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Enrichment Effects on Adult Cognitive Development

Can the Functional Capacity of Older Adults Be Preserved and Enhanced?

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SUMMARY—*In this monograph, we ask whether various kinds of intellectual, physical, and social activities produce cognitive enrichment effects—that is, whether they improve cognitive performance at different points of the adult life span, with a particular emphasis on old age.*

We begin with a theoretical framework that emphasizes the potential of behavior to influence levels of cognitive functioning. According to this framework, the undeniable presence of age-related decline in cognition does not invalidate the view that behavior can enhance cognitive functioning. Instead, the course of normal aging shapes a zone of possible functioning, which reflects person-specific endowments and age-related constraints. Individuals influence whether they function in the higher or lower ranges of this zone by engaging in or refraining from beneficial intellectual, physical, and social activities. From this point of view, the potential for positive change, or plasticity, is maintained in adult cognition. It is an argument that is supported by newer research in neuroscience showing neural plasticity in various aspects of central nervous system functioning, neurochemistry, and architecture. This view of human potential contrasts with static conceptions of cognition in old age, according to which decline in abilities is fixed and individuals cannot slow its course. Furthermore, any understanding of cognition as it occurs in everyday life must make a distinction between basic cognitive mechanisms and skills (such as working-memory capacity) and the functional use of cognition to achieve goals in specific situations. In practice, knowledge and expertise are critical for effective functioning, and the available evidence suggests that older adults effectively employ specific knowledge and expertise and can gain new knowledge when it is required.

We conclude that, on balance, the available evidence favors the hypothesis that maintaining an intellectually engaged and physically active lifestyle promotes successful cognitive aging. First, cognitive-training studies have demonstrated that older adults can improve cognitive functioning when provided with intensive training in strategies that promote thinking and remembering. The early training literature suggested little transfer of function from specifically trained skills to new cognitive tasks; learning was highly specific to the cognitive processes targeted by training. Recently, however, a new generation of studies suggests that providing structured experience in situations demanding executive coordination of skills—such as complex video games, task-switching paradigms, and divided attention tasks—train strategic control over cognition that does show transfer to different task environments. These studies suggest that there is considerable reserve potential in older adults' cognition that can be enhanced through training.

Second, a considerable number of studies indicate that maintaining a lifestyle that is intellectually stimulating predicts better maintenance of cognitive skills and is associated with a reduced risk of developing Alzheimer's disease in late life. Our review focuses on longitudinal evidence of a connection between an active lifestyle and enhanced cognition, because such evidence admits fewer rival explanations of observed effects (or lack of effects) than does cross-sectional evidence. The longitudinal evidence consistently shows that engaging in intellectually stimulating activities is associated with better cognitive

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functioning at later points in time. Other studies show that meaningful social engagement is also predictive of better maintenance of cognitive functioning in old age. These longitudinal findings are also open to important rival explanations, but overall, the available evidence suggests that activities can postpone decline, attenuate decline, or provide prosthetic benefit in the face of normative cognitive decline, while at the same time indicating that late-life cognitive changes can result in curtailment of activities. Given the complexity of the dynamic reciprocal relationships between stimulating activities and cognitive function in old age, additional research will be needed to address the extent to which observed effects validate a causal influence of an intellectually engaged lifestyle on cognition. Nevertheless, the hypothesis that an active lifestyle that requires cognitive effort has long-term benefits for older adults' cognition is at least consistent with the available data. Furthermore, new intervention research that involves multimodal interventions focusing on goal-directed action requiring cognition (such as reading to children) and social interaction will help to address whether an active lifestyle enhances cognitive function.

Third, there is a parallel literature suggesting that physical activity, and aerobic exercise in particular, enhances older adults' cognitive function. Unlike the literature on an active lifestyle, there is already an impressive array of work with humans and animal populations showing that exercise interventions have substantial benefits for cognitive function, particularly for aspects of fluid intelligence and executive function. Recent neuroscience research on this topic indicates that exercise has substantial effects on brain morphology and function, representing a plausible brain substrate for the observed effects of aerobic exercise and other activities on cognition.

Our review identifies a number of areas where additional research is needed to address critical questions. For example, there is considerable epidemiological evidence that stress and chronic psychological distress are negatively associated with changes in cognition. In contrast, less is known about how positive attributes, such as self-efficacy, a sense of control, and a sense of meaning in life, might contribute to preservation of cognitive function in old age. It is well known that certain personality characteristics such as conscientiousness predict adherence to an exercise regimen, but we do not know whether these attributes are also relevant to predicting maintenance of cognitive function or effective compensation for cognitive decline when it occurs. Likewise, more information is needed on the factors that encourage maintenance of an active lifestyle in old age in the face of elevated risk for physiological decline, mechanical wear and tear on the body, and incidence of diseases with disabling consequences, and whether efforts to maintain an active lifestyle are associated with successful aging, both in terms of cognitive function and psychological and emotional well-being.

We also discuss briefly some interesting issues for society and public policy regarding cognitive-enrichment effects. For example, should efforts to enhance cognitive function be included as part of a general prevention model for enhancing health and vitality in old age? We also comment on the recent trend of business marketing interventions claimed to build brain power and prevent age-related cognitive decline, and the desirability of direct research evidence to back claims of effectiveness for specific products.

INTRODUCTION

In this monograph, we address the scientific evidence for the argument that individuals' behaviors and environmental contexts can enhance their cognitive functioning and development in adulthood and old age. This idea is extremely important to individuals and to society. Due to improvements in medical care and declining birth rates in recent history, the proportion of older adults in the United States and other industrial nations continues to grow (e.g., Martin & Preston, 1994). This "graying" of the population has major policy implications, including issues such as the future solvency of retirement pension plans, the Social Security System, and the Medicare system. What are perhaps less well recognized are the implications for society if prolonging the typical life span is accompanied by more years of disability and infirmity rather than productive life. We must consider not just the longevity of members of our population but also the quality of the life they will experience. The concepts of successful aging (e.g., Rowe & Kahn, 1998) and morbidity compression (Fries & Crapo, 1981) both highlight the idea of maintaining physical and psychological well-being in older adults by maximizing the span of effective functioning and minimizing the length of time in which individuals are functionally impaired. From a societal point of view, prolonging independent functioning is both a desirable goal in itself and a way of deferring costs of long-term care. From the individual's point of view, maintaining effective cognitive functioning is desirable simply because it promises to enhance the quality of life in old age.

The Concept of Cognitive Enrichment

If maintaining effective cognitive functioning in old age is a highly desirable goal, what can be done to achieve it? Certainly, advances in medical science that address the prevalence of cognitive disability, for example by finding effective treatments for Alzheimer's disease, are a critical goal for the future. In this monograph, we do not address such advances, however desir-

able they indeed are. Instead, we ask the question: What can people do now, in terms of how they live their lives, to maintain and optimize their cognitive functioning?

How to enhance cognition in old age is a question that has been actively considered since the earliest philosophical writings on record, if not before. This question is also widely discussed in contemporary society. Wellness practitioners offer advice on nutrition and health practices designed to maintain a healthy mind and brain (e.g., Chopra, 2001; Weil, 2006). Cognitive psychologists have written books on how to maintain memory, one of the more vulnerable facets of cognition, in old age (e.g., Einstein & McDaniel, 2004; West, 1985). Individuals have marketed, with some success, software designed to "maintain brain fitness" through mental exercises (see http://www.sharpbrains.com/ for a description of much of this software). History is replete with instances of individuals offering cures for aging or, at least, remedies to forestall its consequences. One such "remedy," called Gerovital by its creator (Aslan et al., 1965) though it is in fact little more than procaine (a topical anesthetic), is still widely marketed on the Internet as an essential "anti-aging" drug, despite having been discredited for years as having no slowing effects on the aging process. Are the recommendations regarding cognitive enrichment currently being offered to the public likely to be effective? Or are they just a 21st-century version of snake-oil salesmanship?

Because we take a broad view of the relevant theory and empirical evidence, we have chosen to cast this discussion in terms of the widest possible range of behaviors that might affect adult cognition. Thus, our review of the literature features but does not focus solely on what has been popularly termed "the use it or lose it" hypothesis. According to this hypothesis, exercising one's cognitive machinery by performing cognitively demanding activities stimulates the mind and preserves cognitive functioning. In fact, variants of this hypothesis need to be considered, because one can speak of relatively direct effects of "cognitive exercise"—whether or not using specific cognitive mechanisms actually helps to maintain their viability—but one can also speak of relatively generic effects of stimulating cognition and of an intellectually varied lifestyle as having rather broad-spectrum effects mediated through a number of mechanisms such as attitudes, beliefs, and aspirations. We shall review evidence for and against this class of hypotheses in some detail. But we shall also consider an even broader class of behavioral interventions that could enhance cognitive functioning. Thus, rather than speaking of cognitive use or cognitive exercise, we generically refer to all behaviors that potentially enhance cognition as forms of cognitive enrichment. The cognitive-enrichment hypothesis states that the behaviors of an individual (including cognitive activity, social engagement, exercise, and other behaviors) have a meaningful positive impact on the level of effective cognitive functioning in old age. We subsume the use-it-or-lose-it hypothesis under this more general cognitive-enrichment umbrella.

To circumscribe our task, we do not consider in any detail the evidence for accelerated cognitive loss as a function of chronic illness, smoking, or other factors that are suspected or even demonstrated to detract from effective functioning in old age (see Fillit et al., 2002, for a discussion of this research). We also do not review the evidence for or against the effects of good nutrition, vitamin and herbal supplements, and pharmaceutical treatments on cognitive functioning (see Einstein & McDaniel, 2004). Instead, we focus on the extent to which an individual's behaviors and lifestyle influence cognitive functioning in old age.

After reviewing the evidence regarding the cognitive-enrichment hypothesis in its several forms, we turn to some of the policy issues raised by what is known and, possibly more importantly, by what is not known regarding the cognitive-enrichment hypothesis.

Attitudes and Beliefs About Aging and Cognition

One way to think about cognitive enrichment is to ask what individuals in our society believe to be true about aging and the possibilities of warding off negative outcomes such as dementia. It is well known that being old is often associated with social stereotypes that are negative, including trait adjectives such as "senile," "crotchety," "rigid," "forgetful," "confused," and "feeble" (e.g., Hummert, 1990; Hummert, Garstka, O'Brien, Greenwald, & Mellott, 2002). There is little question that ageism is a prevalent and enduring problem in the United States and elsewhere (Nelson, 2005).

Adults of all ages explicitly associate aging with cognitive decline (e.g., Ryan, 1992). Lineweaver and Hertzog (1998) showed that individuals of all ages believe that memory undergoes a relatively precipitous decline after age 40. Moreover, there is good evidence that some middle-aged individuals experience anxiety about growing older or contracting Alzheimer's disease, precisely because they fear the potential negative consequences of aging, including physical disability, cognitive disability, and death (Hodgson & Cutler, 2003; Lynch, 2000). A classic finding in gerontology that reflects such attitudes is that individuals perceive themselves to be younger than their chronological age (e.g., Montepare & Lachman, 1989; Rubin & Berntsen, 2006). Recently, a friend told one of us that her 80-year-old grandmother dismissed the idea of living in an intermediate care facility by saying, "Honey, I'm not old yet!" To an extent, attitudes that reject the dominant aging stereotypes of infirmity and incapacity as irrelevant to oneself could well be critical to effective self-regulation and successful aging (e.g., Elliott & Lachman, 1989; Schulz & Heckhausen, 1996). Conversely, when negative stereotypes of aging are activated in a cognitive-performance context, older adults' performance may suffer due to stereotype threat, perhaps because of the interfering effects of the anxiety it produces (Hess, 2006).

What is less well recognized is that there are also positive stereotypes about older adulthood. Hummert, Garstka, Shaner,

and Strahm (1994) found that adults hold prototypes of successful aging—such as the engaged volunteer—that can positively influence their appraisal of an older adult. Likewise, Heckhausen, Dixon, and Baltes (1989) showed that individuals asked to scale the age at which different attributes start to change varied their ratings quite widely, depending on the attribute. Older adults are often perceived as being "experienced," "knowledgeable," and "wise." Thus, along with scientists, adults in Western societies tend to view older adults as having some preserved aspects of cognition associated with knowledge and experience but also as being likely to decline in other aspects of cognition, such as memory.

An interesting issue is whether there has been a major change in attitudes toward cognitive functioning in older adults in the modern era. Fifty years ago, the predominant Western stereotype of older adults was one of universal cognitive impairment, if not outright senility. Today, attitudes about aging, although still often negative, have been tempered by the belief that decline may be neither universal nor inevitable. One reason for this change is that public institutions like the National Institute on Aging and private organizations such as the American Association of Retired Persons have successfully persuaded the public that dementia is a disease that happens to some but not all individuals. Furthermore, our society is now more apt to adopt a "use it or lose it" perspective, not merely because of repetition of the time-worn adage itself but also because this perspective has been promoted in the popular press and in statements by scientists.

There is some data to suggest that older adults have internalized the use-it-or-lose-it hypothesis, perhaps because it is relevant to them (see Langer, 1989). Hertzog, McGuire, Horhota, and Jopp (2008) collected open-ended interview data in which individuals were asked how they achieved control over memory. Younger adults were most likely to mention use of strategies, external aids, and the like. Older adults had different beliefs about means of controlling memory. Between 30 and 40% of older adults spontaneously mentioned cognitive stimulation or cognitive exercise as means for achieving control over memory, many stating that these could prevent age-related decline. Far fewer of the younger adults in their sample mentioned these mechanisms. Scientists are speaking, and the public is apparently listening. Some would argue, however, that the positive pronouncements about successful cognitive aging that are catching the public eye are little more than wishful thinking (Salthouse, 2006).

In the next section, we develop a general theoretical perspective for framing the cognitive-enrichment hypothesis. We consider key features of the concept and methodological issues that arise in testing the hypothesis. We then turn to evaluating the relevant evidence.

CONCEPTUAL FRAMEWORK

We frame our discussion of the cognitive-enrichment hypothesis in terms of a life-span perspective on development, informed in particular by the thinking of Paul Baltes and colleagues (e.g., Baltes, 1987; Baltes & Labouvie, 1973; Baltes, Lindenberger, & Staudinger, 2006). This perspective recognizes that there are both gains and losses in cognitive function across adulthood but that, with advancing age, gains become less common and losses predominate. In particular, two important features of this perspective are that (a) levels of performance are malleable and open to enhancement throughout the human life span, but (b) upper limits of performance are constrained by the boundaries created by biological aging. An open question is how malleable these biologically defined boundaries could be (for example, with pharmacological interventions or genetic engineering). We review later evidence that old brains can grow new neurons, synaptic connections, and new vasculature. Although such neural plasticity is reduced in old age, it remains more substantial than previously recognized (Greenwood, 2007; Kempermann, 2008; Kramer, Bherer, Colcombe, Dong, & Greenough, 2004; Park & Reuter-Lorenz, 2009). Although biological aging puts increasingly severe constraints on maximal levels of cognitive performance with advancing age, performance can still be improved in very old persons (Kramer & Willis, 2003; Singer, Lindenberger, & Baltes, 2003; Yang, Krampe, & Baltes, 2006).

From a biological perspective, aging-induced constraints come to the fore when basic cognitive mechanisms govern cognitive performance. However, observed changes in cognition generally are not a direct reflection of age-graded biological limits. Instead, our perspective suggests that individuals at any given age operate within ranges of cognitive functioning that generally do not approximate their maximum performance potential (cf. Brim, 1992). Movement up or down within this range of possible performance can be considered a form of behavioral plasticity that is continuously reshaped by the individual's environmental context, biological state, health, and cognition-relevant behaviors (Denney, 1984). The top end of this range of functioning is limited by optimal gene–environment fits and by the joint forces of maturation, learning, and senescence. We hasten to add that this notion of optimal performance is a theoretical concept that cannot be easily or directly established by empirical methods. Nevertheless, it is useful to assume that individuals have at least some degree of plasticity, that is, potential for improvement (or decline); that this plasticity can be influenced by a number of factors; and that plasticity has upper limits that change with age. Developmental psychologists (e.g., Lerner, 1984) have used the term "probabilistic epigenesis" to capture the idea of plasticity created by probabilistic involvement of variables influencing the course of development (see also Molenaar, Boomsma, & Dolan, 1993).

Figure 1 captures this basic concept. It shows ranges of possible development for a single individual across that person's life course. At the onset of maturity (which we have arbitrarily associated with the chronological age of 20) there is a range of possible levels of cognitive function, determined by early

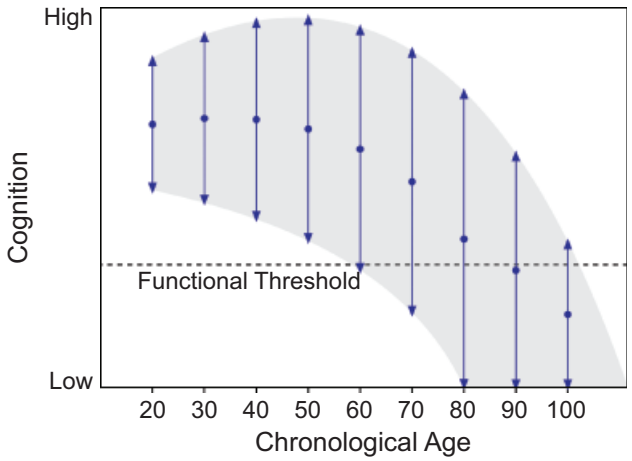

Fig. 1. Depiction of the zone of possible cognitive development across adult life for a given individual. The blue dots indicate a general developmental trend for the individual under typical circumstances. The upper and lower curves indicate optimal and suboptimal boundaries that define the zone of possibility (shaded gray area). Upward and downward movements at a given age (arrows) are influenced by biological, behavioral, and environmental influences. The functional threshold indicates a point at which goal-directed cognition in the ecology will be compromised.

development and a person's specific life history from conception to early adulthood. For this individual, there is an upper limit on maximum possible cognitive function that declines as a function of biological aging constraints. The lower limit as drawn in Figure 1 assumes that we are ruling out acute pathological insult or traumatic incidents that harm cognition (e.g., brain injury following an automobile accident). Instead, it depicts an expected minimal level of function for this individual across the life course, assuming a representative set of causal influences on cognition are operating, but in a manner that produces no cognitive enrichment. The vertical lines within the range of possible development in Figure 1 represent the amount of plasticity available at each age. Finally, the horizontal line in Figure 1 represents a threshold at which an individual would transition into a dysfunctional state, in which cognition drops below the point at which it can serve the requirements of independent living, such as might occur with Alzheimer's disease. We shall comment more on the issue of normal aging versus dementing illness below. The point for now is that, when this threshold is reached, individuals' level of cognitive functioning would compromise their adaptive functioning in the world.

It is important to emphasize that the shape of this region of possible development will differ among individuals, given different genetic profiles, prenatal environments, and other factors known to influence the shape of developmental change. For instance, an individual with Down syndrome would in all likelihood not have a region of possible cognitive development that would include high levels of function, particularly past age 40. More generally, individual differences in the shape of the upper and lower limits would be expected. Each of us develops and grows older in our own unique niche, which we co-create with nature and the physical and social environment.

Within a single person, what promotes upward movements within the zone of possible development? According to our perspective, a number of variables can influence more or less optimal changes during adulthood. Psychologists have often studied effects of practice, experience, and training of specific cognitive abilities (e.g., Baltes & Willis, 1977; Willis, 1996), arguing that cognitive mechanisms that are exercised can be maintained or improved during adulthood. Denney (1984) discussed this concept in terms of optimally exercised potential, where exercise referred to use or practice of relevant cognitive abilities and training referred to interventions designed to shape effective cognitive function (cf. Baltes & Lindenberger, 1988). We shall review below evidence relevant to the hypothesis that physical exercise and cognitive training can improve cognitive development over the adult life course.

However, we take the broader view that cognitive enrichment can in principle be influenced by a large number of variables, including ones that directly enhance the metabolic and physiological functioning of the neural substrate (e.g., pharmacological interventions, nutrition, and physical exercise); those that operate at the level of cognition itself (e.g., use or training); and those that influence the larger context in which an individual thinks, learns, and remembers (e.g., quality of social interaction). Some of these variables form part of an individual's attempt to adopt a health-promoting lifestyle, whereas others may form part of an individual's behavioral repertoire or environment without being accompanied by cognition-related intentions. All of these variables, if effective, are associated with functional, anatomical, or chemical changes in the brain, calling for the simultaneous consideration of plasticity at societal, behavioral, and neuronal levels of analysis (cf. Baltes, Reuter-Lorenz, & Rösler, 2006; Lindenberger, Li, & Bäckman, 2006a).

Our treatment of the issue assumes that cognitive function is influenced by the extent to which individuals develop relevant knowledge and expertise for and in a given cognitive domain (Ericsson & Charness, 1994; Masunaga & Horn, 2000; Yang et al., 2006). That is, although one can speak of relatively general cognitive abilities (such as Horn and Cattell's fluid-intelligence construct; Cattell, 1971; Horn, 1989; Horn & Cattell, 1966), cognition in the real world is, in our view, usually influenced by relevant knowledge structures (Bartlett, 1932; Ericsson & Kintsch, 1995; Masunaga & Horn, 2001). For instance, knowledge plays a critical role in activities such as reading comprehension, reasoning about possible actions in social contexts, and learning new information (e.g., Hertzog, Dunlosky, & Robinson, 2008; Stine-Morrow, Miller, & Hertzog, 2006). Almost inevitably, new learning builds on the scaffold of what is already known. Furthermore, virtually all cognitive tasks (including tests of fluid intelligence) involve mixtures of basic cognitive mechanisms (processes) operating on relevant information structures (knowledge) using relevant procedures or algorithms (Hertzog, 2008; Hunt, 1978). Hence performance on

cognitive tasks in both laboratory and naturalistic settings can vary for an individual depending on a variety of contextual factors and personal attributes.

Most importantly for our discussions of cognitive enrichment, an individual's level of function depends on the extent to which he or she has mastered procedural skills and relevant knowledge (i.e., expertise) needed to successfully undertake a given cognitive task. These aspects typically interact to govern task performance; and these interactions influence observed age differences in task performance. For example, older chess players show inferior spatial working memory for pieces randomly placed on a chess board but relatively spared memory for locations of pieces that are part of well-learned schemata involving standard chess-game sequences (Charness, 1981). Moreover, even though working memory is a critical cognitive component of chess performance, maintenance of chess expertise through actively playing chess produces life-span curves of chess performance that do not resemble the curves for standard working-memory tasks (Roring & Charness, 2007).

One reason for emphasizing the general relevance of knowledge structures is that gerontologists often argue that underlying cognitive mechanisms or fundamental abilities (such as fluid intelligence or spatial visualization) are relatively immune to improvement in adulthood (e.g., Baltes, 1997; Horn & Donaldson, 1976; Salthouse, 1991a). We defer discussion of this issue for the moment. Our claim is that growth in relevant knowledge and expertise matters for most forms of cognition as they are used in everyday life, creating a possibility for optimization of cognitive function, irrespective of whether the basic mechanisms themselves can be trained or improved.

Please consider again the range of possible development charted in Figure 1. Why does the top range of possible functioning shrink as people grow older? Biological constraints on the possible range of functioning increase to different degrees with aging, depending on what types of processing mechanisms or knowledge structures are involved. Biological-aging change will shrink the level of maximum achievable levels of performance, and it will also dampen performance when individuals operate at less than their maximum possible level of effectiveness. It does so because biological changes affecting the brain lead to less effective or efficient execution of cognitive, perceptual, and sensory aspects of information processing.

Using the resource metaphor (Norman & Bobrow, 1975), one can say that aging affects cognition through cognitive-resource limitations or through data-quality limitations that degrade cognitive operations. By cognitive resources, we refer to processing resources involved in attending to or working with information (Kane & Engle, 2003). Cognitive resources are best conceptualized as functional capacity created by the interaction between cognitive-processing efficiency and task-relevant knowledge (e.g., Ericsson & Kintsch, 1995; Stine-Morrow et al., 2006). Age changes in functional attentional and working-memory capacity can place major constraints on cognitive performance (Craik & Jennings, 1992; Hultsch, Hertzog, Dixon, & Small, 1998; Salthouse, 1991b). However, data-quality limitations place performance-specific constraints on older adults' cognitive performance for reasons having little to do with cognitive mechanisms per se. For instance, tasks closely tied to sensory functioning (e.g., recognizing objects in a dark-adapted environment) will be more at risk for declining functioning due to age-related changes in sensation and perception (Nagel, Werkle-Bergner, Li, & Lindenberger, 2007; Schneider & Pichora-Fuller, 2000). Likewise, age-related changes in speed of information processing will constrain performance in time-limited decisions (Birren, 1970; Salthouse, 1996).

An important principle governing cognitive development is that individuals are selected into particular contexts and create unique developmental histories (Baltes & Baltes, 1990). Individuals select particular areas in which they invest time, energy, and cognitive resources to gain knowledge and experience (Ackerman, 2000; Ackerman & Rolfhus, 1999; Baltes, 1997; Beier & Ackerman, 2005; Cattell, 1971). Some aspects of cognitive function, particularly those heavily imbued with knowledge or experience (what Baltes, 1997, refers to as the pragmatics of cognition), will be relatively well preserved in adulthood, provided that the performance context does not introduce performance-specific constraints due to challenges to impaired processing mechanisms (e.g., Hertzog, 1989). However, any one individual cannot develop knowledge and expertise in all domains, given the vast amounts of knowledge available in modern society and the fact that knowledge acquisition consumes finite resources of available energy and time. Instead, one must be selective, and this implies that plasticity, as defined earlier, will operate in many domains where one does not function optimally and in a few domains where one does, as a function of investment of time and effort to master relevant information. Given that cognition usually involves the use of knowledge to interpret and filter information for particular uses in specific contexts, individuals' lifelong patterns of investment and efforts in particular domains construct idiosyncratic profiles of experience and expertise that are relevant to effective cognitive functioning (e.g., Cianciolo et al., 2006) and that set limits for potential improvement. For individuals without prior relevant knowledge, efforts to learn new information in a domain may lead to substantial improvements in performance relevant to that domain, though at comparably low levels of overall proficiency. For individuals with prior knowledge and experience, improvements or maintenance in performance may build upon the scaffold of prior experience in ways that not only enable superior performance, relative to one with minimal relevant experience, but also create a higher probability of maintenance or improvement in cognitive function.

Of course, we must acknowledge that the cumulative effects of experience and knowledge on cognition are not all positive. Expertise in a problem domain also has costs, because individuals may fail to notice how a new problem differs from, rather

than resembles, problems they have solved before. Identifying the higher-order generalities in information can also lead to an individual paying less attention to distinctive aspects of information, which can be critical in governing the likelihood of later retrieval of that information (e.g., Hunt & Smith, 1996).

At the level of cognition itself, there are typically multiple pathways by which effective problem solutions can be achieved (Hunt, 1978; Lautrey, 2003). Individuals may differ in preferred strategies or cognitive styles, but they can shift strategies if contextual demands and constraints require them to (Hertzog & Dunlosky, 2004; Hertzog & Robinson, 2005; Schunn & Reder, 2001; Touron & Hertzog, 2004). Because of this, cognitive development over the life course is likely to involve compensatory adaptations to age or experience-related change in the form of shifting cognitive procedures or strategies (Bäckman & Dixon, 1987; Baltes, Maas, Wilms, Borchelt, & Little, 1999; Hertzog, 1985). For example, older adults may use more intensive organizational strategies to support learning information when incidental learning makes spontaneous remembering of critical information less likely. Or they may rely on different varieties of contextual support to overcome age-related processing limitations (Bäckman, 1989; Craik & Byrd, 1982). They may also rely on a variety of external aids that seek to reduce demands on compromised cognitive mechanisms (e.g., Intons-Peterson & Fournier, 1986). In short, at a given point in time there are multiple procedures available to an individual to achieve cognitive goals.

In response to developmental losses in cognitive mechanisms over the adult life course, individuals can choose different processing strategies when a particular mode of processing no longer achieves desirable outcomes. These compensatory goal-directed actions are a form of adaptive self-regulation and intentional self-development (e.g., Brandtstädter, 2006; Carver & Scheier, 1998; Riediger, Li, & Lindenberger, 2006), as they require monitoring of current cognitive states, performance outcomes, and flexible strategic choice (Hertzog & Robinson, 2005; Nelson & Narens, 1990; Stine-Morrow et al., 2006). At another level, compensation may occur by competition and rearrangements among relatively autonomous processing circuits, without explicit awareness on the part of the individual of how he or she is compensating (e.g., Cabeza, 2002; Colcombe, Kramer, Erickson, & Scalf, 2005; Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Cappel, 2008; Salthouse, 1984; cf. Edelman, 1987). In either case, compensatory behaviors are one means of mitigating effects of aging on basic cognitive mechanisms.

An important implication of this argument is that older adults often achieve excellent levels of functioning in everyday life in tasks that seem to require cognitive mechanisms that have declined. As noted earlier, this can occur because of beneficial-expertise effects, but it can also occur because individuals develop strategic approaches to life tasks that minimize the role of cognitive mechanisms, per se, in achieving cognitive outcomes (Salthouse, 1991a). For example, despite their age-related cognitive decline, older rheumatoid patients actually do better at remembering to take medications than do their younger and middle-aged peers, probably because they develop helpful daily routines that support remembering in context (Park et al., 1999). Again, however, knowledge of appropriate strategies and habitual use of strategies can also create problems for adaptive functioning. The inertia of maintaining a well-learned and nominally effective strategy at one point in the life course puts one at risk for failing to adaptively shift to a new and more effective strategy at a later point in time (Hertzog, 2008).

Another aspect of our perspective is the assumption that individuals' neurobiological status is influenced by their social context and personal behavior, and vice versa (e.g., Baltes, Reuter-Lorenz, & Rösler, 2006; Cacioppo, 2002; Li & Lindenberger, 2002). It is helpful to think of the brain as a substrate that affords cognitive plasticity, and as such is influenced by the behaviors of an individual (Cacioppo et al., 2003; Lerner, 1984). Contemporary neuroscience research suggests that individuals selected into particular environments show neuronal changes as a function of the specific cognitive-processing requirements of those environments (e.g., Maguire, Woollett, & Spiers, 2006). In line with these findings, short-term training such as learning to juggle or studying for an academic exam has been found to induce structural alterations in the brain (Draganski et al., 2004, 2006). Likewise, animal studies have shown major changes in a variety of mechanisms, such as neurogenesis (growth of new neurons), even in mature animals, as a function of changing environmental contingencies (e.g., Cotman, 1995; Kempermann, 2008). Conversely, psychological stress and loneliness can have profound negative effects on brain structure and function (Cacioppo, Hughes, Waite, Hawkley, & Thisted, 2006; McEwen, 2002; Sapolsky, 1992). Such findings encourage us to view brain–behavior relationships as dynamic and reciprocal rather than as static and hierarchical (Lindenberger, Li, & Bäckman, 2006b). Although aging may constrain the degree of neuronal plasticity that is possible, studies suggest that enriched-environment effects can be observed in older organisms (Brown et al., 2003; Jessberger & Gage, 2008; Kempermann, Kuhn, & Gage, 1998). Moreover, the kinds of adaptation discussed above at the behavioral level may be paralleled in the neuronal substrate. For instance, Edelman's (1987) theory of neuronal group selection states that variants of neuronal circuits are constantly generated and selected during an organism's development to assure adaptive behavior in the ecology.

Given these principles, the core argument is that the life course of the individual is forged from experience and choice (Stine-Morrow, 2007) and that this has consequences for the structure and function of cognition and its neuronal substrate. With respect to Figure 1, one can think of the zone of possible development as creating a finite but large universe of possible selves (Frazier & Hooker, 2006) with respect to cognitive functioning in old age (Dark-Freudman, West, & Viverito, 2006). Some paths are feared, others are desired. These selves

can be thought of as possible pathways through life over time, the cumulative effect of roads taken and not taken (Frost, 1920; cf. Tetens, 1777). Figure 2 illustrates this concept by charting possible developmental paths for a hypothetical individual during adulthood and aging (see also Denney, 1984). These possible cognitive curves are constrained by the ranges of possible development illustrated in Figure 1, which is the background in which these possible life trajectories emerge. At the left-hand side of Figure 2 (age 20), the individual operates at a particular point in a range of possible development governed by influences that act prior to early adulthood. At later ages, the level of cognitive function is influenced by the prior level of function (given the accumulated cognitive history) and the variables that operate to determine cognition in the intervening time period.

In the case of Curve A, optimization of function causes the individual to approach maximum levels of cognitive performance. To use an analogy from sports, this could be the path of an Olympic champion in a specific type of cognition, where an optimal behavioral regimen leads to performance that is essentially at its peak. In the worst case, Curve D, maladaptive behaviors lead to atrophy of cognition and a rather quick and precipitous decline in cognition over the adult life course.

The middle two curves illustrate a couple of concepts that are crucial to our discussion. Curve B represents relatively gradual and benign decline in cognitive functioning. Perhaps the individual in question has moderately good lifestyle practices and a typical degree of cognitive engagement in work and leisure activities in young adulthood and middle age. Nevertheless, how would one interpret the rate of decline after age 50? Although this might be seen as a normative curve, given that it parallels more or less the biological aging curve that constrains maximum possible performance, our view is that it is not necessarily a reflection of biological aging per se. Instead, it may also reflect inertial tendencies of the individual not to adapt to or compensate for a changing mechanistic basis for cognition. Or it could be influenced by the cumulative effects of limited and ineffective attempts to exercise the body and the mind over the adult life span. In short, what appears to be a normative, biologically graded decline may reflect, to a major degree, inertial resistance to behaviors that could optimize development and set one on a different developmental trajectory. Stability, in the sense of unchanging behavior, does not imply immutability (Caspi, Roberts, & Shiner, 2005; Kagan, 1999).

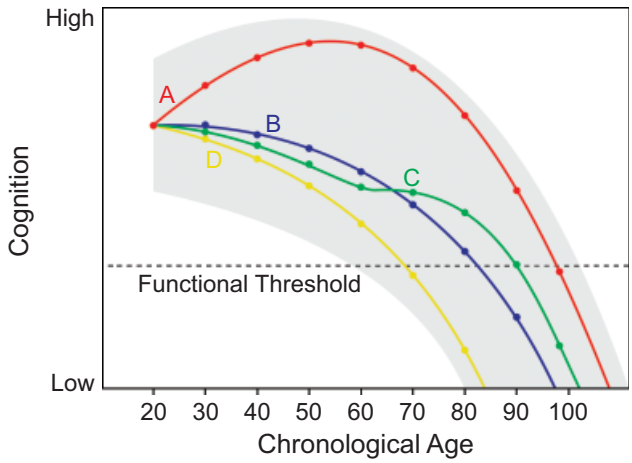

Fig. 2. Depiction of the zone of possible cognitive development for a given individual, along with four developmental curves (A, B, C, & D) indicating specific possible outcomes. Each possible curve starts from the same functional level at age 20, with different trajectories resulting as a function of interactions among behavioral, environmental, and genetic factors that permit vertical movement within the zone at different points in the life span.

Curve C suggests that late-life improvement in cognitive functioning is possible if an individual engages in enrichment behaviors in midlife that are of a quality and degree not previously manifested at earlier ages, with those behaviors pushing the individual toward optimality. We have drawn the curve to suggest that the potential degree of enrichment may be constrained to lie below that of a person who has engaged in lifelong optimal enrichment behaviors (Curve A), and to reflect a conjecture that such enrichment behaviors will have diminishing returns in old age as a function of the increasing cascade of loss described by Baltes (1997). The possibility that Curve C could cross Curve B, even in old age, suggests that efforts to enrich cognition could have substantial impact, even in midlife. In general, an individual's realized developmental pathway is cumulative, inevitably building on what has happened before, but it also contains the potential for discontinuity in the positive direction (as in Curve C) given a discontinuous increase in cognition-enriching behaviors or environmental influences. Though past life histories certainly condition the range of aging outcomes to a more or less substantial degree, the present framework posits that any given age period offers a range of more or less desirable continuations of given developmental paths, depending on what happens in the age periods thereafter.

Of course the curves we show in Figure 2 are simplifications and mere illustrations of our conceptual framework. They are not necessarily the most probable or normative curves one might generate for an actual person, but merely depict possible worlds (Bruner, 1986) for the individual. They also do not capture a number of phenomena that would emerge if an individual's cognition were empirically tracked over long periods of time. For example, they are smoothed long-term intraindividual-change functions that ignore the likelihood of short-term intraindividual variability in cognition over time (e.g., Hertzog, Dixon, & Hultsch, 1992; Nesselroade, 1991; Ram, Rabbitt, Stollery, & Nesselroade, 2005). They also ignore the likelihood that different aspects of cognition might show very different pathways within a single individual, given the fact that different cognitive abilities appear to change at different rates, and given the types of self-selection mechanisms discussed earlier. Nevertheless, they convey the idea that the developmental trajectory of cognition in adulthood is not necessarily fixed but can, in principle, be influenced and shaped by events and behaviors.

In sum, cognitive-enrichment effects can occur in the face of, and perhaps even despite, normative changes in the mechanisms often studied by cognitive psychologists. At the same time, enrichment effects could, in principle, act to alter the observed course of cognitive development even when aging constrains the levels of theoretical maximal performance. As we develop in more detail shortly, framing cognitive enrichment effects in this manner helps us to contemplate the broad range of relevant phenomena and, at the same time, shows us the potential complexity and problems confronting efforts to empirically demonstrate such enrichment effects.

Before proceeding to a discussion of empirical methods and empirical evidence regarding cognitive enrichment in adulthood, we highlight three conceptual issues that are particularly relevant to our inquiry.

Scope of Enrichment Effects

An important dimension in reviewing and evaluating cognitive-enrichment effects is their scope. Phrased in terms of hierarchical models of intelligence (Carroll, 1993), what is at stake is the level of the cognitive hierarchy at which training effects are operating. In Carroll's taxonomy of cognitive and intellectual abilities (which was strongly influenced by other theories and large amounts of empirical work, e.g., Cattell, 1971; Horn, 1989), general intelligence is at the highest level, with several broad second-order factors (e.g., fluid intelligence, general speed of processing) just below it. In turn, the broad second-order factors account for relationships among a number of what Thurstone (1938) termed primary abilities (e.g., inductive reasoning). One can further consider these primary abilities as collections or constellations of specific cognitive mechanisms (Horn, 1989).

What is also in play is the extent to which cognitive-enrichment effects are due to influences at broad or narrow loci of effects. If the enrichment effect operates on specific psychological mechanisms, its impact may be narrow. If the enrichment effect operates at the level of general improvements of the functioning of entire neural circuits or the biochemical substrates that serve cognition more generally (e.g., changes in circulating hormone levels or neurotrophic factors), then the effects could be relatively general.

One could imagine types of interventions for cognitive enrichment that could have relatively broad impact due to widespread loci of effective action (e.g., improvements in nutrition and physical activity) and types of interventions that would have very narrow scopes of impact. For instance, research suggests that when individuals participate in a cognitive-training program, the beneficial effects on cognitive performance tend to be relatively narrow in scope, usually localized to the specific cognitive test that was trained (e.g., Ball et al., 2002; Willis et al., 2006; but see Tranter & Koutstaal, 2008). If enrichment effects were operative at the level of broad cognitive abilities, then it would make sense, from an applied perspective, to train individuals on a test that is known to be a reliable and valid indicator of the ability in question, regardless of whether performance on this test, taken by itself, is of any direct practical utility. For instance, if long-term practice on a marker test of visual-perception speed, such as the Digit Symbol Substitution test of the Wechsler Adult Intelligence Scale (WAIS), would generalize to the ability in question, then participation in such a training program should have beneficial effects on all those aspects of everyday competence that require the fast and accurate perception and comparison of visual stimuli. If, on the contrary, enrichment effects operate at the level of elements of skill (Thorndike, 1906), then participating in such a training program may have few or no direct effects on everyday cognitive competence because the fast mapping of arbitrary symbols to digits plays no major role in the cognitive ecology of most elderly individuals. This does not necessarily imply that such training programs would be ineffective from an applied perspective. They could lead to enhanced self-perceptions of cognitive efficacy, which in turn may influence individuals' readiness to engage in cognitively stimulating activities. Be that as it may, the practical utility of this kind of training for enhancing everyday life would be limited and indirect, at best.

We will consider these issues in more detail later, as we review the available empirical literature. As will become evident in the course of this review, some enrichment effects appear to operate predominantly at the skill level, whereas others also operate at the ability level. Moreover, these differences between types of enrichment are modulated by differences between individuals. Therefore, statements about the scope and practical relevance of enrichment effects will need to be qualified in more than one way.

Sustainability of Enrichment Effects

In addition to their scope, enrichment effects also vary in their sustainability. In intervention work, this issue is generally addressed by assessing the maintenance of training effects over time relative to a control group. But of course, the question of enrichment sustainability also holds for beneficial behaviors and environmental agents in the individuals' natural ecologies. For instance, when an enrichment mechanism is introduced and later withdrawn, will the individual eventually "fall back" onto the developmental trajectory prior to enrichment (e.g., Curve D of Figure 2)? During sensitive periods early in development, exposure to different environments is known to have long-lasting and largely irreversible effects on brain structure and function (cf. Hensch, 2004, 2005). However, plasticity during sensitive periods differs in important ways from plasticity before and after such periods (cf. Hensch, 2004; Knudsen, 2002), and it may often require sustained efforts to be maintained.

Ameliorating Normal Cognitive Aging Versus Postponing Dementia Onset

A point of some contention in the gerontological literature is whether there is a qualitative difference between normative

cognitive decline (caused, say, by biological aging that is universal to all individuals—Birren's [1964] term was primary aging) and age-related neurological conditions such as Alzheimer's disease. Although a qualitative distinction between normal aging and age-related pathology is part of the foundation of many theoretical discussions of aging (e.g., Baltes & Willis, 1977), clinical-pathological data suggest that the difference is mainly quantitative. Thus, the pathologic lesions most commonly associated with late-life dementia—amyloid plaques, neurofibrillary tangles, Lewy bodies, and cerebral infarction—are also seen in a substantial number of older person who die with mild cognitive impairment (Bennett, Schneider, Wilson, Bienias, & Arnold, 2005a; Guillozet, Weintraub, Mash, & Mesulam, 2003; Markesbery et al., 2006; Petersen et al., 2006) or no cognitive impairment (Bennett, Schneider, Tang, Arnold, & Wilson, 2006; Driscoll et al., 2006). Figure 3 shows data from one of these studies (Bennett, Schneider, et al., 2005a) on the correlation of a composite measure of Alzheimer's disease pathology with a composite measure of global cognition measured close to death. Not only are neuropathologic changes not confined to those with dementia (square data points, dotted regression line), the correlation of pathology with cognition in those with mild cognitive impairment proximate to death (triangular data points, solid regression line) or none (circular data points, dashed regression line) is comparable to the correlation in those with dementia. Thus, excluding persons with dementia or its precursor from aging studies does not eliminate age-related neuropathology or its deleterious impact on cognition. The relatively modest size of the correlation of common neuropathologic lesions with cognition that is evident in this figure and many other studies has long suggested that some individuals are better able than others to tolerate this age-related pathology. To the extent that behavior or neural plasticity in response to age-related neuropathologic changes is an important part of cognitive aging, excluding individuals showing early signs of a condition such as Alzheimer's disease might be counterproductive. For the present purposes, therefore, we will treat the distinction between dementia and normal aging as a continuum of disease and cognitive decline, and report the evidence on enrichment across the entire spectrum of cognitive-performance levels that can be observed in aging populations. Specifically, we also include interesting recent data on enrichment effects in individuals diagnosed with mild cognitive impairment. Recent research argues that most people with mild cognitive impairment will eventually develop dementia, indicating that many people with major cognitive decline in old age may be showing preclinical symptoms of a dementing illness (Albert, Blacker, Moss, Tanzi, & McArdle, 2007; Lopez, Li, Shing, & Lindenberger, 2007; Petersen et al., 2006). Also, taking a view on cognitive enrichment that encompasses a broad range of ability levels allows us to examine the extent to which processes that enhance cognition at the high end of the ability spectrum are similar to or distinct from the processes that postpone diagnosis of a dementing illness at the low end of the scale of cognitive performance. Answers to this question may, in turn, inform the debate about the nature of the difference between normal and pathological cognitive aging.

