Mental Exercise and Mental Aging

Evaluating the Validity of the "Use It or Lose It" Hypothesis

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ABSTRACT—***It is widely believed that keeping mentally active will prevent age-related mental decline. The primary prediction of this mental-exercise hypothesis is that the rate of age-related decline in measures of cognitive functioning will be less pronounced for people who are more mentally active, or, equivalently, that the cognitive differences among people who vary in level of mental activity will be greater with increased age. Although many training studies, and comparisons involving experts, people in specific occupations, and people whose mental activity levels are determined by their self-reports, have found a positive relation between level of activity and level of cognitive functioning, very few studies have found an interactive effect of age and mental activity on measures of cognitive functioning. Despite the current lack of empirical evidence for the idea that the rate of mental aging is moderated by amount of mental activity, there may be personal benefits to assuming that the mental-exercise hypothesis is true.***

Cross-sectional comparisons of people of different ages have consistently revealed that increased age is associated with lower levels of performance on a wide variety of cognitive measures. Differences of this type have been reported in studies in which relatively small samples of college students were compared with adults in their 60s and 70s on single variables, and in larger projects involving hundreds of adults ranging from 18 to 100 years of age and comparisons of multiple variables.

Typical patterns from past research can be illustrated with results from a number of studies conducted in my laboratory. Similar relations between age and performance have been reported for many variables (e.g., Salthouse, 2004), and thus the trends can be illustrated with four variables representing episodic memory (paired associates), perceptual reasoning (spatial relations), perceptual speed (Wechsler Adult Intelligence Scale, WAIS, Digit Symbol test), and word knowledge (WAIS Vocabulary test). Figure 1 portrays the means of these four variables as a function of age for samples of between 1,200 and 2,500 individuals each. To facilitate comparisons across variables, the measures from different tasks have been converted to standard deviation units based on the scores from the entire sample. As the figure shows, the cross-sectional age differences on these variables begin when adults are in their 20s or 30s, and the decline that begins at that time possibly accelerates around age 50. The primary exception to this pattern is for variables with a large knowledge component, such as measures of vocabulary. With these variables, the trend is for an increase until about age 50 or 60, followed by a gradual decline. The existence of different age trends for different variables has led to an important distinction between two types of cognition. Many labels have been proposed for the two types, such as fluid and crystallized, but the terms *process* and *product* may be the most descriptive. That is, process measures of intelligence reflect the efficiency of processing at the time of assessment, and product measures of intelligence reflect the cumulative products of processing carried out in the past.

Almost as soon as age-related differences in mean level of performance were found, it was recognized that there is also substantial variability in cognitive performance among individuals at every age. Figure 2 illustrates this type of variability with data from a paired-associates task in which participants viewed six pairs of unrelated words and later attempted to recall the second member of each pair when presented with the first member. The figure portrays the distribution of paired-associates scores for 358 adults between 60 and 69 years of age. The graph shows considerable variability among people of nearly the same age, with a few individuals recalling all of the pairs and some individuals recalling none of them.

Quantitative estimates of the variability that is unrelated to age can be obtained from the correlation coefficient relating age

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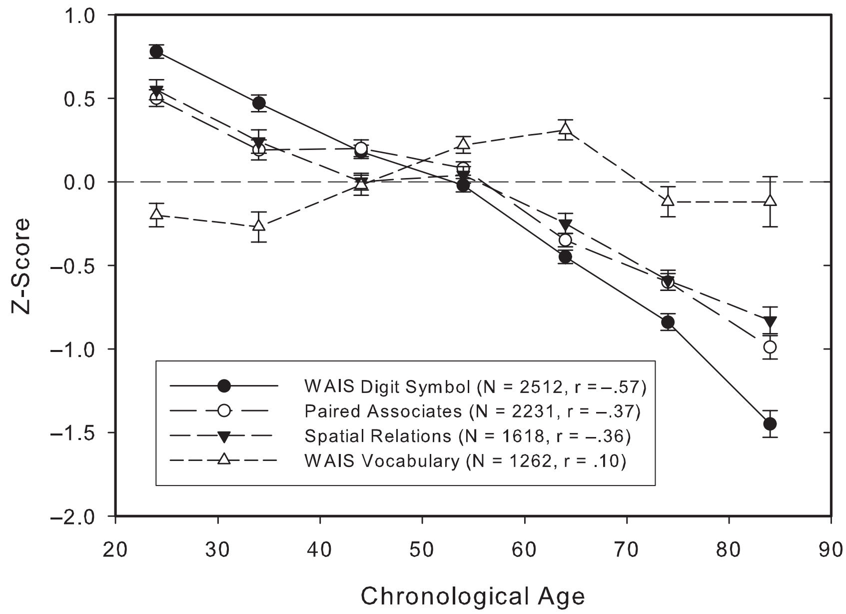

