. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 1–90). Mahwah, NJ: Erlbaum.

Raz, N., Rodrigue, K. M., Kennedy, K. M., Dahle, C., Head, D., & Acker, J. D. (2003). Differential age-related changes in the regional metencephalic volumes in humans: A 5-year follow-up. *Neuroscience Letters, 349,* 163–166.

Rendell, P. G., & Thomson, D. M. (1999). Aging and prospective memory: Differences between naturalistic and laboratory tasks. *Journals of Gerontology, Psychological Sciences and Social Sciences, 54B,* 256–269.

Salthouse, T. A. (1985). *A theory of cognitive aging.* Amsterdam: North-Holland.

Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging.* Hillsdale, NJ: Erlbaum.

Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428.

Salthouse, T. A. (2000). Methodological assumptions in cognitive aging research. In F. I. M. Craik & T. A. Salthouse (Eds.). *The handbook of aging and cognition* (2nd ed., pp. 467–498). Mawah, NJ: Erlbaum.

Salthouse, T. A. (2001). The broader context of Craik's self-initiated processing hypothesis. In M. Naveh-Benjamin, M. Moscovitch, & H. L. Roediger III (Eds.), *Perspectives on human memory and cognitive aging: Essays in honour of Fergus Craik* (pp. 277–297). New York: Psychology Press.

Salthouse, T. A., & Ferrer-Caja, E. (2003). What needs to be explained to account for age-related effects on multiple cognitive variables? *Psychology and Aging, 18,* 91–110.

Schacter, D. L., Wagner, A. D., & Buckner, R. L. (2000). Memory systems of 1999. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 627–643). New York: Oxford University Press.

Schaie, K. W. (2004). *Developmental influences on adult intelligence: The Seattle Longitudinal Study.* New York: Oxford University Press.

Scialfa, C. T. (2002). The role of sensory factors in cognitive aging research. *Canadian Journal of Experimental Psychology, 56,* 153–163.

Schneider, B. A., Daneman, M., & Pichora-Fuller, M. K. (2002). Listening in aging adults: From discourse comprehension to psychoacoustics. *Canadian Journal of Experimental Psychology, 56,* 139–152.

Schneider, B. A., & Pichora-Fuller, M. K. (2000). Implications of perceptual deterioration for cognitive aging research. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed., pp. 155–219). Mahwah, NJ: Erlbaum.

Schroeder, D. H., & Salthouse, T. A. (2004). Age-related effects on cognition between 20 and 50 years of age. *Personality and Individual Differences, 36,* 393–404.

Stoltzfus, E. R., Hasher, L., & Zacks, R. T. (1996). Working memory and aging: Current status of the inhibitory view. In J. T. E. Richardson (Ed.), *Working memory and human cognition* (pp. 66–68). New York: Oxford University Press.

Titchener, E. B. (1898). The postulates of a structural psychology. *Philosophical Review, 7,* 449–465

Tulving, E. (1983). *Elements of episodic memory.* New York: Oxford University Press.

Tulving, E. (1999). Study of memory: Processes and systems. In J. K. Foster & M. Jelicic (Eds.), *Memory: Systems, process, or function?* (pp. 11–30). New York: Oxford University Press.

Verhaeghen, P., & Marcoen, A. (1996). On the mechanisms of plasticity in young and older adults after instruction in the method of loci: Evidence for an amplification model. *Psychology and Aging, 11,* 164–178.

Zacks, R. T., Hasher, L., & Li, K. Z. H. (2000). Human memory. In T. A. Salthouse & F. I. M. Craik (Eds.), *Handbook of aging and cognition* (2nd ed., pp. 293–357). Mahwah, NJ: Erlbaum.