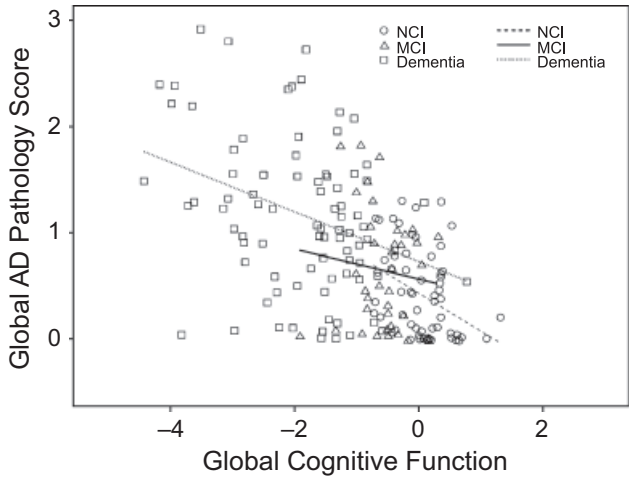

Fig. 3. Regression of a composite measure of Alzheimer's disease (AD) pathology on cognitive function score in three different diagnostic groups: no cognitive impairment (NCI), mild cognitive impairment (MCI), and dementia. Note that there is a negative relationship of pathology to cognition in all three subgroups. Reprinted from ''Mild Cognitive Impairment Is Related to Alzheimer Disease Pathology and Cerebral Infarctions,'' by D.A. Bennett, J.A. Schneider, J.L. Bienias, D.A. Evans, & R.S. Wilson, 2005, *Neurology*, *64*, 834–841 (the figure is in an unpaged supplement to the article, labeled ''E1''). Copyright 2005, American Academy of Neurology. Reprinted with permission.

METHODOLOGICAL ISSUES

Empirical evidence from a large variety of research designs and disciplines has been brought to bear upon the evaluation of the cognitive-enrichment hypothesis. As in any research, inferences about cognitive enrichment involve methodological assumptions about how to observe and/or manipulate phenomena pertinent to the hypothesis. But the problems are especially difficult when it comes to cognitive enrichment, because the hypothesis entails that changes in cognition over the life course will be affected by individuals' lifestyle and behavior. The methodological problems encountered in evaluating explanatory hypotheses about adult development are formidable (e.g, Baltes, Reese, & Nesselroade, 1988; Hertzog & Dixon, 1996; Nesselroade & Labouvie, 1985).

Given the problems associated with assessment of change over long time intervals (years or even decades, in the case of the cognitive-enrichment hypothesis), developmental researchers must consider evidence from multiple, different observational and intervention designs. The sources of evidence range from cross-sectional associations, longitudinal panel studies, experimental intervention in human and animal populations, and neuroimaging studies to computational models. The characteristics of each of these different approaches—their strengths and

weaknesses regarding the enrichment process—need to be taken into account as one is attempting to identify the mechanisms and estimate the possible amount of cognitive-enrichment effects in human cognition.

Cross-Sectional Studies

Cross-sectional studies measure individuals of different ages at only one point in time (e.g., Baltes et al., 1988). A common strategy in behaviorally oriented cross-sectional studies targeting the effects of task-relevant activities on cognitive performance is to classify individuals of different ages into high- versus low-activity groups on the basis of self-report variables that index the degree to which individuals engage in such activities. According to this strategy, a widening of the performance gap between high-activity and low-activity groups with increasing age, or "differential preservation" (e.g., Salthouse, 2006; Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990), can be taken to support the hypothesis that these activities exert beneficial effects on the maintenance in the face of aging. Conversely, parallel or decreasing group differences for low- and high-activity groups with advancing age are taken to indicate the absence of attenuating effects of activities on negative age changes in cognition. The hypothesis can also be tested, with greater statistical power, by moderated regression analysis treating activity as a continuous variable (e.g., Cohen, Cohen, West, & Aiken, 2003). The issues we discuss here apply to the design logic irrespective of the statistical analysis applied to its evaluation.

There are a number of problems with this approach. First, the cross-sectional method is not necessarily a good approximation of average developmental change, for a variety of methodological reasons (Schaie, 1977). For example, differential sampling and selection effects (including differential mortality in the population) can distort the cross-sectional curve (Nesselroade & Labouvie, 1985). Hertzog (in press) argues that differential volunteering in midlife, combined with selection artifacts in old age due to morbidity and mortality effects, could produce parallel cognitive functions for different levels of activity in cross-sectional data, even when the actual function is a Cognition × Activity interaction. Arguments concerning the general utility of cross-sectional data for estimating aggregate developmental functions have a long history in developmental research; we shall say only a little more about it here.

Second, even if one presumes that cross-sectional age trends approximate the mean or average age curve, this does not imply that partitioning cross-sectional trends by levels of activity provides strong evidence regarding the cognitive-enrichment hypothesis. This argument assumes that cross-sectional comparisons of individuals with different levels of self-reported activity serve as valid surrogates for the activity-induced modulation of aging changes within persons over time. This approach also assumes that the dose–response relation between amounts of activity and cognitive performance is similar for individuals operating at high and low levels of cognitive skill. However, especially at older ages, maintaining high performance levels may require greater ability-relevant behavioral investments than maintaining lower levels of performance. When operating close to the limits of performance, individuals tend to experience substantial dropoffs in performance unless they exert sustained, deliberate efforts to maintain peak performance levels (Ericsson, 2006). In a sense, the likelihood of regression to the mean increases as an individual becomes more extreme in a distribution of scores (Nesselroade, Stigler, & Baltes, 1980). If sustained efforts to maintain maximal performance lag, high performers can be expected to regress back toward their own average. By implication, the lag in effort will cause high performers to become more like their more average peers (see Fig. 1). In addition, general laws of learning (e.g., Thorndike, 1906) indicate that performance improvements are more difficult to obtain at high levels of cognitive skill.

Third, the interpretation of activity-segregated cross-sectional data is further complicated by the fact that individuals in the high-activity groups usually perform above the level of the low-activity groups throughout all age periods considered, including the youngest age bracket. These group differences in performance may not be due solely to the effects of activity, and the variables that actually govern the differences could overshadow or interact with activity differences in the course of aging to produce or obscure cross-sectional differences in activity subgroups.

As we noted earlier, empirical tests of the cognitive-enrichment hypothesis seek to detect individual differences in intraindividual cognitive change, given individual differences in activity patterns. However, recent work indicates that individual differences in intraindividual change can be obscured in cross-sectional data because of the contributions of other sources of variance in cognition. Specifically, variance due to (a) age differences in (aggregate) mean performance and (b) stable individual differences may be more important contributors to cross-sectional variance in cognition than individual differences in intraindividual change (Hofer, Flaherty, & Hoffman, 2006; Hultsch et al., 1998; Lindenberger, von Oertzen, Ghisletta, & Hertzog, 2008). Thus, Activity × Age interaction effects may fail to emerge because individual differences in change due to different enrichment behaviors are overshadowed by the aggregate mean curves, making it difficult to detect the interaction effects. Logically, failing to find differential effects in cross-sectional data constitutes a failure to reject a null hypothesis of parallel curves at different levels of activity. As in any statistical application, accepting the null hypothesis (in this case, a null hypothesis of no interaction) should be understood as being distinct from a failure to reject it (Cohen, 1994). Accepting the null hypothesis is a risky inference about a small (in practical terms, a near-zero) effect size. At minimum, it requires justification in terms of available statistical power, given the likelihood that true cognitive-enrichment effects will probably

produce small interaction effect sizes. Such effects may be difficult to observe even if the assumptions of the cross-sectional method are fully met.

In this context, it should also be noted that measurements of activity levels are often based on self-reports and other indirect estimates of ability-relevant activities. The validity of such measures has usually not been directly assessed (e.g., by comparing questionnaire self-reports to other observations of activity levels). Self-reported activities may be particularly susceptible to age/cohort differences and to individual differences in standards for reporting activities or judging frequency of activities. For instance, individuals with higher cognitive abilities may use more conservative standards when judging the cognitive demands of their daily activities than might individuals with lower cognitive abilities (see Rabbitt, Maylor, McInnes, Bent, & Moore, 1995).

In sum, we argue that age-comparative cross-sectional data do not provide strong evidence for evaluating the cognitive-enrichment hypothesis. In particular, parallel rather than diverging age trends in cognitive performance for consecutive age brackets of high- and low-activity groups do not provide firm evidence against the existence of cognitive-enrichment effects in human cognition.

Longitudinal Panel Studies

Longitudinal studies of cognition in old age have two strong advantages in comparison to cross-sectional age comparisons. First, a longitudinal design permits direct observation of the key outcome in cognitive research: person-specific rates of change in cognitive function (Baltes & Nesselroade, 1979). Cross-sectional measures of level of cognitive function account for relatively little of the variability among people in rate of change in cognition in old age (Wilson, Beckett, Bennett, Albert, & Evans, 1999; Wilson, Beckett, et al., 2002). Second, it is possible to assess exposure variables (e.g., cognitive enrichment) before outcome variables (e.g., change in cognitive function) in a longitudinal study, which substantially reduces the risk of bias in estimating exposure–outcome associations. For these reasons, we have focused primarily on longitudinal studies of the cognitive-enrichment hypothesis.

Be that as it may, the use of longitudinal data from passive observational studies creates its own set of methodological issues. As with the cross-sectional design, the interpretation of data from a longitudinal design is not straightforward because lifestyles are not randomly assigned to individuals (Shadish, Cook, & Campbell, 2002). As a consequence, effects of cognition on lifestyle are difficult to disentangle from effects of lifestyle on cognition and from third-variable (omitted-variable) explanations (e.g., James, Mulaik, & Brett, 1982). The logic of accumulating relevant evidence from a quasiexperimental design perspective (Shadish et al., 2002) suggests that it is critically important to test specific claims about patterns of activity in relation to cognition in observational data that address rival explanations (Hertzog, Hultsch, & Dixon, 1999). Strong substantive hypotheses about patterns of effects that would be produced by relevant mechanisms, and empirical assessment of such hypotheses, are needed; assessing these hypotheses may require more intensive and complicated event- and time-sampling procedures than are typical in longitudinal panel design studies.

Any use of longitudinal data to address the cognitive-enrichment hypothesis necessarily involves using advanced statistical models for longitudinal data (e.g., Hertzog & Nesselroade, 2003). A large number of statistical approaches are available, and different studies often employ very different methods, rendering comparisons of results difficult. Much of the epidemiological evidence is based on random-effects (multilevel) regression analysis for examining predictors of longitudinal change. With respect to causal inference about activity affecting cognition, dynamic modeling of causal influences of variables on one another, as in Hamagami and McArdle's (2007) dynamic dual change score models (e.g., Lövdén, Ghisletta, & Lindenberger, 2005), may help to attenuate these ambiguities. Unfortunately, we currently know relatively little about the behavior of these statistical models and whether they can actually recover effects that exist, or whether and when they are susceptible to erroneous inferences about how one variable influences another, and vice versa. As in any structural regression model, the validity of dynamic causal inferences depends on the dynamics of relationships to omitted variables—unmeasured variables that cannot be included in the statistical model (Hertzog & Nesselroade, 2003).

As with any developmental design, longitudinal designs have major potential methodological issues that are not always addressed in empirical applications. One major issue in longitudinal studies is selective attrition (Baltes et al., 1988; Schaie, 1977). Individuals who drop out from a longitudinal study often differ from those who stay on dimensions of interest—they tend to be less healthy, less cognitively fit, and less engaged in stimulating activities, thereby restricting the observable range of variation (e.g., Ghisletta, McArdle, & Lindenberger, 2006; Lindenberger, Singer, & Baltes, 2002) and potentially biasing estimates of the relation of enrichment variables to cognitive outcomes.

Another challenge in longitudinal studies of cognitive function is that performance tends to improve when people take a test multiple times—referred to as retest or practice effects. Assessing practice effects inside a longitudinal design is in and of itself a difficult modeling exercise that requires a number of assumptions, because longitudinal designs explicitly targeting practice effects are rarely employed (see Baltes et al., 1988; McArdle & Woodcock, 1997). Nonetheless, there is broad agreement that practice effects in longitudinal aging studies have led to underestimation of the average amount of age-related cognitive decline (Ferrer, Salthouse, McArdle, Stewart, &

Schwartz, 2005; Ferrer, Salthouse, Stewart, & Schwartz, 2004; Rabbitt, Diggle, Holland, & McInness, 2004; Wilson, Beckett, et al., 2002; Wilson, Li, Bienias, & Bennett, 2006). In cognitive-enrichment research, however, the focus is on the relation of enrichment variables to individual differences in cognitive change rather than on the absolute level of change taking place. The critical methodological issues, therefore, are the extent to which individuals differentially benefit from practice and whether these individual differences are related to person-specific attributes.

There are individual differences in practice effects, but these individual differences do not appear particularly consistent across measures or strongly related to basic demographic variables like age, sex, and education that are linked to both enrichment variables and cognitive outcomes (Wilson, Li, et al., 2006; Wilson et al., 2009). This suggests that practice effects may not overly affect correlations between enrichment variables and cognitive outcomes, other than as another source of unexplained variability. Some studies build in the use of rotating alternate forms to minimize practice effects, under the assumption that practice effects will be specific to exposure to particular items, not to the test procedure or format itself (e.g., Hertzog, Dixon, Hultsch, & MacDonald, 2003). Studies using an item-response-theory approach (Embretson & Reise, 2000) should also be less prone to these kinds of practice effects because items in the discriminating difficulty range are randomly assigned to persons at different points in time. Yet alternate forms do not eliminate practice effects, due to general enhancement of test-taking skills (Dikmen, Heaton, Grant, & Temkin, 1999; Hultsch et al., 1998; Watson, Pasteur, Healy, & Hughes, 1994), and to the extent that the alternate forms are not truly equivalent, they introduce a new source of variability.

In general, however, we believe that the advantages of the longitudinal method far outweigh its disadvantages, relative to the cross-sectional procedure, for evaluating the cognitive-enrichment hypothesis with observational data. For this reason, we feature longitudinal studies, not cross-sectional studies, when we evaluate the evidence in the existing literature.

Intervention Studies

Intervention studies offer a more controlled way to assess cognitive-enrichment effects, because assignment of individuals to treatments, and the treatments themselves, are under experimental control. By comparing the pretest–posttest differences between the experimental and one or more control groups, the effectiveness of the intervention can be assessed on three basic dimensions: (a) the *magnitude* of intervention effects (did the training lead to enhancement in performance on the target activity?); (b) the *scope*, or substantive extension, of intervention effects (did the benefits of the intervention generalize to other tests of the same ability domain, and to other ability domains, and to measures of everyday competence, or were the benefits confined to the specific skill that was trained?); and (c) the *maintenance*, or temporal extension, of intervention effects (are the beneficial effects of the intervention maintained over time, or do they dissipate quickly after the intervention has ended?).

Intervention studies are a powerful methodological tool to explore the range and magnitude of enrichment effects in human cognition and to probe mechanisms that may mediate these effects by contrasting treatment groups with appropriate control groups. One problem with such studies is that different aspects of lifestyle may be more or less amenable to intervention. Compliance with an exercise program may be easier to implement, measure, and validate than compliance with a regimen of performing intellectually engaging activities such as reading or doing crossword puzzles.

The relevance of intervention studies for the cognitive-enrichment hypothesis has also been called into question because maintenance is rarely assessed beyond 1 or 2 years following the end of the intervention (e.g., Salthouse, 2006). Also, when assessed, intervention effects often dissipate within the period of months or a few years unless there are additional attempts to provide reinforcement (booster training) to maintain the intervened behavior. Although we agree that evidence of long-term maintenance and benefit is highly relevant and should be assessed, we do not think that intervention studies without maintenance assessment are irrelevant, or that studies reporting low maintenance necessarily refute the enrichment hypothesis. First, the initial boost in performance achieved by an intervention is relevant in itself because it represents a necessary condition for moving individuals onto a different developmental path (see Fig. 1). Second, failures to maintain intervention effects, or regressions back to the preintervention path, could reflect the fact that the altered physical or cognitive activities practiced during the intervention period were discontinued at the end of the intervention period. Assessment of the maintenance of the hypothetically enriching behavior is critical to understanding when enrichment should be achieved or should dissipate. To expect maintenance of intervention effects if the enriching behavior is not maintained would imply a "vaccination" concept of intervention, in which a one-shot intervention experience is sufficient to alter the developmental path in a lasting manner. However, in most cases, the performance-enhancing mechanisms operating during the intervention will not vaccinate against cognitive decline. Instead—and similar to mechanisms associated with healthy and unhealthy lifestyles—continued expression of intervention-related beneficial mechanisms may require the continuation of intervention-related activities after the actual intervention has ended. As implied in Figure 2, plasticity is not a one-way street, and performance may start relapsing to preintervention levels (e.g., display negative plasticity) as soon as intervention activities are given up.

Intervention studies are not immune to issues about causal inference, in part because assignment to conditions cannot

always be fully randomized and because of internal validity threats like imitation of treatments—in which individuals assigned to the control group spontaneously behave as if they were in the intervention (Shadish et al., 2002). Nevertheless, randomized intervention studies, where practical, provide much stronger causal inference about the mechanisms of enrichment and their impact. Therefore, intervention studies figure prominently in this report, even when maintenance was low or has not been assessed, because they inform us about the potential for short-term modifiability of aging trajectories even if the evidence regarding long-term effects is inconclusive.

Intraperson Time Series

Cross-sectional comparisons, longitudinal panel studies, and most intervention studies rest on the assumption that between-person differences and within-person changes are equivalent (e.g., Hertzog, 1996; Lindenberger & von Oertzen, 2006; Molenaar, in press; Nesselroade, 1991). This assumption requires that samples are homogeneous in the sense that the development of all individuals in the sample is governed by similar mechanisms and follows similar paths. Given the considerable degree of heterogeneity in aging samples, this assumption is likely to be violated in most if not all cases. Hence, empirical research on the cognitive-enrichment hypothesis eventually has to differentiate among individuals with different genotypes, life histories, current lifestyles, and current physical and cognitive resources. In order to arrive at such individualized estimates of improvement potential, researchers have begun to complement and expand traditional longitudinal panel designs by intensive observations of short-term variability and long-term changes in collections of single individuals (e.g., Lövdén, Li, Shing, & Lindenberger, 2007; Ram et al., 2005). In line with these recent developments, and as far as the available evidence permits it, the present report seeks to arrive at conclusions and recommendations that take into account the heterogeneity of aging populations and variability among individuals.

Across-Level Integration of Brain and Behavior: Imaging and Clinical-Pathologic Studies, Animal Models, and Neurocomputational Modeling

During the last 2 decades, the empirical gap between the human behavioral sciences and developmental neuroscience has been narrowing, and the cognitive neuroscience of aging has become an active field of research (Cabeza, Nyberg, & Park, 2005). Modern imaging techniques allow researchers to investigate the neurochemical (e.g., Li, Brehmer, Shing, Werkle-Bergner, & Lindenberger, 2006), neuroanatomical (e.g., Raz & Rodrigue, 2006; Sullivan & Pfefferbaum, 2006), and neurofunctional (e.g., Nyberg et al., 2003) consequences and expressions of learning and senescence. As a consequence, the dialogue between animal models of cognitive enrichment and corresponding research on experience-dependent alterations of senescent changes in humans has become richer and more precise in recent years. In this context, neurocomputational models (e.g., Li et al., 2006) serve as conceptual bridge between levels of analysis, because they specify mechanisms and system properties at an abstract level and express our current understanding of causal mechanisms.

COGNITIVE PLASTICITY AND SKILL DEVELOPMENT

We begin our review of the empirical literature by focusing on the question of whether behavior and lifestyle can move an individual's cognitive performance vertically upward (as in Fig. 1). Can people change their level of cognitive functioning?

Expertise and Skill Acquisition

Acquisition of novel cognitive and psychomotor skills is one way to evaluate how much plasticity is possible as people grow older. At one time, the accepted social stereotype was that "old dogs can't learn new tricks." What scientists have discovered is that this dictum needs to be discarded. Age-related changes in cognitive processing mechanisms do, apparently, alter *rates* of skill acquisition (Charness, 2006; Krampe & Ericsson, 1996), and they place formidable constraints on the maximum level of skill that can be attained or perhaps even maintained. In human motor performance, for example, slowing of information processing makes it difficult, if not impossible, for athletes in sports with high real-time processing demands to maintain peak levels of performance past midlife (Schulz & Curnow, 1988). Again, however, we are dealing with evidence about what is, not what could be. In recent historical times, the continued excellent levels of performance into their mid- and late 40s by athletes such as Nolan Ryan, Julio Franco, and Jack Nicklaus attests to the possibility that well-trained, well-conditioned, and highly skilled athletes can accomplish feats considered virtually impossible beyond age 40 for a previous generation. Who knows how well Tiger Woods will play golf in his 40s and 50s? It may depend far more on his motivation to maintain his extraordinary level of conditioning and mastery than on limitations placed on his performance by aging per se.

A simple example of older adults acquiring expertise is the development of automaticity in pure memory search, as typified by the Sternberg (1966) task. In the standard memory-search task, search times are a linearly increasing function of the number of elements held in memory (the set-size effect). It is well known that, in the standard task, older adults are slower to search their memory to verify whether a probe stimulus is an element of the memory set (e.g., Waugh, Thomas, & Fozard, 1978); this slower rate of search creates larger age differences in response times (RT) with increasing memory-set size, producing age-related increases in linear RT slopes with increasing set sizes (Anders, Fozard, & Lillyquist, 1972). Moreover, age differences in memory-search RT have been linked to

differential activation patterns in the dorsolateral prefrontal cortex (Rypma, Eldreth, & Rebbechi, 2007), suggesting a neural basis for age-related slowing in short-term memory retrieval. If stimuli can serve on one trial as targets, but on other trials as distracters—what has been termed varied mapping (Shiffrin & Schneider, 1977)—then extensive practice can result in somewhat more efficient rates of memory search, but set-size slopes remain, even after extended practice on the task. However, if the stimuli that are searched for are consistently mapped—that is, when some stimuli are always used as targets but never as distracters, and vice versa (Shiffrin & Schneider, 1977)—individuals can develop a long-term-memory retrieval structure (Ericsson & Kintsch, 1995). That is, they can rapidly respond because they know on the basis of a fast, fluent retrieval from long-term memory that a stimulus is a target without the need to search their short-term memory. This kind of automatic retrieval eliminates the set-size effect for both older and younger adults—it no longer matters how many items are held in short-term memory.

Data from Hertzog, Cooper, and Fisk (1996) illustrate this effect. They tested younger and older adults' RT in a category-memory-search task in which target stimuli were consistently mapped to members of the same taxonomic category (like animals or fruits) across two extended sessions of practice. Figure 4, Panel A shows learning curves for RT. Notice the aggregate power law of learning for both younger and older adults, in which RT decreases as a power function of the number of practice trials with the stimuli (Delaney, Reder, Staszewski, & Ritter, 1998). Clearly, older adults learned (achieving maximal or asymptotic RT) much more slowly than the younger adults. Nevertheless, they did achieve asymptotic performance. Panel B plots the set-size effects—that is, slopes of the RT function across the number of elements in the memory set. For varied mapping, the slopes persist with practice for both age groups, with older adults taking longer to search short-term memory. For consistently mapped stimuli, task practice eliminated the set-size effect—that is, the set-size slopes became zero, indicating no RT costs of additional elements held in memory for either age group. This automaticity in memory search was acquired more slowly for older adults (see also Strayer & Kramer, 1994), but it was achieved.

The slower rate of learning probably reflects age-related changes in associative-learning mechanisms (see Kausler, 1994, for a review). Nevertheless, older adults do achieve asymptotic performance in this task, despite the associative-learning deficit. Furthermore, when they were transferred to a reversal condition (i.e., when searched-for targets now become distractors and former distractors become targets), they showed disruption relative to search rates for new stimuli that had not been previously tested, just like younger adults did (Hertzog et al., 1996). Disruptions of search RTs in a reversal condition (in which former targets become distracters, and vice versa) were substantial for both age groups, providing evidence that automatic access to the long-term-memory structure had been thwarted by the reversal. Hence, one can conclude the older adults achieved automaticity in the memory-search task. For similar evidence of older adults attaining automaticity in elementary visual-search tasks, see Scialfa, Jenkins, Hamaluk, and Skaloud (2000).

Certainly there are conditions under which older adults' acquisition of automaticity in simple search-detection tasks is more fundamentally impaired, either early or late in learning (e.g., Rogers, Fisk, & Hertzog, 1994; Strayer & Kramer, 1994).

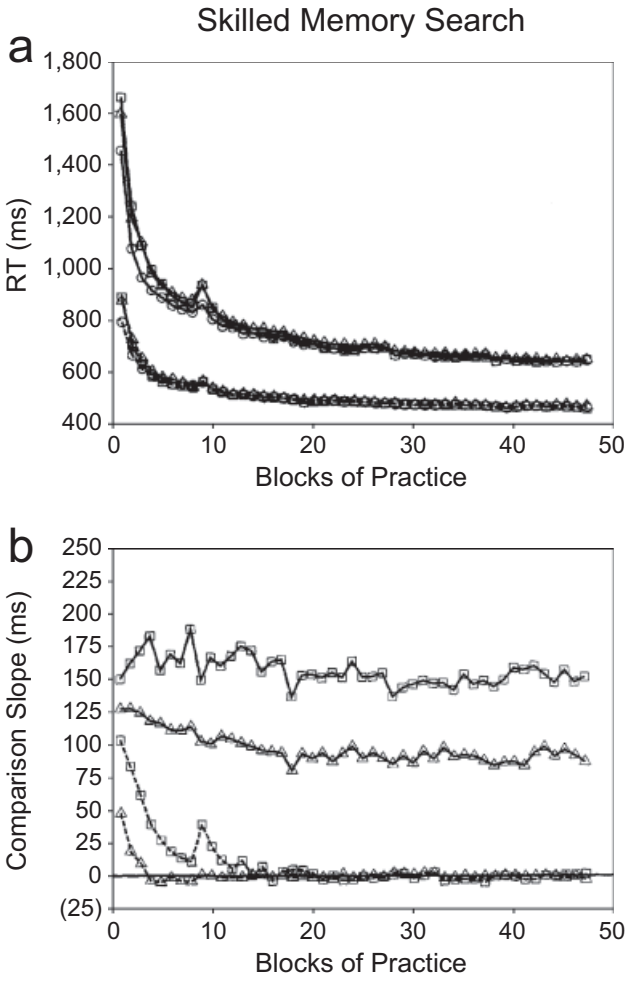

Fig. 4. Improvements in performance on a category-memory-search task for younger and older adults with extended practice. Panel a: Changes in reaction time (RT) in consistently mapped trials over blocks of practice for young individuals (dashed lines) and older individuals (solid lines) for three memory set-size conditions (2, 3, and 4 elements held in short-term memory, denoted by circles, triangles, and squares, respectively). Panel b: Changes in linear RT slopes (increases in RT to compare the probe with the number of items held in memory) as a function of practice in varied mapping (solid lines) and consistent mapping (dashed lines) for young adults (triangles) and older adults (squares). Creation of unitized memory structure in long-term memory is possible only in the consistent-mapping condition, resulting in elimination of set-size effects. Reprinted from "Aging and Individual Differences in the Development of Skilled Memory Search Performance," by C. Hertzog, B.P. Cooper, & A.D. Fisk, 1996, *Psychology and Aging*, *11*, p. 504. Copyright 1996, American Psychological Association. Reprinted with permission.

Moreover, asymptotic performance declines more with age whenever the nature of the skill offers only limited opportunity for automatization, as is the case for complex skilled-memory performance (e.g., Baltes & Kliegl, 1992; Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003). Skill acquisition depends on the particular ensemble of skills that must be integrated, and it is influenced by a wide variety of experimental variables that may differentially affect middle-aged and older adults. However, one should not necessarily conclude from such studies that skill acquisition is impossible for older adults. Often, it is merely more difficult and time consuming (Li et al., 2008).

One important factor in the maintenance of all types of skills is that expertise involves highly structured knowledge systems that can be flexibly and adaptively searched by experts to achieve processing goals in performance contexts (Ericsson & Charness, 1994). Consider work by Hoyer and his colleagues (Clancy & Hoyer, 1994; Hoyer & Ingolfsdottir, 2003) on the role of knowledge and expertise in situated skilled cognition in older adults. They have shown that experts are much faster when searching for specific, complex targets that are used in their typical job environments (e.g., medical X-ray technicians searching for problematic signs in an X-ray) than they are when searching for targets used in standard experimental visual-search tasks. Furthermore age differences in rates of visual search are larger for these experts when they are searching for novel stimuli than they are when they are searching for familiar, expertise-related stimuli. A major benefit of expertise, then, is that tasks performance by expertst may be less sensitive to age-related changes in basic information-processing mechanisms than the type of novel task often studied in the experimental laboratory (see Kramer, Cassavaugh, Horrey, Becic, & Mayhugh, 2007, for a similar example in obstacle avoidance in driving).

We draw two simple conclusions from our assessment of the aging and skill literature. First, one cannot necessarily generalize from lab to life, due to the importance of proceduralized skills and knowledge-based information processing in cognition as it is situated in natural ecologies (e.g., Colonia-Willner, 1998). This means that age-related declines in cognitive mechanisms should not be assumed to inevitably imply poor performance by older adults. Indeed, the job-performance literature suggests the opposite (e.g., Avolio & Waldman, 1990; Ng & Feldman, 2008). Older workers can rely on knowledge and experience to perform well in occupational settings (Kanfer & Ackerman, 2004).

Second, older adults maintain previously learned skills as they practice them, and they can often gain new skills even if their rate of skill acquisition is slowed. Referring back to our theoretical framework (Fig. 1), upward movements in the zone of possible cognitive performance are possible, even if such movements become more difficult with advancing age. This idea has been directly tested in the cognitive-training literature, to which we now turn.

Cognitive-Training Studies

Intervention work, in which specific cognitive mechanisms are isolated and trained (Baltes & Willis, 1982; Kramer & Willis, 2003), is a direct, experimentally controlled way to explore the degree of plasticity in intellectual functioning. There has been extensive research on training of specific cognitive skills in adulthood and old age. In this section, we consider only interventions specifically targeting cognitive skills and abilities. We review other forms of intervention that may have cognitive impact, such as exercise regimens, in a later section of this monograph.

We can distinguish three different generations of intervention studies that have evaluated cognitive plasticity in adulthood. The first generation of studies, which began in the late 1970s, examined whether age-based decrements in standard psychometric tests of intellectual functioning and episodic-memory functioning are reversible, in full or in part, through training and practice (Schaie & Willis, 1986; Willis & Nesselroade, 1990). For the most part, interventions involved older adults only, consisted of about three to six sessions of training or practice of the target tasks, and focused on tests from the fluid-ability domain. The major results of this first period of cognitive-intervention work can be summarized in five points (cf. Baltes & Lindenberger, 1988; Baltes, Lindenberger, & Staudinger, 2006): (a) Training gains in the practiced tests among healthy older adults are substantial (i.e., they roughly correspond to the amount of naturally occurring longitudinal decline between 60 and 80 years of age); (b) transfer, however, is entirely absent, or limited to tests of the same ability that share surface features and strategies with the trained task; (c) training gains are maintained over lengthy periods of time, up to several years (Neely & Bäckman, 1993; Willis & Nesselroade, 1990); (d) the fundamental nature of the constructs, as revealed by the factor structure of the ability tests, is not altered substantially through training (Schaie, Willis, Hertzog, & Schulenberg, 1987); and (e) in persons at risk for Alzheimer's disease or afflicted by other forms of brain pathology (Nebes, 1992), training gains are restricted to experimental conditions with high external support (Bäckman, Josephsson, Herlitz, Stigsdotter, & Viitanen, 1991) or are nonexistent (Baltes, Kuhl, & Sowarka, 1992; Baltes, Kuhl, Sowarka, & Gutzmann, 1995).

In general, results from this first generation of training studies indicated that the majority of healthy older adults, including those who display the typical pattern of age-related losses in fluid abilities, are able to greatly improve performance after a few sessions of task-related training or practice. Thus, among healthy older adults, the mechanics of cognition are sufficiently preserved to permit the acquisition of task-relevant declarative and procedural knowledge. At the same time, many of the studies did not include young adults. Thus, it was unclear whether the intervention resulted in a reduction or magnification of age differences in performance relative to trained young adults.

In part as a reaction to these interpretational ambiguities, a second generation of studies introduced testing-the-limits paradigms as a research strategy to uncover age differences in the upper limits of mechanic functioning (Baltes, 1987; Kliegl & Baltes, 1987; Lindenberger & Baltes, 1995). Similar to stress tests in biology and medicine (Baltes et al., 1995; Fries & Crapo, 1981), testing-the-limits aims at the assessment of age differences in maximum levels of cognitive performance by providing large amounts of practice and/or training combined with systematic variations in task difficulty. Similar to process-oriented research on mechanisms of cognitive change in childhood (Kuhn, 1995; Siegler, 2006; Siegler & Crowley, 1991), testing-the-limits research on cognition in old age is based on the assumption that research on mechanisms driving short-term cognitive change may help to identify mechanisms driving age-related changes in cognition (Li, Huxhold, & Schmiedek, 2004; Lindenberger & von Oertzen, 2006; Lövdén et al., 2007; cf. Werner, 1948). Therefore, in addition to the more general goal of measurement purification, the detailed analysis of time-compressed developmental-change functions is assumed to enhance our understanding of the mechanisms and the range of medium- and long-term developmental changes (cf. Hultsch & MacDonald, 2004; Shing, Werkle-Bergner, Li, & Lindenberger, 2008).

Figure 5, taken from Baltes and Kliegl (1992), shows the result of a study involving a total of 38 sessions of training and practice in the Method of Loci, a mnemonic technique for the serial recall of word lists. Two findings from this study are noteworthy. First, adults in both age groups greatly improved their memory performance. This finding confirms findings from the first generation of studies, documenting the continued existence of cognitive plasticity in cognitively healthy older adults (Baltes & Lindenberger, 1988; Baltes & Willis, 1982; Denney, 1984; Verhaeghen, Marcoen, & Goossens, 1992). Second, however, practice and training resulted in a close-to-perfect separation of the two age groups, thereby demonstrating the existence of sizable negative age differences at limits of functioning. Even after 38 sessions of training, many older adults did not reach the level of performance that young adults had reached after only a few sessions. Moreover, at the end of the study, not a single older person functioned above the mean of the young-adult group. The observation of robust negative adult age differences in upper limits of episodic-memory performance has been confirmed in several studies (Brehmer, Li, Müller, von Oertzen, & Lindenberger, 2007; Kliegl, Smith, & Baltes, 1989, 1990; Singer, Lindenberger, & Baltes, 2003; but see Baron & Mattila, 1989; Bherer et al., 2006). For example, Singer, Lindenberger, and Baltes (2003) showed that individuals greater than 80 years of age show less benefit from training in the Method of Loci than do adults in their 60s and 70s.

Taken together, the first two generations of cognitive-intervention studies demonstrated that healthy older adults are able to improve levels of performance to a greater extent than previously assumed and that negative adult age differences often are magnified (increased) rather than diminished when adults of different ages are assessed near asymptotic levels of performance. However, central issues that motivated the cognitive-intervention movement in the first place remained unanswered. Four of them are especially relevant: (a) positive transfer to untrained or unpracticed tasks and abilities, (b) maintenance of intervention effects over time, (c) applicability of intervention gains to everyday life, and (d) generalization to the larger population. Transfer and maintenance assessments are needed to judge the generality of the changes induced by the cognitive

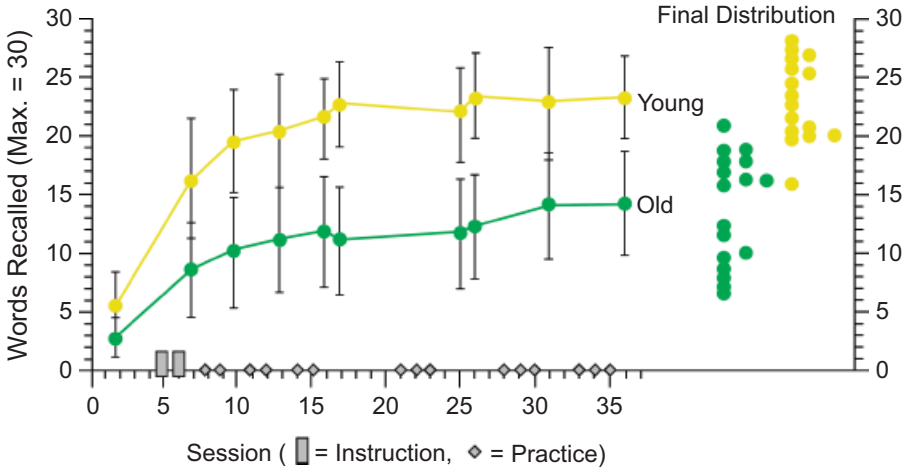

Fig. 5. Results of extensive training of younger and older adults in the Method of Loci, plotting serial-recall scores against number of training sessions for both age groups. Despite extensive training improvements, distributions of final serial-recall scores for older and younger individuals (right-hand area of graph) are widely separated. Adapted from "Further Testing of Limits of Cognitive Plasticity: Negative Age Differences in a Mnemonic Skill Are Robust," by P.B. Baltes & R. Kliegl, 1992, *Developmental Psychology*, *28*, p. 123. Copyright 1992, American Psychological Association. Adapted with permission.

intervention (cf. Horn & Donaldson, 1976; Thorndike, 1906). Transfer tasks varying in processing overlap to the trained or practiced tasks need to be administered before and after the intervention to examine the scope and magnitude of plastic changes in behavior. In addition, maintenance of intervention effects on the trained or practiced tasks and the transfer tasks needs to be assessed. Without information on transfer and maintenance, it is difficult to discern whether intervention effects are restricted to the formation of a new skill, with little consequences for behavior unrelated to this skill, or whether cognitive mechanisms and capacities of general applicability have been enhanced.

Currently, these unresolved issues are being addressed by a third, rather heterogeneous generation of intervention studies. Ball et al. (2002) conducted a large, multisite intervention study targeting three different cognitive constructs. Over 2,500 individuals over the age of 65 ultimately completed the training study, which lasted for about 10 sessions. They were randomly assigned to be given cognitive-process training in memory, reasoning, or visual search or to to receive no training (a test-only control group). At a 2-year follow-up, a randomly selected set of initially trained individuals was assigned to booster training prior to test. The results showed strong training effect sizes in each group relative to controls, and also showed a pattern of specificity in performance improvements. For example, individuals trained in visual search showed strong gains in visual-search performance but little improvement, relative to controls, in performance on the memory and reasoning tests. Willis et al. (2006) reported 5-year retest data on the sample, showing that training benefits were still observed after the longer retention interval. No transfer effects were observed on performance-based measures of everyday problem solving or everyday speed of processing. These findings confirm that cognitive training does show substantial benefits for older adults and that these effects can be relatively long lasting.

Other studies have also shown at least some maintenance of trained skills in older adults. By far the most commonly studied intervention is in the area of memory research. Here, there is relatively good evidence that intensive training of strategic processes for improving encoding shows at least some sparing, even if interventions targeting negative subjective memory beliefs do not (Floyd & Scogin, 1997; Lachman, Weaver, Bandura, Elliott, & Lewkowicz, 1992). Neely and Bäckman (1993) reported long-term maintenance for their multimodal memory-intervention program for older adults, as did O'Hara et al. (2007) and Brehmer et al. (2008).

An important issue for evaluating maintenance in intervention research is participants' actual compliance with mnemonic-strategy instructions immediately following the test and then again after a delay. Are individuals using the trained strategies as prescribed? This is especially an issue for difficult mnemonics like the Method of Loci. Verhaeghen and Marcoen (1996) found that older adults instructed to use this method are more likely than young adults to use other strategies, such as semantic grouping or making up a narrative to mediate serial recall. However, compliance with instructions was far from perfect even in the young group. Presumably, a lack of maintenance could also be due to poorer-quality implementation of the strategy (Dunlosky, Hertzog, & Powell-Moman, 2005; Kausler, 1994) or (and perhaps more likely) extinction of its use. Such outcomes point to the need to explicitly evaluate strategies that are being used in this kind of research so that the causes of maintenance or its failures can be better localized and understood.

As noted earlier, for example, Ball et al. (2002) found training benefits to be specific to the cognitive processes targeted by training, with little generalization to the two nontrained domains. On the other hand, there remains the promise that interventions may enhance components of the cognitive system that are relevant for a number of different skills, resulting in a more fundamental reorganization and amelioration of the cognitive system. Note that the answer to this question has profound consequences for intervention policies. If the beneficial effects of the intervention are restricted to "elements of skill" (Thorndike, 1906), then interventions deemed to enhance everyday competence would need to be tailored to those skills and routines that are relevant for a given person in a given environment (e.g., preparing tea). If, however, interventions are capable of changing the cognitive system in a more fundamental manner, then training in highly artificial laboratory tasks may be of eminent practical value if it is able to enhance the functioning of a central and aging-sensitive component of the cognitive system. Aptitude $\times$ Treatment interactions may complicate matters. Whereas direct training of everyday skills may be the appropriate intervention strategy for individuals with mild cognitive impairment and early stages of dementia, enhancement of processing components with more widespread consequences may be the more promising strategy for individuals with better-preserved latent cognitive potential.

There have been at least some suggestions of derivative benefits of training for nontargeted mechanisms (Ball, Edwards, & Ross, 2007). For example, Willis et al. (2006) showed that reasoning training had 5-year lagged benefits on self-reported aspects of instrumental activities of daily living (IADL) by older adults (see also Wolinsky et al., 2006). All older adults showed some aggregate decline in IADL, but this decline was milder in the reasoning training group. The memory training and speed-of-processing training did not show differential preservation, relative to controls. Even so, the degree of transfer between the three major training domains was certainly circumscribed.

Interventions that aim at more general alterations in processing efficiency have profited considerably from progress in developmental behavioral neuroscience and have focused, to a large extent, on cognitive functions that critically involve prefrontal cortex (PFC) circuitry. In early development, the PFC and associated neural networks undergo profound anatomical,

chemical, and functional changes, and these changes extend well into adolescence. Neural plasticity during cortical development entails the production and experience-dependent elimination of neuronal connections (Huttenlocher & Dabholkar, 1997). During brain development, the zone of maximum plasticity moves from primary sensory and motor areas to secondary association areas, and then to prefrontal areas (Chugani, Phelps, & Mazziotta, 1987). Computational models suggest that later-maturing areas require input from earlier-maturing areas to represent higher-order concepts (Shrager & Johnson, 1996). Thus, the gradual and orderly progression of maximum plasticity of cortical areas constrains the synchronization of the development of cerebral cortex in space and time.

In later adulthood, the prefrontal cortex and the functionally connected basal ganglia also show greater and earlier signs of decline than most other areas of the brain. In a comprehensive review of the neuroanatomical literature, Raz (2000) reported average linear reductions in brain weight and volume, of about 2% per decade during adulthood, that were more pronounced for anterior parts of the brain. At the neurochemical level, age changes in the neural systems using dopamine as a neurotransmitter play a prominent role (Bäckman, Nyberg, Lindenberger, Li, & Farde, 2006; Li, Lindenberger, Nyberg, Heekeren, & Bäckman, in press). Neurofunctional studies point to profound age-associated changes in the functional organization of the prefrontal cortex, such as a reduction in the asymmetry of hemispheric activation (e.g., Cabeza, 2002; Park & Reuter-Lorenz, in press; Reuter-Lorenz & Lustig, 2005). Other studies have found that the coordination of different regions within the prefrontal cortex, as well as the coordination of prefrontal with posterior brain regions, is disrupted in older adults (Andrews-Hanna et al., 2007; Colcombe et al., 2005). The late maturation of the prefrontal cortex during childhood as well as the relatively early deterioration of certain areas of the prefrontal cortex during adulthood are consistent with Ribot's "law" (Ribot, 1882), or the empirical observation that cognitive functions appearing late during phylogeny and ontogeny are among the earliest to show signs of decline during adulthood and old age (i.e., last in, first out).