Fig. 1. Means (and standard errors) of *z* scores for four cognitive variables as a function of age. WAIS = Wechsler Adult Intelligence Scale.

to test score. That is, the square of a correlation indicates the proportion of variance that is shared between two variables, and thus 1 minus the squared correlation between age and test score indicates the proportion of variance in performance that is not shared with age. For the three variables in Figure 1 with the strongest correlations with age, between 68% and 87% of the total variance in the scores was not related to age. It is therefore clear that although on average increased age is associated with lower levels of performance on many cognitive tests, there is also substantial variation in performance at each age.

Two key questions in the field of cognitive aging are, what is responsible for this large between-person variation among individuals of nearly the same age, and to what extent does the variability reflect processes related to differential aging? A particularly intriguing possibility is that factors associated with lifestyle, such as the degree of engagement in mentally stimulating activities, contribute to the variation among people at each age, and perhaps also to variation in the rate of mental aging. The idea that lifestyle factors can affect both the level of cognitive functioning and the rate of age-related change in

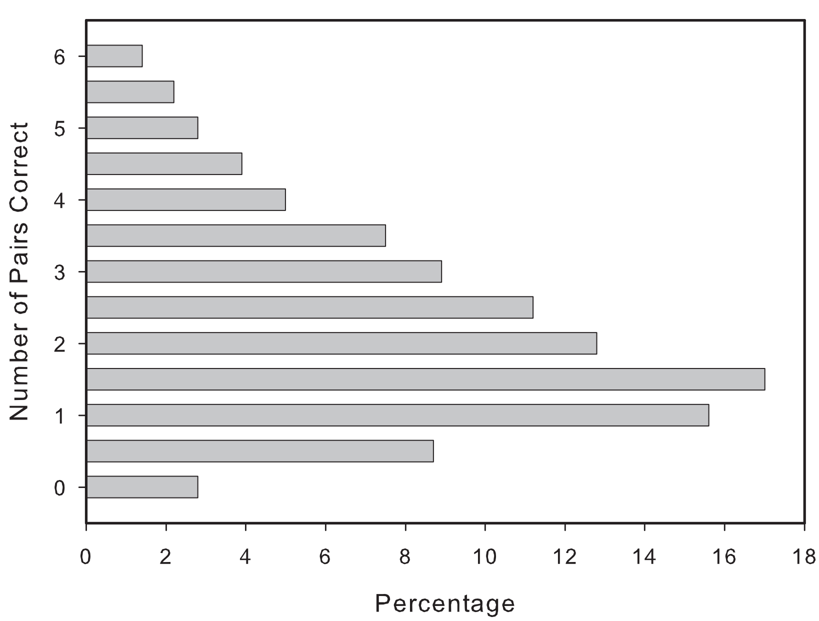

Fig. 2. Distribution of scores on a paired-associates memory test for 358 adults between 60 and 69 years of age.

cognitive functioning is obviously very appealing because it implies that individuals can control aspects of their own destiny. Many dimensions of lifestyle have been investigated with respect to their relation to cognitive functioning, but the focus in this article is restricted to mental stimulation, and does not extend to other characteristics, such as diet, physical activity, or amount of social interaction.