Though the precise relations between life-span changes in prefrontal circuitry and behavioral changes remain to be uncovered, there appears to be a growing consensus that functions subsumed under the heading of "executive functions" or "cognitive control" are involved at the behavioral level (Duncan, Emslie, Williams, Johnson, & Freer, 1996; Kliegl, Krampe, & Mayr, 2003). Situations deemed to be particularly dependent upon prefrontal circuitry require the coordination of multiple tasks or task components. Typical examples include the suppression of stimulus-driven action tendencies (Metcalfe & Mischel, 1999; Salthouse & Meinz, 1995), dual-tasking and multitasking of all kinds (Kramer & Madden, 2008; Mayr, Kliegl, & Krampe, 1996; Salthouse, Hambrick, Lukas, & Dell, 1996), as well as selection and shifting between tasks under conditions of high stimulus ambiguity (Kramer, Hahn, & Gopher, 1999; Kray & Lindenberger, 2000; Kray, Eber, & Lindenberger, 2004).

Differential susceptibility to coordinative demands may also help to explain why life-span age differences in marker tests of fluid intelligence such as Raven's matrices tend to persist when participants are given unlimited amounts of time to solve the items (cf. the simultaneity mechanism in Salthouse, 1996). Although some have argued that there is insufficient empirical evidence that the multiple components of executive functioning have construct validity and can be independently verified (e.g., Salthouse, Atkinson, & Berish, 2003), evidence is mounting for potential process specificity in age effects on executive function. For example, in a meta-analysis of the extant literature on aging and dual-task performance, Verhaeghen, Steitz, Sliwinski, and Cerella (2003) concluded that evidence exists for a specific age-related difference in dual-task response latency costs over and above age-related general slowing.

Kramer and colleagues (Kramer, Larish, & Strayer, 1995; Kramer, Larish, Weber, & Bardell, 1999) provided both young and older adults with training in dual-task performance and examined the effects of variable- and fixed-priority training on the rate of learning of single and dual tasks, level of mastery achieved on the trained tasks, retention of the trained tasks, and, perhaps more importantly, transfer of training to untrained tasks. Both fixed- and variable-priority training entailed providing subjects with individualized adaptive feedback concerning their performance. In addition, variable-priority training entailed the requirement to frequently shift priorities among the concurrently performed tasks (see also Schmidt & Bjork, 1992). Previous studies have found that military flight candidates trained with the variable-priority procedure on video games showed substantial improvements in flight performance. The authors concluded the attentional-control skills—that is, the ability to set and change processing priorities and coordinate multiple skills required to perform a complex task—were learned with variable-priority training of the impoverished video game and transferred to piloting (Gopher et al., 1994; Hart & Battiste, 1992).

In the studies by Kramer, Larish, et al. (1995, 1999), older adults in the variable-priority training group, as compared to individuals trained with fixed priorities, showed faster rates of acquisition of dual-task performance, higher levels of mastery on the trained dual tasks, higher levels of retention after 2 months, and, most importantly, better transfer to novel dual tasks (see also Bherer et al., 2005; Erickson, Colcombe, Wadhwa, et al., 2007). Thus, at least in some situations in which specific training strategies, such as adaptive training to shift processing priorities between tasks (Kramer et al., 1995; Kramer, Larish, et al., 1999) or training to shift emphasis between speed and accuracy, are employed (Baron & Mattila, 1989), older adults are capable of developing and transferring efficient and effective attentional-control skills.

Karbach and Kray (in press) trained children, younger adults, and older adults in task-set switching, a cognitive-control task showing sizable impairment in old age. In the computerized task-switching training, participants switched between two tasks on every second trial. Four training sessions were administered. Task-specific training effects were reliable for all age groups. In addition, Karbach and Kray (in press) observed robust transfer effects to verbal working memory, spatial working memory, and reasoning in all age groups, with effect sizes around 0.3. By Cohen's (1988) standards, this would be a small to medium-sized effect.

In a study by Dahlin, Stigsdotter-Neely, Larsson, Bäckman, and Nyberg (2008), younger and older adults practiced a task that taxed the information-updating aspect of working memory. Both younger and older adults improved on the practiced task. Transfer to another working-memory task requiring continuous updating was reliable in younger adults but not in older adults. In younger adults, brain activations substantially increased in a specific subcortical region, the striatum, while performing the trained task and the transfer task after the intervention. In older adults, intervention-related activation changes in the striatum were restricted to the practiced task. Hence, Dahlin et al. (2008) conclude that the observed age differences in plasticity are connected to age-related changes in the striatum, which has been proposed to be specifically involved in updating operations (O'Reilly & Frank, 2006).

Li et al. (2008) investigated the effects of extensive working-memory practice on target performance, transfer, and short-term maintenance of practice gains and transfer. Adults aged 20 to 30 and 70 to 80 years practiced a spatial version of the *n*-back working-memory task in 45 daily sessions. The *n*-back task presents a running series of stimuli, in which individuals are frequently asked to report the stimulus that was *n* places before the current stumulus. In both age groups, and relative to age-matched control groups, the authors found near transfer to a more demanding spatial *n*-back task and to numerical *n*-back performance, and 3-month maintenance of practice gains and near-transfer effects, with decrements relative to post-practice performance among older but not younger adults. No evidence for far transfer to more complex working-memory tasks was found.

These recent studies suggest that training or practice for process coordination and working memory might have greater transfer benefits than simply training a restricted set of task-specific strategies or processing steps, such as how to mentally rotate a figure (Schaie & Willis, 1986). This conclusion is consistent with a recent report that training in real-time strategy video games that entail learning and coordinating the implementation of a number of complex strategies can engender transfer to a variety of tasks that tap different aspects of executive-control processes (Basak, Boot, Voss, & Kramer, 2008).

The use of metacognitive interventions is a different approach to achieving the same end. Metacognition involves using monitoring of ongoing performance to determine whether strategies being employed are effective or ineffective, as part of adaptive self-regulation in cognitive-task contexts (e.g., Winne, 1996). Metacognitively oriented interventions have proved effective in classroom contexts (Pintrich, Wolters, & Baxter, 2000) and in simulated decision-making tasks (e.g., Batha & Carroll, 2007). The essential feature of metacognitive interventions is to train individuals to assess the processing demands of task contexts and to select, implement, and evaluate strategies during task performance. The selection of strategies depends critically on declarative knowledge about strategy effectiveness (e.g., Hertzog, Price, & Dunlosky, 2008). However, adjusting strategy use to reflect ongoing success with the strategy is a critical feature of metacognitive self-regulation. The central idea is that online monitoring of cognitive operations and performance outcomes can be used to optimize performance by maintaining or changing strategy use, based on different strategies' perceived effectiveness.

We begin our treatment of metacognitively oriented interventions by reviewing intervention studies involving flexible use of strategies in appropriate contexts. Although these interventions are not explicitly metacognitive in the sense that they train adaptive strategy use through monitoring strategy effectiveness, they illustrate the importance of training adaptive, self-initiated strategy use.

Work by Camp and colleagues (e.g., Camp, Foss, O'Hanlon, & Stevens, 1996; Cherry, Simmons, & Camp, 1999) has shown that instrumental functioning in memory-impaired older individuals can be supported by training them with spaced-retrieval techniques to remember how to seek needed support. Spaced retrieval involves practicing the retrieval of information until it can be accessed. For example, by training retrieval of the intention to check a location (e.g., a refrigerator door) for needed information, Camp and his colleagues have been able to foster the use of self-initiated control strategies for self-management, even in patients with moderate dementia. Presumably the technique would work effectively in nonimpaired populations as well, and could in principle generalize to a number of different behavioral contexts. Training the use of spaced retrieval as a strategy for managing memory represents one of a number of possible mechanisms by which cognitive control over successful remembering could be achieved.

In that vein, Jennings and colleagues (Jennings & Jacoby, 2003; Jennings, Webster, Klaykamp, & Dagenbach, 2005) developed a recollection-training paradigm that has good near transfer to task contexts beyond the focus of training. Jacoby and colleages have repeatedly shown that older adults often rely on habit rather than recollection in contexts requiring controlled retrieval (e.g., Jacoby, 1999) and that a major part of the problem is poor original encoding of the information combined with nonselective retrieval evaluations and attributions at time of testing. Their recollection-training procedure focuses on shaping conscious recollection of details of specific events, using a

repetition-lag paradigm to assist older adults' discrimination between originally encoded words and familiarity induced by probe-word repetitions. The paradigm expands the lag interval between repetitions, shaping discriminations of originally encoded words from familiarity-enhanced lures presented during the recognition test. Bissig and Lustig (2007) showed that benefit from the recollection-training paradigm was associated with increases in the time spent encoding the target list; they argued that participants were learning to encode distinctive details and then search for those details at test to avoid being lured by repeated foils. Jennings et al. (2005) showed transfer from recollection training in this paradigm to performance on other classes of memory task that are prone to proactive interference and requirements to weigh competing information—including the *n*-back task, self-ordered pointing, source recall, and digit-symbol substitution. The substantial transfer in Jennings et al. (2005) arguably occurred because a specifically trained procedure—selective retrieval and evaluation of disambiguating contextual detail at test—is applicable in the transfer task contexts as well. In a sense, the problem is one of encouraging the self-initiated use of effective cognitive strategies.

In all likelihood, the recollection-training procedure of Jennings and colleagues involves metacognitive self-regulation during training, because individuals must learn to apply strategies at encoding and retrieval that avoid the repeated lures. However, in that paradigm, metacognitive self-regulation is not explicitly trained by the experimenter but is implicitly discovered by the trainee in the training context. This may result in some individuals failing to acquire the new procedures, even though self-discovery may reinforce their use in other trainees to a greater extent than would experimenter guidance.

Dunlosky, Kubat-Silman, and Hertzog (2003) evaluated an intervention to explicitly train older adults in the use of a metacognitive self-testing approach for learning. The metacognitive intervention was used to supplement training in using mediational strategies for learning lists of paired associates. Self-testing involves monitoring whether an item has been sufficiently well learned to be retrieved when cued to do so. If the monitoring test fails, individuals are instructed to restudy the item, perhaps with a new strategy (see also Dunlosky, Hertzog, Kennedy, & Thiede, 2005). Dunlosky et al. (2003) showed an incremental-training benefit for combining self-testing training with strategy training, but self-testing training did not increase the likelihood of transfer of self-testing to a different memory task. However, a recent intervention study using self-testing (Dunlosky et al., 2007) suggests that explicitly discussing generalization of the self-testing strategy to other contexts may induce a wider range of transfer.

In sum, the training literature indicates that older adults benefit from cognitive training. In general, the effects of training are relatively specific to the processes being trained, but there are two potentially important exceptions. One is training designed to target mechanisms, such as executive functioning and working memory (e.g., Basak et al., 2008; Bherer et al., 2005, 2006; Dahlin et al., 2008; Karbach & Kray, in press; Li et al., 2008), that are arguably generalizable to multiple-task environments. The second exception is metacognitively oriented interventions, which train processing approaches that supplement mnemonic strategies by developing procedural routines for using them. The limitations on transfer in the classical training studies may be, from this perspective, a consequence of the nature of the training programs' focus on micro-level processes and task-specific strategies rather than on mechanisms by which people achieve cognitive control in a wider variety of task contexts.

The issues about transfer become particularly important when we consider the nature of cognitive enrichment effects through mentally stimulating activities, where effects appear to be more general and pervasive on cognitive functioning than would be assumed from the classical training studies that show a very narrow range of transfer. We shall return to this issue after discussing the broader literature on cognitive-enrichment effects.

In closing this section, we would like to point to another dimension that needs to be taken into account as one is trying to gauge the evidence for plasticity in old age on the basis of existing data. Any developing cognitive system has to strike a balance between preservation of existing structures and functions and a readiness for change through experience. Clearly, total plasticity would be as dysfunctional as complete inertia. In this context, it is worth noting that the vast majority of training studies implemented so far has been restricted to less than 10 sessions of training. Relative to a lifetime of experience, this is definitely a low-dosage treatment. Thus, some of the failures to observe profound and generalized intervention effects may primarily reflect the restricted range and dosage of treatments that have been tried.

MENTALLY STIMULATING ACTIVITY

In this section, we consider research evidence regarding the relation of mentally stimulating activity to risk for cognitive loss in adulthood. We review studies using change in cognitive function in the general population as an outcome, as well as studies that examine conditions characterized by forms of cognitive dysfunction like mild cognitive impairment and dementia.

A substantial challenge to research in this area has been assessing participation in mentally stimulating activity. Most activities involve cognition to some extent, and it is unclear how best to quantify this involvement, particularly for people from different birth cohorts, socioeconomic positions, and cultural backgrounds. As a result, a diverse array of activities has been argued to be mentally stimulating, and these activities have been used in several different ways to scale potential cognitive-enrichment effects (Jopp & Hertzog, 2007). A major issue is that broadly classified activities may have highly variable effects on cognition, depending on the degree of cognitive engagement

actually required in a given context. For example, one activity, watching television, has been included on several general scales of activity (Crowe, Andel, Pedersen, Johansson, & Gatz, 2003; Schinka et al., 2005; Wilson, Bennett, et al., 1999). Yet watching television is negatively associated with cognition, cross-sectionally (Jopp & Hertzog, 2007), and has been associated in one longitudinal study with an *increased* risk of developing cognitive impairment (Wang et al., 2006).

Some studies have rated the degree of cognitive demand involved in a given activity, using expert or peer raters (Arbuckle, Gold, Chaikelson, & Lapidus, 1994; Christensen & Mackinnon, 1993; Wilson, Bennett, et al., 1999) or even allowing each participant to rate their own activities with respect to cognitive demand or engagement (Salthouse, Berish, & Miles, 2002). These types of weighting approaches have not been notably successful in increasing the predictive validity of activity scales for cognition or for cognitive change. Some initial efforts to develop mental-stimulation scales included traditional indicators of socioeconomic status like education and occupation as part of the measure (Gold et al., 1995; Gribbin, Schaie, & Parham, 1980). More recently, however, investigators have argued for separating socioeconomic status from the construct of mentally stimulating activity (Hertzog et al., 1999).

Most studies have scaled activities by collecting self-reports of specific activities deemed to be cognitively stimulating, like reading a book, attending a play, or playing chess, and asking people to indicate whether or not or how frequently they participated in each activity during a specified time period (e.g., Arbuckle et al., 1994; Hultsch, Small, Hertzog, & Dixon, 1999; Mackinnon, Christensen, Hofer, Korten, & Jorm, 2003; Schinka et al., 2005; Wilson, Bennett, et al., 1999; Wilson, Barnes, & Bennett, 2003; Wilson, Barnes, Kreuger, et al., 2005). These frequency reports are then typically summed into a general activity scale or into activity subscales (e.g., Hultsch, Hammer, & Small, 1993; Jopp & Hertzog, 2007).

We reviewed evidence on activity-related cognitive-enrichment effects from more than a dozen longitudinal studies of older persons with a quantitative indicator of level of participation in cognitively stimulating activity as a predictor and with either change in clinical status (i.e., incident mild cognitive impairment or dementia) or change in cognitive function as outcomes. We excluded studies that did not separate cognitive activities from other kinds of activities (e.g., Fabrigoule et al., 1995; Mackinnon et al., 2003) or that did not focus on cognitive change past midlife (e.g., Gold et al., 1995). Seven of the included studies used change in cognitive function as an outcome, and all except one (Aartsen, Smits, van Tilburg, Knipscheer, & Deeg, 2002) found that a higher level of engagement in mentally stimulating activities was associated with reduced rate of cognitive decline (Bosma et al., 2002; Hultsch et al., 1999; Schooler & Mulatu, 2001; Wilson, Bennett, et al., 2003; Wilson, Mendes de Leon, et al., 2002; Wilson, Scherr, Schneider, Li, & Bennett, 2007). In one study (Wilson, Bennett, et al., 2003), more than 4,000 old people from a single community rated their frequency of participation in seven cognitive activities (e.g., reading magazines). At 3-year intervals for a mean of nearly 6 years, participants completed an in-home interview that included brief tests of cognitive function. More frequent cognitive activity at baseline was associated with reduced rate of cognitive decline even after controlling multiple covariates.

The one study failing to find cognitive-enrichment effects also followed a large (>2,000) population-based sample of older persons for about 6 years (Aarsten et al., 2002). There was no association between a measure of cognitive activity and change in cognitive function, but the cognitive-activity measure was based on a single activity in which less than 15% participated (i.e., attending a course or study), and this may have limited the ability to detect an association with subsequent rate of cognitive decline.

The association of mentally stimulating activity with the incidence of cognitive impairment (often Alzheimer's disease) has been examined in nine studies. In each case, a higher level of cognitive activity has been associated with reduced risk of developing incident dementia (Crowe et al., 2003; Scarmeas, Albert, Manly, & Stern, 2001; Verghese et al., 2003; Wang, Karp, Winblad, & Fratiglioni, 2002; Wilson, Bennett, Bienias, et al., 2002; Wilson, Mendes de Leon, et al., 2002; Wilson, Scherr, et al., 2007), or incident cognitive impairment (Verghese et al., 2006; Wang et al., 2006). In one study (Wilson, Scherr, et al., 2007), 775 older persons without dementia rated their frequency of participation in nine cognitively stimulating activities. During up to 5 years of annual follow-up clinical evaluations, 90 individuals developed Alzheimer's disease. As shown in Figure 6, those with low cognitive-activity participation were about 2.5 times more likely to develop Alzheimer's disease than were persons with high levels of cognitive activity. In another study

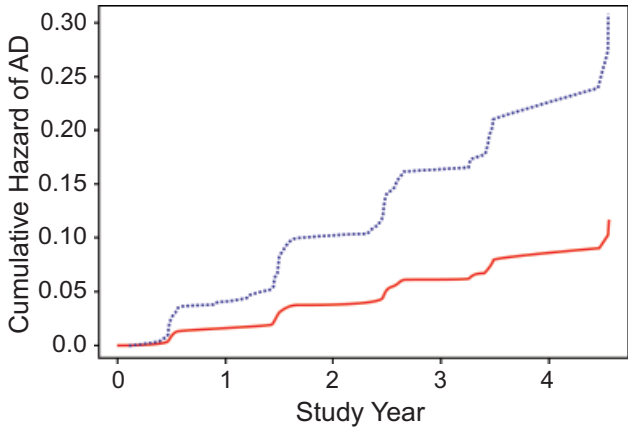

Fig. 6. Cumulative hazard from a survival analysis of incidence of Alzheimer's disease (AD) diagnosis as a function of number of years in the study, for high-activity (solid red line) and low-activity (dashed blue line) older adults. Adapted from "The Relation of Cognitive Activity to Risk of Developing Alzheimer's Disease," by R.S. Wilson, P.A. Scherr, J.A. Schneider, Y. Li, & D.A. Bennett, 2007, *Neurology*, *69*, p. 1915 . Copyright 2007, American Academy of Neurology. Adapted with permission.

(Verghese et al., 2003), a group of about 500 people aged 75 years or older rated their frequency of participation in six cognitive activities (e.g., writing for pleasure, playing musical instruments). More frequent cognitive activity was associated with a reduced risk of developing dementia during up to 20 years of follow-up. This association remained even after excluding people whose dementia developed during the first 7 years of observation, showing that the effect was not due to reduced activity in a subgroup about to develop dementia. In another study (Crowe et al., 2003), about 100 older twins discordant for dementia had been interviewed 20 years previously about participation in four cognitive activities (e.g., reading, cultural activities). Greater participation in cognitive activities was associated with a reduced risk of Alzheimer's disease 20 years later, although the association in this small cohort was only significant for women. Overall, these data strongly support the hypothesis that a higher level of engagement in mentally stimulating activity is associated with reduced loss of cognition in old age. The fact that prospective studies have yielded relatively consistent results despite the heterogeneity and psychometric shortcomings of the cognitive-activity measures suggests that the underlying association is quite robust.

One methodological concern regarding the available evidence is that the quality of measurement of cognition varies across studies. The gold standard, so to speak, would be the use of well-validated cognitive tasks and psychometric tests to measure widely accepted cognitive constructs, such as fluid intelligence. Many large-scale surveys settle for a single measure of cognition, including screening instruments like the Mini-Mental Status Examination that lack sensitivity to individual differences in cognition in normal populations. Only a few studies, like the Victoria Longitudinal Study, measure multiple aspects of cognition with converging indicators for each target construct.

Those studies that do find cognitive-enrichment effects do not necessarily find them on all cognitive measures. For example, when Hultsch et al. (1999) evaluated latent-change correlations of cognitive variables with activity, only changes in working memory were reliably associated with an active lifestyle. Such findings raise the concern that studies may be capitalizing on statistical chance when reporting positive effects on one or a few cognitive variables but not on others.

We are inclined, on the other hand, to view the problem as being one of limited statistical power to detect small effect sizes in typical longitudinal studies (e.g., Hertzog, Lindenberger, Ghisletta, & von Oertzen, 2006). Hertzog et al. (2006) showed that power to detect individual differences in change is dramatically affected by growth-curve reliability, which in turn is influenced by measurement reliability. Structural regression models that use multiple indicators to correct for random measurement error have greater power to detect latent change than do models using a univariate approach to define constructs (von Oertzen, Hertzog, Lindenberger, & Ghisletta, 2008). In particular, the Hultsch et al. (1999) study is illuminating in this regard. Only one of nine of the cognitive variables provided significant univariate evidence of activity effects on cognition. However, a second-order general cognitive-change factor, defined by these nine cognitive factors, did produce a highly significant association of cognitive change with intellectually stimulating activities. This outcome argues against statistical chance as the explanation and instead indicates that difficulties in detecting individual differences in change make it difficult to detect enrichment effects in longitudinal studies.

Although the preponderance of evidence indicates that older people who are more mentally active are less likely to develop dementia or experience cognitive decline than their less mentally active counterparts, interpretation of this association has been controversial. One rival hypothesis to the cognitive-enrichment hypothesis is that reduced cognitive activity in older people is actually an early sign of the neuropathology causing dementia rather than an influence on cognitive change. Consistent with this hypothesis, level of participation in cognitive activities does appear to decline somewhat in old age (Hultsch et al., 1999; Wilson, Scherr, et al., 2007) and is undoubtedly reduced in persons with manifest dementia. However, level of cognitive activity has long-term predictive validity for the incidence of dementia, including prospective prediction over a 2-decade span in one study (Crowe et al., 2003). Although a prodromal period characterized by mild cognitive impairment precedes overt dementia in Alzheimer's disease, this preclinical phase likely lasts a few years (Hall, Lipton, Sliwinski, & Stewart, 2000), not a few decades. In addition, perhaps because the relatively crude self-report scales used in these studies are not sensitive enough to capture much of this age-related decrease in cognitive activity, research on the relation of cognitive function to change in cognitive activity is mixed, with one study finding that level of cognitive impairment did not predict change in cognitive activity (Wilson, Scherr, et al., 2007) and two studies reporting a more reciprocal association between changes in cognitive activity and cognitive function (Bosma et al., 2002; Schooler & Mulatu, 2001). Finally, level of cognitive activity is not related to brain levels of amyloid-beta immunoreactive plaques or tau-immunoreactive neurofibrillary tangles, the pathologic hallmarks of Alzheimer's disease (Wilson, Scherr, et al., 2007), whereas established early signs of the disease, like olfactory dysfunction, gait impairment, and low body mass, not only predict dementia (Buchman et al., 2005; Wilson, Schneider, Arnold, et al., 2007; Wilson, Schneider, Bienias, et al., 2003) but are also related to Alzheimer's disease pathology in postmortem examinations of the brain (Buchman, Schneider, Wilson, Bienias, & Bennett, 2006; Schneider et al., 2006; Wilson, Arnold, Schneider, Tang, & Bennett, 2007). On the basis of currently available evidence, therefore, we believe it is unlikely that cognitively stimulating activity predicts cognitive decline merely because it is a subtle sign of incipient dementia.

Another rival hypothesis is that late-life mental activity simply reflects the causal impact of some other variable that, though

correlated with activity, is the true cause of a more benign course of cognitive decline or dementia in later life. In particular, older people who engage in mentally stimulating activities may have always been more cognitively active and enjoyed a higher socioeconomic status earlier in their adult life, which conferred advantage with respect to quality of health care and other variables that may influence cognitive change in later years. Consistent with this idea, retrospective estimates of early-life cognitive activity and indicators of early-life socioeconomic status are positively correlated with late-life level of cognitive activity, but the associations are far from perfect (Wilson, Barnes, Krueger, et al., 2005). Further, in a recent study (Wilson, Scherr, et al., 2007), a retrospective measure of cognitive activity prior to old age was related to risk of Alzheimer's disease, but the association was eliminated after controlling for late-life cognitive activity, and more frequent late-life cognitive activity was associated with reduced risk of Alzheimer's disease even after controlling for previous level of cognitive activity and indicators of socioeconomic status across the life span. Also, the association of mentally stimulating activity with loss of cognitive function in old age has been observed after controlling for social and physical activity (Wang et al., 2002; Wilson, Scherr, et al., 2007) or depressive symptomatology (Scarmeas, Levy, Tang, Manly, & Stern, 2001; Wang et al., 2002; Wilson, Bennett, et al., 2002; Wilson, Bennett, et al., 2003; Wilson, Mendes de Leon, et al., 2002).

Finally, evidence regarding socioeconomic status, cognition, and activities suggests that social class is more related to crystallized intelligence, including world knowledge and verbal ability, than to more fluid aspects of cognition (e.g., Matarazzo, 1972). Likewise, intellectual pursuits in young adulthood reflect investment of fluid intelligence in active learning of new information, with self-report measures of interest and activity often correlating more highly with crystallized intelligence than with general or fluid intelligence (Ackerman, 2000; Beier & Ackerman, 2005). Salthouse (2006) found Age × Activity interactions in his cross-sectional data set for verbal ability, consistent with acculturation and knowledge-acquisition effects. In contrast, the cognitive-enrichment effects identified in old age in the longitudinal studies we have reviewed are associated with general cognitive functioning, broadly defined, including an array of specific constructs like reasoning, working memory, and episodic memory (e.g., Hultsch et al., 1999). In short, the cognitive-enrichment effects observed in the longitudinal studies we have reviewed do not behave as if they were merely reflecting benefits of acculturation and knowledge acquisition.

The observation that persons with higher educational or occupational attainment have a reduced risk of Alzheimer's disease compared to those with less attainment (Evans et al., 1997; Stern et al., 1994) has stimulated research on cognitive activity and disease risk. In this regard, it is noteworthy that the associations of years of schooling and occupational prestige with risk of developing Alzheimer's disease in a large population-based study were eliminated after controlling for level of cognitive activity at study onset (Wilson, Bennett, et al., 2002). This finding suggests that mentally stimulating activity may mediate a substantial portion of the association of educational and occupational attainment with risk of dementia in old age.

A third rival hypothesis is that mentally stimulating activity is associated with features of brain structure or function that somehow reduce the deleterious effects of common age-related neuropathology (Katzman et al., 1988; Satz, 1993; Stern, 2002; Wilson & Bennett, 2003). Clinical-radiologic studies have shown that the volumes of selected brain regions are associated with specific occupational experiences (Maguire et al., 2000; Sluing et al., 2002) and increase following new learning activities (Draganski et al., 2004, 2006). This suggests that cognitive activity may help maintain efficiency in neural systems that support memory and cognition, thereby enhancing adaptation to age-related pathologic changes. Support for this hypothesis comes from a clinical-pathologic study of old Catholic priests, nuns, and monks who underwent annual clinical evaluations and brain autopsy at death (Bennett et al., 2003). As expected, higher level of Alzheimer's disease pathology, as indicated by a composite index of cortical plaques and neurofibrillary tangles from five brain regions, was associated with lower level of cognitive function proximate to death. The size of this correlation was reduced, however, as level of education increased. As shown in Figure 7, the negative impact of Alzheimer's disease pathology on cognition was much stronger in those with a low educational level (dotted line) compared to those with a high level (solid line), consistent with the idea that education, or something related to education, lowers the likelihood that Alzheimer's disease pathology will result in cognitive dysfunction and dementia. Subsequent data collection suggested that this

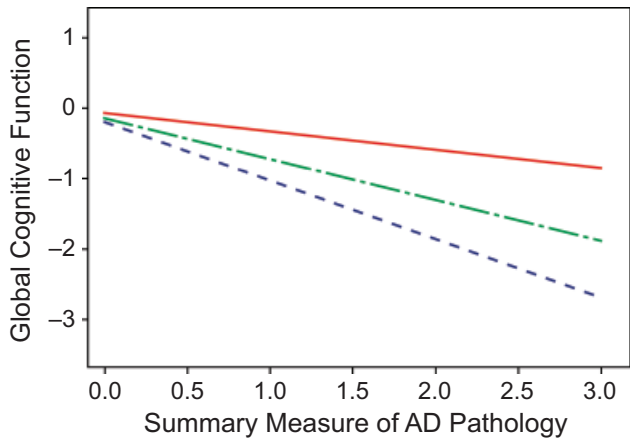

Fig. 7. Impact of Alzheimer's disease (AD) pathology on cognitive function for older adults with low (dashed blue line), average (dashed/dotted green line), and high (solid red line) levels of education. Adapted from ''Education Modifies the Relation of AD Pathology to Level of Cognitive Function in Older Persons,'' by D.A. Bennett, R.S. Wilson, J.A. Schneider, D.A. Evans, C.F. Mendes de Leon, S.E. Arnold, et al., 2003, *Neurology*, *60*, p. 1912. Copyright 2003, American Academy of Neurology. Adapted with permission.

possible protective effect applied to plaques but not to tangles (Bennett, Schneider, Wilson, Bienias, & Arnold, 2005b).

The hypothesized protective effects of cognitive activity/education are widely assumed to decrease as age-related pathologic lesions accumulate in the brain (Cummings, Vinters, Cole, & Khachaturian, 1998). Paradoxically, this leads to the prediction that among those with clinically manifest dementia or cognitive impairment, persons with a higher level of education/premorbid cognitive activity ought to experience more rapid cognitive decline than less educated/active persons. In general, this prediction has been supported in studies of cognitive activity (Helzner, Scarmeas, Cosentino, Portet, & Stern, 2007; Wilson et al., 2000) and education (Bruandet et al., 2008; Hall et al., 2007; Scarmeas et al., 2006; Teri, McCurry, Edland, Kulkull, & Larson, 1995; Wilson, Li, et al., 2004). One of these studies (Hall et al., 2007) examined cognitive decline in participants in the Bronx aging study prior to the onset of dementia. As shown in Figure 8, cognitive decline began earlier in those with low education (blue line) compared to those with high education (green line), but once decline began, the rate was faster in the high-education subgroup than in the low-education subgroup. In another study (Wilson et al., 2000), higher level of premorbid reading, assessed by retrospective informant report, was associated with more rapid decline in verbal cognitive ability but not nonverbal cognitive ability. These findings are important because they suggest that mentally stimulating activity compresses morbidity by delaying the onset of cognitive decline and subsequently accelerating its course, thereby reducing the proportion of old age spent in a cognitively disabled state.

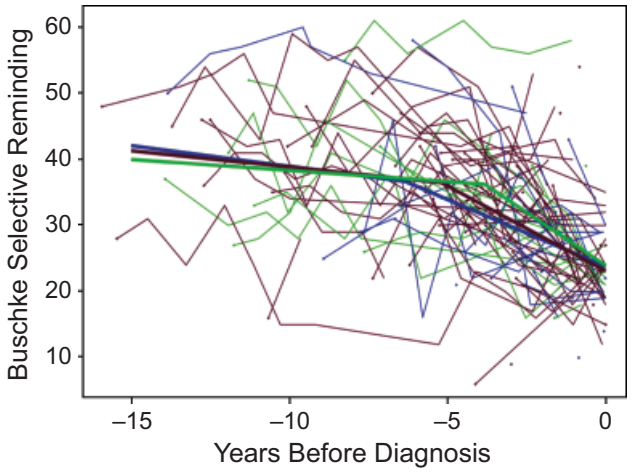

Fig. 8. Trajectories of change in episodic memory (Buschke selective reminding task) for selected individuals (thin lines) and aggregate functions (thick lines) as a function of years before Alzheimer's disease diagnosis for those with low (blue), average (purple), and high (green) levels of education. Adapted from ''Education Delays Accelerated Decline on a Memory Test in Persons Who Develop Dementia,'' by C.B. Hall, C. Derby, A. LeValley, M.J. Katz, J. Verghese, & R.B. Lipton, 2007, *Neurology*, *69*, p.1661. Copyright 2007, American Academy of Neurology. Adapted with permission.

In sum, the available longitudinal evidence supports the argument that engaging in mentally stimulating activities during adulthood is associated with less cognitive decline and a reduced incidence of mild cognitive impairment and dementia.

PHYSICAL ACTIVITY AND EXERCISE

Although it is readily apparent why one might expect there to be a positive relationship between participation in mentally stimulating activities and cognition, it is perhaps less clear why one would expect there to be a relationship between physical activity and cognition. One reason why we might expect such a relationship, though, is the increasingly well-documented relationship between physical activity and disease. Ever since the pioneering research of Morris, Heady, Raffle, Roberts, and Parks (1953) on the relationship between physical activity and death from coronary heart disease, there have been many studies examining the health benefits of exercise and physical activity for primary and secondary prevention of disease. For example, studies have reported an inverse relationship between physical activity and the risk of cardiovascular-related death (Oguma & Shinoda-Tagawa, 2004), Type 2 diabetes (Laaksonen et al., 2005), colon and breast cancer (Lee, 2003), and osteoporosis (Kelley, 1998). Indeed, physical activity has also been demonstrated to be beneficial for secondary as well as primary prevention of these diseases (Warburton, Nicol, & Bredin, 2006). It is also the case that cardiovascular disease, diabetes, and cancer have been associated with compromised cognition (Cukierman, Gerstein, & Williamson, 2005; Daliento, Mapelli, & Volpe, 2006; Nail, 2006). Therefore, increased physical activity and exercise might be expected to maintain cognition through reduced risk of diseases associated with cognitive decline.

A second potential reason for expecting a relationship between physical activity and cognition is the association between compromised cardiorespiratory function and cognition. It is well established that reductions in pulmonary function with diseases such as chronic obstructive pulmonary disease and chronic asthma are linked to decreased performance on memory and attentional tasks (Moss, Franks, Briggs, Kennedy, & Scholey, 2005; Ortapamuk & Naldoken, 2006) and that exercise can both ease the symptoms of these diseases and improve cognition (Emery, Shermer, Hauck, Hsiao, & MacIntyre, 2003; Etnier & Berry, 2001). Other evidence for a link between cognition and hypoxia has been provided both from studies of breath-holding divers (Ridgway & McFarland, 2006) and mountaineers who spend considerable time at high altitude (Kramer, Coyne, & Strayer, 1993). Reestablishment of normal levels of oxygen saturation eliminates cognitive and motor deficits (Virues-Ortega, Buela-Casal, Garrido, & Alcazar, 2004). Given these results, one might expect that improved cardiorespiratory function and tissue oxygenation, especially in older adults who show declines in these functions, will result in improvements in cognition.

Third, a large body of nonhuman animal research has observed a number of changes in brain structure and function when animals are exposed to enriched or complex environments. Enriched environments usually include a multitude of toys and objects to climb that are changed frequently, running wheels, and often other animals. Exposure to such environments has been found to increase dendritic branching and creation of new synapses, to lead to changes in supportive glial cells, to increase the brain's capillary network, and to lead to the development of new neurons presumably from adult stem cells, as well as a cascade of molecular and neurochemical changes (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990; Ehninger & Kempermann, 2003; Jones, Hawrylak, & Greenough, 1996; Kempermann, Kuhn, & Gage, 1997; Rosenzweig & Bennett, 1996). Given the physical-activity component of enriched environments, it would appear conceivable that exercise and physical activity may be responsible, in part, for a subset of the reported brain changes.

In the present section, we examine the science behind the assumption that physical activity and exercise are beneficial for mind and brain. We begin with a brief review of prospective and retrospective observational studies of the influence of exercise and physical activity on cognition and also on the risk for dementia. Next, we examine human randomized-intervention trials of fitness training on cognition and the brain. Finally, we conclude with a brief discussion of the nonhuman animal research that has examined fitness-training effects on the brain as well as on learning and memory. It is this research that provides important clues to the molecular and cellular mechanisms that may support the link between exercise and cognition.

Prospective and Retrospective Observational Studies

Over the past decade, there has been a substantial increase in the number of published observational studies of the relationship between physical activity and cognition. In general, these epidemiological studies assess physical activity and/or exercise, often with self-report questionnaires, at one point in time, and then at some point in the future these initial activity data are related to measures of cognition or diagnosis of some form of dementia. The delay between the two, or more, time points is often 5 to 8 years, although some studies in which the delay is substantially longer have been reported. Given the observational nature of these studies, confounding factors or covariates are always a concern, as are undiagnosed disorders that have a negative impact on cognition. Therefore, these studies also generally assess medical conditions, prescription drugs, and other lifestyle choices such as smoking, alcohol consumption, and sometimes diet, so that these variables can serve as covariates in the analysis of the relationship between physical activity and cognition. Participants are also generally carefully screened at the initial assessment to ensure that they do not have undiagnosed diseases, such as Alzheimer's disease or vascular dementia, that may influence their level of cognitive function or physical activity.

A study by Yaffe, Barnes, Nevitt, Lui, and Covinsky (2001) illustrates the general approach pursued in many observational studies of physical activity and cognition. In this study, 5,925 women over the age of 65 were recruited from four different medical centers across the United States. Each of the participants was free of any physical disability that would limit their ability to walk or pursue other physical activities. The women were also screened to ensure that they did not have a diagnosable cognitive impairment. Following this initial screening, physical activity was assessed (a) by asking the women how many city blocks they walked per day and how many flights of stairs they climbed each day; and (b) through the use of a self-report physical activity, recreation, and sport questionnaire that assessed the frequency, duration, and intensity of 33 different physical activities. After a delay of 6 to 8 years, the women's level of cognitive function was assessed with the modified Mini Mental State Exam (mMMSE). A decrease of 3 or more points on the mMMSE was defined as evidence for cognitive decline. Women were divided into quartiles based on two different but related measures of physical activity at initial assessment—blocks walked per week and total kilocalories expended per week. Results indicated that, for both activity measures, 24% of the women in the least-active quartile showed cognitive decline, as compared to 17% of the women in the most-active quartile, a reduction in risk of cognitive decline of approximately 30%. Indeed, the benefit of physical activity remained after adjusting for baseline age, education level, health status, functional limitations, depression score, stroke, diabetes, myocardial infarction, smoking, and estrogen use. Interestingly while walking distance was related to cognition, walking speed was not. Thus, these data suggest that moderate levels of physical activity can serve to limit cognitive declines in older adults.

Other epidemiological studies have observed similar relationships between physical activity and cognition. In a study of 1,192 healthy 70- to 79-year-olds, Albert et al. (1995) found that the best predictors of cognitive change over a 2-year period were education, strenuous activity, peak pulmonary expiratory flow rate, and self-efficacy. Cognition was measured with a battery of tasks that took approximately 30 minutes to complete and included tests of language, verbal memory, nonverbal memory, conceptualization, and visuospatial ability. Weuve et al. (2004) also examined the relationship between physical activity and cognitive change over a 2-year period in a population of 16,466 nurses over the age of 70. This study was particularly interesting both for its large sample and for the fact that cognition was assessed in a telephone interview (which was validated, in a smaller sample, with laboratory assessments of cognition). Self-report measures of the time that participants spent per week in a variety of physical activities (e.g., running, jogging, walking, hiking, racquet sports, swimming, bicycling, aerobic dance) over the previous year were collected, as were self-reports of

walking pace in minutes per mile. A significant relationship between energy expended in physical activities and cognition, across a large set of cognitive measures, was observed, and this relationship remained significant after adjusting for medical conditions, prescription drugs, and lifestyle factors (see also Almeida, Norman, Hankey, Jamrozik, & Flicker, 2006; Lytle, Vander Bilt, Pandav, Dodge, & Ganguli, 2004). Indeed, even for women who did not participate in vigorous activity, those in the highest two quartiles of walking displayed higher cognitive function than did women who walked slower or less frequently. Given the ever-present concern about reverse causation (i.e., undiagnosed diseases that negatively impact cognition at time 1 influencing physical activity) with observational studies, Weuve et al. also examined, in a well-screened subset of their sample (7,907 participants), the relationship between physical activity at 60 to 62 years of age and cognition when individuals were in their 70s. The relationship between physical activity and cognition was similar in this group to that observed in the women who were examined only in their 70s. Thus, such data make a reverse-causation explanation of the physical activity–cognition effect less likely.

The studies discussed above examined the relationship between physical activity and cognition within the normal range. However, other observational studies have examined whether physical activity at one point in time was associated with the risk of developing some form of dementia later in life. For example, Abbott et al. (2004) examined the association between walking and future risk of dementia in 2,257 men between the ages of 71 and 93. Distance walked per day was reported at the initial assessment, and then follow-ups for dementia were performed approximately 3 and 6 years later. Dementia was examined in a two-stage process: Initial assessment with the Cognitive Abilities Screening instrument (CASI) was followed up, depending on CASI score, by a thorough neurological examination. After adjusting for a variety of medical conditions, lifestyle factors, age, baseline cognitive ability, and presence of e4 alleles on the *apoe* gene (a genetic polymorphism that has been linked to increased risk of Alzheimer's disease), a 1.9-fold excess risk of total dementia was found for men who walked less than .25 mile/day as compared to men who walked more than 2 miles/day. It is also important to note that this was a particularly healthy and physically capable sample at initial assessment, as the study excluded men who smoked, who were physically sedentary, or who scored poorly in the cognitive assessment.

Other studies have also reported an association between physical activity and dementia. Larson et al. (2006) conducted a study in which 1,740 men and women over the age of 65 were asked to report the number of times per week that, over the previous year, they had performed a variety of different physical activities lasting at least 15 minutes. After an average follow-up period of 6.2 years, 158 individuals had developed Alzheimer's dementia. Following adjustment for lifestyle and medical conditions, the incidence rate for Alzheimer's was significantly higher for individuals who exercised fewer than three times per week (19.7 per 1,000 person years) than it was for those who exercised more than three times per week (13.0 per 1,000 person years). Podewils et al. (2005) reported a similar relationship between physical activity and dementia over the course of a 5.4-year period in a population of 3,375 elderly men and women (see also Laurin, Verreault, Lindsay, MacPherson, & Rockwood, 2001; Scarmeas et al., 2001; Yoshitake et al., 1995).

The studies that have been described thus far have examined the relationship between physical activity and cognition or dementia over relatively short time periods, from 2 to 8 years. However, an important question, particularly with regard to the cognitive-enrichment hypothesis, is whether individual differences in physical activity at earlier points in the life span influence cognitive decline among the elderly. As might be expected, such a literature is relatively sparse. However, there are a few observational studies that begin to address this issue. Richards, Hardy, and Wadsworth (2003) examined, in a cohort of 1,919 males and females, the influence of self-reported physical exercise and leisure-time activities at 36 years of age on memory at 43 years of age and memory change from 43 to 53 years of age. Analyses indicated that engagement in physical exercise and other leisure-time activities at 36 years of age was associated with higher memory scores at 43. Physical activity at 36 was also associated with a slower rate of memory decline from 43 to 53 years of age after adjusting for spare-time activity and other variables. Interestingly, change in physical activity from 36 to 43 years of age reduced the relationship between physical activity at 36 and memory change from 43 to 53 years of age. These data suggest little memory protection for those who stopped exercise after age 36 but protection for those individuals who began exercise after this time. Other leisure-time activity was not associated with change in memory over this interval.

Rovio et al. (2005) examined the relationship between physical activity at middle age and risk of dementia an average of 21 years later, when the cohort was between 65 and 79 years of age. Participants were asked to indicate how often they participated in leisure-time physical activities that lasted at least 20 to 30 minutes and caused breathlessness and sweating. Leisure-time physical activity at midlife at least twice a week was associated with a reduced risk of dementia in later life. This relationship between activity and dementia was maintained even after adjusting for midlife age, sex, education, medical conditions, vascular risk factors, smoking, and drinking. Indeed, participants in the more active group had a 52% lower chance of dementia than did participants in the more sedentary group.

Finally, Dik, Deeg, Visser, and Jonker (2003) conducted a retrospective study in which they asked 1,241 62- to 85-year-old men and women about their physical activities from 15 to 25 years of age. After adjustments for a number of lifestyle and demographic variables, it was observed that men, but not women, who had been active at low or moderate levels when they were young displayed faster processing speed later in life.

However, no significant relationship was obtained for physical activity and a general measure of cognition, the MMSE. Interestingly, the most active men did not show cognitive benefits. The authors speculate that this could be due to the fact that high levels of activity for these men were work-related and therefore less likely to be aerobic activities than leisure activities. The failure to find a significant relationship between physical activity and processing speed for women could have been the result of lower-intensity activities pursued by women in this cohort.

The studies reviewed above suggest a modest relationship between physical activity and cognition. Although the majority of these studies are relatively short-term, they do suggest benefits, with regard to maintenance of cognition and delay of dementia, when older adults pursue physical activities. The few prospective and retrospective studies that have examined relationships between physical activity and cognition over the longer term also tentatively suggest that benefits may extend over substantial periods of time. However, there is clearly a need for additional long-term prospective studies that assess the influence of a multitude of lifestyle choices—including those that are intellectual, physical, social, and nutritional—on later-life cognition.

It is also important to point out that not all observational studies have found a positive relationship between physical activity and cognition (Verghese et al., 2003; Wilson, Mendes de Leon, Barnes, et al., 2002; Wilson, Bennett, Bienias, et al., 2002; Yamada et al., 2003). A study by Sturman et al. (2006) is particularly interesting in that these investigators addressed the question of whether, over a 6.4-year period, participation in physical activity by older adults reduces the rate of cognitive decline after accounting for participation in cognitively stimulating activities. After statistical adjustment for cognitive activities, each additional physical activity hour per week was associated with a slower rate of cognitive decline. However, this relationship was no longer significant after adjusting for cognitive activities (but see Richards et al., 2003, for a report of a relationship between physical but not intellectual activities and later-life cognition).

At present, it is difficult to know which factors are most important in moderating the influence of physical activity on later-life cognition and dementia. However, some possibilities that merit further study include the distinction between aerobic and nonaerobic physical activities; the utility of self-report versus more objectively measured physical activities; the role of physical-activity duration, intensity, and frequency; the nature of the components of cognition that serve as the criterion variables; the age of participants at initial and final assessment; and genetic factors.

A 6-year prospective observational study by Barnes, Yaffe, Satariano, and Tager (2003) included both self-report of physical activity and objective (i.e., volume of expiratory oxygen [VO_2] at peak exertion) measures of cardiorespiratory fitness in 349 individuals over the age of 55. Interestingly, whereas a significant inverse relationship was observed for the objective fitness measures and cognitive decline, this was not the case for the self-report activity measures. Although the explanation for this dissociation cannot be unequivocally discerned in these data, it is conceivable that it is the aerobic aspects of the physical activities—which are more reliably indexed by the objective than self-report measures—that is more strongly related to spared cognition than is those activities' nonaerobic aspects. A number of investigators have also examined whether possession of e4 alleles on the *apoe* gene moderates the relationship between physical activity and cognition. Unfortunately, however, results obtained thus far are equivocal with regard to whether possession of an e4 allele has a positive effect, negative effect, or no effect on the relationship between physical activity and cognition (Abbott et al., 2004; Larson et al., 2006; Podewils et al., 2005; Rovio et al., 2005; Schuit, Feskens, Launer, & Kromhout, 2001). This ambiguity could be the result of a number of different factors that may interact with genotype (such as those factors described above) in determining the relationship between physical activity and cognition. As will be discussed below, a number of other genes also produce proteins relevant to neurotransmitter systems and nerve-growth factors that appear to play an important role in the relationship between physical activity and cognition. Such genes will be important to study in the future.

Human Fitness-Training Intervention Studies

The observational studies described above suggest a potentially important association between physical activity and cognition. However, despite the care with which potential covarying factors were assessed, observational studies cannot definitively establish causation. Therefore, in this section, we examine studies that have included fitness-training interventions in which individuals are randomly assigned to training and control groups. These studies have a number of general characteristics. First, unlike the observational studies, intervention studies are relatively short-term, usually lasting no more than a year (although see Rikli & Edwards, 1991, for a 3-year study). Second, fitness levels and fitness activities are generally objectively assessed with measures of cardiorespiratory function such as VO_2 at maximum or peak exertion. Third, with few exceptions, the older participants tend to be sedentary but young-old (i.e., below 70 years of age) and healthy. Fourth, cognition is generally assessed with a variety of different experimental cognitive tasks rather than standardized, and often general, neuropsychological tests, as has been the case in observational studies. Finally, sample sizes are usually quite small, rarely exceeding 100 participants in a study.

An example is provided by a study reported by Kramer, Hahn, Cohen, et al. (1999). A sample of 124 sedentary but healthy older adults was randomized into two groups, an aerobic-exercise (walking) training group and a nonaerobic exercise

(stretching and toning) control group. Subjects participated in fitness training 3 days a week, for approximately 1 hour per day, for 6 months. A number of different aspects of cognition were assessed before and after the 6-month training intervention. Relative to participants in the nonaerobic control group, those in the aerobic-training group showed selective improvements in a number of aspects of cognition, including the ability to selectively process task-relevant information and ignore task-irrelevant information, the ability to abort a preprogrammed response, and the ability to rapidly switch between multiple tasks. Aerobic-group subjects also showed a modest but significant improvement in aerobic fitness as measured by VO_2 peak.

However, as with observational studies, not all training interventions have reported positive results. Blumenthal et al. (1991) examined the influence of aerobic training on several measures of cognition and psychiatric symptoms over a 4-month period in men and women over the age of 60. One hundred one participants were randomized to either an aerobic-training group, a yoga-training group, or a wait-list control group. The aerobic group showed an 11.6% improvement in peak $V0_2$ while the other two groups did not show any improvement in cardiorespiratory fitness. Improvements in performance in a number of cognitive tasks were observed. However, these improvements were equivalent across groups.

One way to examine the potential reasons for the discrepancy between these intervention studies and others is with a meta-analysis. Fortunately, several such meta-analyses have been reported in recent years. Colcombe and Kramer (2003) reported a meta-analysis of all of the accessible randomized aerobic-fitness-training studies published between 1966 and 2001 that had control groups and involved 55- to 80-year-old participants. The main question examined was whether, across the 18 intervention studies in the analysis, fitness training had a positive influence on cognition. The answer was affirmative. A moderate effect size (.48) for fitness training was obtained in the analysis. The meta-analysis also revealed a number of interesting moderators of the relationship between fitness training and cognition. First, although fitness training broadly influenced a variety of cognitive processes, the type of cognition involved was associated with different effect sizes. Figure 9 plots the effect sizes from the meta-analysis for different types of cognitive functioning. The largest benefits of exercise were observed for executive-control processes (effect size = .68). Executive-control processes include components of cognition such as planning, scheduling, working memory, inhibitory processes, and multitasking. Interestingly, these are many of the processes that show substantial age-related decline. Second, effects of fitness training were larger when programs of aerobic training were combined with strength and flexibility training. Combinations of different treatment protocols may both engender more-varied brain changes (e.g., Black et al., 1990) and serve to further reduce age-associated cardiovascular and muscular-skeletal disorders (Dishman et al., 2006). Third, aerobic-training-group participants over the age of 65 showed larger improvements in cognition than younger participants did. Fourth, fitness-training sessions that lasted longer than 30 minutes resulted in larger cognitive improvements than shorter training sessions did. Finally, and perhaps most interestingly, studies that included more women showed larger fitness-training benefits on cognition than studies with fewer women (see below for a discussion of this finding).

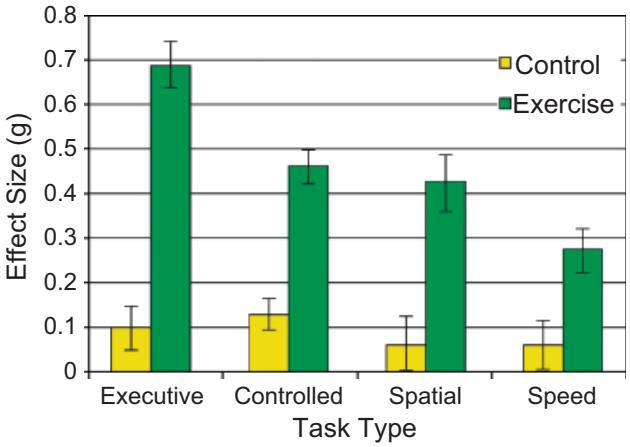

Fig. 9. Effect sizes of mean differences in cognitive performance between older adults in aerobic fitness training (green bars) and those in a control condition (yellow bars) for different types of cognitive tasks. Adapted from Colcombe and Kramer (2003).

Two additional meta-analyses of fitness-training effects, each with a different focus, have also been published recently. Heyn, Abreu, and Ottenbacher (2004) asked whether exercise is beneficial for people with dementia and related cognitive impairments. Studies with cognitively impaired adults over the age of 65 published from 1970 through 2003 were included in their meta-analysis. The outcome variables were broader in this study then they were in Colcombe and Kramer (2003), encompassing exercise effects on a variety of physiological, behavioral, and cognitive endpoints. Twelve intervention studies that targeted cognition were examined. These studies ranged in duration from 2 to 28 weeks and included a variety of different low-intensity exercises, including walking and strength and resistance training. A moderate effect size of .57, very similar to that observed by Colcombe and Kramer (2003) for nondemented older adults, was obtained. Unfortunately, however, the authors did not examine potential moderators of the relationship between exercise and cognition.

Etnier, Nowell, Landers, and Sibley (2006) examined a very specific hypothesis in their meta-analysis. The cardiovascular-fitness hypothesis suggests that changes in aerobic fitness, as measured by some variant of VO_2, are necessary for cognitive benefits of physical activity to be realized. Their meta-analysis was broader than the previous two in that participants ranged from 11 to 85 years of age, both cross-sectional and intervention

studies were included, and the intervention studies included both randomized and nonrandomized designs. Like Colcombe and Kramer (2003) and Heyn et al. (2004), Etnier and colleagues found a significant improvement in cognition as a function of physical-activity training. However, overall, no significant relationship was found between fitness change (or difference) and cognitive change (or difference). In the few conditions in which a significant relationship was found, studies with smaller fitness changes were associated with larger cognitive changes. Clearly, the negative relationship between fitness change and cognitive change was unexpected. However, the lack of a significant relationship (in the majority of the conditions in the meta-analysis) between fitness change and cognition is less surprising since VO_2 is not specific for brain oxygen consumption—and the brain requires only about 20% of total body oxygen (see also Colcombe & Kramer, 2003; Dustman et al., 1984). Indeed, given this imperfect relationship, researchers might consider examining the association between physical-activity training and quantitative measures of brain-based oxygen utilization such as those that can be obtained from techniques such as positron emission tomography (Raichle et al., 2001). Of course, it would be ideal if such measures were included in studies that examined the influence of different doses (i.e., conditions differing in intensity, length, and frequency) of physical-activity training on cognition. Methodologically, it needs to be kept in mind that the Etnier et al. (2006) meta-analysis examined covariation of physical- and cognitive-intervention effects across studies, rather than across people within studies. For reasons unknown, some studies may have been better at reliably assessing intervention effects in the fitness domain, and others may have been better at reliably assessing corresponding effects in the cognitive domain. Hence, the absence of a positive covariation at the study level does not warrant the conclusion that the two effects are not positively correlated at the individual level.

Although there are clearly a number of important unanswered questions, the literature reviewed thus far suggests a relatively robust effect of physical-activity training on cognition. However, we know far less about the relationship between physical-activity training and human brain function and structure (see the next section for animal research on this issue). Indeed, we know of only a few studies to date that have examined the influence of physical-activity training on the human brain. Colcombe and colleagues (2004) randomly assigned twenty-nine 58- to 77-year-olds to participate in either a walking group or a stretching-and-toning-exercise control group for a 6-month period. Each of the two groups participated in supervised exercise for three 45-minute sessions per week for 6 months. The improvement in cardiovascular fitness over the 6-month intevention, as measured by VO_2 max, was 10.2 and 2.9% for the walking and toning groups, respectively. All participants also performed a focused-attention task during an event-related functional magnetic resonance imaging (fMRI) protocol that was administered prior to and after the intervention. This task requires participants to focus on a single, central object while ignoring irrelevant distractor objects that flank the target item. Older adults who participated in the walking protocol were better able to ignore the misleading flanking items, but the older adults in the control group were not. Importantly, the walking-group participants, but not the toning controls, showed increased activity in frontal and parietal regions of the brain that are thought to be involved in efficient attentional control and performance on this task, as well as reduced activity in the dorsal region of the anterior cingulate cortex, a region thought to be sensitive to behavioral conflict or the need for increased cognitive control. Thus, these data suggest that more efficent neural processing is associated with improved aerobic fitness in older adults (see also Pereira et al., 2007).

Colcombe et al. (2006; see also Colcombe at al., 2003) examined the influence of fitness training on potential changes in brain structure in a similiar intervention. Like the study described above, 59 healthy but sedentary community-dwelling volunteers, aged 60 to 79, participated in the 6-month randomized clinical trial. Half of these participants served in an aerobic-training (walking) group, and the other half participated in a nonaerobic (toning-and-stretching) control group. High-resolution MRI data were obtained before and after the intervention, and a semiautomated image-segmentation technique was used to assess longitudinal changes in participants' brain structure. This technique provides a means to estimate tissue atrophy on a point-by-point fashion throughout the brain, with reasonably high spatial resolution. The results indicated that the older adults who participated in the aerobic-training group showed a significant increase in gray-matter volume in regions of the frontal and superior temporal lobe, compared to controls. These results suggest that even relatively short exercise interventions can begin to restore some of the losses in brain volume associated with normal aging. However, it should be noted that the limitations of the semiautomated segmentation technique do not allow one to infer precisely what mechanism results in these changes (e.g., increase in cell body size, increased dendritic connections, increased capillary bed volume, increased glial size or number, etc.).

Before concluding this section, we would like to discuss one recent study reported in the Colcombe and Kramer meta-analysis that provides some insight into the larger benefit of physical-activity training on cognition for women than for men. Erickson, Colcombe, Elavsky, et al. (2007) examined the relationship between hormone replacement therapy (HRT) and cardiovascular fitness, as measured by VO_2, on brain volume and executive-control processes in postmenopausal women. The 54 women who participated in the study varied in (a) their fitness level and (b) whether they had taken HRT (and if so, how long). There were several interesting findings obtained in this cross-sectional study. First, all women, regardless of HRT status, showed cognitive and brain-volume benefits of being more

physically fit. Second, short-term HRT use (10 years or less) had a beneficial effect on brain volume and executive control, whereas long-term HRT use (longer than 16 years) negatively affected both cognition and brain volume. However, being more physically fit reliably offset negative effects of long-term HRT use and augmented the short-term benefits of HRT use. This interesting finding not only indicates that multiple lifestyle factors can have interactive effects on the brain and cognition in old age, but also may help explain the finding that studies with more female participants show larger effects of exercise.

In summary, the human intervention studies we have reviewed, when considered along with the observational studies, suggest a moderate relationship between physical-activity training and improved cognition. The meta-analyses have also begun to suggest some important moderators of the physical-activity–cognition relationship, including the age of the participants, the type of cognitive processes assessed, the length of the training sessions, and the gender of partipants. Clearly, however, additional intervention studies are needed to further examine the relationship between different fitness-training protocols and aspects of cognition and brain function and structure, preferably over much more extended time periods than have been previously examined.

Animal Research on Fitness-Training Effects

In the present section, we provide a brief review of the animal research that has begun to reveal the cellular and molecular mechanisms supporting fitness-training effects on brain structure and function and performance on learning and memory tasks. More detailed reviews of this literature can be found in Cotman, Berchtold, and Christie (2007), Vaynman and Gomez-Pinilla (2006), and Kempermann (2008).

The focus on fitness training can be seen as an extension of earlier animal research on brain plasticity engendered by enriched or complex environments. Enriched environments were often defined in terms of plentiful and frequently changed obstacles and objects, other animals, and the opportunity for exercise (e.g., the availability of running wheels). Much of the early research on brain plasticity examined the influence of enriched versus impoverished environments with rats and mice but was restricted to the study of young animals, largely because brain plasticity was believed to exist only in young organisms. However, later research revealed that morphological changes in brain structure could also be obtained with older animals, albeit to a lesser extent. The changes engendered by enriched environments include increased dendritic branching, capillary development, the development of new neurons from adult stem cells, enhanced learning and memory, as well as a cascade of molecular and neurochemical changes (Kempermann et al., 1997, 1998; Rosenzweig & Bennett, 1996; Turner & Greenough, 1985).

Given the multimodal nature of enriched environments, researchers have also attempted to decompose the relative contribution of intellectual, social, and physical-activity factors to changes in learning, memory, and brain function. For example, Black et al. (1990) contrasted the effects of fitness training with motor-skill learning. Groups of rats either had access to activity wheels or learned nonaerobic motor skills (e.g., traversing rope bridges, climbing over and under obstacles, etc.). Animals with access to an activity wheel were found to have a higher density of capillaries in the cerebellum than were either the animals trained on motor skills or the inactive control animals. Interestingly, the animals in the motor-skill group showed a larger number of synapses in the cerebellum than the other three groups did. Thus, these two different forms of training, aerobic and motor skill, had differential effects on the vasculature and synaptic connectivity of the brain. Subsequent studies have shown that fitness training can also enhance vascularization of other regions of the brain, such as the motor cortex, in primates as well as rats. It has been suggested that increases in vascularization serve an important function in providing a greater reserve capacity to respond in situations requiring increased oxygen (Swain et al., 2003).

Other studies have shown additional benefits for physical activity. For example, Van Praag, Christie, Sejnowski, and Gage (1999) examined the influence of a number of different interventions including enriched environments, standard living (controls), voluntary exercise (running wheel), hidden-platform-water-maze learning, and forced exercise (swimming) on cell proliferation and neurogenesis in the adult mouse dentate gyrus of the hippocampus. Only the running-wheel and enriched groups showed increased cell proliferation and survival and neurogenesis following the interventions. In another study with running mice, Van Praag, Kempermann, and Gage (1999) found that cell proliferation in the dentate gyrus, the relatively narrow input structure to the hippocampus proper, was related to improved performance on the Morris water-maze task (a test of spatial learning and memory) and enhancement of long-term potentiation, a cellular model of learning and memory. A number of other studies have replicated and extended the effects of fitness training on neurogenesis (Brown et al., 2003; Rhodes et al., 2003; van Praag, Shubert, Zhao, & Gage, 2005).

Studies have also found that exercise increases levels of neurotrophic factors that have been shown to be neuroprotective, to enhance cell and neuron growth, and to engender synaptic plasticity (Lu, Pang, & Woo, 2005; Smith & Zigmond, 2003). For example, Neeper, Gomez-Pinilla, Choi, and Cotman (1995) observed a monotonic dose-response function between the production of brain-derived neurotrophic factor (BDNF; a neuroprotective molecule that facilitates synaptic transmission) in the hippocampus and the amount of distance run per day by mice (see also Vaynman, Ying, & Gomez-Pinilla, 2004). Other researchers have reported exercise-related increased productions of other neurotrophic factors such as insulin-like growth

factor 1 and vascular endothelial growth factor, which have been linked with angiogenesis (the growth of new vasculature) and neurogenesis (Ding et al., 2004; Trejo, Carro, & Torres-Aleman, 2001). Neurotransmitter systems are also affected by exercise. For example, serotonin (Blomstrand, Perret, Parry-Billings, & Newsholme, 1989) and acetylcholine (Fordyce & Farrar, 1991) levels are increased in exercising rats, and medial septal GABAergic neurons have been suggested to play a key role in exercise-induced benefits on cognition (Berchtold, Kesslak, & Cotman, 2002). Interestingly, BDNF has been shown to regulate neurotransmitters, including dopaminergic and cholinergic neurons (Knusel et al., 1992), and may be playing an important role in the exercise-induced effects on neurotransmitter systems.

An animal study conducted by Berchtold, Kesslak, Pike, Adlard, and Cotman (2001) may help explain the interaction between fitness, HRT, cognition, and brain structure reported by Erickson, Colcombe, Elavsky, et al. (2007) in their cross-sectional study in women. Berchtold et al. (2001) examined the interaction between exercise and estrogen, in the form of 17-beta estradiol, on BDNF in a study of adult female rats that had had their ovaries removed. Several interesting results were obtained in their study. First, voluntary wheel running was reduced in the ovariectmized rats but not in the control (sham-operated) rats. Interestingly, the administration of estradiol increased estrogen to levels observed prior to surgery, and it increased voluntary running. Second, as has been previously reported in male animals (Neeper et al., 1995), voluntary running increased BDNF gene expression in the hippocampus. Third, estrogen deprivation reduced BDNF gene expression in sedentary animals. However, 5 days of exercise increased BDNF levels to that of presurgical baseline in animals that had been estrogen deprived for 3 weeks. In sum, these data suggest that BDNF, an important neuroprotective molecule, can be influenced by estrogen and exercise both separately and in combination—which may help explain the within- and between-gender effects on the exercise–cognition relationship reported in the human literature.

Finally, Kempermann (2008) recently summarized the rodent evidence on neurogenesis in the dentate gyrus of the hippocampus, and proposed the "neurogenic reserve hypothesis" to explain how such neurogenesis serves to maintain and promote learning, memory, and emotion regulation throughout the life span. His hypothesis makes explicit reference to the general notion of a neural reserve protecting against behavioral manifestations of age-related cognitive decline and age-associated cognitive pathology (Katzman et al., 1988; Satz, 1993; Stern, 2002). According to Kempermann (2008), exposure and training at younger ages builds a hippocampal neurogenic reserve for cellular and functional plasticity in old age. He hypothesized that combining cognitive challenges with physical exercise will be most effective in maintaining a pool of new neurons in the dentate gyrus that can be recruited later in development to confront cognitive challenges. Extrapolating the animal data to the situation in humans, Kempermann (2008) proposes that "broad ranges of activity early in life would not only help to build a highly optimized hippocampal network adapted to a complex life . . . [but] would also contribute to a neurogenic reserve by keeping precursor cells in cycle" (p. 167).

SOCIAL ENGAGEMENT

There is also longitudinal evidence supporting the hypothesis that social engagement has beneficial effects on cognition in old age. Social engagement has typically been defined in rather broad terms as being socially active and maintaining numerous social connections (Bassuk, Glass, & Berkman, 1999). Perhaps as a result, it has been operationalized with diverse indicators that have been combined in different ways, complicating comparisons across studies. The traditional focus of this research has been on relatively objective measures of social isolation/connectedness, including participation in activities that prominently involve social interaction (e.g., doing volunteer work), number of friends and relatives contacted regularly (i.e., social-networks size), and marital status. More recently, studies have begun to examine perceived social isolation/connectedness with quantitative measures of social support and loneliness. Here we summarize studies of social engagement, first in relation to change in cognitive function and then in relation to the development of incident dementia.

In one of the first evaluations of social engagement and cognitive decline, Bassuk et al. (1999) studied a probability sample of 2,812 persons aged 65 or older who were residing in New Haven, Connecticut, in 1982 as part of the Established Populations for Epidemiologic Studies of the Elderly project (Cornoni-Huntley, Brock, Ostfeld, Taylor, & Wallace, 1986). They constructed a composite index that included indicators of social activity (e.g., membership in groups, attendance at religious services) and social networks (e.g., monthly contact with at least three friends or relatives). Cognition was assessed with a brief mental-status test four times during a 12-year period. Those persons with higher engagement experienced less cognitive decline. A subsequent population-based study in Hong Kong, with a similar composite of social activity and social-network data, found no association with rate of cognitive decline, though this may have been partially due to use of a self-rated cognitive-outcome measure (Ho, Woo, Sham, Chan, & Yu, 2001).

Studies focusing exclusively on measuring social activity and participation have yielded positive results (Barnes, Mendes de Leon, Wilson, Bienias, & Evans, 2004; Lövdén et al., 2005; Zunzunegui, Alvarado, Del Ser, & Otoro, 2003), whereas analyses of social-network size have had mixed results (Barnes et al., 2004; Seeman, Lusignolo, Albert, & Berkman, 2001; Zunzunegui et al., 2003), suggesting that mixing network data with activity data may dilute any effects of social engagement on cognition. With respect to perceived social isolation/connectedness, loneliness has been associated with more rapid cognitive

decline (Tilvis et al., 2004; Wilson, Krueger, et al., 2007), but evidence on social support has been mixed (Seeman et al., 2001; Zunzunegui et al., 2003). Overall, these studies suggest that persons who are more socially active and who do not feel socially disconnected experience less cognitive decline than do their less-active and more-disconnected counterparts.

Studies of social engagement and dementia have yielded similar results. Higher level of social activity has been associated with reduced risk of developing dementia in four prospective studies (Fabrigoule et al., 1995; Scarmeas et al., 2001; Wang et al., 2002; Wilson, Kreuger, et al., 2007), three of which were based on defined populations of older persons (Scarmeas et al., 2001; Wang et al., 2002; Fabrigoule et al., 1995). Thus, among more than 1,000 older persons from the Kungsholmen district in Stockholm, persons reporting daily to weekly participation in social activities like attending the theater or participating in a pension organization were about 40% less likely to develop dementia during 6 years of observation than were persons reporting no participation in such activities (Wang et al., 2002). Such effects could represent cognitive stimulation rather than social participation per se. However, in this same population, incidence of dementia was decreased in older persons with more extensive social networks, as indicated by being married, consistent with two previous studies (Bickel & Cooper, 1994; Helmer et al., 1999); not living alone; having children; and having close social ties. Also, more frequent contact with children and friends and being satisfied with these contacts were each related to reduced risk of dementia. A more recent study found no association between social-network size and dementia risk, but feeling lonely was related to increased incidence of dementia even after controlling for social-network size and frequency of social activity (Wilson, Krueger, et al., 2007).

Studies of social networks and risk of dementia have had mixed results. Thus, social-network size was not related to dementia risk in two studies (Helmer et al., 1999; Wilson, Krueger, et al., 2007). A third study that took into account both size of and satisfaction with social networks did find reduced risk with a more extensive network (Fratiglioni, Wang, Ericsson, Maytan, & Winblad, 2000). These studies suggest that the quality of social relationships may be more important than the quantity.

Taken together, these data support the idea that a higher level of social engagement is related to a reduced risk of cognitive decline and dementia in old age. The basis of the association is not well understood, however. One possibility is that declining social engagement is a consequence of incipient dementia rather than an antecedent. Saczynski et al. (2006) examined this issue in more than 2,500 older Japanese American men who were followed since 1964 as part of the Honolulu Heart Program and the Honolulu-Asia Aging Study. Social engagement was measured at midlife and old age with similar composite measures, each based on indicators such as marital status and participation in groups. Consistent with prior research, level of social engagement in old age predicted subsequent development of dementia. Midlife engagement did not predict dementia, but individuals who experienced a downward shift in engagement from midlife to old age were more likely to develop dementia than were those who had consistently high engagement. The authors suggest that the downward shift may be a prodromal sign of dementia. Although this inference is plausible, the data are also compatible with a risk-factor interpretation. Further, because (a) it is difficult to statistically separate change from level with only two measurement points and (b) the risk for persons manifesting low engagement at both points was similar to risk in the group showing change in engagement, the results may impy the that the effect on incidence of dementia depends more on chronic low levels of social engagement in late life than on whether social engagement declines in late life.

Lövdén et al. (2005) examined the direction of the association between social engagement and cognition with data from the Berlin Aging Study. Participants' engagement in social activities and their cognitive status were assessed at three occasions separated by about 2 years. Levels of participation in social activities predicted the rate of decline in perceptual speed, but initial levels of perceptual speed did not predict change in social-activity participation. It should be noted, however, that some of the social activities measured in this study overlap with cognitive activities reviewed earlier (e.g., attending lectures). Another study found an association between social engagement and dementia incidence during a 6-year period after excluding those who developed dementia during the first 3 years of observation (Wang et al., 2002). Finally, although there has been limited clinical-pathologic research, results to date do not indicate an association between indicators of social engagement and Alzheimer's disease pathology (Bennett, Schneider, Tang, Arnold, & Wilson, 2006; Wilson, Krueger, et al., 2007), the leading cause of dementia. These data do not support the hypothesis that social disengagement is an early indicator of cognitive decline or dementia.

Social disengagement might also predict age-related loss of cognition because of an association with other risk factors for cognitive decline. Depressive symptomatology, cognitive activity, and physical activity are each related to loss of cognition in old age. The relation of social engagement with loss of cognition has been observed after controlling for some (Bassuk et al., 1999; Fratiglioni et al., 2000; Scarmeas et al., 2001; Zunzunegui et al., 2003) or all (Barnes et al., 2004; Wang et al., 2002; Wilson, Krueger, et al., 2007) of these variables, however, making this explanation less likely.

Another possibility is that social participation is an index of behavioral or neural plasticity (Katzman et al., 1988; Satz, 1993; Stern, 2002). That is, a socially engaged lifestyle might somehow help older persons compensate for age-related degenerative changes in neural systems involved in cognitive functioning. Support for this hypothesis comes from a clinical-pathologic study that found that social-network size modified the relation of neurofibrillary tangles to level of cognition proximate to death

(Bennett et al., 2006). As social-network size increased, the association of tangle density with semantic memory and working memory decreased. These findings suggest that neural systems involved in developing and maintaining a large social network may somehow help compensate for the effects of Alzheimer's disease pathology on cognitive systems, possibly by recruiting alternate neural systems to help support cognitive functioning.

CHRONIC PSYCHOLOGICAL DISTRESS

Just as maintaining some activity patterns in old age may reduce risk of cognitive decline, the persistence of other patterns of behavior may actually increase risk of cognitive decline. Chronic psychological distress is associated with a variety of negative outcomes in adulthood, including, perhaps, cognitive decline. Psychological distress refers to negative emotions like depression, anxiety, anger, and shame. The tendency to experience psychological distress, variously referred to as neuroticism (Costa & McCrae, 1992), negative affectivity (Watson & Clark, 1984), emotional instability (Goldberg, 1992), emotionality (Borgatta, 1964), or poor emotional control (Fiske, 1949), is recognized in most typologies of human personality

Individuals differ widely in trait neuroticism. By and large, individual differences in this trait complex are relatively stable throughout adulthood and old age, although recent literature suggests that there are some individual differences in change in psychological distress, possibly associated with negative life events (Allemand, Zimprich, & Hertzog, 2007; Mroczek & Spiro, 2003; Small, Hertzog, Hultsch, & Dixon, 2003; Steunenberg, Twisk, Beekman, Deeg, & Kerkhof, 2005; Terracciano, McCrae, & Costa, 2006). Nevertheless, stability more than change is the rule, with 6-year test–retest correlations approaching a perfect correlation of 1.0 in some studies (e.g., Costa & McCrae, 1998).

Longitudinal studies have shown that neuroticism is a good predictor of the level of negative emotions and negative life events that people subsequently experience (de Beurs, Beekman, van Dyck, & van Tilburg, 2000; Magnus, Diener, Fujita, & Pavot, 1993; Ormel & Wohlfarth, 1991). In old age, therefore, it is a good indicator of the cumulative level of psychological distress that has been experienced during the life span.

Longitudinal studies also have consistently found higher level of the neuroticism trait to be associated with an increased incidence of Alzheimer's disease (Wilson, Arnold, et al., 2006; Wilson, Barnes, Bennett, et al., 2005; Wilson, Evans, et al., 2003) and mild cognitive impairment (Wilson, Schneider, Boyle, et al., 2007) in old age. In one of these studies (Wilson, Evans, et al., 2003), a group of about 800 older persons without dementia completed a standard self-report measure of neuroticism (Costa & McCrae, 1992) and then had annual clinical evaluations for a mean of about 5 years. During follow-up, 140 persons were diagnosed with Alzheimer's disease. As shown in Figure 10, those with a high level of the trait (solid line) were nearly twice as likely to develop the disease as were those low in the trait (dotted line).

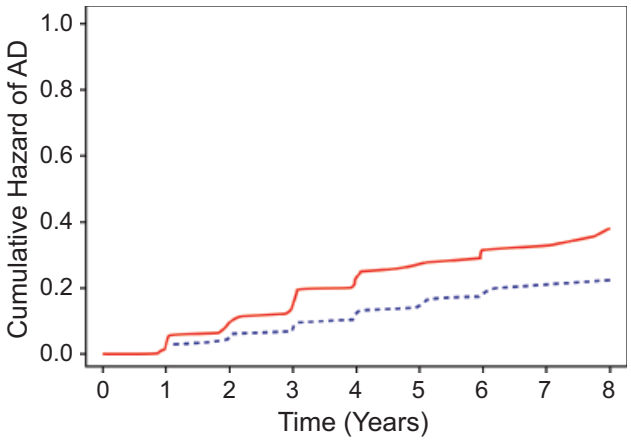

Fig. 10. Cumulative hazard of the incidence of Alzheimer's disease (AD) as a function of time in the study for persons with high (solid red line) or low (dashed blue line) neuroticism index scores. Adapted from "Proneness to Psychological Distress Is Associated With Risk of Alzheimer's Disease," by R.S. Wilson, D.A. Evans, J.L. Bienias, C.F. Mendes de Leon, J.A. Schneider, & D.A. Bennett, 2003, *Neurology*, *61*, p. 1481. Copyright 2003, American Academy of Neurology. Adapted with permission.

Higher neuroticism has also been shown to predict more rapid cognitive decline (Wilson, Arnold, et al., 2006; Wilson, Bennett, et al., 2005; Wilson, Evans, et al., 2003; Wilson, Schneider, et al., 2007). The association of neuroticism with cognitive decline is especially strong for episodic memory (Wilson, Arnold, et al., 2006; Wilson, Evans, et al., 2003; Wilson, Schneider, et al., 2007). Thus, as shown in Figure 11, one study found a high level of neuroticism (solid line) to be associated with a nearly tenfold increase in annual rate of episodic-memory decline compared to a low level of the trait (dotted line) but to be unrelated to decline in other cognitive domains (Wilson, Evans,

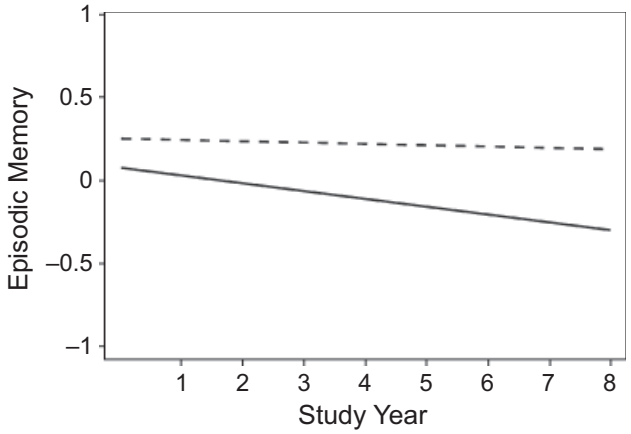

Fig. 11. Predicted paths of change in episodic memory for high (solid red line) or low (dotted blue line) levels of neuroticism. Adapted from "Proneness to Psychological Distress Is Associated With Risk of Alzheimer's Disease," by R.S. Wilson, D.A. Evans, J.L. Bienias, C.F. Mendes de Leon, J.A. Schneider, & D.A. Bennett, 2003, *Neurology*, *61*, p. 1482. Copyright 2003, American Academy of Neurology. Adapted with permission.

et al., 2003). By contrast, four other studies have not observed a correlation between neuroticism and cognitive decline. (Arbuckle, Maag, Pushkar, & Chaikelson, 1998; Hultsch et al., 1999; Jelicic et al., 2003; Wetherell, Reynolds, Gatz, & Pedersen, 2002). Several factors may have contributed to the negative results of the latter studies, including having fewer participants (one with > 500 versus all four positive studies with > 500) and lower follow-up participation (none with $> 85\%$ versus all four positive studies with $> 85\%$). In addition, the mean age was over 70 in all four studies observing the association and under 70 in all of the negative studies, consistent with the idea that the deleterious effects of psychological distress are cumulative and therefore most evident in the oldest old. Finally, neuroticism was assessed with items from the Eysenck Personality Inventory (Eysenck & Eysenck, 1968) in all but one (Hultsch et al., 1999) of the negative studies and with items from the NEO Personality Inventory-Revised (Costa & McCrae, 1992) in all of the positive studies, suggesting that subtle differences in how the trait is measured may have contributed to differential results. Overall, these data support the idea that chronic psychological distress is associated with loss of cognition in old age.

Because neuroticism is strongly associated with the occurrence of negative emotional states, measures of these negative emotions themselves should also be associated with cognitive decline and dementia, though the temporal instability of emotional states might attenuate associations. Relevant research has, with few exceptions (van Hooren et al., 2005), focused on depressed mood. Of 20 published studies, 13 found higher depressive symptomatology to be associated with higher incidence of mild cognitive impairment (Barnes, Alexopoulos, Lopez, Williamson, & Yaffe, 2006; Geda et al., 2006; Wilson, Schneider, et al., 2007) or dementia (Berger, Fratiglioni, Forsell, Winblad, & Backman, 1999; Devanand et al., 1996; Gatz, Tyas, St. John, & Montgomery, 2005; Wilson, Barnes, et al., 2002; Wilson, Krueger, et al., 2007; Modrego & Ferrnadez, 2004) or more rapid cognitive decline (Paterniti, Verdier-Tillefer, Dufouil, & Alperovitch, 2002; Sachs-Ericsson, Joiner, Plant, & Blazer, 2005; Wilson, Barnes, et al., 2002; Wilson, Mendes de Leon, Bennett, Bienias, & Evans, 2004), and another 4 studies found evidence of this association to be conditional on some covariate, such as sex (Dal Forno et al., 2005; Fuhrer, Dufouil, & Dartigues, 2003), education (Geerlings et al., 2000), or baseline level of cognition (Bassuk, Berkman, & Wypij, 1998). Of the three negative studies, one (Dufouil, Fuhrer, Dartigues, & Alperovitch, 1996) subsequently found evidence of the association after collecting further data (Fuhrer et al., 2003); a second study (Vinkers, Gussekloo, Stek, Westendrop, & van der Mast, 2004) may have reduced the validity of self-report about depressive symptoms by including participants with dementia (Gilley & Wilson, 1997); and a third study (Ganguli, Du, Dodge, Ratcliff, & Chang, 2006) excluded persons who developed dementia during the observation period. This greatly reduces the spectrum of cognitive decline and the likelihood that covariates will be related to cognitive decline without removing the influence of the underlying disease, because the pathologic changes associated with dementia are commonly found in the brains of older persons who died with mild (Bennett, Schneider, Bienias, et al., 2005; Guillozet et al., 2003; Markesbery et al., 2006; Petersen et al., 2006) or no (Bennett et al., 2006; Driscoll et al., 2006) cognitive impairment. Overall, therefore, these data indicate that a higher level of depressive symptomatology is associated with greater age-related cognitive decline. Further, controlling for neuroticism substantially reduces the association of depressive symptoms with loss of cognition (Wilson, Schneider, et al., 2007), supporting the idea that depressive symptomatology predicts cognitive decline because it is a proxy for chronic psychological distress.

Although the weight of epidemiologic evidence supports an association between neuroticism and depressive symptomatology on the one hand and cognitive decline and dementia on the other, the basis of the association is uncertain. A common interpretation has been that depressive symptomatology (neuroticism) is an early sign of the pathologies causing dementia rather than a true risk factor. In support of this idea, case-control studies suggest that depressive symptoms are somewhat more common in older people with mild cognitive impairment or dementia compared to those without cognitive impairment (Lyketsos et al., 2002), although investigation of this issue is complicated by the diminishing value of self-report as cognitive impairment increases. However, clinical-pathologic studies do not suggest that depressive symptoms or neuroticism are related to the pathologies associated with dementia (i.e., neurofibrillary tangles, neuritic plaques, cerebral infarction, Lewy bodies; Bennett, Wilson, Schneider, Bienias, & Arnold, 2004; Wilson, Arnold, Schneider, Li, & Bennett, 2007; Wilson, Evans, et al., 2003; Wilson, Schneider, Bienias, et al., 2003). In one study of more than 200 older people who died and underwent brain autopsy, measures of neuroticism and depressive symptoms were not associated with composite measures of amyloid plaques, neurofibrillary tangles, Lewy bodies, or cerebral infarction but were related to cognitive function and dementia proximate to death even after controlling for these neuropathologic features (Wilson, Arnold, Schneider, Li, & Bennett, 2007). By contrast, several other clinical conditions that predict dementia and cognitive decline, like gait disorder (Schneider et al., 2006), olfactory dysfunction (Wilson, Arnold, Schneider, Tang, & Bennett, 2007), loss of body mass (Buchman et al., 2006), and diabetes (Arvanitakis, Wilson, & Bennett, 2006), have been shown to be related to Alzheimer's disease pathology or cerebral infarction.

In addition, if negative affect predicts mild cognitive impairment and dementia because it is a sign of the underlying disease, there should be an uptick in depressive symptoms at some point prior to the onset of dementia. In a recent study of this issue, a 10-item measure of depressive symptoms was admin-

istered annually to a group of more than 900 older persons without dementia at study onset (Wilson, Arnold, Beck, Bienias, & Bennett, in press). During up to 13 years of follow-up, 190 individuals developed Alzheimer's disease and 727 were free of dementia (with 17 other forms of dementia excluded). The incident Alzheimer's disease subgroup did not show any increase in depression before the diagnosis, with a mean of about 4 years of observation. Similarly, among those without any cognitive impairment at baseline, depressive symptoms did not increase prior to the incidence of mild cognitive impairment during a mean of about 3 years of observation.

The hypothesis that negative affect is a sign of dementia also suggests that there should be an increase in negative affect in old age, as seen with other noncognitive manifestations of dementia, at a time when the pathologies associated with dementia are accumulating in the brain. Yet longitudinal studies do not suggest a systematic increase in depressive symptoms (Barefoot, Mortensen, Helms, Avlund, & Schroll, 2001; Davey, Halverson, Zonderman, & Costa, 2004; Haynie, Berg, Johansson, Gatz, & Zarit, 2001; Pitkala, Kahonen-Valvanne, Strandberg, & Tilvis, 2003; Skarupski et al., 2005; Wallace & O'Hara, 1992) or neuroticism (Mroczek & Spiro, 2003; Small et al., 2003; Steunenberg et al., 2005; Terracciano et al., 2006) in old age. Admittedly, selective survival for those low in psychological distress could attenuate the effects that have been observed. A related hypothesis is that negative affect is a reaction to incipient cognitive decline. Yet this hypothesis also suggests that negative affect should increase in old age and be correlated with dementia-associated pathology. In sum, current evidence does not support the hypothesis that depressive symptomatology or neuroticism predict dementia because they are direct or indirect signs of its pathology.

Insight into the association may be gleaned from research with animals in which conditions designed to induce distress are experimentally manipulated. Animal research has clearly established that distress-inducing experience can have deleterious effects on brain structure and function (McEwen, 1999; Uno, Tarara, Else, Suleman, & Sapolsky, 1989). A spectrum of changes, most notably in areas within the hippocampal formation and medial prefrontal cortex, has been described; they include reduced dendritic branching and synaptic density, downregulation of glucocorticoid receptors, reduced expression of brain-derived neurotrophic factor and its tyrosine kinase B receptor, and reduced neurogenesis in the dentate gyrus, with accompanying impairments in learning and memory (Herman, Adams, & Prewitt, 1995; Johren, Flugge, & Fuchs, 1994; Magarinos & McEwen, 1995; Magarinos, McEwen, Flugge, & Fuchs, 1996; Radley et al., 2004; Rasmusson, Shi, & Duman, 2002; Smith, Makino, Kvetnansky, & Post, 1995). That this animal research may have relevance to humans is suggested by studies of persons with psychiatric conditions characterized by very high levels of psychological distress. Thus, major depression and posttraumatic stress disorder have been associated with atrophy of the hippocampus and anterior cingulate gyrus as revealed in neuroimaging studies (Hull, 2002; Sheline, Wang, Gado, & Csernansky, 1996). In addition, postmortem studies have found evidence of downregulation of glucocorticoid receptors in patients who had mood disorders prior to death (Webster, Knable, O'Grady, Orthman, & Weickert, 2002) and of reduced expression of brain-derived neurotrophic factor and its receptor in persons who committed suicide (Dwivedi et al., 2003). Taken together, these data suggest that chronic psychological distress may contribute to late-life loss of cognition by causing neurodeteriorative changes in portions of the limbic system that help regulate affect and cognition, changes that do not leave a pathologic footprint (e.g., dendritic atrophy) or whose pathology is not recognizable with currently available methods. These changes, when extreme, might actually be sufficient to cause dementia, but it is more likely that they contribute to cognitive impairment and thereby increase the likelihood that other common age-related neuropathologies are clinically expressed as dementia. Further research is needed to investigate the neurobiological bases of the association of chronic distress with age-related cognitive impairment in humans, particularly because animal research suggests that some of the deleterious effects of chronic distress on the brain can be reduced by diverse means, including antidepressant medication (Shakesby, Anwyl, & Rowan, 2002; Wood, Young, Reagan, Chen, & McEwen, 2004), physical exercise (Adlard & Cotman, 2004), diet (Xu et al., 2006), and gene therapy (Nicholas, Munhoz, Ferguson, Campbell, & Sapolsky, 2006).

POSITIVE ATTITUDES AND BELIEFS

As we have just seen, adverse stress reactions, loneliness, neuroticism, depression, and negative emotions may be associated with greater risk for cognitive decline in old age. Is there evidence that other personality and attitudinal variables are positively associated with cognitive-enrichment effects and the maintenance of functioning in late life? The evidence for positive effects of attitudes and beliefs on adult cognition is much more limited and spotty. In this section, we review some of the available evidence. In large part, we argue that positive beliefs and attitudes may have important indirect effects on cognitive enrichment because of their influence on the kinds of behaviors (e.g., exercise, mentally stimulating activities) that are known to be associated with cognitive-enrichment effects.

One class of variables that should, in principle, be associated with positive outcomes includes the constructs of personal control and self-efficacy (e.g., Bandura, 1997). Self-efficacy can be broadly defined as the belief one has in one's own capability to achieve a desired goal in a particular situation. The closely related construct of personal control can be defined as the belief that a desired outcome is contingent on one's actions (Skinner, 1996). Although control beliefs can be construed in various ways, one critical aspect of the trait complex involving personal

control appears to be the belief that one has the means to achieve desired ends (e.g., Chapman, Skinner, & Baltes, 1990). A sense of personal control can be seen as implying that outcomes are contingent on one's behaviors and that one's behavioral repertoire includes means that can be competently executed to achieve outcomes. Given that social psychologists continue to argue about the differences and commonalities between self-efficacy and control, and about the best ways of construing the critical aspects of the constructs that matter for understanding behavior, we will not attempt to unravel these issues further here.

Why should these constructs relate to positive patterns of adult cognitive development? One reason is that research consistently shows that individuals who are high in self-efficacy and a sense of personal control are more likely to engage in the behaviors they believe will achieve desired goals. They are more likely to adhere to physician regimens, to be active in everyday life, and to maintain exercise programs (e.g., Marcus, Eaton, Rossi, & Harlow, 1994; Schwarzer, 2008). In general, Bandura (1997) argues that persons high in self-efficacy are low in performance anxiety, are more strategic in their efforts to achieve goals, and are more persistent in goal pursuit when faced with adversity or complicating circumstances. A high sense of personal agency and control may well lead to direct effects on cognitive performance (Berry, 1999; Hess, 2005) and everyday problem solving (Artistico, Cervone, & Pezzuti, 2003).

One crucial aspect of control and self-efficacy beliefs is the degree to which these constructs are seen as being a generalized trait or attribute that manifests broad cross-situational consistency or whether they are seen as specific to a given situation (and highly variable, within a person, across situations). Bandura and his colleagues emphasize that self-efficacy is grounded in the specific performance context one evaluates, and they measure self-efficacy with scales designed to assess the likelihood of achieving a goal in a particular context. This approach has the potential advantage of maximizing predictive validity for specific behaviors in specific contexts. However, a number of questionnaires also measure general self-efficacy beliefs (e.g., Paulhus, 1983). Questions on these scales typically ask about whether a person feels, in general, able to achieve goals they have set for themselves, without specific reference to a domain of behavior let alone to a specific context (see Hertzog, Park, Morrell, & Martin, 2000, for elaboration on these distinctions). To those who adhere to Bandura's contextual approach, such questionnaires are not measuring self-efficacy but rather a type of self-concept.

The available data on prediction of long-term cognitive functioning from self-efficacy is somewhat limited. As noted earlier, Albert et al. (1995) and Seeman, McAvay, Merrill, Albert, and Rodin (1996) reported that general self-efficacy beliefs regarding instrumental functioning were associated with lower rates of cognitive decline in the MacArthur Successful Aging studies. Seeman, Unger, McAvay, and Mendes de Leon (1999) also reported that instrumental self-efficacy beliefs were associated with self-reported functional disability, as measured by instrumental activities of daily living (e.g., personal care), but were not associated with measures of physical disability, including gait and balance. Such findings suggest that self-efficacy beliefs may have an impact on whether individuals maintain an active lifestyle, especially in the face of perceived physical disabilities associated with aging.

Timmer and Aartsen (2003) reported that general self-efficacy beliefs were associated with self-reported activities. However, Jopp and Hertzog (2007) found that general self-efficacy beliefs had no relationship to self-reported activities. In contrast, their results indicated domain-specific measures of memory self-efficacy were correlated with activities and also with cognitive performance, as measured by a number of different intellectual-ability and memory tests.

Such findings suggest that longitudinal changes in cognition could be associated with prior self-efficacy beliefs. In general, findings in this area are mixed. Some studies find associations of changes in cognition with memory complaints and self-efficacy beliefs (e.g., Lane & Zelinski, 2003), but other data suggest that self-reported memory beliefs and beliefs about changes in one's own memory have limited predictive validity for actual cognitive change (e.g., McDonald-Miszczak, Hertzog, & Hultsch, 1995). In part, the problem is that attitudes about aging and stereotypes about age-related decline in cognition could influence the changes in perceived memory ability. In that sense, growing older causes both changes in memory and changes in memory beliefs, but the changes in memory beliefs neither cause nor result from changes in memory. Furthermore, one could argue that any association between beliefs about cognition and cognition is an outcome rather than a cause. That is, it could reflect the degree to which beliefs are influenced by a person monitoring actual cognitive changes as they occur, rather than reflecting a direct impact of self-efficacy beliefs on cognition or of self-efficacy beliefs on variables that influence cognitive change (Hertzog & Hultsch, 2000; Jopp & Hertzog, 2007).

Self-efficacy theorists acknowledge the reciprocal nature of self-efficacy–cognition relationships (e.g., Bandura, 1989). Such influences make it difficult to assess the directional effect of self-efficacy on cognition. Given the central importance of effective cognitive functioning for well-being in older adults, it could also be the case that monitoring cognitive changes is a major influence on perceived disability and general self-efficacy.

Parallel issues regarding relationships of personal control beliefs to cognitive change arise. As with self-efficacy, questionnaires exist that inquire about a general sense of personal control and characterize persons in terms of whether they have an internal locus of control (outcomes depend upon my behavior) or an external locus of control (outcomes depend on factors outside of my control, including other persons or chance; Lefcourt, 1981). However, these general control scales typically show much lower correlations with specific behavior than do domain-specific control beliefs (e.g., Lachman, 1986). Measures

of personal control over one's own health better predict older adults' seeking of treatment for illness than do general control measures (Lachman, 1991). Likewise, general control beliefs often have low, nonsignificant correlations with cognition in adult samples, whereas measures of perceived control over cognition correlate reliably with cognitive performance (Hertzog & Hultsch, 2000; Lachman, 1991).

Do control beliefs influence activities and cognition? To our knowledge, no one has evaluated the domain-specific beliefs about control over different kinds of activities, and how those beliefs might change as a function of age-associated disease or disability. Such beliefs could be relevant to cessation or continuation of activities related to cognitive-enhancement effects. Jopp and Hertzog (2007) found that belief in personal control over memory was positively correlated with self-reported activities and with cognition. There is mixed evidence regarding the importance of control beliefs for influencing cognition, both immediately and in terms of long-term cognitive development. A critical variable for evaluating concurrent control–cognition relationships seems to be whether cognitive tasks require (or at least benefit from) self-initiated memory-task strategies. It appears that a sense of control over memory (e.g., "there are things I can do to influence my memory") is positively associated with spontaneous use of mnemonic strategies that aid memory performance (Hertzog, Dunlosky, & Robinson, 2008; Lachman & Andreoletti, 2006; Lachman, Andreoletti, & Pearman, 2006). Hertzog, Dunlosky, & Robinson (2008) also found a strong relationship between performance on measures of fluid and crystallized intelligence and memory-control beliefs. Control beliefs may also be related to self-regulation during cognitive tests (Riggs, Lachman, & Wingfield, 1997).

Control beliefs and self-efficacy predict cognitive performance and activities, but they are only one part of a larger set of interrelated traits and attributes that predict activities and cognition and that could account for cognitive-enrichment effects (e.g., Ackerman & Rolfhus, 1999). For example, recent research indicates that goal setting and planning are also important for initiating and maintaining physical-exercise routines (e.g., Armitage & Conner, 2000; Huang, Lee, & Chang, 2007; Scholz, Sniehotta, Schuez, & Oeberst, 2007). Having a specific plan for implementing a general intention may also differentiate those who exercise from those who do not (Chasteen, Park, & Schwarz, 2001; Gollwitzer, 1999; Schwarzer, 2008). Furthermore, personality variables that correlate with self-efficacy beliefs, especially conscientiousness (Pearman & Storandt, 2005), also correlate with physical activity and exercise adherence (Conner, Rodgers, & Murray, 2007; Huang et al., 2007; Ingledew, Markland, & Sheppard, 2004; Rhodes & Smith, 2006). Integrative models should consider a number of characteristics that combine to produce active lifestyles in older adults (Rhodes, Couneya, Blanchard, & Plotnikoff, 2007). For example, effective emotional self-regulation, as manifested in the construct of emotional intelligence, may also play a role (Saklofske, Austin, Rohr, & Andrews, 2007). Openness to Experience, especially its specific subfactor of Ideas, relates strongly to pursuit of intellectually engaging activities (Hultsch et al., 1999). A related construct, Typical Intellectual Engagement, has been shown to relate to knowledge acquisition and crystallized intelligence in older adults (Dellenbach & Zimprich, 2008).

Current theorizing about a positive psychology of aging emphasizes the importance of positive attitudes and beliefs (including but not limited to beliefs about agency and control) as relevant to whether individuals act to maintain high quality of life in the face of age-related and disease-related challenges. One can argue that active life management requires selection, optimization, and compensation processes to enable the older adult to construct the best possible quality of life given losses in aspects of functioning that accompany the aging process (Freund & Baltes, 2002). As reviewed by Riediger et al. (2006), there is evidence that selection and compensation behaviors in old age are positively associated with successful adaptations to aging and with specific criteria for positive psychological functioning, including well-being (e.g., Freund & Baltes, 1998).

More generally, theorists have argued that individuals who are optimistic, agreeable, open to experience, conscientious, positively motivated, and goal-directed are more likely to experience successful aging, to take advantage of opportunities, to cope more effectively with life circumstances, to effectively regulate emotional reactions to events, and to maintain a sense of well-being and life satisfaction in the face of challenge (Aldwin, Spiro, & Park, 2006; Frederickson, 2001; Segerstrom & Roach, 2008). Whether these variables are involved in a kind of general positive psychological profile of personality and attitudes that benefits adjustment in adulthood and old age is an interesting and open question, but preliminary research suggests that there are linkages between positive self-construal, goal strivings, and psychological adjustment (e.g., Sheldon & Kasser, 2001).

The construct of resilience has been discussed as being related to a trait complex that enables one to adjust to challenge and loss in ways that optimize functioning or compensate for loss (Greve & Staudinger, 2006). Research on resilience under stress suggests that maintaining positive affect and attitude in the face of adversity can help one adapt to negative life events (Zautra, 2003). For example, Ong and colleagues have shown that adaptation to events such as widowhood is assisted by experiencing positive affect and feelings of hope for the future (Ong, Bergeman, Bisconti, & Wallace, 2006; Ong, Edwards, & Bergeman, 2006). At present, we do not know whether an engaged lifestyle is associated with a general positive outlook on life, with resilience, or with other aspects of attitudes and personality. Nor do we know how this positive profile or profiles of attributes might help individuals maintain the kinds of physical, social, and intellectual activities that could enhance cognitive function in old age.

MULTIMODAL INFLUENCES ON COGNITION

As described in previous sections, the great majority of laboratory studies of factors that influence the level and trajectories of cognitive function focus on single factors. This is a reasonable scientific approach given the potential complexity and cost of simultaneously studying multiple interacting factors. However, clearly a disadvantage of such an approach is that it may miss the potential power of interactions for maintaining and enhancing cognition.

There are at least two different approaches to the study of multifactor influences on cognition that have been pursued in the literature. One approach is represented by the early study of complex or enriched environments on brain function and performance in animals (Black et al., 1990; Ehninger & Kempermann, 2003; Jones et al., 1996; Kempermann, 2008; Kempermann et al., 1997; Rosenzweig & Bennett, 1996). Such an approach can establish the influence of some combination of either separately acting or interacting factors such as social interaction, cognitive challenge, physical activity, and nutrition on performance and the brain. This approach cannot assess the relative contribution of individual factors (or their interaction). Nonetheless, such an approach has been instrumental in establishing the importance of potential lifestyle factors in cognitive maintenance and enhancement. A second approach that has been represented in observational studies for some time and is beginning to evolve in human and nonhuman interventions is the orthogonal examination of multiple factors and their interactions in separate groups of subjects. Such an approach is costly in terms of time and the number of subjects required. However, this approach also has the potential to decompose the relative benefits of different factors and their potential mechanisms. Studies that have pursued each of these approaches will be discussed below.

Prospective Observational Studies

A number of prospective observational studies, some of which we already reviewed in the context of single lifestyle factors, have investigated the relative contribution of intellectual, physical, and social engagement as predictors of cognitive change and transition to dementia. For example, Wilson and colleagues (Wilson, Mendes de Leon, et al., 2002; Wilson, Bennett, et al., 2002) reported that while participation in cognitive activities (such as reading, listening to the radio, playing games) reduced the risk of succumbing to Alzheimer's disease, participation in physical activities (such as jogging, gardening, bicycle riding, dancing) was unrelated to the development of Alzheimer's disease 4 years in the future (see also Verghese et al., 2006; Wang et al., 2006). Both the cognitive and physical activities were assessed via self-report, and while the cognitive activities were assessed relative to a 1-year time frame, physical activities were referenced to a 2-week period prior to the assessment.

A study by Sturman et al. (2006) is particularly interesting, because it addressed the question of whether, over a 6.4-year period, participation in physical activities by older adults reduces the rate of cognitive decline after accounting for participation in cognitively stimulating activities. Prior to adjustment for cognitive activities, each additional hour per week of physical activity was associated with a slower rate of cognitive decline. However, this relationship was no longer significant after adjusting for cognitive activities. On the other hand, Richards et al. (2003) reported that physical activity at 36 years of age was associated with a slower rate of decline in memory from 43 to 53 years of age and that this relationship was unchanged after adjusting for cognitive activities. Cognitive activities were not associated with change in memory over this interval.

The studies described above generally employ different activities to represent cognitive or physical demands. However, a recent study by Karp and colleagues (2006) has taken a different approach to examining the relative contribution to cognitive change and dementia of cognitive, physical, and social engagement. They argue that most leisure activities engage some combination of these three types of demands. On this basis, they had the researchers and a panel of older adults rate the relative intensity, on a scale of 0 to 3, of social, cognitive, and physical demands of a set of 30 leisure activities. Agreement was quite high among raters. As an example of the ratings, attending courses was rated 3, 1, and 2 for mental, physical, and social demands, respectively (with 3 being the most intense). These ratings were then applied to the activities pursued by 776 individuals over age 75 to predict diagnosis of dementia 6 years in the future. After adjusting for a variety of covariates, social, cognitive, and physical activities were each found to be associated with a reduced risk for dementia. In any event, characterizing leisure activities in terms of their multidimensional nature is an interesting and potentially important alternative to the dichotomous approach adopted by other observational studies.

In summary, in observational studies that examine more than one lifestyle factor, cognitive activities appear to be the strongest predictor of cognitive change. However, this could be the result of several factors, including the following: (a) Rarely are physical activities characterized in terms of intensity, frequency, and duration; (b) the period across which activities are assessed has been different for cognitive and physical activities; (c) with one exception, activities have been treated as unidimensional in nature. Clearly, these issues require additional consideration in future studies.

Human Intervention Studies

To our knowledge, there have been only two randomized trials that have examined the separate and combined influence of multiple lifestyle factors on the cognitive function of older adults. Both of these studies were conducted by the same re-

search group and involved two months of training with eight 60- to 75-year-old participants in each of four experimental groups. In both studies, subjects either participated in an aerobic-training group (walking and jogging), a memory-training group (including general encoding and retrieval instructions, association and attentional training), a combined group, and a control group. Fabre et al. (1999) found that all three training groups but not the control group showed improved performance on logical and paired-associate-memory tasks across the 2-month intervention. However, combined training did not show additional benefits as compared to aerobic or memory training by themselves. Fabre, Charmi, Mucci, Masse-Biron, and Prefaut (2002) used an elaborated memory-training protocol and a physical-training protocol similar to that used in their previous study; a more thorough assessment of changes in memory was also used. Results indicated improvements in a general memory metric in all three of the training groups. However, in this experiment, benefits were largest for the combined-training group.

The two studies described above attempted to decompose the relative contribution of cognitive training and physical training to improvement in cognitive function. A number of other human intervention trials have taken a multimodal approach, much like enriched-environment experiments with animals, in examining the influence of multiple lifestyle factors on cognition. The Experience Corps project, conducted at Johns Hopkins, is an example of one such project (Fried et al., 2004). This project places teams of older adults in inner-city elementary schools to address unmet needs. The older adult participants are trained to provide literacy, numeracy, library, and other support in kindergarten through third grade. After entering the program and completing training, the older adults devote at least 15 hours per week to the schools for an academic year. The Experience Corps program stresses a combination of social, cognitive, and physical-activity engagement in support activities in the schools. An intervention with 128 participants who were randomized to the Experience Corps program and a wait-list control group found that individuals with poor baseline executive function showed a 44 to 51% improvement in executive function and memory in the postintervention follow-up. These improvements were not observed for the control participants (Carlson et al., 2008). In another small randomized intervention (Carlson, Colcombe, Kramer, Mielke, & Fried, 2006), Experience Corps subjects, but not control subjects, displayed improved efficiency in brain activation, as indexed by event-related fMRI and performance in an inhibitory-control task.

Another recently completed multimodal intervention was conducted by Small et al. (2006). In this study, a small sample of middle-aged participants was randomized either to a 2-week healthy-lifestyle program or to a wait-list control group. Subjects in the healthy-lifestyle group, which included a healthy diet, physical exercise, relaxation training, and memory training, showed improvements in verbal fluency and decreases in activation in the left dorsolateral prefrontal cortex as assessed via positron emission tomography. Other multimodal interventions that have combined social and cognitive components have also shown training-specific benefits in cognition and psychosocial function as compared to wait-list control groups (Fernandez-Ballesteros, 2005; Stine-Morrow, Parisi, Morrow, Greene, & Park, 2007; Stuss et al., 2007).

In summary, thus far there are few studies that have systematically examined either the separate or combined contribution of multimodal interventions to enhanced cognitive and brain function in older adults. Clearly, the nature and mechanisms of multimodal intervention programs, particularly those like the Experience Corps project that can be implemented in community setting, are important topics for future longer-term studies (Park, Gutchess, Meade, & Stine-Morrow, 2007).

Multimodal Animal Research

As we described earlier, the great majority of animal studies that have examined the influence of multimodal interventions on brain function, learning, and memory have done so in the context of enriched or complex environments in which animals are often housed together with the opportunity for physical activity and exploration of a multitude of novel objects (Black et al., 1990; Ehninger & Kempermann, 2003; Jones et al., 1996; Kempermann et al., 1997; Rosenzweig & Bennett, 1996). These studies have generally found beneficial effects of this multimodal environment on brain structure, function, and performance. However, a smaller set of studies has examined the separate and joint contributions to brain health and cognition of different interventions.

Two studies have focused on the separate and combined effects of diet and cognitive training or exercise. Molteni et al. (2004) examined the effects of a high-fat diet and voluntary exercise on learning and a variety of molecules that support neural function. Female rats were randomized into four different groups created by combining a regular or high-fat diet with voluntary exercise or a sedentary environment. After two months of the interventions, the regular-diet/exercise group was found to show the fastest spatial learning on the Morris Water Maze task, followed by the regular-diet/sedentary and high-fat/exercise groups, with the high-fat/sedentary group showing the poorest learning. Additionally, a combination of a regular diet and exercise was observed to produce the largest increase in BDNF as compared to the regular diet/sedentary group. Furthermore, decreases in BDNF engendered by a high-fat diet were abolished by exercise. Thus, these data suggest that the costs of a high-fat diet can, under some conditions, be offset by regular exercise. Milgram et al. (2005) conducted a 2-year intervention with separate and combined diet (regular and enhanced antioxidant) and enriched (including discrimination training and exercise and a nonenriched control) conditions with older beagles. Both the antioxidant-diet and enriched-environment groups displayed a number of benefits in learning in memory

across a variety of discrimination tasks. Furthermore, the group that received both the antioxidant diet and the enriched environment showed the most dramatic benefits in learning and memory. Indeed, these data suggest there was reduced cognitive decline, over the 2-year period of the study, in the older dogs who received behavioral enrichment and/or dietary fortification with antioxidants.

Stranahan, Kahlil, and Gould (2006) examined the interaction between social isolation and exercise on neurogenesis in the hippocampus of adult male rats. Animals were either housed individually or in groups and either did or did not have access to a running wheel. Several interesting results were obtained. First, the positive effects of short-term running on neurogenesis in the adult hippocampus were found only in group-housed animals, not those that were housed individually. Furthermore, in the presence of additional stressors, the influence of short-term running was negative for the socially isolated animals, resulting in a net decrease in the number of neurons relative to sedentary animals. Second, group-housed runners produced the largest number of new neurons in the hippocampus. Finally, longer-duration running was able to enhance cell proliferation of the socially isolated animals but not to the level of group-housed animals.

In summary, the previously reviewed studies and others (Berchtold et al., 2001; Russo-Neustadt, Ryan, & Cotman, 1999) suggest potentially mutually interdependent relationships of a number of different lifestyle factors on brain and cognitive health of both young and older organisms. Clearly, however, although the extant literature provides some clues concerning the molecular and cellular pathways that support the interactive effects of different factors, much remains to be discovered in further research on multimodal interventions (Gobbo & O'Mara, 2006; Kempermann, 2008; Wolf et al., 2006).

SUMMARY: WHAT WE KNOW

We have reviewed a large number of studies across disparate areas of research. What can we say at this point about cognitive enrichment effects? The literature is far from definitive, which is no surprise given the inherent difficulties in empirically testing the enrichment hypothesis. However, we believe there is a strong and sound empirical basis for arguing that a variety of factors, including engaging in intellectually and mentally stimulating activities, both (a) slow rates of cognitive aging and (b) enhance levels of cognitive functioning in later life. It is also clear that a variety of variables, such as social isolation, neuroticism, and adverse stress reactions are risk factors for cognitive decline and incipient dementia in old age. There is much we do not yet know and need to know—a topic we take up shortly.

The evidence for different types of cognitive-enrichment effects varies in strength. The longitudinal evidence suggesting benefits of an intellectually engaged lifestyle may be the most controversial, because enrichment effect sizes tend to be small and studies vary in the quality of their assessment of cognition, the representativeness of their samples, and their ability to control for rival hypotheses. Likewise, the literature on cognitive training has only recently identified interventions that appear to produce some degree of transfer and generalization. Until recently, one would have concluded that the training literature indicates minimal transfer beyond the specific kinds of cognitive construct that is the target of training. Recent studies have persuaded us that training cognitive- and metacognitive-control strategies produces transfer effects and are thus encouraging as interventions for cognitive enrichment.

What is most impressive to us is the evidence demonstrating benefits of aerobic physical exercise on cognitive functioning in older adults. Such a conclusion would have been controversial in the not-too-distant past, but the evidence that has accumulated since 2000 from both human and animal studies argues overwhelmingly that aerobic exercise enhances cognitive function in older adults. The hypothesis of exercise-induced cognitive-enrichment effects is supported by longitudinal studies of predictors of cognitive decline and incidence of dementia, but also by short-term intervention studies in human and animal populations. The exercise-intervention work suggest relatively general cognitive benefits of aerobic exercise but indicates that cognitive tasks that require executive functioning, working memory, and attentional control are most likely to benefit.

Furthermore, research on exercise and enriched-environment effects with animal populations point to some of the possible mechanisms for these effects. Exercise and environmental enrichment lead to cell proliferation in critical areas of the central nervous system (CNS), including the dentate gyrus of the hippocampus, but they also promote a variety of positive changes in CNS function, including angiogenesis, synaptic growth, increased production of neurotrophins, and other forms of neural plasticity.

Why do our conclusions differ from those of Salthouse (2006), who argued there was little evidence favoring the enrichment hypothesis? There are several reasons. Salthouse (2006) based his conclusions on his own cross-sectional data with self-report measures of different types of intellectually stimulating activities. He did not review most of the available longitudinal evidence, restricting his coverage to arguments against the longitudinal evidence provided by Schooler and colleagues (e.g., Schooler, Mulatu, & Oates, 1999). Salthouse's critique was based primarily on the construct validity of Schooler's measures of cognition (see Schooler, 2007). In particular, Salthouse (2006) did not cite the kinds of longitudinal studies reviewed in this monograph that have produced evidence favoring the enrichment hypothesis.

To ignore this longitudinal evidence is to discount some of the strongest evidence for cognitive-enrichment effects. As we noted earlier, the sensitivity of cross-sectional studies to detect differential benefits of activities, including exercise, across the

life span is probably low, for a variety of methodological reasons. To some degree, the problem may be one of limited statistical power to detect small interaction effects in cross-sectional data (see Hertzog, in press, for further discussion of this issue).

One influence limiting the magnitude of effect sizes is the typical use of somewhat crude self-report measures of activities that do not scale intellectual challenge or aerobic-exercise benefits in ways that validly measure individual differences in challenge and potential benefit. Salthouse (2006) notes some of the problems with these self-report measures. We agree that they are subject to concerns about construct validity and contaminating influences of social desirability and self-enhancement effects. Certainly, failure to detect enrichment effects in cross-sectional data, when defined by different age slopes in cognition, is not specific to Salthouse's work. Jopp and Hertzog (2007) also found no evidence of Age × Activity interactions in their cross-sectional data. However, the very same activity scale used by Jopp and Hertzog (2007) that detected no Age × Activity interactions on cognition produced differential cognitive change as a function of activity in the longitudinal study of Hultsch et al. (1999).

Salthouse et al. (2002) actually found Age × Activity interactions for crystallized intelligence but dismissed them as acculturation effects that were not paralleled in measures of fluid intelligence, working memory, and the like. In our view, enhancements due to gains of new knowledge are an important part of an overall picture of the beneficial effects of different types of activities (Hertzog, in press). As noted earlier, actual cognition in real-life contexts is critically dependent on knowledge and experience. Nevertheless, we agree that the effects on fluid-like cognitive abilities are far more important than effects on crystallized intelligence for the general form of the cognitive-enrichment hypothesis.

It is also useful to remember that the criterion of Age × Activity interactions advocated by Salthouse (2006) may not be necessary to produce important cognitive-enrichment effects for intellectually stimulating activities. To the extent that one's goal is to maximize the period of productive benefits of cognitive functioning, then anything that acts to raise the level of cognitive functioning defers the point in time when cognitive decline reaches levels that have negative functional consequences for productive work and autonomous functioning in society. With reference back to Figure 2, we would argue that cognitive-enrichment effects that raise the level of cognitive function are just as important, functionally speaking, as effects that alter the rates of change over the life course. Furthermore, the amount of cognitive enrichment needed to resist age-related decline at high levels of functioning may be disproportionately higher than the amount of enrichment needed to resist decline at lower levels of functioning. Therefore, the absence of Age × Activity interactions in cross-sectional data does not preclude the presence of cognitive enrichment.

On the other hand, one might discount our conclusions on the basis of methodological issues in longitudinal research, such as contaminating influences of practice effects. We have dealt with these issues already, and will not revisit them in detail here. Our view is that the longitudinal results suggesting differential change in persons who are active are not a methodological artifact. For example, enrichment effects have been found in studies that use schemes for dealing with practice effects, such as rotating alternate forms (Hultsch et al., 1999) and data-analytic techniques minimizing the effects of error on measuring change (Lövdén et al., 2005). The generality of the results across these different methods argues against item-specific learning and practice effects as the confounded source of cognitive-enrichment effects. Moreover, the exercise-intervention studies and animal population studies provide strong corroborative evidence for enrichment effects for social and physical activities. Such findings are important because they partly address the concern that correlations of changes in cognition and changes in activity could reflect limiting effects of impaired cognition on activities rather than long-term enrichment effects. The epidemiological evidence on long-term longitudinal outcomes and the results of lagged regression models suggesting strong effects of activities on cognition also weigh in favor of the cognitive-enrichment hypothesis.

We certainly agree with Salthouse (2006) that more evidence is needed to cement the case for enrichment effects, to address some apparent discrepancies between work on cognitive-training effects (with limited breadth of transfer) and cognitive-enrichment effects (which appear to be rather broad-spectrum and general in their scope). Most importantly, new research is needed to definitively identify the mechanisms that explain enrichment effects and the parameters that optimize such effects across the adult life span. However, our view is that the current evidence is sufficiently strong to warrant a discussion of the implications of cognitive-enrichment effects for public policy. We now turn to a discussion of the larger policy implications of our review, including especially a discussion about the specific needs for further research that will increase our knowledge and clarify outstanding issues in this area.

RESEARCH AGENDA

Our critical review of the literature on cognitive-enrichment studies with older human and nonhuman participants has suggested that a number of activities including exercise or physical activity, intellectual engagement, and social engagement have shown promise in either reducing cognitive decline, delaying the onset of age-associated neurodegenerative diseases, or enhancing aspects of cognition in older adults. However, as is the case with any nascent field of study, the extant research literature raises a number of important theoretical and practical questions that provide the basis for a future research agenda.

Observational Studies

Measurement of Activities

Most of the available evidence on cognitive enrichment through an active lifestyle rests on retrospective reports of activity frequency (e.g., Hultsch et al., 1993). As Salthouse (2006) noted, there are interesting measurement issues with these self-reports, because frequency estimation is a fallible process and the multiple-item scales do not encourage the kind of thoughtful reconstruction that maximizes validity of the self-reports (e.g., Jobe & Mingay, 1991). An open question, then, is the construct validity of these questionnaires. Jopp and Hertzog (2008), for instance, considered the content coverage of the Hultsch et al. (1993) questionnaire in the social-activity and physical-activity domains to be limited, and added items targeting these facets (see also Parslow, Jorm, Christensen, & Mackinnon, 2006). There is a need for alternative methods (e.g., intensive time sampling through activity diaries, use of beeper technology to sample activities, direct observation, concurrent use of informant reports) that would produce evidence on the validity of standard retrospective-questionnaire scales. Latent-variable models can address the problem of random measurement error, but any model assessing different facets of activity from the same questionnaire inevitably includes systematic measurement-error variance in the latent variable. Measurement studies could assist the field by inventing multimethod approaches to measuring activities in different domains.

Prospective Longitudinal Studies

The bulk of the evidence on cognitive enrichment comes from prospective observational longitudinal designs, in which individuals are followed over time and activities and cognition are assessed at fixed time intervals. Although evidence favorable to the enrichment hypothesis is accumulating, three general research areas urgently require additional attention.

Ruling Out Rival Explanations. As we noted in our review, evidence favoring the enrichment hypothesis from observational studies is inherently correlational in nature. For the most part, this is inevitable (although see Tranter & Koutstaal, 2008, for a small-scale activity-intervention program with some reported success). However, it is critical that additional research be undertaken that puts the cognitive-enrichment hypothesis at risk by testing alternative accounts. Although we considered and argued against rival explanations for enrichment effects in the literature, what is needed is new empirical research explicitly designed to test alternative explanations in a more definitive manner.

For example, the argument that the predictive validity of activities for subsequent cognitive change is an artifact of decline (as discussed earlier) can be assessed by large-scale longitudinal studies that target activity benefits for cognition in midlife, prior to major onset of age-related changes and subclinical dementia. Furthermore, better evidence is needed on the dose-response functions relating activities to cognition, as well as on the differential benefits of some constellations of activities over others. Is physical activity only beneficial when it produces aerobic challenges to the body and brain? Is it the case that intellectually engaging activities provide the best benefits, as would be expected from some brain-plasticity-based accounts, or is it really the case that a generically active lifestyle provides generic cognitive benefits? Does social stimulation set the stage for intellectually stimulating activities to have benefits (e.g., in social interactions or in group activities) or does it operate as a facilitator in its own right? There is enough variability in designs, measures, and outcomes to render it difficult to make convincing claims about cognitive enrichment from available observational studies. It may well be time for the implementation of large-scale, multisite longitudinal studies with probability sampling to enable sufficient initial sample size and a standardized set of target constructs and measures to address more refined questions about activity-related benefits.

Attention to the sensitivity of current statistical models is also needed to be able to examine cognitive-enrichment effects. For instance, recent applications of the bivariate dual-change score model to longitudinal data from older adult samples have claimed that activities cause cognitive change but that the reverse is not true (e.g., Ghisletta, Bickel, & Lövdén, 2006; Lövdén et al., 2005). This is a surprising outcome, because one might have expected mutual effects in old-age samples, given the likelihood that terminal decline would adversely affect both cognition and activities (e.g., Hultsch et al., 1999). Such outcomes lead one to question whether there are attrition issues or statistical artifacts of these complex models that produce evidence of a causal effect of activities on cognition but not vice versa. A critical problem with two-variable models is the issue of omitted variables, and hence one would like to see extensions of these results to include static and dynamic covariates that might alter the lagged dynamic regression coefficients (and hence, the interpretation that activity causes cognitive change). There is also a critical need for statistical-simulation work in these contexts that determines how misspecified models might lead to erroneous conclusions. Likewise, with the more complex mixed-effect regression models we reviewed, there can be concerns about statistical artifacts, such as reduced power through the use of observed variables rather than latent variables in the regression models (Hertzog et al., 2006). We need a better understanding about how results from our complex models are informative or perhaps misleading (Hertzog & Nesselroade, 2003).

Understanding Mediating and Moderating Mechanisms. Although research evaluating specific mediating mechanisms for enrichment effects (e.g., exercise interventions) has been done, little attention has been paid to the idea of including measures of possible mediators in prospective longitudinal studies. For example, the results we briefly reviewed on the effects of stress and

cortisol secretion on brain functioning in adulthood suggest that there would be benefit in measuring stress reactivity and metabolic outcomes in the context of studies of social integration, activity, and cognitive functioning. Nor have such studies typically included genetic biomarkers that may be related to individual differences in neurogenesis, synaptogenesis, and the like that may set the stage for benefits from cognitively enriching activities. Studies with interesting biological covariates are often limited in terms of cognitive measurements or scaling of activities; studies measuring potential biological mechanisms are often hampered by inadequate instrumentation of cognition and activities. Likewise, adding information on variables like vital capacity, blood pressure, and other easily obtained measures of physiological status may help explain benefits of self-reported physical exercise.

As noted earlier, too little is known also about the extent to which personality traits, positive attitudes, and positive beliefs foster healthy lifestyles that facilitate cognitive enrichment. Most of the epidemiological research has focused on effects of neuroticism and related constructs, showing definite relationships of low neuroticism with enrichment effects. But other aspects of attitudes and beliefs that foster maintenance of an active lifestyle, particularly with respect to adaptation to loss or life stress, have received little attention. Constructs like conscientiousness, goal-setting, and implementation behaviors have been shown to predict exercise behavior in older and younger adults, but these variables have typically not been incorporated into studies of cognitive-enrichment effects in old age.

Implementing Alternative Research Designs. Most of the available evidence about cognitive enrichment relies on longitudinal panel designs, with fixed and infrequently spaced time intervals for measurement. Such designs do not assess people in a way that is directly linked to the timing of critical events, so that they are measured before, during, and after critical life events (e.g., coronary infarctions, major illnesses, death of a spouse, falls, new caregiving requirements) that may have major impact on psychological function and that may lead to major changes in activity patterns and cognition. Yet this kind of data is precisely what is needed to separate some explanations of longitudinal cognition–activity correlations from others. Hence there is a need for more intensive intraindividual studies that enable a more fine-grained understanding of different endogenous cycles of cognition–activity relations.

Measurement-burst designs are an important means to this end, because they allow evaluation of activity–cognition relations in the context of intraindividual flux and variability, not merely long-term changes. Research on the relationship of stress to working-memory performance, for instance, finds reliable correlations of within-person variability of stress and working memory—that is, how ups and downs in stress within a person relate to ups and downs in working-memory performance (e.g., Sliwinski, Smyth, Hofer, & Stawski, 2006). When an individual's stress increases, his or her working-memory performance decreases; conversely, when an individual's stress level is lowered, working-memory performance improves. Interestingly, these within-person correlations of stress and working memory may be larger than more traditional between-person correlations—that is, those that assess whether an individual with chronic high stress, on average, has lower working-memory performance than a person with chronic low stress levels (Sliwinski et al., 2006). Such outcomes point to the need for intensive intraindividual designs with long-term follow-ups as a means of gaining leverage on the cognitive-enrichment hypothesis. It could be the case that increases in enrichment activities raise a person's cognitive performance but that these within-person effects do not have a major impact on individual differences in cognition. We will return to this point after discussing training and intervention studies.

Training and Intervention Studies

With regard to the literature already reviewed, it is clear that both younger and older adults benefit from practice and training, although not always to the same extent. It is also the case, with a few notable exceptions (e.g., Bherer et al., 2006; Edwards et al., 2002; Jennings et al., 2005; Kramer, Larish, et al., 1999; Stuss et al., 2007; Willis et al., 2006), that transfer-of-training effects are relatively narrow. That is, training of skills relevant for one ability has not generally been found to improve performance on other abilities (e.g., Ball et al., 2002). The exceptions point to interesting avenues for further research. Jennings et al. (2005) showed transfer of training in their memory-control task to other memory tasks in which the same control processes were relevant to performance. Likewise, the successes with attentional-control training (e.g., Bherer et al., 2006, 2008) in achieving transfer involves tasks in which executive control in dividing attention or task-switching should generalize to tasks with dissimilar content but similar processing demands. Training cognitive-control strategies, including attentional control and metacognitive self-regulation, may prove to have more broad generalizability to cognitive task environments than training approaches that teach specific strategies relevant to specific cognitive tasks.

Transfer and Generalization

With respect to transfer effects, cognitive-enrichment effects due to exercise have been observed to be substantially broader than those observed for most cognitive-training protocols (e.g., Colcombe & Kramer, 2003). Therefore, one important question is under what conditions can cognitive abilities, skills, or procedures be trained such as to enhance the breadth of training to both a broader set of laboratory tasks and, perhaps more importantly, to real-world tasks and skills. To the extent that training acts to change beliefs or habits of thinking that are broadly involved in cognition, they have more potential for

generalization across cognition in different contexts. Training approaches that target executive control, use of attention to enhance encoding, speed-of-processing training to overcome response conservatism, or conscious cognitive control (such as with metacognitive skills) may have a chance for broader transfer because these mechanisms can be helpful in a wide variety of cognitive contexts. Research that focuses explicitly on how to train individuals to consider, evaluate, and apply the tools they have learned in new contexts may be required to create the broadest range of transfer to new situations.

In this regard, little attention has yet been paid to the issue of skills training relevant to cognitive self-management in everyday life. Appropriately, our review has focused on training studies that have potential for cognitive enrichment. But taking the broadest possible view, it could be the case that providing individuals with techniques that assist with life management may boost their morale, positive affect, self-efficacy, and perceived control, with derivative benefits for both their quality of life and their engagement in a broader range of cognitively enriching activities. For example, encouraging the use of spaced retrieval when confronted with the need to learn new names may assist in effective social networking and reduce avoidance of social situations. Similarly, training individuals with strategies to combat failures of prospective memory—remembering to act on intentions—may have more benefit in everyday life than training standard memorization techniques. These approaches could produce better cognitive-enrichment effects, but at present we do not know, because interventions targeting cognition in everyday life are relatively rare.

It may also be the case that belief-restructuring paradigms should routinely be added to training regimens to promote maintenance and transfer in everyday life. Recently, West, Bagwell, and Dark-Freudeman (2008) showed that an intervention that targeted negative age stereotypes and promoted self-efficacy—combined with strategy training—had beneficial effects on older adults' memory performance. Belief-restructuring approaches on their own have not been shown to produce maintenance of training benefits (e.g., Lachman, Weaver, Bandura, Elliott, & Lewkowicz, 1992), but this may be due to the discouraging effects of everyday cognitive failures and the chronic accessibility of attributions of failure to cognitive aging. Programs that combine effective techniques for assisting everyday cognition with belief restructuring may have the best chances of long-term success (Stigsdottir Neely & Bäckman, 1993).

Parametric Studies of Predictors of Training Benefit

In addition to the issue of transfer of trained skills, systematic studies are also needed to explore the contribution, both separately and together, of other important training parameters such as the intensity, frequency, duration, and schedule of practice (e.g., massed versus distributed practice, type and frequency of feedback, etc.) on the rate of learning, level of mastery, and retention of trained skills. Clearly, one important question is how best to adapt training for older individuals given this population's substantial variability in life-history trajectories, genotypes, and cognitive and physical functioning.

More broadly, it is important to further explore different models of intervention effects on the cognitive processes of older adults. Some previous studies have adopted what might be termed an inoculation or vaccination model. That is, a single "dose" of an intervention is provided, occasionally followed by a small number of refresher doses (e.g., Ball et al., 2002; Willis et al., 2006). Assessment of retention and transfer is then carried out at several points in the future. It seems obvious that this approach would be ineffective with physical-exercise interventions. Physical exercise can only provide benefit, in the largest sense, when it has become a regular and frequent event that is part of the lifestyle of an individual. A massive exercise-training program without a sustained change in exercise behavior will have little long-term benefit. An open question is whether this type of approach should be effective in producing cognitive-training benefits. What we don't yet know is how to optimize both initial intervention experiences as well as the frequency, intensity, and duration of refresher or booster follow-up interventions. It may be the case that existing training studies don't invest enough time and effort to make new procedures that they train well-learned or routinized prior to cessation of training. Modest levels of training may not overcome the tendency of individuals not to continue to practice and develop new skills outside of the training environment. Treating interventions as one-shot inoculations, however intensive, may not be as effective as creating contexts in which newly trained procedures are reinforced by contact with trainers and others, communication about challenges to implementing the procedures in everyday life, and instruction in how to overcome those challenges by adapting trained procedures to contextual variations.

Indeed, strategies for embedding refresher training into everyday leisure, work, or volunteer activities, as have been developed for the Experience Corp program conducted at Johns Hopkins (Fried et al., 2004)—especially with regards to enhancing adherence (McAuley et al., 2007) to an intervention regimen—is an important topic for future research. It could well be the case, for example, that the group experience in an intervention like Experience Corps provides important social reinforcement for maintaining intellectually engaging activities. Another general issue is the relationship of the timing of interventions across the life span to cognitive function in old age. How early in the life span should cognitively oriented interventions be started? Is there an optimal sequence of different interventions in relation to other lifestyle choices? Is there a point of no return, in terms of age or physical or cognitive disability, in which cognitive interventions show little or no effect on the enhancement or maintenance of cognition? Answering such questions will enable us to more intelligently structure formal and informal educational programs throughout the life

span to decrease cognitive deterioration and enhance quality of life for our older citizens.

Long-Term Follow-Up Studies of Maintenance

There is a need for longitudinal follow-ups to intervention research. Years ago, Schaie and Willis (1986) demonstrated the benefits of conducting training research on persons with well-characterized histories of cognitive change, assessed longitudinally. They showed that training gains were just as likely with persons who showed prior history of age-related cognitive decline as they were with persons who had shown maintenance of functioning. However, there is relatively little evidence from studies following people who have experienced major interventions over long periods of time. With few exceptions, the main focus of research on cognitive enhancement has been cross-sectional in nature, providing a snapshot of the effectiveness of different interventions at different points in the life span. While such designs provide valuable insights into the strategies for cognitive enhancement, they cannot easily disambiguate cohort effects or address whether intervention strategies have meaningful long-term effects on cognitive maintenance and enhancement. To this end, we believe it important that both more extended interventions with diverse populations, ideally across national boundaries, and much more extended follow-ups, over the course of decades, are necessary to enhance our knowledge concerning cognitive enhancement across the life span.

Salthouse (2006) has claimed that one can only evaluate the benefits of mental-exercise-program interventions with very-long-term follow-up studies that show sustained and continuing benefits; one should not overgeneralize from positive results in short-term interventions. With respect to physical exercise, one could only expect continuing benefits in those who continue to exercise, and the same may be true of mental exercise as well. Nevertheless, the point is well taken. Long-term follow-up of people who exercise, compared to well-matched controls who do not, would be important evidence for the long-term benefits of aerobic fitness on health outcomes, including cognitive functioning.

Multimodal Interventions

We also suggest that multimodal interventions (Carlson et al., 2008; Noice & Noice, 2006; Stine-Morrow et al., 2007), especially those in which training is provided in real-world meaningful settings (e.g., Experience Corps), merit additional examination. We believe that the assessments of multimodal interventions are important both with regard to the comparison of their efficacy to more targeted unimodal interventions as well as for their potential to maintain high levels of participation in stimulating, cognitively enriching activities both in the time frame of formal interventions and following the cessation of the interventions. Given the nature of these interventions and their potential to influence many aspects of cognitive, brain, and psychosocial function, assessment batteries for both retention and transfer will likely need to be broader than assessment batteries typically selected for more targeted interventions. Of course, as with the more traditional unimodal interventions, questions of when, how much, how often, and, in the present case, in which sequence components of the intervention should be implemented will require systematic study.

Midlife Interventions and Long-Term Maintenance

A critical issue for future research will be to understand how an engaged lifestyle can be promoted and implemented in midlife, during the working years. There is some evidence that complexity of work and its intellectual demands may be related to better cognitive development in midlife and old age (Schooler et al., 1999). At issue, however, is the extent to which an engaged lifestyle can coordinate stimulating and beneficial activities in leisure time as well as during work, so as to optimize human development. Given inevitable conflicts between work demands and time available for other roles (e.g., parenting) and activities, it would be useful to know whether work-related activity programs (e.g., availability and use of physical-exercise facilities at or near the workplace) could help foster an enriching lifestyle.

In general, specific attention needs to be paid to the issue of how interventions in midlife could be structured to promote and enhance health and well-being, productivity, and cognitive development. At present we know more about what can be done to create short-term gain in older populations than we do about effective interventions at earlier points in the life span. Harking back to Figure 2, it could well be the case that optimizing functioning in early and middle adulthood puts an individual on a life-course trajectory that would be far more beneficial, in terms of optimal cognitive functioning, than any altered trajectory produced by a late-life intervention, no matter how successful. Furthermore, crafting effective interventions in midlife with persons still employed full time may require different principles and approaches for maximizing benefit with contrainted opportunities for time investment. It could well be the case, for example, that time-management training would need to be added to the intervention to assure that individuals who are challenged by multiple-role strain can create the time they need for physical exercise or for intellectually stimulating activities. Finally, research on midlife interventions would also enable evaluation of the kind of long-term maintenance and differential long-term benefits alluded to above. Targeted multimodal interventions, followed by longitudinal assessment of psychological and physiological status over extended periods, would produce data that are critically needed to understand the scope and nature of cognitive-enrichment effects.

Biological Mechanisms of Enrichment Effects

Our understanding of the mechanisms supporting cognitive enhancement, within and across molecular, cellular, and

psychological levels of description, is still fragile and incomplete. Furthermore, we have little understanding of the potential common or separate mechanisms that support different lifestyle choices (or interventions). We believe that further understanding of cognitive-enhancement mechanisms will require attention to multiple levels of analysis. In human populations, behavioral measures of activities will need to be linked to physiological functioning, both systemically and in the CNS specifically (e.g., with MRI, fMRI, electroencephalography/magnetoencephalography, event-related brain potentials, diffusion tensor imaging, positron emission tomography, magnetic resonance spectroscopy, event-related optical imaging, chemical shift imaging, transcranial magnetic stimulation, and more). Is an intellectually engaged lifestyle associated with morphological changes in the human brain? To what extent does the benefit of intellectual, physical, and social activities involve changes in biological systems? Is it associated with changes in experienced stress, reduced catabolic effects of cortisol, and the like—that is, protection against risk factors for brain health? Or is it more associated with direct, positive effects on the organization of the brain itself? As we noted in the section on training interventions, there is a need for research demonstrating that changes in brain function, morphology, and biochemistry are due to activities that have long-term benefits. In particular, is it possible to demonstrate that populations of older adults differing in history of activity also differ in their status of brain functioning?

In part, more satisfying answers to these questions will require strong links between animal models and research with human populations, in concert with computational models. Molecular, genetic, and histological techniques that are unethical in human populations can be used in animals to delineate the chemical and anatomical substrates of enrichment effects. In humans, performance and brain activity on analogous tasks can be assessed to establish mechanistic connections to animal models. In many cases, computational models may provide the appropriate level of abstraction to delineate commonalities in mechanism and network dynamics. Finally, as emphasized throughout this monograph, the core of the cognitive-enrichment hypothesis is longitudinal, positing beneficial effects of earlier lifestyle choices and affordances on late-life outcomes. Thus, a substantial portion of both the animal research and investigations in human populations will need to be longitudinal, investigating the effects of earlier behavioral ecologies on late-life cognition, both at neuronal and behavioral levels of analysis.

PUBLIC POLICY IMPLICATIONS

We conclude this monograph with a brief discussion of several ideas about the policy implications of cognitive-enrichment effects. We caution that none of us are experts in public policy, health-service administration, or other related fields. Hence our policy-implications statement should be regarded as food for thought for those who understand better than us the limitations in mapping scientific findings onto their public-policy implications.

Encouraging Successful Aging Through Cognitive Enrichment

Taken together, the available evidence from animal models, aerobic-fitness interventions, some of the cognitive interventions, and epidemiological studies lends support to the hypothesis that a cognitively enriched lifestyle can influence the course of intellectual development in late adulthood and old age. Specifically, such a lifestyle may attenuate cognitive decline in late adulthood and old age, extend the ability to lead an independent life, and postpone the onset of a dementing illness. The available evidence does not permit a precise quantification of enrichment benefits for aging individuals and an aging society, from an economic perspective. The chief reason for this statement is that there has been relatively little work on the practical long-term benefits of enrichment. Given at least some evidence that training programs may be associated with improvements in functional status (e.g., Willis et al., 2006), it is certainly the case that the potential for reducing morbidity and dependence in older populations through long-term cognitive enrichment programs is real. Note, also, that any reduction in or deferral of the need for assisted living, however small, would improve personal well-being and reduce health-care costs at individual and societal levels.

We believe that cognitive enrichment effects accrue when an active, engaged person includes enhancing activities as part of a larger lifestyle. There is no magic pill or no one-shot vaccine that inoculates the individual against the possibility of cognitive decline in old age. As noted earlier, participation in intervention programs is unlikely to affect long-term outcomes unless the relevant behaviors are continued over time. Thus, public policy regarding cognitive enrichment should follow a health prevention model. Specifically, it should focus on the sustainability and maintenance of cognitive enrichment. This includes the promotion of intellectual activities that are inherently meaningful for older adults, perhaps as embedded in larger social contexts (e.g., Experience Corps, the elderhostel movement, and adult continuing education). Given the strong preference of older adults to remain in independent living situations, persuading the public that an active lifestyle maximizes the duration of independent living may be key to improving, at a societal level, adults' lifestyle practices. Research on adherence to lifestyle changes in different domains, including exercise, suggests that activities that increase a sense of agency and that provide mastery experiences are self-reinforcing and are most likely to lead to creation of the integrated and sustained lifestyle that is probably needed to realize cognitive enrichment.

The Marketing of Cognitive Enrichment

A major issue at present is that businesses and entrepreneurs are moving aggressively to market products allegedly able to

preserve the mind and the brain. For example, Nintendo has been quite successful in promoting their cognitive- and brain-training software packages such as Brain Age and Brain Age^2 (the Web site http://www.sharpbrains.com/ provides a description and discussion of brain-training software, as well as a market report for these software products). An interesting public policy issue is whether and how claims of product benefits can be evaluated. General claims that using a computer training program or game or solving certain kinds of puzzles will lead to enhanced brain function are difficult to prove or disprove. Having said that, we would argue that the efficacy of software marketed as enhancing cognition and/or the brain needs to be empirically validated and reported according to scientific standards of good practice (see Mahncke, Bronstone, & Merzenich, 2006, for an initial effort in this direction, albeit one that lacks some important features of experimental control and analysis). The majority of software programs marketed as enhancing cognition or brain function lack supporting empirical evidence for training and transfer effects. Clearly, there is a need to introduce standards of good practice in this area. Software developers should be urged to report the reliability and validity of the trained tasks, the magnitude of training effects, the scope and maintenance of transfer to untrained tasks, and the population to which effects are likely to generalize. Arriving at this information requires experiments with random assignment to treatment and control groups, and an adequate sample description. Just as the pharmaceutical industry is required to show benefit and provide evidence regarding potential side-effects, companies marketing cognitive-enhancement products should be required to provide empirical evidence of product effectiveness. There is undoubtedly a parallel in this emerging part of the market to alternative medicine, a history that includes failed attempts by the U.S. Food and Drug Administration to regulate the marketing of herbal supplements and vitamins. Some would claim, in response, that regulatory oversight by industry or government might inhibit product development. One can also claim that there is little harm done in using such software, so the potential for worrisome side effects is minimal, thereby weighing against the need for product evaluation. (But consider that the time spent playing unproven computer training programs and games may reduce time spent in intellectual and exercise activities with clearer benefits.) Nevertheless, attention to this issue by society as a whole is needed.

Design and Technology for Older Adults

Psychologists need to enter a dialogue with people from disparate domains to help determine how to best promote cognitive enrichment. Psychologists, clinicians, sociologists, urban planners, engineers, economists, and philosophers need to engage in a dialogue to suggest scenarios and products for cognitively enriched environments that integrate different periods of the life span and allow individuals so stay in their homes as long as possible (e.g., living in place). Technology will play a key role in this effort, as a means both for cognitive stimulation and for environmental support (Lindenberger, Lövdén, Schellenbach, Li, & Krüger, 2008; Pew & Van Hamel, 2004). The proportion of older individuals living in computerized households is increasing steadily, offering novel opportunities for cognitive training even as those households supply levels of support tailored to the level of an individual's functioning that would have seemed impossible just a few years ago. At the same time, development of technologically supportive and enriching environments can raise privacy issues, as well as concerns about whether well-intentioned support and service provision would also involve loss of autonomy and personal control.

Cautionary Notes

We close this final section with two notes of caution regarding cognitive-enrichment effects. First, although we have offered comments regarding policy implications, we wish to avoid leaving readers with the impression that the evidence on cognitive enrichment is overwhelming and that the case is closed. Clearly, what we do not know still exceeds what we do know. However, our society is proceeding forward as if the case is closed, and public policy will need to understand that reality and attend to it. There is sufficient evidence favoring cognitive-enrichment effects to encourage these kinds of dialogues.

Second, cognitive enrichment is not a panacea against the risk of cognitive decline and dementia. We do not know what the limits on interventions are, because those limits have not yet been tested. What we do know is that the effect sizes for cognitive-enrichment effects that have been observed to date—often involving the examination of a single factor or lifestyle variable—are small relative to the large individual differences in cognitive functioning. Moreover, at least at the present time, biological-aging mechanisms that influence brain functioning can only be delayed, not prevented. A wide range of variables can lead to cognitive decline, and not all of these influences can be addressed by behavioral interventions that produce cognitive-enrichment effects. Our point has been that enrichment effects can have positive benefits even when they do not address the underlying cause of incipient cognitive decline. For instance, physical activity can delay the onset of cognitive loss associated with dementia and normal aging. Nevertheless, an active lifestyle may not provide much protection from a wide variety of negative influences on cognitive morbidity and mortality in old age.

Recognizing the apparent duality of enrichment phenomena—their benefit in the face of inexorable aging processes—is important. Given the staggering health-care costs in the United States, an individual's failure to engage in positive lifestyles that promote cognition might be viewed as similar to other negative behaviors (e.g., nicotine addiction, alcoholism) that raise health-care expenditures. An analogy can be made to

obesity as a risk factor for many diseases, such as Type 2 diabetes and hypertension. To the extent that individuals' behaviors are seen as a proximal cause of the risk factor, they can be viewed as responsible, at least in part, for creating the problem the health-care system must address. In principle, insurance companies, corporations, and other employers could implement schemes that reward those who engage in activities that enhance cognitive fitness or punish those who do not, justified by the putative health-care costs that ensue from neglecting to maintain an active lifestyle. Make no mistake; discussion about how to promote cognitive fitness is justified based on our reading of the literature. Public campaigns have raised public awareness about the risks of tobacco consumption and have influenced prevalence of its use, and similar efforts may lead to better fitness, more active engagement in life, and so on, with derivative benefits. Nevertheless, as a society we must be careful to avoid the fallacy of "blaming the victim"—that is, of assuming that cognitive decline in old age is essentially a consequence of personal neglect. Even individuals who engage in optimal enrichment behaviors will probably experience adverse cognitive changes at some point in the end-game of life, and wellness practices that increase longevity and vitality can do so only on a probabilistic basis.

CONCLUSION

The next decades offer much promise for expanding our knowledge about aging and cognition. We may soon discover whether the limits on successful cognitive functioning in old age that were once seen as insurmountable can ultimately be viewed as pessimistic assumptions that focused on observable age-related decline rather than on the potential for maximizing human performance through cognitive enrichment. As new cohorts of adults enter old age, it is important that society adjusts its attitudes and practices to foster integrity, autonomy, and functional capability of older adults, at the same time that it modifies governmental policies to adjust to the new demands and pressures the changing composition of the population will create. Just as advances in medical science may lead to increased longevity through vehicles such as effective treatments for dementing illnesses, advances in psychological science can make important contributions to improving the quality of life of long-living older adults, in part by empirically demonstrating that attitudes and behaviors can promote cognitive functioning in old age and, more generally, by showing how behavioral interventions can contribute to optimizing successful aging.

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REFERENCES

Aartsen, M.J., Smits, C.H.M., van Tilburg, T., Knipscheer, K.C.P.M., & Deeg, D.J.H. (2002). Activity in older adults: Cause or consequence of cognitive functioning? A longitudinal study on everyday activities and cognitive performance in older adults. *Journals of Gerontology: Psychological Sciences*, *57*, P153–P162.

Abbott, R.D., White, L.R., Ross, G.W., Masaki, K.H., Curb, J.D., & Petrovitch, H. (2004). Walking and dementia in physically capable men. *Journal of the American Medical Association*, *292*, 1447–1453.

Ackerman, P.L. (2000). Domain-specific knowledge as the "dark matter" of adult intelligence: Gf/Gc personality and interest correlates. *Journal of Gerontology: Psychological Sciences*, *55*, P69–P84.

Ackerman, P.L., & Rolfhus, E.L. (1999). The locus of adult intelligence: Knowledge, abilities, and nonability traits. *Psychology and Aging*, *14*, 314–330.

Adlard, P.A., & Cotman, C.W. (2004). Voluntary exercise protects against stress-induced decreases in brain-derived neurotrophic factor protein expression. *Neuroscience*, *124*, 985–992.

Albert, M., Blacker, D., Moss, M.B., Tanzi, R., & McArdle, J.J. (2007). Longitudinal change in cognitive performance among individuals with mild cognitive impairment. *Neuropsychology*, *21*, 158–169.

Albert, M.S., Jones, K., Savage, C.R., Berkman, L., Seeman, T., Blazer, D., et al. (1995). Predictors of cognitive change in older persons. MacArthur Studies of Successful Aging. *Psychology & Aging*, *10*, 578–589.

Aldwin, C.M., Spiro, A., III, & Park, C.L. (2006). Health, behavior, and optimal aging: A life-span developmental perspective. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (6th ed, pp. 85–104). San Diego, CA: Academic Press.

Allemand, M., Zimprich, D., & Hertzog, C. (2007). Cross-sectional age differences and longitudinal age changes of personality in middle adulthood and old age. *Journal of Personality*, *75*, 323–358.

Almeida, O.P., Norman, P., Hankey, G., Jamrozik, K., & Flicker, L. (2006). Successful mental health aging: Results from a longitudinal study of older Australian men. *American Journal of Geriatric Psychiatry*, *14*, 27–35.

Anders, T.R., Fozard, J.L., & Lillyquist, T.D. (1972). Effects of age upon retrieval from short-term memory. *Developmental Psychology*, *6*, 214–217.

Andrews-Hanna, J.R., Snyder, A.Z., Vincent, J.L., Lustig, C., Head, D., Raichle, M.E., & Buckner, R.L. (2007). Disruption of large-scale systems in advanced aging. *Neuron*, *56*, 924–935.

Arbuckle, T., Gold, D., Chaikelson, J., & Lapidus, S. (1994). Measurement of activity in the elderly: The activities checklist. *Canadian Journal on Aging*, *13*, 550–565.

Arbuckle, T.Y., Maag, U., Pushkar, D., & Chaikelson, J.S. (1998). Individual differences in trajectory of intellectual development over 45 years of adulthood. *Psychology and Aging*, *13*, 663–675.

Armitage, C.J., & Conner, M. (2000). Social cognition models and health behaviour: A structured review. *Psychology and Health*, *15*, 173–189.

Artistico, D., Cervone, D., & Pezzuti, L. (2003). Perceived self-efficacy and everyday problem solving among young and older adults. *Psychology and Aging*, *18*, 68–79.

Arvanitakis, Z., Wilson, R.S., & Bennett, D.A. (2006). Diabetes mellitus, dementia, and cognitive function in older persons. *Journal of Nutrition Health & Aging*, *10*, 287–291.

Aslan, A., Vrabiescu, A., Domilescu, C., Campeanu, L., Costiniu, M., & Stanescu, S. (1965). Long-term treatment with procaine (Gerovital H3) in albino rats. *Journal of Gerontology*, *20*, 1–8.

Avolio, B.J., & Waldman, D.A. (1990). An examination of age and cognitive test performance across job complexity and occupational types. *Journal of Applied Psychology*, *75*, 43–50.

Bäckman, L. (1989). Varieties of memory compensation by older adults in episodic remembering. In L.W. Poon, D.C. Rubin, & B.A. Wilson (Eds.), *Everyday cognition in adulthood and late life* (pp. 509–544). Cambridge, England: Cambridge University Press.

Bäckman, L., & Dixon, R.A. (1987). Psychological compensation: A theoretical framework. *Psychological Bulletin*, *112*, 259–283.

Bäckman, L., Josephsson, S., Herlitz, A., Stigsdotter, A., & Viitanen, M. (1991). The generalizability of training gains in dementia: Effects of an imagery-based mnemonic on face-name retention duration. *Psychology and Aging*, *6*, 489–492.

Bäckman, L., Nyberg, L., Lindenberger, U., Li, S.-C., & Farde, L. (2006). The correlative triad among aging, dopamine, and cognition: Current status and future prospects. *Neuroscience and Biobehavioral Reviews*, *30*, 791–807.

Ball, K., Berch, D.B., Helmer, K.F., Jobe, J.B., Leveck, M.D., Marsiske, M., et al. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *Journal of the American Medical Association*, *288*, 2271–2281.

Ball, K., Edwards, J.D., & Ross, L.A. (2007). The impact of speed of processing training on cognitive and everyday functions. *Journal of Gerontology: Psychological Sciences*, *62B*(Special Issue I), 19–31.

Baltes, M.M., Kühl, K.-P., & Sowarka, D. (1992). Testing for limits of cognitive reserve capacity: A promising strategy for early diagnosis of dementia? *Journals of Gerontology: Psychological Sciences*, *47*, P165–P167.

Baltes, M.M., Kühl, K.-P., Sowarka, D., & Gutzmann, H. (1995). Potential of cognitive plasticity as a diagnostic instrument: A cross-validation and extension. *Psychology and Aging*, *10*, 167–172.

Baltes, M.M., Maas, I., Wilms, H.-U., Borchelt, M., & Little, T.D. (1999). Everyday competence in old and very old age: Theoretical considerations and empirical findings. In P.B. Baltes & K.U. Mayer (Eds.), *The Berlin Aging Study: Aging from 70 to 100* (pp. 384–402). New York: Cambridge University Press.

Baltes, P.B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. *Developmental Psychology*, *23*, 611–626.

Baltes, P.B. (1997). On the incomplete architecture of human ontogeny: Selection, optimization, and compensation as a foundation for developmental theory. *American Psychologist*, *52*, 366–380.

Baltes, P.B., & Baltes, M.M. (Eds.). (1990). *Successful aging: Perspectives from the behavioral sciences*. Cambridge, England: Cambridge University Press.

Baltes, P.B., & Kliegl, R. (1992). Further testing of limits of cognitive plasticity: Negative age differences in a mnemonic skill are robust. *Developmental Psychology*, *28*, 121–125.

Baltes, P.B., & Labouvie, G.V. (1973). Adult development of intellectual performance: Description, explanation, and modification. In C. Eisdorfer & M.P. Lawton (Eds.), *The psychology of adult development and aging* (pp. 157–219). Washington, DC: American Psychological Association.

Baltes, P.B., & Lindenberger, U. (1988). On the range of cognitive plasticity in old age as a function of experience: 15 years of intervention research. *Behavior Therapy*, *19*, 283–300.

Baltes, P.B., Lindenberger, U., & Staudinger, U.M. (2006). Lifespan theory in developmental psychology. In W. Damon & R.M. Lerner (Eds.), *Handbook of child psychology* (6th ed. Vol. 1, pp. 569–664). New York: Wiley.

Baltes, P.B., & Nesselroade, J.R. (1979). History and rationale of longitudinal research. In J.R. Nesselroade & P.B. Baltes (Eds.), *Longitudinal research in the study of behavior and development* (pp. 1–39). New York: Academic Press.

Baltes, P.B., Reese, H.W., & Nesselroade, J.R. (1988). *Life-span developmental psychology: Introduction to research methods*. Hillsdale,NJ: Erlbaum.

Baltes, P.B., Reuter-Lorenz, P., & Rösler, F. (Eds.). (2006). *Lifespan development and the brain. The perspective of biocultural co-constructivism*. Cambridge, England: Cambridge University Press.

Baltes, P.B., & Willis, S.L. (1982). Plasticity and enhancement of intellectual functioning in old age: Penn State's Adult Development and Enrichment Project (ADEPT). In F.I.M. Craik & S.E. Trehub (Eds.), *Aging and cognitive processes* (pp. 353–389). New York: Plenum Press.

Baltes, P.B., & Willis, S.W. (1977). Toward psychological theories of aging and development. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 128–154). New York: Van Nostrand Reinhold.

Bandura, A. (1989). Regulation of cognitive processes through self-efficacy. *Developmental Psychology*, *25*, 729–735.

Bandura, A. (1997). *Self efficacy: The exercise of control*. New York: Freeman.

Barefoot, J.C., Mortensen, E.L., Helms, M.J., Avlund, K., & Schroll, M. (2001). A longitudinal study of gender differences in depressive symptoms from age 50 to 80. *Psychology and Aging*, *16*, 342–345.

Barnes, D.E., Alexopoulos, G.S., Lopez, O.L., Williamson, J.D., & Yaffe, K. (2006). Depressive symptoms, vascular disease, and mild cognitive impairment. *Archives of General Psychiatry*, *63*, 273–280.

Barnes, D.E., Yaffe, K., Satariano, W.A., & Tager, I.B. (2003). A longitudinal study of cardiorespiratory fitness and cognitive function in healthy older adults. *Journal of the American Geriatrics Society*, *51*, 459–465.

Barnes, L.L., Mendes de Leon, C.F., Wilson, R.S., Bienias, J.L., & Evans, D.A. (2004). Social resources and cognitive decline in a population of older African Americans and Whites. *Neurology*, *63*, 2322–2326.

Baron, A., & Mattila, W. (1989). Response slowing of older adults: Effects of time-limit contingencies on single and dual-task performance. *Psychology and Aging*, *4*, 66–72.

Bartlett, F.C. (1932). *Remembering. A study in experimental and social psychology*. Cambridge, England: Cambridge University Press.

Basak, C., Boot, W.R., Voss, M.W., & Kramer, A.F. (2008). Can training in a real-time strategy videogame attenuate cognitive decline in older adults? *Psychology and Aging*, *23*, 765–777.

Bassuk, S.S., Berkman, L.F., & Wypij, D. (1998). Depressive symptomatology and incident cognitive decline in an elderly community sample. *Archives of General Psychiatry*, *55*, 1073–1081.

Bassuk, S.S., Glass, T.A., & Berkman, L.F. (1999). Social disengagement and incident cognitive decline in community-dwelling elderly persons. *Annals of Internal Medicine*, *131*, 165–173.

Batha, K., & Carroll, M. (2007). Metacognitive training aids decision making. *Australian Journal of Psychology*, *59*, 64–69.

Beier, M., & Ackerman, P.L. (2005). Age, ability, and the role of prior knowledge on the acquisition of new domain knowledge: Promising results in a real-world learning environment. *Psychology and Aging*, *20*, 341–355.

Bennett, D.A., Schneider, J.A., Tang, Y., Arnold, S.E., & Wilson, R.S. (2006). The effect of social networks on the relation between Alzheimer's disease pathology and level of cognitive function in old people: A longitudinal cohort study. *Lancet Neurology*, *5*, 406–412.

Bennett, D.A., Schneider, J.A., Wilson, R.S., Bienias, J.L., & Arnold, S.E. (2005a). Mild cognitive impairment is related to Alzheimer's disease pathology and cerebral infarctions. *Neurology*, *64*, 834–841.

Bennett, D.A., Schneider, J.A., Wilson, R.S., Bienias, J.L., & Arnold, S.E. (2005b). Education modifies the association of amyloid but not tangles with cognitive function. *Neurology*, *65*, 953–955.

Bennett, D.A., Wilson, R.S., Schneider, J.A., Bienias, J.L., & Arnold, S.E. (2004). Cerebral infarctions and the relationship of depressive symptoms to level of cognitive functioning in older persons. *American Journal of Geriatric Psychiatry*, *12*, 211–219.

Bennett, D.A., Wilson, R.S., Schneider, J.A., Evans, D.A., Mendes de Leon, C.F., Arnold, S.E., et al. (2003). Education modifies the relation of AD pathology to level of cognitive function in older persons. *Neurology*, *60*, 1909–1915.

Berchtold, N.C., Kesslak, J.P., & Cotman, C.W. (2002). Hippocampal brain-derived neurotrophic factor gene regulation by exercise and the medial septum. *Journal of Neuroscience Research*, *68*, 511–521.

Berchtold, N.C., Kesslak, J.P., Pike, C.J., Adlard, P.A., & Cotman, C.W. (2001). Estrogen and exercise interact to regulate brain-derived neurotropic factor MMA and protein expression in the hippocampus. *European Journal of Neuroscience*, *14*, 1992–2002.

Berger, A.K., Fratiglioni, L., Forsell, Y., Winblad, B., & Backman, L. (1999). The occurrence of depressive symptoms in the preclinical phase of AD: A population-based study. *Neurology*, *53*, 1998–2002.

Berry, J.M. (1999). Memory self-efficacy in its social cognitive context. In T.M. Hess & F. Blanchard-Fields (Eds.), *Social cognition and aging* (pp. 69–96). San Diego, CA: Academic Press.

Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control? *Psychology and Aging*, *20*, 695–709.

Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K., & Becic, E. (2006). Testing the limits of cognitive plasticity in older adults: Application to attentional control. *Acta Psychologica*, *123*, 261–278.

Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task set cost and dual task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research*, *34*, 188–219.

Bickel, H., & Cooper, B. (1994). Incidence and relative risk of dementia in an urban elderly population. *Psychological Medicine*, *24*, 179–192.

Birren, J.E. (1964). *The psychology of aging*. Englewood Cliffs, NJ: Prentice-Hall.

Birren, J.E. (1970). Toward an experimental psychology of aging. *American Psychologist*, *25*, 124–135.

Bissig, D., & Lustig, C. (2007). Who benefits from memory training? *Psychological Science*, *18*, 720–726.

Black, J.E., Isaacs, K.R., Anderson, B.J., Alcantara, A.A., & Greenough, W.T. (1990). Learning causes synaptogenesis, whereas motor activity causes angiogenesis, in cerebellar cortex of adult rats. *Proceedings of the National Academy of Sciences, USA*, *87*, 5568–5572.

Blomstrand, E., Perret, D., Parry-Billings, M., & Newsholme, E.A. (1989). Effect of sustained exercise on plasma amino acid concentrations on 5-hydroxytryptamine metabolism in six different brain regions in the rat. *Acta Physiologica Scandanavia*, *136*, 473–481.

Blumenthal, J.A., Emery, C.F., Madden, D.J., Schniebolk, S., Walsh-Riddle, M., George, L.K., et al. (1991). Long-term effects of exercise on psychological functioning in older men and women. *Journal of Gerontology: Psychological Sciences*, *46*, 352–361.

Borgatta, E.F. (1964). The structure of personality characteristics. *Behavioral Science*, *9*, 8–17.

Bosma, H., van Boxtel, M.P., Ponds, R.W., Jelicic, M., Houx, P., Metsemakers, J., et al. (2002). Engaged lifestyle and cognitive function in middle and old-aged, non-demented persons: A reciprocal association? *Zeitschrift für Gerontologie und Geriatrie*, *35*, 575–581.

Brandtstädter, J. (2006). Action perspectives on human development. In W. Damon & R.M. Lerner (Eds.), *Handbook of child psychology. Theoretical models of human development* (6th ed Vol. 1, pp. 516–568). New York: Wiley.

Brehmer, Y., Li, S.C., Müller, V., von Oertzen, T., & Lindenberger, U. (2007). Memory plasticity across the life span: Uncovering children's latent potential. *Developmental Psychology*, *43*, 465–478.

Brehmer, Y., Li, S.-C., Straube, B., Stoll, G., von Oertzen, T., Müller, V., & Lindenberger, U. (2008). Comparing memory skill maintenance across the lifespan: Preservation in adults, increase in children. *Psychology and Aging*, *23*, 227–238.

Brim, O.G. Jr. (1992). *Ambition: How we manage success and failure throughout our lives*. New York: Basic Books.

Brown, J., Cooper-Kuhn, C.M., Kemperman, G., van Praag, H., Winkler, J., Gage, F.H., et al. (2003). Enriched environment and physical activity stimulate hippocampal but not olfactory bulb neurogenesis. *European Journal of Neuroscience*, *17*, 2042–2046.

Bruandet, A., Richard, F., Bombois, S., Maurage, C.A., Masse, I., Amouyel, P., & Pasquier, F. (2008). Cognitive decline and survival in Alzheimer's disease according to education level. *Dementia and Geriatric Cognitive Disorders*, *25*, 74–80.

Bruner, J. (1986). *Actual minds, possible worlds*. Cambridge, MA: Harvard University Press.

Buchman, A.S., Schneider, J.A., Wilson, R.S., Bienias, J.L., & Bennett, D.A. (2006). Body mass index in older persons is associated with Alzheimer's disease pathology. *Neurology*, *67*, 1949–1954.

Buchman, AS., Wilson, R.S., Bienias, J.L., Shah, R.C., Evans, D.A., & Bennett, D.A. (2005). Change in body mass index (BMI) and risk of incident Alzheimer's disease (AD). *Neurology*, *65*, 892–897.

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging*, *17*, 85–100.

Cabeza, R., Nyberg, L., & Park, D. (Eds.). (2005). *Cognitive neuroscience of aging: Linking cognitive and cerebral aging*. New York: Oxford University Press.

Cacioppo, J.T. (2002). Social neuroscience: Understanding the pieces fosters understanding the whole and vice versa. *American Psychologist*, *57*, 819–831.

Cacioppo, J.T., Bernston, G.G., Lorig, T.S., Norris, C.J., Rickett, E., & Nusbaum, H. (2003). Just because you're imaging the brain doesn't mean you can stop using your head: A primer and set of first principles. *Journal of Personality and Social Psychology*, *85*, 650–661.

Cacioppo, J.T., Hughes, M.E., Waite, L.J., Hawkley, L.C., & Thisted, R.A. (2006). Loneliness as a specific risk factor for depressive symptoms: Cross-sectional and longitudinal analyses. *Psychology and Aging*, *21*, 140–151.

Camp, C.J., Foss, J.W., O'Hanlon, A.M., & Stevens, A.B. (1996). Memory interventions for persons with dementia. *Applied Cognitive Psychology*, *10*, 193–210.

Carlson, M.C., Colcombe, S.J., Kramer, A.F., Mielke, M., & Fried, L.P. (2006). Exploring effects of experience corps on neurocognitive function. Paper presented at the Cognitive Aging Conference, Atlanta, GA.

Carlson, M.C., Saczynski, J.S., Rebok, G.W., Seeman, T., Glass, T.A., McGill, S., et al. (2008). Exploring the effects of an everyday activity program on executive function and memory in older adults: Experience Corps. *The Gerontologist*, *48*, 793–801.

Carroll, J.B. (1993). *Human cognitive abilities: A survey of factor analytic studies*. Cambridge, England: Cambridge University Press.

Carver, C.S., & Scheier, M.F. (1998). *On the self-regulation of behavior*. New York: Cambridge University Press.

Caspi, A., Roberts, B.W., & Shiner, R.L. (2005). Personality development: Stability and change. *Annual Review of Psychology*, *56*, 453–484.

Cattell, R.B. (1971). *Abilities. Their structure, growth, and action*. Boston: Houghton Mifflin.

Chapman, M., Skinner, E.A., & Baltes, P.B. (1990). Interpreting correlations between children's perceived control and cognitive performance: Control, agency, or means-ends beliefs? *Developmental Psychology*, *26*, 246–253.

Charness, N. (1981). Aging and skilled problem solving. *Journal of Experimental Psychology: General*, *110*, 21–38.

Charness, N. (2006). The influence of work and occupation on brain development. In P.B. Baltes, P.A. Reuter-Lorenz, & F. Rösler (Eds.), *Lifespan development and the brain: The perspective of biocultural co-constructivism* (pp. 255–276). New York: Cambridge University Press.

Chasteen, A.L., Park, D.C., & Schwarz, N. (2001). Implementation intentions and facilitation of prospective memory. *Psychological Science*, *12*, 457–461.

Cherry, K.E., Simmons, S.S., & Camp, C.J. (1999). Spaced retrieval enhances memory in older adults with probable Alzheimer's disease. *Journal of Clinical Gerontology*, *5*, 159–175.

Chopra, D. (2001). *Grow younger, live longer: 10 steps to reverse aging*. New York: Random House.

Christensen, H., & Mackinnon, A. (1993). The association between mental, social, and physical activity and cognitive performance in young and old subjects. *Age and Ageing*, *22*, 175–182.

Chugani, H.T., Phelps, M.E., & Mazziotta, J.C. (1987). Positron emission tomography study of human brain functional development. *Annals of Neurology*, *22*, 487–497.

Cianciolo, A.T., Grigorenko, E.L., Jarvin, L., Gil, G., Drebot, M.E., & Sternberg, R.J. (2006). Practical intelligence and tacit knowledge: Advances in the measurement of developing expertise. *Learning and Individual Differences*, *16*, 235–253.

Clancy, S.M., & Hoyer, W.J. (1994). Age and skill in visual search. *Developmental Psychology*, *30*, 545–552.

Cohen, J. (1988). *Statistical power analysis for the social sciences*. Hillsdale, NJ: Erlbaum.

Cohen, J. (1994). The earth is round ($p < .05$). *American Psychologist*, *49*, 997–1003.

Cohen, J., Cohen, P., West, S.G., & Aiken, L.S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). Mahwah, NJ: Erlbaum.

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

Colcombe, S.J., Erickson, K.I., Scalf, P., Kim, J., Wadhwa, R., McAuley, E., et al. (2006). Aerobic exercise training increases brain volume in aging humans: Evidence from a randomized clinical trial. *Journal of Gerontology: Medical Sciences*, *61B*, M1166–M1170.

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

Colcombe, S.J., Kramer, A.F., Erickson, K.I., & Scalf, P. (2005). The implications of cortical recruitment and brain morphology for individual differences in cognitive performance in aging humans. *Psychology and Aging*, *20*, 363–375.

Colcombe, S.J., Kramer, A.F., Erickson, K.I., Scalf, P., McAuley, E., Cohen, N.J., et al. (2004). Cardiovascular fitness, cortical plasticity, and aging. *Proceedings of the National Academy of Sciences, USA*, *101*, 3316–3321.

Colonia-Willner, R. (1998). Practical intelligence at work: Relationships between aging and cognitive efficiency among managers in a bank environment. *Psychology and Aging*, *13*, 45–57.

Conner, M., Rodgers, W.M., & Murray, T. (2007). Conscientiousness and the intention-behavior relationship: Predicting exercise behavior. *Journal of Sports and Exercise Psychology*, *29*, 518–533.

Cornoni-Huntley, J., Brock, D.B., Ostfeld, A.M., Taylor, J.O., & Wallace, R.B. (Eds.). (1986). *Established populations for epidemiologic studies of the elderly resource data book*. Washington, DC: US Government Printing Office.

Costa, P.T., & McCrae, R.R. (1992). *Revised NEO personality inventory (NEO-PI-R) and NEO five-factor inventory (NEO-FFI) professional manual*. Odessa, FL: Psychological Assessment Resources.

Costa, P.T., & McCrae, R.R. (1998). Personality in adulthood: A six-year longitudinal study of self-reports and spouse ratings on the NEO personality inventory. *Journal of Personality and Social Psychology*, *54*, 853–863.

Cotman, C.W. (1995). *Synaptic plasticity*. New York: Guilford.

Cotman, C.W., Berchtold, N.C., & Christie, B.R. (2007). Exercise builds brain health: Key roles of growth factor cascades and inflammation. *Trends in Neurosciences*, *30*, 464–472.

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

Craik, F.I.M., & Jennings, J.M. (1992). Human memory. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 51–110). Hillsdale, NJ: Erlbaum.

Crowe, M., Andel, R., Pedersen, N.L., Johansson, B., & Gatz, M. (2003). Does participation in leisure activities lead to reduced risk of Alzheimer's disease? A prospective study of Swedish twins. *Journal of Gerontology: Psychological Sciences*, *58B*, P249–P255.

Cukierman, T., Gerstein, H.C., & Williamson, J.D. (2005). Cognitive decline and dementia in diabetes: Systematic overview of prospective observational studies. *Diabetologia*, *48*, 2460–2469.

Cummings, J., Vinters, H., Cole, G., & Khachaturian, Z. (1998). Alzheimer's disease: Etiologies, pathophysiology, cognitive reserve, and treatment opportunities. *Neurology*, *51*(Suppl. 1), S2–S17.

Dahlin, E., Stigsdotter-Neely, A., Larsson, A., Bäckman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science*, *320*, 1510–1512.

Dal Forno, G., Palermo, M.T., Donohue, J.E., Karagiozis, H., Zonderman, A.B., & Kawas, C.H. (2005). Depressive symptoms, sex, and risk for Alzheimer's disease. *Annals of Neurology*, *57*, 381–387.

Daliento, L., Mapelli, D., & Volpe, B. (2006). Measurement of cognitive outcome and quality of life in congenital heart disease. *Heart*, *92*, 569–574.

Dark-Freudeman, A., West, R.L., & Viverito, K.M. (2006). Future selves and aging: Older adults' memory fears. *Educational Gerontology*, *32*, 85–109.

Davey, A., Halverson, C.F., Zonderman, A.B., & Costa, P.T. (2004). Change in depressive symptoms in the Baltimore Longitudinal Study of Aging. *Journal of Gerontology: Psychological Sciences*, *59B*, P270–P277.

de Beurs, E., Beekman, A.T.F., Deeg, D.J.H., van Dyck, R., & van Tilburg, W. (2000). Predictors of change in anxiety symptoms of older persons: Results from the Longitudinal Aging Study of Amsterdam. *Psychological Medicine*, *30*, 515–527.

Delaney, P.F., Reder, L.M., Staszewski, J.J., & Ritter, F.E. (1998). The strategy-specific nature of improvement: The power law applies by strategy within task. *Psychological Science*, *9*, 1–7.

Dellenbach, M., & Zimprich, D. (2008). Typical intellectual engagement and cognition in old age. *Aging, Neuropsychology, and Cognition*, *27*, 6–15.

Denney, N.W. (1984). A model of cognitive development across the life span. *Developmental Review*, *4*, 171–191.

Devanand, D.P., Sano, M., Tang, M.X., Taylor, S., Gurland, B.J., Wilder, D., et al. (1996). Depressed mood and the incidence of Alzheimer's disease in the elderly living in the community. *Archives of General Psychiatry*, *53*, 175–182.

Dik, M.G., Deeg, D.J.H., Visser, M., & Jonker, C. (2003). Early life activity and cognition in old age. *Journal of Clinical and Experimental Neuropsychology*, *25*, 643–653.

Dikmen, S.S., Heaton, R.K., Grant, I., & Temkin, N.R. (1999). Test-retest reliability and practice effects of Expanded Halstead-Reitan Neuropsychological Test Battery. *Journal of the International Neuropsychological Society*, *5*, 346–356.

Ding, Y.H., Luan, X.D., Li, J., Rafoals, J.A., Guthinkonda, M., Diaz, F.G., & Ding, Y. (2004). Exercise-induced overexpression of angiogenic factors and reduction of ischemia/reperfusion injury in stroke. *Current Neurovascular Research*, *1*, 411–420.

Dishman, R.K., Berthoud, H.R., Boot, F.W., Cotman, C.W., Edgerton, V.R., Fleshner, M.R., et al. (2006). The neurobiology of exercise. *Obesity Research*, *14*, 345–356.

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Changes in grey matter induced by training. *Nature*, *427*, 311–312.

Draganski, B., Gaser, C., Kempermann, G., Kuhn, H.G., Winkler, J., Büchel, C., et al. (2006). Temporal and spatial dynamics of brain structure changes during extensive learning. *Journal of Neuroscience*, *26*, 6314–6317.

Driscoll, I., Resnick, S.M., Troncoso, J.C., An, Y., O'Brien, R., & Zonderman, A.B. (2006). Impact of Alzheimer's pathology on cognitive trajectories of nondemented elderly. *Annals of Neurology*, *60*, 688–695.

Dufouil, C., Fuhrer, R., Dartigues, J.F., & Alperovitch, A. (1996). Longitudinal analysis of the association between depressive symptomatology and cognitive deterioration. *American Journal of Epidemiology*, *144*, 634–641.

Duncan, J., Emslie, H., Williams, P., Johnson, R., & Freer, C. (1996). Intelligence and the frontal lobe: The organization of goal-directed behavior. *Cognitive Psychology*, *30*, 257–303.

Dunlosky, J., Cavallini, E., Roth, H., McGuire, C.L., Vecchi, T., & Hertzog, C. (2007). Do self-monitoring interventions improve older adults' learning? *Journal of Gerontology: Psychological Sciences*, *62B*(Special Issue I), 70–76.

Dunlosky, J., Hertzog, C., Kennedy, M.R.T., & Thiede, K.W. (2005). The self-monitoring approach for effective learning. *Cognitive Technology*, *10*, 4–11.

Dunlosky, J., Hertzog, C., & Powell-Moman, A. (2005). The contribution of five mediator-based deficiencies to age-related differences in associative learning. *Developmental Psychology*, *41*, 389–400.

Dunlosky, J., Kubat-Silman, A., & Hertzog, C. (2003). Training metacognitive skills improves older adults' associative learning. *Psychology and Aging*, *18*, 340–345.

Dustman, R.E., Ruhling, R.O., Russell, R.M., Shearer, D.E., Bonekat, H.W., Shigeoka, J.W., et al. (1984). Aerobic exercise training and improved neuropsychological function of older individuals. *Neurobiology of Aging*, *5*, 35–42.

Dwivedi, Y., Rizavi, H.S., Conley, R.R., Roberts, R.C., Tamminga, C.A., & Pandey, G.N. (2003). Altered gene expression of brain-derived neurotrophic factor and receptor tyrosine kinase b in post-mortem brain of suicide subjects. *Archives of General Psychiatry*, *60*, 804–815.

Edelman, G.M. (1987). *Neural Darwinism: The theory of neuronal group selection*. New York: Basic Books.

Edwards, J.D., Wadley, V.G., Myers, R.S., Roenker, D.L., Cissell, G.M., & Ball, K.K. (2002). Transfer of a speed of processing intervention to near and far cognitive functions. *Gerontology*, *48*, 329–340.

Ehninger, D., & Kempermann, G. (2003). Regional effects of wheel running and environmental enrichment on cell genesis and microglia proliferation in the adult murine neocortex. *Cerebral Cortex*, *13*, 845–851.

Einstein, G.O., & McDaniel, M.A. (2004). *Memory fitness: A guide for successful aging*. New Haven, CT: Yale University Press.

Elliott, E., & Lachman, M.E. (1989). Enhancing memory by modifying control beliefs, attributions, and performance goals in the elderly. In P.S. Fry (Ed.), *Psychological perspectives of helplessness and control in the elderly* (pp. 339–367). Oxford, England: North-Holland.

Embretson, S.E., & Reise, S.P. (2000). *Item response theory for psychologists*. Mahwah, NJ: Erlbaum.

Emery, C.F., Shermer, R.L., Hauck, E.R., Hsiao, E.T., & MacIntyre, N.R. (2003). Cognitive and psychological outcomes of exercise in a 1-year follow-up study of patients with chronic obstructive pulmonary disease. *Health Psychology*, *22*, 598–604.

Erickson, K.I., Colcombe, S.J., Elavsky, S., McAuley, E., Korol, D.L., Scalf, P.E., et al. (2007). Interactive effects of fitness and hormone replacement treatment on brain health in postmenopausal women. *Neurobiology of Aging*, *28*, 179–185.

Erickson, K.I., Colcombe, S.J., Wadhwa, R., Bherer, L., Peterson, M.S., Scalf, P.E., et al. (2007). Training-induced plasticity in older adults: Effects of training on hemispheric asymmetry. *Neurobiology of Aging*, *28*, 272–283.

Ericsson, K.A. (2006). The influence of experience and deliberate practice on the development of superior expert performance. In

K.A. Ericsson, N. Charness, P.J. Feltovich, & R.R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 683–703). Cambridge, England: Cambridge University Press.

Ericsson, K.A., & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist*, *49*, 725–747.

Ericsson, K.A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, *102*, 211–245.

Etnier, J.L., & Berry, M. (2001). Fluid intelligence in an older COPD sample after short and long term exercise. *Medicine & Science in Sports & Exercise*, *33*, 1620–1628.

Etnier, J.L., Nowell, P.M., Landers, D.M., & Sibley, B.A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews*, *52*, 119–130.

Evans, D.A., Hebert, L.E., Beckett, L.A., Scherr, P.A., Albert, M.S., Chown, M.J., et al. (1997). Education and other measures of socioeconomic status and risk of incident Alzheimer disease in a defined population of older persons. *Archives of Neurology*, *54*, 1399–1405.

Eysenck, H.J., & Eysenck, S.B.G. (1968). *Manual of the Eysenck Personality Inventory*. San Diego, CA: EDITS.

Fabre, C., Charmi, K., Mucci, P., Masse-Biron, J., & Prefaut, C. (2002). Improvement of cognitive function and/or individualized aerobic training in healthy elderly subjects. *International Journal of Sports Medicine*, *23*, 415–421.

Fabre, C., Massé-Biron, J., Chamari, K., Varray, A., Mucci, P., & Préfaut, C. (1999). Evaluation of quality of life in elderly healthy subjects after aerobic and/or mental training. *Archives of Gerontology and Geriatrics*, *28*, 9–22.

Fabrigoule, C., Letenneur, L., Dartigues, J.F., Zarrouk, M., Commenges, D., & Barberger-Gateau, P. (1995). Social and leisure activities and risk of dementia: A prospective longitudinal study. *Journal of the American Geriatrics Society*, *43*, 485–490.

Fernandez-Ballesteros, R. (2005). Evaluation of "vital-aging m": A psychosocial program for promoting optimal aging. *European Psychologist*, *10*, 146–156.

Ferrer, E., Salthouse, T.A., McArdle, J.J., Stewart, W.F., & Schwartz, B.S. (2005). Multivariate modeling of age and retest in longitudinal studies of cognitive abilities. *Psychology and Aging*, *20*, 412–422.

Ferrer, E., Salthouse, T.A., Stewart, W.F., & Schwartz, B.S. (2004). Modeling age and retest processes in longitudinal studies of cognitive abilities. *Psychology and Aging*, *19*, 243–249.

Fillit, H.M., Albert, M.S., Birren, J.E., Butler, R.N., Carey, L.A., Cotman, K.W., et al. (2002). Achieving and maintaining cognitive vitality with aging. *Mayo Clinic Proceedings*, *77*, 681–696.

Fiske, D.W. (1949). Consistency of the factorial structures of personality ratings from different sources. *Journal of Abnormal and Social Psychology*, *44*, 329–344.

Floyd, M., & Scogin, F. (1997). Effects of memory training on the subjective memory functioning and mental health of older adults: A meta-analysis. *Psychology and Aging*, *12*, 150–161.

Fordyce, D.E., & Farrar, R.P. (1991). Enhancement of spatial learning in f344 rats by physical activity and related learning-associated alterations in hippocampal and cortical cholinergic functioning. *Behavioral & Brain Research*, *46*, 123–133.

Fratiglioni, L., Wang, H.X., Ericsson, K., Maytan, M., & Winblad, B. (2000). Influence of social network on occurrence of dementia: A community-based longitudinal study. *Lancet*, *355*, 1315–1319.

Frazier, L.D., & Hooker, K. (2006). Possible selves in adult development: Linking theory and research. In C. Dunkel & J. Kerpelman (Eds.), *Possible selves: Theory, research and applications*. Hauppauge, NY: Nova Science Publishers.

Frederickson, B.L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist*, *56*, 218–226.

Freund, A.M., & Baltes, P.B. (1998). Selection, optimization, and compensation as strategies of life management: Correlates with subjective indicators of successful well-being. *Psychology and Aging*, *13*, 541–543.

Freund, A.M., & Baltes, P.B. (2002). The adaptiveness of selection, optimization, and compensation as strategies of life management: Evidence from a preference study on proverbs. *Journal of Gerontology: Psychological Sciences*, *57B*, P426–P434.

Fried, L.P., Carlson, M.C., Freedman, M., Frick, K.D., Glass, T.A., Hill, J., et al. (2004). A social model for health promotion for an aging population: Initial evidence on the Experience Corps model. *Journal of Urban Health*, *81*, 64–78.

Fries, J.F., & Crapo, L.M. (1981). *Vitality and aging*. San Francisco: Freeman.

Frost, R. (1920). *Mountain interval*. New York: Henry Holt.

Fuhrer, R., Dufouil, C., & Dartigues, J.-F. (2003). Exploring sex differences in the relationship between depressive symptoms and dementia incidence: Prospective results from the PAQUID study. *Journal of the American Geriatrics Society*, *51*, 1055–1063.

Ganguli, M., Du, Y., Dodge, H.H., Ratcliff, G.C., & Chang, C.C.H. (2006). Depressive symptoms and cognitive decline in late life. *Archives of General Psychiatry*, *63*, 153–160.

Gatz, J.L., Tyas, S.L., St. John, P., & Montgomery, P. (2005). Do depressive symptoms predict Alzheimer's disease and dementia? *Journal of Gerontology: Medical Sciences*, *60A*, 744–747.

Geda, Y.E., Knopman, D.S., Mrazek, D.A., Jicha, G.A., Smith, G.E., Negash, S., et al. (2006). Depression, apolipoprotein e genotype, and the incidence of mild cognitive impairment. *Archives of Neurology*, *63*, 435–440.

Geerlings, M.I., Bouter, L.M., Schoevers, R., Beekman, A.T.F., Jonker, C., Deeg, D.J.H., et al. (2000). Depression and risk of cognitive decline and Alzheimer's disease: Results of two prospective community-based studies in the Netherlands. *British Journal of Psychiatry*, *176*, 568–575.

Ghisletta, P., Bickel, J.F., & Lövdén, M. (2006). Does activity engagement protect against cognitive decline in old age? Methodological and analytical considerations. *Journal of Gerontology: Psychological Sciences*, *61B*, P253–P261.

Ghisletta, P., McArdle, J.J., & Lindenberger, U. (2006). Longitudinal cognition-survival relations in old and very old age: 13-year data from the Berlin Aging Study. *European Psychologist*, *11*, 204–223.

Gilley, D.W., & Wilson, R.S. (1997). Criterion-related validity of the geriatric depression scale in Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology*, *19*, 489–499.

Gobbo, O.L., & O'Mara, S.M. (2006). Exercise, but not environmental enrichment, improves learning after kainic acid induced hippocampal neurodegeneration in association with an increase in brain derived neurotrophic factor. *Behavioral Brain Research*, *159*, 21–26.

Gold, D.P., Andres, D., Etezadi, J., Arbuckle, T., Schwartzman, A., & Chaikelson, J. (1995). Structural equation model of intellectual change and continuity and predictors of intelligence in older men. *Psychology and Aging*, *10*, 294–303.

Goldberg, L.R. (1992). The development of markers for the big-five factor structure. *Psychological Assessment*, *4*, 26–42.

Gollwitzer, P.M. (1999). Implementation intentions: Strong effects of simple plans. *American Psychologist*, *54*, 493–503.

Gopher, D., Weil, M., & Bareket, T. (1994). Transfer of skill from a computer game trainer to flight. *Human Factors*, *36*, 387–405.

Greenwood, P.M. (2007). Functional plasticity in cognitive aging: Review and hypothesis. *Neuropsychology*, *21*, 657–673.

Greve, W., & Staudinger, U.M. (2006). Resilience in later adulthood and old age: Resources and potentials for successful aging. In D. Cicchetti & A. Cohen (Eds.), *Developmental psychopathology* (2nd ed., pp. 796–840). Hoboken, NJ: Wiley.

Gribbin, K., Schaie, K.W., & Parham, I.A. (1980). Complexity of life style and maintenance of intellectual abilities. *Journal of Social Issues*, *36*, 47–61.

Guillozet, A.L., Weintraub, S., Mash, D.C., & Mesulam, M.M. (2003). Neurofibrillary tangles, amyloid, and memory and aging in mild cognitive impairment. *Archives of Neurology*, *60*, 729–736.

Hall, C.B., Derby, C., LeValley, A., Katz, M.J., Verghese, J., & Lipton, R.B. (2007). Education delays accelerated decline on a memory test in persons who develop dementia. *Neurology*, *69*, 1657–1664.

Hall, C.B., Lipton, R.B., Sliwinski, M., & Stewart, W.F. (2000). A change point model for estimating the onset of cognitive decline in preclinical Alzheimer's disease. *Statistics in Medicine*, *19*, 1555–1566.

Hamagami, F., & McArdle, J.J. (2007). Dynamic extensions of latent difference score models. In S.M. Boker & M.J. Wenger (Eds.), *Data analytic techniques for dynamical systems* (pp. 47–85). Mahwah, NJ: Erlbaum.

Hart, S.G., & Battiste, V. (1992). Field test of a video game trainer. *Proceedings of the Human Factors Society*, 36th Annual Meeting, 1291–1295.

Haynie, D.A., Berg, S., Johansson, B., Gatz, M., & Zarit, S.H. (2001). Symptoms of depression in the oldest old: A longitudinal study. *Journal of Gerontology: Psychological Sciences*, *56B*, P111–P118.

Heckhausen, J., Dixon, R.A., & Baltes, P.B. (1989). Gains and losses in development throughout adulthood as perceived by different adult age groups. *Developmental Psychology*, *25*, 109–121.

Helmer, C., Damon, D., Letenneur, L., Fabrigoule, C., Barberger-Gateau, P., Lafont, S., et al. (1999). Marital status and risk of Alzheimer's disease. *Neurology*, *53*, 1953–1958.

Helzner, E.P., Scarmeas, N., Cosentino, S., Portet, F., & Stern, Y. (2007). Leisure activity and cognitive decline in incident Alzheimer's disease. *Archives of Neurology*, *64*, 1749–1754.

Hensch, T.K. (2004). Critical period regulation. *Annual Review Neuroscience*, *27*, 549–579.

Hensch, T.K. (2005). Critical period plasticity in local cortical circuits. *Nature Reviews Neuroscience*, *6*, 877–888.

Herman, J.P., Adams, D., & Prewitt, C. (1995). Regulatory changes in neuroendocrine stress-integrative circuitry produced by a variable stress paradigm. *Neuroendocrinology*, *61*, 180–190.

Hertzog, C. (1985). An individual differences perspective: Implications for cognitive research in gerontology. *Research on Aging*, *7*, 7–45.

Hertzog, C. (1989). The influence of cognitive slowing on age differences in intelligence. *Developmental Psychology*, *25*, 636–651.

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

Hertzog, C. (2008). Theoretical approaches to the study of cognitive aging: An individual differences perspective. In S.M. Hofer & D.F. Alwin (Eds.), *Handbook of cognitive aging* (pp. 34–49). Thousand Oaks, CA: Sage Publications.

Hertzog, C. (in press). Use it or lose it: An old hypothesis, new evidence, and an ongoing controversy. In H. Bosworth & C. Hertzog (Eds.), *Cognition in aging: Methodologies and applications*. Washington, DC: American Psychological Association.

Hertzog, C., Cooper, B.P., & Fisk, A.D. (1996). Aging and individual differences in the development of skilled memory search performance. *Psychology and Aging*, *11*, 497–520.

Hertzog, C., & Dixon, R.A. (1996). Methodological issues in research on cognition and aging. In F. Blanchard-Fields & T. Hess (Eds.), *Perspectives on cognitive change in adult development and aging* (pp. 66–121). New York: McGraw-Hill.

Hertzog, C., Dixon, R.A., & Hultsch, D.F. (1992). Intraindividual change in text recall in the elderly. *Brain and Language*, *42*, 248–269.

Hertzog, C., Dixon, R.A., Hultsch, D.F., & MacDonald, S.W.S. (2003). Latent change models of adult cognition: Are changes in processing speed and working memory associated with changes in episodic memory? *Psychology and Aging*, *18*, 755–769.

Hertzog, C., & Dunlosky, J. (2004). Aging, metacognition, and cognitive control. In B.H. Ross (Ed.), *The psychology of learning and motivation: Advances in research and theory* (pp. 215–251). San Diego, CA: Academic Press.

Hertzog, C., Dunlosky, J., & Robinson, A.E. (2008). *Intellectual abilities and metacognitive beliefs influence spontaneous use of effective encoding strategies*. Unpublished manuscript.

Hertzog, C., & Hultsch, D.F. (2000). Metacognition in adulthood and aging. In T. Salthouse & F.I.M. Craik (Eds.), *Handbook of aging and cognition* (2nd ed., pp. 417–466). Mahwah, NJ: Erlbaum.

Hertzog, C., Hultsch, D.F., & Dixon, R.A. (1999). On the problem of detecting effects of lifestyle on cognitive change in adulthood: Reply to Pushkar et al. (1999). *Psychology and Aging*, *14*, 528–534.

Hertzog, C., Lindenberger, U., Ghisletta, P., & von Oertzen, T. (2006). On the power of latent growth curve models to detect correlated change. *Psychological Methods*, *11*, 244–252.

Hertzog, C., McGuire, C.L., Horhota, M., & Jopp, D. (2008). Age differences in theories about memory control: Does believing in "use it or lose it" have implications for self-rated memory control, strategy use, and free recall performance? Unpublished manuscript.

Hertzog, C., & Nesselroade, J.R. (2003). Assessing psychological change in adulthood: An overview of methodological issues. *Psychology and Aging*, *18*, 639–657.

Hertzog, C., Park, D.C., Morrell, R.W., & Martin, M. (2000). Ask and ye shall receive: Behavioral specificity in the accuracy of subjective memory complaints. *Applied Cognitive Psychology*, *14*, 257–275.

Hertzog, C., Price, J., & Dunlosky, J. (2008). How is knowledge generated about memory encoding strategy effectiveness? *Learning and Individual Differences*, *18*, 430–445.

Hertzog, C., & Robinson, A.E. (2005). Metacognition and intelligence. In O. Wilhelm & R.W. Engle (Eds.), *Understanding and measuring intelligence* (pp. 101–123). London: Sage.

Hess, T.M. (2005). Memory and aging in context. *Psychological Bulletin*, *131*, 383–406.

Hess, T.M. (2006). Adaptive aspects of social cognitive functioning in adulthood: Age-related goal and knowledge influences. *Social Cognition*, *24*, 279–309.

Heyn, P., Abreu, B.C., & Ottenbacher, K.J. (2004). The effects of exercise training on elderly persons with cognitive impairment and dementia: A meta-analysis. *Archives of Physical Medicine and Rehabilitation*, *85*, 1694–1704.

Ho, S.C., Woo, J., Sham, A., Chan, S.G., & Yu, A.L.M. (2001). A 3-year follow-up study of social, lifestyle and health predictors of cognitive impairment in a chinese older cohort. *International Journal of Epidemiology*, *30*, 1389–1396.

Hodgson, L.G., & Cutler, S.J. (2003). Looking for signs of Alzheimer's diseases. *International Journal of Aging and Human Development*, *56*, 323–343.

Hofer, S.M., Flaherty, B.P., & Hoffman, L. (2006). Cross-sectional analysis of time-dependent data: Mean-induced association in age-heterogeneous samples and an alternative method based on sequential narrow age-cohort samples. *Multivariate Behavioral Research*, *41*, 165–187.

Horn, J.L. (1989). Cognitive diversity: A framework for learning. In P.L. Ackerman, R.J. Sternberg, & R. Glaser (Eds.), *Learning and individual differences: Advances in theory and research* (pp. 61–116). New York: Freeman.

Horn, J.L., & Cattell, R.B. (1966). Refinement and test of the theory of fluid and crystallized intelligence. *Journal of Educational Psychology*, *57*, 253–270.

Horn, J.L., & Donaldson, G. (1976). On the myth of intellectual decline in adulthood. *American Psychologist*, *31*, 701–719.

Hoyer, W.J., & Ingolfsdottir, D. (2003). Age, skill, and contextual cueing in target detection. *Psychology and Aging*, *18*, 210–218.

Huang, C.H., Lee, L.Y., & Chang, M.L. (2007). The influence of personality and motivation on exercise participation and quality of life. *Social Behavior and Personality*, *35*, 1189–1209.

Hull, A.M. (2002). Neuroimaging findings in post-tramatic stress disorder. *British Journal of Psychiatry*, *81*, 101–110.

Hultsch, D.F., Hammer, M., & Small, B.J. (1993). Age differences in cognitive performance in later life: Relationships to self-reported health and activity life style. *Journals of Gerontology*, *48*, 1–11.

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

Hultsch, D.F., & MacDonald, S.W.S. (2004). Intraindividual variability in performance as a theoretical window onto cognitive aging. In R.A. Dixon, L. Bäckman, & L.-G. Nilsson (Eds.), *New frontiers in cognitive aging* (pp. 65–88). New York: Oxford University Press.

Hultsch, D.F., Small, B.J., Hertzog, C., & Dixon, R.A. (1999). Use it or lose it: Engaged lifestyle as a buffer of cognitive decline in aging. *Psychology and Aging*, *14*, 245–263.

Hummert, M.L. (1990). Multiple stereotypes of elderly and young adults: A comparison of structure and evaluations. *Psychology and Aging*, *5*, 182–193.

Hummert, M.L. (2003). When is an age stereotype an aging self-stereotype? A commentary on Levy (2003). *Journal of Gerontology: Psychological Sciences*, *58B*, P212–P213.

Hummert, M.L., Garstka, T.A., O'Brien, L., Greenwald, A.G., & Mellott, D.S. (2002). Using the Implicit Association Test to measure age differences in implicit social perceptions. *Psychology and Aging*, *17*, 482–495.

Hummert, M.L., Garstka, T.A., Shaner, J.L., & Strahm, S. (1994). Stereotypes of the elderly held by young, middle-aged, and elderly adults. *Journals of Gerontology*, *49*, P240–P249.

Hunt, E. (1978). Mechanics of verbal ability. *Psychological Review*, *85*, 109–130.

Hunt, R.R., & Smith, R.E. (1996). Accessing the particular from the general: The power of distinctiveness in the context of organization. *Memory & Cognition*, *24*, 217–225.

Huttenlocher, P.R., & Dabholkar, A.S. (1997). Regional differences in synaptogenesis in human cerebral cortex. *Journal of Comparative Neurology*, *387*, 167–178.

Ingledew, D.K., Markland, D., & Sheppard, K.E. (2004). Personality and self-determination of exercise behavior. *Personality and Individual Differences*, *36*, 1921–1932.

Intons-Peterson, M.J., & Fourrier, J. (1986). External and internal memory aids: When and how often do we use them? *Journal of Experimental Psychology: General*, *115*, 267–280.

Jacoby, L.L. (1999). Deceiving the elderly: Effects of accessibility bias in cued-recall performance. *Cognitive Neuropsychology*, *16*, 417–436.

James, L.R., Mulaik, S.A., & Brett, J.M. (1982). *Causal analysis: Assumptions, models, and data*. Beverly Hills, CA: Sage.

Jelicic, M., Bosma, H., Ponds, R.W.H.M., Van Boxtel, M.P.J., Houx, P.J., & Jolles, J. (2003). Neuroticism does not affect cognitive functioning in later life. *Experimental Aging Research*, *29*, 73–78.

Jennings, J.M., & Jacoby, L.L. (2003). Improving memory in older adults: Training recollection. *Neuropsychological Rehabilitation*, *13*, 417–440.

Jennings, J.M., Webster, L.M., Kleykamp, B.A., & Dagenbach, D. (2005). Recollection training and transfer effects in older adults: Successful use of a repetition-lag procedure. *Aging, Neuropsychology and Cognition*, *12*, 278–298.

Jessberger, S., & Gage, F.H. (2008). Structural and functional plasticity of the aging hippocampus. *Psychology & Aging*, *23*, 684–691.

Jobe, J.B., & Mingay, D.J. (1991). Cognition and survey measurement: History and overview. *Applied Cognitive Psychology*, *5*, 175–192.

Johren, O., Flugge, G., & Fuchs, E. (1994). Hippocampal glucocorticoid receptor expression in the tree shrew: Regulation by psychosocial conflict. *Cellular and Molecular Neurobiology*, *14*, 281–296.

Jones, T.A., Hawrylak, N., & Greenough, W.T. (1996). Rapid laminar-dependent changes in gfap immunoreactive astrocytes in the visual cortex of rats reared in a complex environment. *Psychoneuroendocrinology*, *21*, 189–201.

Jopp, D., & Hertzog, C. (2007). Activities, self-referent memory beliefs, and cognitive performance: Evidence for direct and mediated effects. *Psychology and Aging*, *22*, 811–825.

Jopp, D., & Hertzog, C. (2008). *Assessing adult leisure activities: An extension of a self-report activity questionnaire*. Unpublished manuscript.

Kagan, J. (1999). Two forms of discontinuity. *Human Development*, *42*, 257–259.

Kane, M.J., & Engle, R.W. (2003). Working memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to stroop interference. *Journal of Experimental Psychology: General*, *132*, 47–70.

Kanfer, R., & Ackerman, P.L. (2004). Aging, adult development, and work motivation. *Academy of Management Review*, *29*, 440–458.

Karbach, J., & Kray, J. (in press). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science*.

Karp, A., Paillard-Borg, S., Wang, H.X., Silverstein, M., Winblad, B., & Fratiglioni, L. (2006). Mental, physical and social components in leisure activities equally contribute to decrease dementia risk. *Dementia and Geriatric Disorders*, *21*, 65–73.

Katzman, R., Terry, R., DeTeresa, R., Brown, T., Davies, P., Fuld, P., et al. (1988). Clinical, pathological, and neurochemical changes in dementia: A subgroup with preserved mental status and numerous neocortical plaques. *Annals of Neurology*, *23*, 138–144.

Kausler, D.H. (1994). *Learning and memory in normal aging*. San Diego, CA: Academic Press.

Kelley, G.A. (1998). Exercise and regional bone mineral density in postmenopausal women: A meta-analytic review of randomized trials. *American Journal of Physical Medicine and Rehabilitation*, *77*, 76–87.

Kempermann, G. (2008). The neurogenic reserve hypothesis: What is adult hippocampal neurogenesis good for? *Trends in Neuroscience*, *31*, 163–169.

Kempermann, G., Kuhn, H.G., & Gage, F.H. (1997). More hippocampal neurons in adult mice living in an enriched environment. *Nature*, *386*, 493–495.

Kempermann, G., Kuhn, H.G., & Gage, F.H. (1998). Experience-induced neurogenesis in the senescent dentate gyrus. *Journal of Neuroscience*, *18*, 3206–3212.

Kliegl, R., & Baltes, P.B. (1987). Theory-guided analysis of mechanisms of development and aging mechanisms through testing-the-limits and research on expertise. In C. Schooler & K.W. Schaie (Eds.), *Cognitive functioning and social structure over the life course* (pp. 95–119). Norwood, NJ: Ablex.

Kliegl, R., Krampe, R.T., & Mayr, U. (2003). Formal models of age differences in task-complexity effects. In U.M. Staudinger & U. Lindenberger (Eds.), *Understanding human development: Dialogues with lifespan psychology* (pp. 289–313). Boston: Kluwer Academic.

Kliegl, R., Smith, J., & Baltes, P.B. (1989). Testing-the-limits and the study of adult age differences in cognitive plasticity of a mnemonic skill. *Developmental Psychology*, *25*, 247–256.

Kliegl, R., Smith, J., & Baltes, P.B. (1990). On the locus and process of magnification of age differences during mnemonic training. *Developmental Psychology*, *26*, 894–904.

Knudsen, E.I. (2002). Instructed learning in the auditory localization pathway of the barn owl. *Nature*, *417*, 322–328.

Knusel, B., Winslow, J.W., Rosenthal, A., Burton, L.E., Seid, D.P., Nikolics, K., et al. (1992). Promotion of central cholinergic and dopaminergic neuron differentiation by brain-derived neurotrophic factor but not neurotrophin 3. *Proceedings of the National Academy of Sciences, USA*, *88*, 961–965.

Kramer, A.F., Bherer, L., Colcombe, S., Dong, W., & Greenough, W.T. (2004). Environmental influences on cognitive and brain plasticity during aging. *Journal of Gerontology: Medical Sciences*, *59A*, 940–957.

Kramer, A.F., Cassavaugh, N., Horrey, W., Becic, E., & Mayhugh, J. (2007). Influence of age and proximity warning devices on collision avoidance in simulated driving. *Human Factors*, *49*, 935–949.

Kramer, A.F., Coyne, J.T., & Strayer, D.L. (1993). Cognitive function at high altitude. *Human Factors*, *35*, 329–344.

Kramer, A.F., Hahn, H., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica*, *101*, 339–378.

Kramer, A.F., Hahn, S., Cohen, N.J., Banich, M.T., McAuley, E., Harrison, C.R., et al. (1999). Ageing, fitness and neurocognitive function. *Nature*, *400*, 418–419.

Kramer, A.F., Larish, J., & Strayer, D.L. (1995). Training for attentional control in dual-task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied*, *1*, 50–76.

Kramer, A.F., Larish, J., Weber, T., & Bardell, L. (1999). Training for executive control: Task coordination strategies and aging. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII* (pp. 617–652). Cambridge, MA: MIT Press.

Kramer, A.F., & Madden, D. (2008). Attention. In F.I.M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (3rd ed., pp. 189–250). Mahwah, NJ: Erlbaum.

Kramer, A.F., & Willis, S. (2003). Cognitive plasticity and aging. In B. Ross (Ed), *Psychology of learning and motivation* (Vol 43, pp. 267–302). New York: Academic Press.

Krampe, R.T., & Ericsson, K.A. (1996). Maintaining excellence: Deliberate practice and elite performance in young and old pianists. *Journal of Experimental Psychology: General*, *125*, 331–359.

Kray, J., Eber, J., & Lindenberger, U. (2004). Age differences in executive functioning across the lifespan: The role of verbalization in task preparation. *Acta Psychologica*, *115*, 143–165.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging*, *15*, 126–147.

Kuhn, D. (1995). Microgenetic study of change: What has it told us? *Psychological Science*, *6*, 133–139.

Laaksonen, D.E., Lindström, J., Lakka, T.A., Eriksson, J.G., Niskanen, L., Wikström, K., et al. (2005). Physical activity in the prevention of type 2 diabetes. The Finnish Diabetes Prevention Study. *Diabetes*, *54*, 158–165.

Lachman, M.E. (1986). Locus of control in aging research: A case for multidimensional and domain-specific assessment. *Psychology and Aging*, *1*, 34–40.

Lachman, M.E. (1991). Perceived control over memory aging: Developmental and intervention perspectives. *Journal of Social Issues*, *47*, 159–175.

Lachman, M.E., & Andreoletti, C. (2006). Strategy use mediates the relationship between control beliefs and memory performance for middle-aged and older adults. *Journal of Gerontology: Psychological Sciences and Social Sciences*, *61B*, P88–P94.

Lachman, M.E., Andreoletti, C., & Pearman, A. (2006). Memory control beliefs: How are they related to age, strategy use, and memory improvement? *Social Cognition*, *24*, 359–385.

Lachman, M.E., Weaver, S.L., Bandura, M., Elliott, E., & Lewkowicz, C.J. (1992). Improving memory and control beliefs through cognitive restructuring and self-generated strategies. *Journal of Gerontology: Psychological Sciences*, *47B*, P293–P299.

Lane, C.J., & Zelinski, E.M. (2003). Longitudinal hierarchical linear models of the Memory Functioning Questionnaire. *Psychology and Aging*, *18*, 38–53.

Langer, E.J. (1989). *Mindfulness*. Reading, MA: Addison-Wesley.

Larson, E.B., Wang, L., Bowen, J.D., McCormick, W.C., Teri, L., Crane, P., et al. (2006). Exercise is associated with reduced risk for incident dementia among persons 65 years of age or older. *Annals of Internal Medicine*, *144*, 73–81.

Laurin, D., Verreault, R., Lindsay, J., MacPherson, K., & Rockwood, K. (2001). Physical activity and risk of cognitive impairment and dementia in elderly persons. *Archives of Neurology*, *58*, 498–504.

Lautrey, J. (2003). A pluralistic approach to cognitive differentiation and development. In R.J. Sternberg, J. Lautrey, & T.I. Lubart (Eds.), *Models of intelligence: International perspectives* (pp. 117–131). Washington, DC: American Psychological Association.

Lee, I.M. (2003). Physical activity and cancer prevention – data from epidemiologic studies. *Medical Science in Sports & Exercise*, *35*, 823–827.

Lefcourt, H.M. (Ed.). (1981). *Research with the locus of control construct: Assessment methods* (Vol. 1). New York: Academic Press.

Lerner, R.M. (1984). *On the nature of human plasticity*. New York: Cambridge University Press.

Li, S.-C., Huxhold, O., & Schmiedek, F. (2004). Aging and attentuated processing robustness—evidence from cognitive and sensorimotor functioning. *Gerontology*, *50*, 28–34.

Li, S.-C., & Lindenberger, U. (2002). Coconstructed functionality instead of functional normality. *Behavioral and Brain Sciences*, *25*, 761–762.

Li, S.C., Brehmer, Y., Shing, Y.L., Werkle-Bergner, M., & Lindenberger, U. (2006). Neuromodulation of associative and organizational plasticity across the life span: Empirical evidence and neurocomputational modeling. *Neuroscience and Biobehavioral Reviews*, *30*, 775–790.

Li, S.-C., Lindenberger, U., Nyberg, L., Heekeren, H.R., & Bäckman, L. (in press). Dopaminergic modulation of cognition in human aging. In W. Jagust & M. D'Esposito (Eds.), *Imaging the aging brain*. Oxford, England: Oxford University Press.

Li, S.-C., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., & Lindenberger, U. (2008). Working memory plasticity in old age: Transfer and maintenance. *Psychology and Aging*, *23*, 731–742.

Lindenberger, U. (2001). Lifespan theories of cognitive development. In N.J. Smelser & P.B. Baltes (Eds.), *International encyclopedia of the social and behavioral sciences* (Vol. 13, pp. 8848–8854). Oxford, England: Elsevier Science.

Lindenberger, U., & Baltes, P.B. (1995). Testing the limits and experimental simulation—2 methods to explicate the role of learning in development. *Human Development*, *38*, 349–360.

Lindenberger, U., Li, S.-C., & Bäckman, L. (2006a). Delineating brain-behavior mappings across the lifespan: Substantive and methodological advances in developmental neuroscience. *Neuroscience and Biobehavioral Reviews*, *30*, 713–717.

Lindenberger, U., Li, S.-C., & Bäckman, L. (Eds.). (2006b). Methodological and conceptual advances in the study of brain-behavior dynamics: A multivariate lifespan perspective [Special issue]. *Neuroscience and Biobehavioral Reviews*, *30*(6).

Lindenberger, U., Lövdén, M., Schellenbach, M., Li, S.-C., & Krüger, A. (2008). Psychological principles of successful aging technologies: A mini-review. *Gerontology*, *54*, 59–68.

Lindenberger, U., & von Oertzen, T. (2006). Variability in cognitive aging: From taxonomy to theory. In F.I.M. Craik & E. Bialystok (Eds.), *Lifespan cognition: Mechanisms of change* (pp. 297–314). Oxford, England: Oxford University Press.

Lindenberger, U., von Oertzen, T., Ghisletta, P., & Hertzog, C. (2008) *Cross-sectional age variance extraction: What's change got to do with it?* Unpublished manuscript.

Lindenberger, U., Singer, T., & Baltes, P.B. (2002). Longitudinal selectivity in aging populations: Separating mortality-associated versus experimental components in the Berlin Aging Study (BASE). *Journal of Gerontology: Psychological Sciences*, *57B*, P474–P482.

Lineweaver, T.T., & Hertzog, C. (1998). Adults' efficacy and control beliefs regarding memory and aging: Separating general from personal beliefs. *Aging, Neuropsychology, and Cognition*, *5*, 264–296.

Lopez, O.L., Kuller, L.H., Becker, J.T., Dulberg, C., Sweet, R.A., Gach, H.M., & DeKosky, S.T. (2007). Incidence of dementia in mild cognitive impairment in the Cardiovascular Health Study Cognition Study. *Archives of Neurology*, *64*, 416–420.

Lövdén, M., Ghisletta, P., & Lindenberger, U. (2005). Social participation attentuates decline in perceptual speed in old and very old age. *Psychology and Aging*, *20*, 423–434.

Lövdén, M., Li, S.-C., Shing, Y.L., & Lindenberger, U. (2007). Within-person trial-to-trial variability precedes and predicts cognitive decline in old and very old age: Longitudinal data from the Berlin Aging Study. *Neuropsychologia*, *45*, 2827–2838.

Lu, B., Pang, P.T., & Woo, N.H. (2005). The yin and yang of neurotrophin action. *Nature Reviews Neuroscience*, *6*, 603–614.

Lyketsos, C.G., Lopez, O., Jones, B., Fitzpatrick, A.L., Breitner, J., & DeKosky, S. (2002). Prevalence of neuropsychiatric symptoms in dementia and mild cognitive impairment: Results from the Cardiovascular Health Study. *Journal of the American Medical Association*, *288*, 1475–1483.

Lynch, S.M. (2000). Measurement and prediction of aging anxiety. *Research on Aging*, *22*, 533–558.

Lytle, M.E., Vander Bilt, J., Pandav, R.S., Dodge, H.H., & Ganguli, M. (2004). Exercise level and cognitive decline: The MoVIES Project. *Alzheimers Disease and Associated Disorders*, *18*, 57–63.

Mackinnon, A., Christensen, H., Hofer, S.M., Korten, A.E., & Jorm, A.F. (2003). Use it and still lose it? The association between activity and cognitive performance established using latent growth techniques in a community sample. *Aging Neuropsychology and Cognition*, *10*, 215–222.

Magarinos, A.M., & McEwen, B.S. (1995). Stress-induced atrophy of apical dendrites of hippocampal CA3c neurons: Comparison of stressors. *Neuroscience*, *69*, 83–88.

Magarinos, A.M., McEwen, B.S., Flugge, G., & Fuchs, E. (1996). Chronic psychosocial stress causes apical dendrite atrophy of hippocampal CA3 pyramidal neurons in subordinate tree shrews. *Journal of Neuroscience*, *6*, 3534–3540.

Magnus, K., Diener, E., Fujita, F., & Pavot, W. (1993). Extraversion and neuroticism as predictors of objective life events: A longitudinal analysis. *Journal of Personality and Social Psychology*, *65*, 1046–1053.

Maguire, E.A., Woollett, K., & Spiers, H.J. (2006). London taxi drivers and bus drivers: A structural MRI and neuropsychological analysis. *Hippocampus*, *16*, 1091–1101.

Maguire, E.A., Gadian, D.G., Johnsrude, I.S., Good, C.D., Ashburner, J., Frackowiak, R.S.J., et al. (2000). Navigation-related structural changes in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences, USA*, *97*, 4398–4403.

Mahncke, H.W., Bronstone, A., & Merzenich, M.M. (2006). Brain plasticity and functional losses in the aged: Scientific bases for a novel intervention. *Reprogramming the Brain*, *157*, 81–109.

Marcus, B.H., Eaton, C.A., Rossi, J.S., & Harlow, L.L. (1994). Self-efficacy, decision-making, and stages of change: An integrative model of physical exercise. *Journal of Applied Social Psychology*, *24*, 489–508.

Markesbery, W.R., Schmitt, F.A., Kryscio, R.J., Davis, D.G., Smith, C.D., & Wekstein, D.R. (2006). Neuropathologic substrate of mild cognitive impairment. *Archives of Neurology*, *63*, 38–46.

Martin, L.G., & Preston, S.H. (Eds.) (1994). *The demography of aging*. Washington DC: National Academies Press.

Masunaga, H., & Horn, J. (2000). Characterizing mature human intelligence: Expertise development. *Learning and Individual Differences*, *12*, 5–33.

Masunaga, H., & Horn, J.L. (2001). Expertise and age-related changes in components of intelligence. *Psychology and Aging*, *16*, 293–311.

Matarazzo, J.D. (1972). *Wechsler's measurement and appraisal of adult intelligence* (5th ed.). Oxford, England: Williams & Wilkins.

Mayr, U., Kliegl, R., & Krampe, R.T. (1996). Sequential and coordinative processing dynamics in figural transformation across the life span. *Cognition*, *59*, 61–90.

McArdle, J.J., & Woodcock, R.W. (1997). Expanding test-restest designs to include developmental time-lag components. *Psychological Methods*, *2*, 403–435.

McAuley, E., Morris, K., Motl, R., Hu, L., Konopack, J., & Elavsky, S. (2007). Long term follow-up of physical activity behavior in older adults. *Health Psychology*, *26*, 375–380.

McDonald-Miszczak, L., Hertzog, C., & Hultsch, D.F. (1995). Stability and accuracy of metamemory in adulthood and aging. *Psychology and Aging*, *10*, 553–564.

McEwen, B.S. (1999). Stress and hippocampal plasticity. *Annual Review of Neuroscience*, *22*, 105–122.

McEwen, B.S. (2002). Sex, stress and the hippocampus: Allostasis, allostatic load and the aging process. *Neurobiology of Aging*, *23*, 921–939.

Metcalfe, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: Dynamics of willpower. *Psychological Review*, *106*, 3–19.

Milgram, N.W., Head, E., Zicker, S.C., Ikeda-Douglas, C.J., Murphey, H., Muggenburg, B., et al. (2005). Learning ability in aged beagle dogs is preserved by behavioral enrichment and dietary fortification: A two-year longitudinal study. *Neurobiology of Aging*, *26*, 77–90.

Modrego, P.J., & Ferrandez, J. (2004). Depression in patients with mild cognitive impairment increases the risk of developing dementia of Alzheimer type. *Archives of Neurology*, *61*, 1290–1293.

Molenaar, P.C.M. (in press). The nonequivalence of structures of inter- and intra-individual variation associated with nonergodic psychological processes. *Current Directions in Psychological Research*.

Molenaar, P.C.M., Boomsma, D.I., & Dolan, C.V. (1993). A third source of developmental differences. *Behavior Genetics*, *23*, 519–524.

Molteni, R., Wu, A., Vayman, S., Ying, Z., Barnard, R.J., & Gomez-Pinilla, F. (2004). Exercise reverses the harmful effects of consumption of a high fat diet on synaptic and behavioral plasticity associated to the action of brain-derived neurotrophic factor. *Neuroscience and Biobehavioral Reviews*, *123*, 429–440.

Montepare, J.M., & Lachman, M.E. (1989). 'You're only as old as you feel': Self-perceptions of age, fears of aging, and life satisfaction from adolescence to old age. *Psychology and Aging*, *41*, 73–78.

Morris, J.N., Heady, J.A., Raffle, P.A.B., Roberts, C.G., & Parks, J.W. (1953). Coronary heart disease and physical activity of work. *Lancet*, *265*, 1111–1120.

Moss, M., Franks, M., Briggs, P., Kennedy, D., & Scholey, A. (2005). Compromised arterial oxygen saturation in elderly asthma suffers results in selective cognitive impairment. *Journal of Clinical and Experimental Neuropsychology*, *27*, 139–150.

Mroczek, D.K., & Spiro, A. (2003). Modeling intraindividual change in personality traits: Findings from the normative aging study. *Journal of Gerontology: Psychological Sciences*, *58B*, P153–P165.

Nagel, I.E., Werkle-Bergner, M., Li, S.-C., & Lindenberger, U. (2007). Perception. In J.E. Birren (Ed.), *Encyclopedia of gerontology: Age, aging, and the aged* (2nd ed., Vol. 2, pp. 334–342). Amsterdam: Elsevier.

Nail, L.M. (2006). Cognitive changes in cancer survivors. *American Journal of Nursing*, *106*, 48–54.

Nebes, R.D. (1992). Cognitive dysfunction in Alzheimer's disease. In F.I.M. Craik & T.A. Salthouse (Eds.), *Handbook of aging and cognition* (pp. 373–446). Hillsdale, NJ: Erlbaum.

Neely, A.S., & Bäckman, L. (1993). Long-term maintenance of gains from memory training in older adults: 2 3- 1/2-year follow-up studies. *Journal of Gerontology: Psychological Sciences*, *48*, P233–P237.

Neeper, S., Gomez-Pinilla, F., Choi, J., & Cottman, C. (1995). Exercise and brain neurotrophins. *Nature*, *373*, 109.

Nelson, T.D. (2005). Ageism: Prejudice against our feared future self. *Journal of Social Issues*, *61*, 207–221.

Nelson, T.O., & Narens, L. (1990). Metamemory: A theoretical framework and new findings. In G.H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 26, pp. 125–141). New York: Academic Press.

Nesselroade, J.R. (1991). The warp and the woof of the developmental fabric. In R.M. Downs, L.S. Liben, & D.S. Palermo (Eds.), *Visions of aesthetics, the environment and development: The legacy of Joachim Wohlwill* (pp. 213–240). Hillsdale, NJ: Erlbaum.

Nesselroade, J.R., & Labouvie, E.W. (1985). Experimental design in research on aging. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (2nd ed., pp. 35–60). New York: Van Nostrand Reinhold.

Nesselroade, J.R., Stigler, S.M., & Baltes, P.B. (1980). Regression toward the mean and the study of change. *Psychological Bulletin*, *88*, 622–637.

Nicholas, A., Munhoz, C.D., Ferguson, D., Campbell, L., & Sapolsky, R. (2006). Enhancing cognition after stress with gene therapy. *Journal of Neuroscience*, *26*, 11637–11643.

Ng, T.W.H., & Feldman, D.C. (2008). The relationship of age to ten dimensions of job performance. *Journal of Applied Psychology*, *93*, 392–423.

Noice, H., & Noice, T. (2006). What studies of actors and acting can tell us about memory and cognitive functioning. *Current Directions in Psychological Science*, *15*, 14–18.

Norman, D.A., & Bobrow, D.G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, *7*, 44–64.

Nyberg, L., Sandblom, J., Jones, S., Neely, A.S., Petersson, K.M., & Ingvar, M.I., et al. (2003). Neural correlates of training-related memory improvement in adulthood and aging. *Proceedings of the National Academy of Sciences, USA*, *100*, 13728–13733.

Oguma, Y., & Shinoda-Tagawa, T. (2004). Physical activity decreases cardiovascular disease risk in women: Review and meta-analysis. *American Journal of Preventive Medicine*, *26*, 407–418.

O'Hara, R., Brooks, J.O., Friedman, L., Schroder, C.M., Morgan, K.S., & Kraemer, H.C. (2007). Long-term effects of mnemonic training in community-dwelling older adults. *Journal of Psychiatric Research*, *41*, 585–590.

Ong, A.D., Bergeman, C.S., Bisconti, T.L., & Wallace, K.A. (2006). Psychological resilience, positive emotions, and successful adaptation to stress in later life. *Journal of Personality and Social Psychology*, *91*, 730–749.

Ong, A.D., Edwards, L.M., & Bergeman, C.S. (2006). Hope as a source of resilience in later adulthood. *Personality and Individual Differences*, *41*, 1263–1273.

O'Reilly, R.C., & Frank, M.J. (2006). Making working memory work: A computational model of learning in the frontal cortex and basal ganglia. *Neural Computation*, *18*, 283–328.

Ormel, J., & Wohlfarth, T. (1991). How neuroticism, long-term difficulties, and life situation change influence psychological distress:

A longitudinal model. *Journal of Personality and Social Psychology*, *60*, 744–755.

Ortapamuk, H., & Naldoken, S. (2006). Brain perfusion abnormalities in chronic obstructive pulmonary disease: Comparison with cognitive impairment. *Annals of Nuclear Medicine*, *20*, 99–106.

Park, D.C., Gutchess, A.H., Meade, M.L., & Stine-Morrow, E.A.L. (2007). Improving cognitive function in older adults: Nontraditional approaches. *Journal of Gerontology: Psychological Sciences*, *62B*(Special Issue I), 45–52.

Park, D.C., Hertzog, C., Leventhal, H., Morrell, R.W., Leventhal, E., Birchmore, D., et al. (1999). Medication adherence in rheumatoid arthritis patients: Older is wiser. *Journal of the American Geriatrics Society*, *47*, 172–183.

Park, D.C., & Reuter-Lorenz, P. (2009). The adaptive brain: Aging and neurocognitive scaffolding. *Annual Review of Psychology*, *60*, 173–196.

Parslow, R.A., Jorm, A.F., Christensen, H., & Mackinnon, A. (2006). An instrument to measure engagement in life: Factor analysis and associations with sociodemographic, health, and cognition measures. *Gerontology*, *52*, 188–198.

Paterniti, S., Verdier-Taillefer, M.-H., Dufouil, C., & Alperovitch, A. (2002). Depressive symptoms and cognitive decline in elderly people. *British Journal of Psychiatry*, *181*, 404–410.

Paulhus, D. (1983). Sphere-specific measures of personal control. *Journal of Personality and Social Psychology*, *44*, 1253–1265.

Pearman, A., & Storandt, M. (2005). Self-discipline and self-consciousness predict subjective memory in older adults. *Journal of Gerontology: Psychological Sciences*, *60B*, P153–P157.

Pereira, A.C., Huddleston, D.E., Brickman, A.M., Sosunov, A.A., Hen, R., McKhann, G.M., et al. (2007). An in vivo correlate of exercise-induced neurogenesis in the adult dentate gyrus. *Proceedings of the National Academy of Sciences, USA*, *104*, 5638–5643.

Petersen, R.C., Parisi, J.E., Dickson, D.W., Johnson, K.A., Knopman, D.S., Boeve, B.F., et al. (2006). Neuropathologic features of amnestic mild cognitive impairment. *Archives of Neurology*, *63*, 665–672.

Pew, R.W., & Van Hamel, S.B. (Eds.). (2004). *Technology for adaptive aging*. Washington, DC: National Academies Press.

Pintrich, P.R., Wolters, C.A., & Baxter, G.P. (2000). Assessing metacognition and self-regulated learning. In G. Schraw & J.C. Impara (Eds.), *Issues in the measurement of metacognition* (pp. 43–97). Lincoln, NE: Buros Institute of Mental Measurements.

Pitkala, K., Kahonen-Vare, M., Valvanne, J., Strandberg, R.S., & Tilvis, R.S. (2003). Long-term changes in mood of an aged population: Repeated zung-tests during a 10-year follow-up. *Archives of Gerontology and Geriatrics*, *36*, 185–195.

Podewils, L.J., Guallar, E., Kuller, L.H., Fried, L.P., Lopez, O.L., Carlson, M., & Lyketsos, C.G. (2005). Physical activity, Apoe genotype, and dementia risk: Findings from the Cardiovascular Health Cognition Study. *American Journal of Epidemiology*, *161*, 639–651.

Rabbitt, P., Diggle, P., Holland, F., & McInnes, L. (2004). Practice and drop-out effects during a 17-year longitudinal study of cognitive aging. *Journal of Gerontology, Series B: Psychological Sciences and Social Sciences*, *59*, P84–P97.

Rabbitt, P., Maylor, E., McInnes, L., Bent, N., & Moore, B. (1995). What goods can self-assessment questionnaires deliver for cognitive gerontology? *Applied Cognitive Psychology*, *9*, S127–S152.

Radley, J.J., Sisti, H.M., Hao, J., Rocher, A.B., McCall, T., Hof, P.R., et al. (2004). Chronic behavioral stress induces apical dendritic reorganization in pyramidal neurons of the medial prefrontal cortex. *Neuroscience*, *125*, 1–6.

Raichle, M.E., MacLeod, A.M., Snyder, A.Z., Powers, W.J., Gusnard, D.A., & Shulman, G.L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences, USA*, *98*, 676–682.

Ram, N., Rabbitt, P., Stollery, B., & Nesselroade, J.R. (2005). Cognitive performance inconsistency: Intraindividual change and variability. *Psychology and Aging*, *20*, 623–633.

Rasmusson, A.M., Shi, L., & Duman, R. (2002). Downregulation of BDNF mRNA in the hippocampal dentate gyrus after re-exposure to cues previously associated with footshock. *Neuropsychopharmacology*, *27*, 133–142.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F.I.M. Craik & T.A. Salthouse (Eds.), *Handbook of aging and cognition* (2nd ed., pp. 1–90). Mahwah, NJ: Erlbaum.

Raz, N., & Rodrigue, K. (2006). Differential aging of the brain: Patterns, cognitive correlates, and modifiers. *Neuroscience & Biobehavioral Reviews*, *30*, 730–748.

Reuter-Lorenz, P.A., & Cappel, K.A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science*, *17*, 177–182.

Reuter-Lorenz, P.A., & Lustig, C. (2005). Brain aging: Reorganizing discoveries about the aging mind. *Current Opinions in Neurobiology*, *15*, 245–251.

Rhodes, J.S., van Praag, H., Jeffrey, S., Giard, I., Mitchell, G.S., Garland, T., et al. (2003). Exercise increases hippocampal neurogenesis to high levels but does not improve spatial learning in mice bread for increased voluntary wheel running. *Behavioral Neuroscience*, *117*, 1006–1016.

Rhodes, R.E., Couneya, K.S., Blanchard, C.M., & Plotnikoff, R.C. (2007). Prediction of leisure-time walking: An integration of social cognitive, perceived environmental, and personality factors. *International Journal of Behavioral Nutrition and Physical Health*, *4*, 51.

Rhodes, R.E., & Smith, N.E.I. (2006). Personality correlates of physical activity: A review and metaanalysis. *British Journal of Sports Medicine*, *40*, 958–965.

Ribot, T. (1882). *Diseases of memory*. New York: Appleton.

Richards, M., Hardy, R., & Wadsworth, M.E.J. (2003). Does active leisure protect cognition? Evidence from a national birth cohort. *Social Science & Medicine*, *56*, 785–792.

Ridgway, L., & McFarland, K. (2006). Apnea diving: Long-term neurocognitive sequelae of repeated hypoxemia. *Clinical Neuropsychology*, *20*, 160–176.

Riediger, M., Li, S.C., & Lindenberger, U. (2006). Selection, optimization, and compensation (SOC) as developmental mechanisms of adaptive resource allocations: Review and preview. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (6th ed., pp. 289–313). Amsterdam: Elsevier.

Riggs, K.M., Lachman, M.E., & Wingfield, A. (1997). Taking charge of remembering: Locus of control and older adults' memory for speech. *Experimental Aging Research*, *23*, 237–256.

Rikli, R., & Edwards, D. (1991). Effects of a three year exercise program on motor function and cognitive processing speed in older women. *Research Quarterly for Exercise and Sport*, *62*, 61–67.

Rogers, W.A., Fisk, A.D., & Hertzog, C. (1994). Do ability performance relationships differentiate age and practice effects in visual-search? *Journal of Experimental Psychology*, *20*, 710–738.

Roring, R.W., & Charness, N. (2007). A multilevel model analysis of expertise in chess across the life span. *Psychology and Aging*, *22*, 291–299.

Rosenzweig, M.R., & Bennett, E.L. (1996). Psychobiology of plasticity: Effects of training and experience on brain and behavior. *Behavioral Brain Research*, *78*, 57–65.

Rovio, S., Kåreholt, I., Helkala, E.L., Viitanen, M., Winblad, B., Tuomilehto, J., et al. (2005). Leisure time physical activity at midlife and the risk of dementia and Alzheimer's disease. *Lancet Neurology*, *4*, 705–711.

Rowe, J.W., & Kahn, R.L. (1998). *Successful aging*. New York: Random House (Pantheon).

Rubin, D.C., & Berntsen, D. (2006). People over forty feel 20% younger than their age: Subjective age across the lifespan. *Psychonomic Bulletin and Review*, *13*, 776–780.

Russo-Neustadt, A., Ryan, C.B., & Cotman, C.W. (1999). Exercise, antidepressant medications, and enhanced brain derived neurotrophic factor expression. *Neuropsychopharmacology*, *21*, 679–682.

Ryan, E.B. (1992). Beliefs about memory changes across the adult life span. *Journal of Gerontology*, *47*, P41–P46.

Rypma, B., Eldreth, D.A., & Rebbechi, D. (2007). Age-related differences in activation-performance relations in delayed-response tasks: A multiple component analysis. *Cortex*, *43*, 65–76.

Sachs-Ericsson, N., Joiner, T., Plant, E.A., & Blazer, D.G. (2005). The influence of depression on cognitive decline in community-dwelling elderly persons. *American Journal of Geriatric Psychiatry*, *5*, 402–408.

Saczynski, J.S., Pfeifer, L.A., Masaki, K., Korf, E.S.C., Laurin, D., White, L., & Launer, L. (2006). The effect of social engagement on incident dementia. The Honolulu-Asia Aging Study. *American Journal of Epidemiology*, *163*, 433–440.

Saklofske, D.H., Austin, E.J., Rohr, B.A., & Andrews, J.J.W. (2007). Personality, emotional intelligence, and exercise. *Journal of Health Psychology*, *12*, 937–948.

Salthouse, T.A. (1984). Effects of age and skill in typing. *Journal of Experimental Psychology: General*, *113*, 345–371.

Salthouse, T.A. (1991a). Expertise as the circumvention of human processing limitations. In K.A. Ericsson & J. Smith (Eds.), *Towards a general theory of expertise: Prospects and limits* (pp. 286–300). New York: Cambridge University Press.

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

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

Salthouse, T.A. (2006). Mental exercise and mental aging: Evaluating the validity of the "use it or lose it" hypothesis. *Perspectives on Psychological Science*, *1*, 68–87.

Salthouse, T.A., Atkinson, T.M., & Berish, D.E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology*, *132*, 566–594.

Salthouse, T.A., Babcock, R.L., Skovronek, E., Mitchell, D.R.D., & Palmon, R. (1990). Age and experience effects in spatial visualization. *Developmental Psychology*, *26*, 128–136.

Salthouse, T.A., Berish, D.E., & Miles, J.D. (2002). The role of cognitive stimulation on the relations between age and cognitive functioning. *Psychology and Aging*, *17*, 548–557.

Salthouse, T.A., Hambrick, D.Z., Lukas, K.E., & Dell, T.C. (1996). Determinants of adult age differences on synthetic work performance. *Journal of Experimental Psychology: Applied*, *2*, 305–329.

Salthouse, T.A., & Meinz, E.J. (1995). Aging, inhibition, working memory, and speed. *Journal of Gerontology: Psychological Sciences*, *50B*, 297–306.

Sapolsky, R.M. (1992). *Stress, the aging brain, and the mechanisms of neuron death*. Cambridge, MA: MIT Press.

Satz, P. (1993). Brain reserve capacity on symptom onset after brain injury: A formulation and review of evidence for threshold theory. *Neuropsychology*, *7*, 273–295.

Scarmeas, N., Albert, S.M., Manly, J.J., & Stern, Y. (2006). Education and rates of cognitive decline in incident Alzheimer's disease. *Journal of Neurology, Neurosurgery and Psychiatry*, *77*, 308–316.

Scarmeas, N., Levy, G., Tang, M.X., Manly, J., & Stern, Y. (2001). Influence of leisure activity on the incidence of Alzheimer's disease. *Neurology*, *7*, 2236–2242.

Schaie, K.W. (1977). Toward a stage theory of adult cognitive-development. *International Journal of Aging and Human Development*, *8*, 129–138.

Schaie, K.W., & Willis, S.L. (1986). Can intellectual decline be reversed? *Developmental Psychology*, *22*, 223–232.

Schaie, K.W., Willis, S.L., Hertzog, C., & Schulenberg, J.E. (1987). Effects of cognitive training on primary metal ability structure. *Psychology and Aging*, *2*, 233–242.

Schinka, J.A., McBride, A., Vanderploeg, R.D., Tennyson, K., Borenstein, A.R., & Mortimer, J.A. (2005). Florida Cognitive Activities scale: Initial development and validation. *Journal of the International Neuropsychological Society*, *11*, 108–116.

Schmidt, R.A., & Bjork, R.A. (1992). New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychological Science*, *3*, 207–217.

Schneider, J.A., Li, J.-L., Li, Y., Wilson, R.S., Kordower, J.H., & Bennett, D.A. (2006). Neurofibrillary tangles in the substantia nigra are related to gait impairment in older persons. *Annals of Neurology*, *59*, 166–173.

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

Scholz, U., Sniehotta, F.F., Schuez, B., & Oeberst, A. (2007). Dynamics in self-regulation: Plan execution, self-efficacy, and mastery of action plans. *Journal of Applied Social Psychology*, *37*, 2706–2725.

Schooler, C. (2007). Use it—and keep it, longer, probably: A reply to Salthouse (2006). *Perspectives on Psychological Science*, *2*, 24–29.

Schooler, C., & Mulatu, M.S. (2001). The reciprocal effects of leisure time activities and intellectual functioning in older people: A longitudinal analysis. *Psychology and Aging*, *16*, 466–482.

Schooler, C., Mulatu, M.S., & Oates, G. (1999). The continuing effects of substantively complex work on the intellectual functioning of older workers. *Psychology and Aging*, *14*, 483–506.

Schuit, A.J., Feskens, E.J.M., Launer, L.J., & Kromhout, D. (2001). Physical activity and cognitive decline, the role of apoliprotein e4 allele. *Medicine & Science in Sports & Exercise*, *26*, 772–777.

Schulz, R., & Curnow, C. (1988). Peak performance and age among superathletes—track and field, swimming, baseball, tennis, and golf. *Journal of Gerontology: Psychological Sciences*, *43B*, P113–P120.

Schulz, R., & Heckhausen, J. (1996). A life span model of successful aging. *American Psychologist*, *51*, 702–714.

Schunn, C.D., & Reder, L.M. (2001). Another source of individual differences: Strategy adaptivity to changing rates of success. *Journal of Experimental Psychology: General*, *130*, 59–76.

Schwarzer, R. (2008). Modeling health behavior change: How to predict and modify the adoption and maintenance of health behaviors. *Applied Psychology: An International Review*, *57*, 1–29.

Scialfa, C., Jenkins, L., Hamaluk, E., & Skaloud, P. (2000). Aging and the development of automamticity in conjunction search. *Journal of Gerontology: Psychological Sciences*, *55B*, 27–46.

Seeman, T.E., Lusignolo, T.M., Albert, M., & Berkman, L. (2001). Social relationships, social support, and patterns of cognitive aging in healthy, high-functioning older adults: MacArthur Studies of Successful Aging. *Health Psychology*, *20*, 243–255.

Seeman, T.E., McAvay, G., Merrill, S., Albert, M., & Rodin, J. (1996). Self-efficacy beliefs and changes in cognitive performance: MacArthur Studies of Successful Aging. *Psychology and Aging*, *11*, 538–551.

Seeman, T.E., Unger, J.B., McAvay, G., & Mendes de Leon, C.F. (1999). Self-efficacy beliefs and perceived declines in functional ability: MacArthur Studies of Successful Aging. *Journal of Gerontology: Psychological Sciences*, *54B*, P214–P222.

Segerstrom, S.C., & Roach, A.R. (2008). On the physical health benefits of self-enhancement. In E.C. Chang (Ed.), *Self-criticism and self-enhancement: Theory, research, and clinical applications* (pp. 37–54). Washington, DC: American Psychological Association.

Shadish, W., Cook, T.D., & Campbell, D.T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Boston: Houghton Mifflin.

Shakesby, A.C., Anwyl, R., & Rowan, M.J. (2002). Overcoming the effects of stress on synaptic plasticity in the intact hippocampus: Rapid actions of serotonergic and antidepressant agents. *Journal of Neuroscience*, *22*, 3638–3644.

Sheldon, K.M., & Kasser, T. (2001). Getting older, getting better? Personal strivings and psychological maturity across the lifespan. *Developmental Psychology*, *37*, 491–501.

Sheline, Y.I., Wang, P.W., Gado, M.H., Csernansky, J.G., & Vannier, M.W. (1996). Hippocampal atrophy in recurrent major depression. *Proceedings of the National Academy of Sciences, USA*, *93*, 3908–3913.

Shiffrin, R.M., & Schneider, W. (1977). Controlled and automatic human information-processing: 2. Perceptual learning, automatic attending, and a general theory. *Psychological Review*, *84*, 127–190.

Shing, Y.L., Werkle-Bergner, M., Li, S.-C., & Lindenberger, U. (2008). Associative and strategic components of episodic memory: A lifespan dissociation. *Journal of Experimental Psychology: General*, *137*, 495–513.

Shrager, J., & Johnson, M.H. (1996). Dynamic plasticity influences the emergence of function in a simple cortical array. *Neural Networks*, *9*, 1119–1129.

Siegler, R.S. (2006). Inter- and intra-individual differences in problem solving across the life span. In E. Bialystok & F.I.M. Craik (Eds.), *Lifespan cognition: Mechanisms of change* (pp. 285–296). Oxford, England: Oxford University Press.

Siegler, R.S., & Crowley, K. (1991). The microgenetic method: A direct means for studying cognitive development. *American Psychologist*, *46*, 606–620.

Singer, T., Lindenberger, U., & Baltes, P.B. (2003). Plasticity of memory for new learning in very old age: A story of major loss? *Psychology and Aging*, *18*, 306–317.

Singer, T., Verhaeghen, P., Ghisletta, P., Lindenberger, U., & Baltes, P.B. (2003). The fate of cognition in very old age: Six-year longitudinal findings in the Berlin Aging Study (BASE). *Psychology and Aging*, *18*, 318–331.

Skarupski, K.A., Mendes de Leon, C.F., Bienias, J.L., Barnes, L.L., Everson-Rose, S.A., Wilson, R.S., et al. (2005). Black-white differences in depressive symptoms among older adults over time. *Journal of Gerontology: Psychological Sciences*, *60B*, P136–P142.

Skinner, E.A. (1996). A guide to constructs of control. *Journal of Personality and Social Psychology*, *71*, 549–570.

Sliwinski, M.J., Smyth, J.M., Hofer, S.M., & Stawski, R.S. (2006). Intraindividual coupling of daily stress and cognition. *Psychology and Aging*, *21*, 545–557.

Sluming, V., Barrick, T., Howard, M., Cezayirli, E., Mayes, A., & Roberts, N. (2002). Voxel-based morphometry reveals increased gray mattery density in Broca's area in male symphony orchestra musicians. *Neuroimage*, *17*, 1613–1622.

Small, B.J., Hertzog, C., Hultsch, D.F., & Dixon, R.A. (2003). Stability and change in adult personality over 6 years: Findings from the Victoria Longitudinal Study. *Journal of Gerontology: Psychology Sciences*, *58B*, P166–P176.

Small, G.W., Silverman, D., Siddarth, P., Ercoli, L.M., Miller, K.J., Lavretsky, H., et al. (2006). Effects of a 14 day health longevity lifestyle program on cognition and brain function. *American Journal of Geriatric Psychiatry*, *14*, 538–545.

Smith, A.D., & Zigmond, M.J. (2003). Can the brain be protected through exercise? Lessons from an animal model of Parkinsonism. *Experimental Neurology*, *184*, 31–39.

Smith, M.A., Makino, S., Kvetnansky, R., & Post, M. (1995). Stress and glucocorticoids affect the expression of brain-derived neurotrophic factor and neurotrophin −3 mRNAs in the hippocampus. *Journal of Neuroscience*, *15*, 1768–1777.

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, *8*, 448–460.

Stern, Y., Gurland, B., Tatemichi, T.K., Tang, M.X., Wilder, D., & Mayeux, R. (1994). Influence of education and occupation on the incidence of Alzheimer's disease. *Journal of the American Medical Association*, *271*, 1004–1010.

Sternberg, S. (1966). High-speed scanning in human memory. *Science*, *153*, 652–654.

Steunenberg, B., Twisk, J.W.R., Beekman, A.T.F., Deeg, D.J.H., & Kerkhof, A.J.F.M. (2005). Stability and change in neuroticism in aging. *Journal of Gerontology: Psychological Sciences*, *60B*, P27–P33.

Stigsdotter Neely, A., & Bäckman, L. (1993). Long-term maintenance of gains from memory training in older adults: Two 3 1/2 years follow-up studies. *Journals of Gerontology: Psychological Sciences*, *48B*, P233–P237.

Stine-Morrow, E.A.L. (2007). The Dumbledore hypothesis of cognitive aging. *Current Directions in Psychological Science*, *16*, 295–299.

Stine-Morrow, E.A.L., Miller, L.M.S., & Hertzog, C. (2006). Aging and self-regulated language processing. *Psychological Bulletin*, *132*, 582–606.

Stine-Morrow, A.L., Parisi, J.M., Morrow, D.G., Greene, J., & Park, D.C. (2007). The Senior Odyssey Project: A model of intellectual and social engagement. *Journal of Gerontology: Psychological Sciences*, *62B*, P62–P69.

Stranahan, A.M., Kahlil, D., & Gould, E. (2006). Social isolation delays the positive effects of running on adult neurogenesis. *Nature Neuroscience*, *9*, 526–533.

Strayer, D.L., & Kramer, A.F. (1994). Aging and skill acquisition: learning-performance distinctions. *Psychology & Aging*, *9*, 589–605.

Sturman, M.T., Morris, M.C., Mendes de Leon, C.F., Bienias, J.L., Wilson, R.S., & Evans, D.A. (2005). Physical activity, cognitive activity, and cognitive decline in a biracial community population. *Archives of Neurology*, *62*, 1750–1734.

Stuss, D., Robertson, I., Craik, F.I.M., Levine, B., Michale, A., Black, S., et al. (2007). Cognitive rehabilitation in the elderly: A randomized trial to evaluate a new protocol. *Journal of the International Neuropsychological Society*, *13*, 120–131.

Sullivan, E.V., & Pfefferbaum, A. (2006). Diffusion tensor imaging and aging. *Neuroscience & Biobehavioral Reviews*, *30*, 749–761.

Swain, R.A., Harris, E.C., Weiner, M.V., Dutka, H.D., Theien, S., Konda, S., et al. (2003). Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. *Neuroscience*, *117*, 1037–1046.

Teri, L., McCurry, S., Edland, S., Kukull, W., & Larson, E. (1995). Cognitive decline in Alzheimer's disease: A longitudinal investigation of risk factors for accelerated decline. *Journal of Gerontology: Medical Sciences*, *50A*, M49–M55.

Terracciano, A., McCrae, R.R., & Costa, P.T. (2006). Longitudinal trajectories in Guilford-Zimmerman temperament survey data: Results from the Baltimore Longitudinal Study of Aging. *Journal of Gerontology: Psychological Sciences*, *61B*, P108–P116.

Tetens, J.N. (1777). *Philosophische Versuche über die menschliche Natur und ihre Entwicklung (Philosophical essays on human nature and its development)*. Leipzig, Germany: Weidmann, Erbens, und Reich.

Thorndike, E.L. (1906). *The principles of teaching based on psychology*. New York: A.G. Seiler.

Thurstone, L.L. (1938). *Primary mental abilities*. Chicago: University of Chicago Press.

Tilvis, R.S., Kahonen-Vare, M.H., Jolkkonen, J., Valvanne, J., Pitkala, K.H., & Strandberg, T.E. (2004). Predictors of cognitive decline and mortality of aged people over a 10-year period. *Journal of Gerontology: Medical Sciences*, *59A*, M268–M274.

Timmer, E., & Aartsen, M. (2003). Mastery beliefs and productive leisure activities in the third age. *Social Behavior and Personality*, *31*, 643–656.

Touron, D.R., & Hertzog, C. (2004). Distinguishing age differences in knowledge, strategy use, and confidence during strategic skill acquisition. *Psychology and Aging*, *19*, 452–466.

Tranter, L.J., & Koutstaal, W. (2008). Age and flexible thinking: An experimental demonstration of the beneficial effects of increased cognitively stimulating activity on fluid intelligence in healthy older adults. *Aging, Neuropsychology, and Cognition*, *15*, 184–207.

Trejo, J.L., Carro, E., & Torres-Aleman, I. (2001). Circulating insulin-like growth factor mediates exercise-induced increases in the number of new neurons in the adult hippocampus. *The Journal of Neuroscience*, *21*, 1628–1634.

Turner, A., & Greenough, W.T. (1985). Differential rearing effects on rat visual cortex synapses. Synaptic and neuronal density and synapses per neuron. *Brain Research Reviews*, *329*, 195–203.

Uno, H., Tarara, R., Else, J.G., Suleman, M.A., & Sapolsky, R.M. (1989). Hippocampal damage associated with prolonged and fatal stress in primates. *Journal of Neuroscience*, *9*, 1705–1711.

van Hooren, S.A.H., Valentijn, S.A.M., Bosma, H., Ponds, R.W.H.M., van Boxtel, M.P.J., & Jolles, J. (2005). Relation between health status and cognitive functioning: A 6-year follow-up of the Maastricht Aging Study. *Journal of Gerontology: Psychological Sciences*, *60B*, P57–P60.

Van Praag, H., Christie, B.R., Sejnowski, T.J., & Gage, F.H. (1999). Running enhances neurogenesis, learning, and long-term potentiation in mice. *Proceedings of the National Academy of Sciences, USA*, *96*, 13427–13431.

Van Praag, H., Kempermann, G., & Gage, F.H. (1999). Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus. *Nature Neuroscience*, *2*, 266–270.

van Praag, H., Shubert, T., Zhao, C., & Gage, F.H. (2005). Exercise enhances learning and hippocampal neurogenesis in aged mice. *Journal of Neuroscience*, *25*, 8680–8685.

Vaynman, S., & Gomez-Pinilla, F. (2006). Revenge of the "sit": How lifestyle impacts neuronal and cognitive health though molecular systems that interface energy metabolism with neuronal plasticity. *Journal of Neuroscience Research*, *84*, 699–715.

Vaynman, S., Ying, Z., & Gomez-Pinilla, F. (2004). Hippocampal bdnf mediates the efficacy of exercise on synaptic plasticity and cognition. *European Journal of Neuroscience*, *20*, 1030–1034.

Verghese, J., LeValley, A., Derby, C., Kuslansky, G., Katz, M., Hall, C., et al. (2006). Leisure activities and the risk of amnestic mild cognitive impairment in the elderly. *Neurology*, *66*, 821–827.

Verghese, J., Lipton, R.B., Katz, M.J., Hall, C.B., Derby, C.A., Kuslansky, G., et al. (2003). Leisure activities and the risk of dementia in the elderly. *New England Journal of Medicine*, *348*, 2508–2516.

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.

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychology and Aging*, *7*, 242–251.

Verhaeghen, P., Steitz, D.W., Sliwinski, M.J., & Cerella, J. (2003). Aging and dual-task performance: A meta-analysis. *Psychology & Aging*, *18*, 443–460.

Vinkers, D.A., Gussekloo, J., Strek, M.L., Westendorp, R.G.J., van der Mast, R.C. (2004). Temporal relation between depression and cognitive impairment in old age: Prospective population based study. *British Medical Journal*, *329*, e881.

Virues-Ortega, J., Buela-Casal, G., Garrido, E., & Alcazar, B. (2004). Neuropsychological functioning associated with high altitude exposure. *Neuropsychological Review*, *14*, 197–224.

von Oertzen, T., Hertzog, C., Lindenberger, U., & Ghisletta, P. (2008). *The effect of multiple indicators on the power to detect interindividual differences in change*. Unpublished manuscript.

Wallace, J., & O'Hara, M.W. (1992). Increases in depressive symptomatology in the rural elderly, results from a cross-sectional and longitudinal study. *Journal of Abnormal Psychology*, *101*, 398–404.

Wang, H.X., Karp, A., Winbald, B., & Fratiglioni, L. (2002). Late-life engagement in social and leisure activities is associated with a decreased risk of dementia: A longitudinal study from the Kungsholmen Project. *American Journal of Epidemiology*, *155*, 1081–1087.

Wang, J.Y.J., Zhou, D.H.D., Li, J., Zhang, M., Deng, J., Tang, M., et al. (2006). Leisure activities and risk of cognitive impairment: The Chongqing Aging Study. *Neurology*, *66*, 911–913.

Warburton, D.E.R., Nicoi, C.W., & Bredin, S.S.D. (2006). Health benefits of physical activity: The evidence. *Canadian Medical Association Journal*, *174*, 801–809.

Watson, D., & Clark, L.A. (1984). Negative affectivity: The disposition to experience aversive emotional states. *Psychological Bulletin*, *96*, 465–490.

Watson, F.L., Pasteur, M.A.L., Healy, D.T., & Hughes, E.A. (1994). Nine parallel versions of four memory tests: An assessment of form equivalence and the effects of practice on performance. *Human Psychopharmacology*, *9*, 51–61.

Waugh, N.C., Thomas, J.C., & Fozard, J.L. (1978). Retrieval times from different memory stores. *Journal of Gerontology*, *33*, 718–724.

Webster, M.J., Knable, M.B., O'Grady, J., Orthman, J., & Weickert, C.S. (2002). Regional specificity of brain glucocorticoid receptor mRNA alterations in subjects with schizophrenia and mood disorders. *Molecular Psychiatry*, *7*, 985–994.

Weil, A. (2006). *Healthy aging: A lifelong guide to your physical and spiritual well-being*. New York: Random House.

Werner, H. (1948). *Comparative psychology of mental development*. New York: International Universities Press.

West, R.L. (1985). *Memory fitness over 40*. Gainesville, FL: Triad Publishing.

West, R.L., Bagwell, D.K., & Dark-Freudeman, A. (2008). Self-efficacy and memory aging: The impact of a memory intervention based on self-efficacy. *Aging, Neuropsychology, and Cognition*, *15*, 302–329.

Wetherell, J.L., Reynolds, C.A., Gatz, M., & Pedersen, N.L. (2002). Anxiety, cognitive performance and cognitive decline in normal aging. *Journal of Gerontology: Psychological Sciences*, *57B*, P246–P255.

Weuve, J., Kang, J.H., Manson, J.E., Breteler, M.M.B., Ware, J.H., & Grodstein, F. (2004). Physical activity including walking and cognitive function in older women. *Journal of the American Medical Association*, *292*, 1454–1461.

Willis, S.L. (1996). Everyday problem solving. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (4th ed., pp. 287–307). San Diego, CA: Academic Press.

Willis, S.L., & Nesselroade, C.S. (1990). Long-term effects of fluid ability training in old-old age. *Developmental Psychology*, *26*, 905–910.

Willis, S.L., Tennstedt, S.L., Marsiske, M., Ball, K., Elias, J., Koepke, K.M., et al. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Journal of the American Medical Association*, *296*, 2805–2814.

Wilson, R.S., Arnold, S.E., Beck, T.L., Bienias, J.L., & Bennett, D.A. (in press). Change in depressive symptoms during the prodromal phase of Alzheimer's disease. *Archives of General Psychiatry.*

Wilson, R.S., Arnold, S.E., Schneider, J.A., Kelly, J.F., Tang, Y., & Bennett, D.A. (2006). Chronic psychological distress and risk of Alzheimer's disease in old age. *Neuroepidemiology*, *27*, 143–153.

Wilson, R.S., Arnold, S.E., Schneider, J.A., Li, Y., & Bennett, D.A. (2007). Chronic distress, age-related neuropathology, and late life dementia. *Psychosomatic Medicine*, *69*, 47–53.

Wilson, R.S., Arnold, S.E., Schneider, J.A., Tang, Y., & Bennett, D.A. (2007). The relation of cerebral Alzheimer's disease pathology to odor identification in old age. *Journal of Neurology Neurosurgery and Psychiatry*, *78*, 30–35.

Wilson, R.S., Barnes, L.L., & Bennett, D.A. (2003). Assessment of lifetime participation in cognitively stimulating activities. *Journal of Clinical and Experimental Neuropsychology*, *25*, 634–642.

Wilson, R.S., Barnes, L.L., Bennett, D.A., Li, Y., Bienias, J.L., Mendes de Leon, C.F., et al. (2005). Proneness to psychological distress and risk of Alzheimer's disease in a community population. *Neurology*, *64*, 380–382.

Wilson, R.S., Barnes, L.L., Krueger, K.R., Hoganson, G., Bienias, J.L., & Bennett, D.A. (2005). Early and late life cognitive activity and cognitive systems in old age. *Journal of the International Neuropsychological Society*, *11*, 400–407.

Wilson, R.S., Barnes, L.L., Mendes de Leon, C.F., Aggarwal, N.T., Schneider, J.A., Bach, J., et al. (2002). Depressive symptoms, cognitive decline, and risk of AD in older persons. *Neurology*, *59*, 364–370.

Wilson, R.S., Beckett, L.A., Barnes, L.L., Schneider, J.A., Bach, J., Evans, D.A., & Bennett, D.A. (2002). Individual differences in rates of change in cognitive abilities of older persons. *Psychology and Aging*, *17*, 179–193.

Wilson, R.S., Beckett, L.A., Bennett, D.A., Albert, M.S., & Evans, D.A. (1999). Change in cognitive function in older persons from a community population: Relation to age and Alzheimer's disease. *Archives of Neurology*, *56*, 1274–1279.

Wilson, R.S., & Bennett, D.A. (2003). Cognitive activity and risk of Alzheimer's disease. *Current Directions in Psychological Science*, *12*, 87–91.

Wilson, R.S., Bennett, D.A., Beckett, L.A., Morris, M.C., Gilley, D.W., Bienias, J.L., et al. (1999). Cognitive activity in older persons from a geographically defined population. *Journal of Gerontology: Psychological Sciences*, *54B*, P155–P160.

Wilson, R.S., Bennett, D.A., Bienias, J.L., Aggarwal, N.T., Mendes de Leon, C.F., Morris, M.C., et al. (2002). Cognitive activity and incident AD in a population-based sample of older persons. *Neurology*, *59*, 1910–1914.

Wilson, R.S., Bennett, D.A., Bienias, J.L., Mendes de Leon, C.F., Morris, M.C., & Evans, D.A. (2003). Cognitive activity and cognitive decline in a biracial community population. *Neurology*, *61*, 812–816.

Wilson, R.S., Bennett, D.A., Gilley, D.W., Beckett, L.A., Barnes, L.L., & Evans, D.A. (2000). Premorbid reading activity and patterns of cognitive decline in Alzheimer's disease. *Archives of Neurology*, *57*, 1718–1723.

Wilson, R.S., Bennett, D.A., Mendes de Leon, C.F., Bienias, J.L., Morris, M.C., & Evans, D.A. (2005). Distress proneness and cognitive decline in a population of older persons. *Psychoneuroendocrinology*, *30*, 11–17.

Wilson, R.S., Evans, D.A., Bienias, J.L., Mendes de Leon, C.F., Schneider, J.A., & Bennett, D.A. (2003). Proneness to psychological distress is associated with risk of Alzheimer's disease. *Neurology*, *61*, 1479–1485.

Wilson, R.S., Hebert, L.E., Scherr, P.A., Barnes, L.L., Mendes de Leon, C.F., & Evans, D.E. (2009). Educational attainment and cognitive decline in old age. *Neurology*, *72*, 460–465.

Wilson, R.S., Krueger, K.R., Arnold, S.E., Schneider, J.A., Kelly, J.F., Barnes, L.L., et al. (2007). Loneliness and risk of Alzheimer's disease. *Archives of General Psychiatry*, *64*, 234–240.

Wilson, R.S, Li, Y., Aggarwal, N.T., Barnes, L.L., McCann, J.J., Gilley, D.W., & Evans, D.A. (2004). Education and the course of cognitive decline in Alzheimer's disease. *Neurology*, *63*, 1198–1203.

Wilson, R.S., Li, Y., Bienias, J.L., & Bennett, D.A. (2006). Cognitive decline in old age: Separating retest effects from the effects of growing older. *Psychology and Aging*, *21*, 774–789.

Wilson, R.S., Mendes de Leon, C.F., Barnes, L.L., Schneider, J.A., Bienias, J.L., Evans, D.A., et al. (2002). Participation in cognitively stimulating activities and risk of incident Alzheimer's

disease. *Journal of the American Medical Association*, *287*, 742–748.

Wilson, R.S., Mendes de Leon, C.F., Bennett, D.A., Bienias, J.L., & Evans, D.A. (2004). Depressive symptoms and cognitive decline in a community population of older persons. *Journal of Neurology: Neurosurgery & Psychiatry*, *75*, 126–129.

Wilson, R.S., Scherr, P.A., Schneider, J.A., Li, Y., & Bennett, D.A. (2007). The relation of cognitive activity to risk of developing Alzheimer's disease. *Neurology*, *69*, 1911–1920.

Wilson, R.S., Schneider, J.A., Arnold, S.E., Tang, Y., Boyle, P.A., & Bennett, D.A. (2007). Olfactory identification and incidence of mild cognitive impairment in old age. *Archives of General Psychiatry*, *64*, 802–808.

Wilson, R.S., Schneider, J.A., Bienias, J.L., Arnold, S.E., Evans, D.A., & Bennett, D.A. (2003). Depressive symptoms, clinical AD, and cortical plaques and tangles in older persons. *Neurology*, *61*, 1102–1107.

Wilson, R.S., Schneider, J.A., Bienias, J.L., Evans, D.A., & Bennett, D.A. (2003). Parkinsonian-like signs and risk of incident Alzheimer's disease in older persons. *Archives of Neurology*, *60*, 539–544.

Wilson, R.S., Schneider, J.A., Boyle, P.A., Arnold, S.E., Tang, Y., & Bennett, D.A. (2007). Chronic distress and incidence of mild cognitive impairment. *Neurology*, *68*, 2085–2092.

Winne, P.H. (1996). A metacognitive view of individual differences in self-regulated learning. *Learning and Individual Differences*, *8*, 327–353.

Wolf, S.A., Kronenberg, G., Lehmann, K., Blankenship, A., Overall, R., Staufenbiel, M., et al. (2006). Cognitive and physical activity differently modulate disease progression in the amyloid precursor protein (app) −23 model of Alzheimer's disease. *Biological Psychiatry*, *60*, 1314–1323.

Wolinsky, F.D., Unverzagt, F.W., Smith, D.M., Jones, R., Wright, E., & Tennstedt, S.L. (2006). The effects of the ACTIVE cognitive training trial on clinically relevant declines in health-related quality of life. *Journal of Gerontology: Social Sciences*, *61B*, S281–S287.

Wood, G.E., Young, L.T., Reagan, L.P., Chen, B., & McEwen, B.S. (2004). Stress-induced structural remodeling in the hippocampus: Prevention by lithium treatment. *Proceedings of the National Academy of Sciences, USA*, *101*, 3973–3978.

Xu, Y., Ku, B., Tie, L., Yao, H., Jiang, W., Ma, X., & Li, X. (2006). Curcumin reverses the effects of chronic stress on behavior, the HPA axis, BDNF expression and phosphorylation of CREB. *Brain Research*, *1122*, 56–64.

Yaffe, K., Barnes, D., Nevitt, M., Lui, L.Y., & Covinsky, K. (2001). A prospective study of physical activity and cognitive decline in elderly women. *Archives of Internal Medicine*, *161*, 1703–1708.

Yamada, M., Kasagi, F., Sasaki, H., Masunari, N., Mimori, Y., & Suzuki, G. (2003). Association between dementia and midlife risk factors: The radiation effects research foundation adult health study. *Journal of the American Geriatric Society*, *51*, 410–414.

Yang, L., Krampe, R.T., & Baltes, P.B. (2006). Basic forms of cognitive plasticity extended to the oldest-old: Retest learning, age, and cognitive functioning. *Psychology and Aging*, *21*, 372–378.

Yoshitake, T., Kiyohara, Y., Kato, I., Ohmura, T., Iwamoto, H., Nakayama, K., et al. (1995). Incidence and risk factors of vascular dementia and Alzheimer's disease in a defined elderly Japanese population: The Hisayama Study. *Neurology*, *6*, 1161–1168.

Zautra, A.J. (2003). *Emotions, stress, and health*. London: Oxford University Press.

Zunzunegui, M.V., Alvarado, B.E., Del Ser, T., & Otero, A. (2003). Social networks, social integration, and social engagement determine cognitive decline in community-dwelling Spanish older adults. *Journal of Gerontology: Social Sciences*, *58B*, S93–S100.