The mental-exercise hypothesis was mentioned by the earliest researchers in the field of cognitive aging (e.g., Foster & Taylor, 1920; Jones & Conrad, 1933; Miles, 1933; Thorndike, Tilton, & Woodyard, 1928), and it is a prominent theme of many books on aging oriented toward the general public (e.g., Comfort, 1976; McKhann & Albert, 2002; Restak, 1997; Rowe & Kahn, 1998). The view that keeping mentally active will maintain one's level of cognitive functioning, and possibly even prevent cognitive decline and the onset of dementia, is so pervasive in contemporary culture that it is frequently expressed in the "use it or lose it" adage. The wide variety of activities that have been mentioned as offering potential protective benefits includes playing bridge, working on crossword puzzles, learning a foreign language, learning to play a musical instrument, and even shopping. An early proponent of this position (Sorenson, 1938) went so far as to suggest that to prevent cognitive decline, people should order their lives such that they constantly find themselves in new situations and confronted with novel problems.

A relation between mental exercise and mental fitness is intuitively plausible because it is consistent with the well-established relation between physical exercise and physical fitness (e.g., Green & Crouse, 1995), and with neurobiological evidence that new connections may be formed among neurons as a consequence of novel environmental stimulation (e.g., van Praag, Kempermann, & Gage, 2000). The relation also seems to be supported by anecdotal observations that high-functioning older adults often appear to be more intellectually active than lower-functioning older adults. Despite the obvious appeal of the mental-exercise hypothesis, however, the evidence for it has rarely been examined critically, in part because advocates of the hypothesis seldom discuss, or even cite, relevant empirical evidence. A primary goal of this article is to provide such an evaluation of the hypothesis that there is a causal relation between amount of mental activity and rate of mental aging. Because I reviewed much of the early literature relevant to this hypothesis about 15 years ago (Salthouse, 1991), the current article emphasizes material not covered in that book.

A fundamental thesis of this review is that the existence of a relation between level of mental activity and level of mental functioning among adults at any given age is, by itself, not very informative about the mental-exercise hypothesis because there are a number of different ways that a relation of this type could be produced. In particular, the relation could occur because, as proposed by the mental-exercise hypothesis, the amount of mental activity throughout one's life contributes to the level of mental ability at later periods in life, but the relation could also originate because the amount of mental activity at any age is at least partially determined by one's prior, and current, level of mental ability. More generally, although it is tempting to attribute some of the variability in cognitive performance apparent at any given age to individual differences in prior rates of age-related change in cognitive abilities, it is important to consider the possibility that much of that variability was present at earlier ages, and may have little or nothing to do with differential aging. (This argument also applies to many discussions of the concept of "successful aging," because before attributing individuals' current status to dynamic processes of aging, it is important to consider their status at earlier ages. Only if there is evidence that people have differed in their rates of aging does it seem appropriate to characterize them as having "aged" successfully, as opposed to having been successful at every stage in their lives.)

One way to distinguish between the two alternatives involves examining the relation between age and mental performance as a function of amount of mental activity. That is, to the extent that mental activity alters the rate of mental aging, amount of mental exercise would be expected to moderate the relations between age and measures of mental functioning. In a longitudinal study, involving comparisons of the same people at different ages, this situation would be manifested in smaller age-related declines (or possibly even larger age-related improvements) among individuals who engage in greater amounts of mental activity. In cross-sectional comparisons, based on people of different ages examined at the same point in time, the differences in mental performance between individuals with different amounts of mentally stimulating activity would be expected to become progressively larger with increased age as the effects of differential mental activity accumulate over time.

This prediction, which can be designated the *differential-preservation* hypothesis because the degree to which performance is preserved across increasing age is postulated to differ according to level of mental activity (Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990), is portrayed in the left panel of Figure 3. Notice that individuals with greater amounts of mental stimulation are postulated to have less negative (or more positive) relations between age and level of performance on cognitive tasks. However, the right panel of Figure 3 portrays an alternative possibility that needs to be considered, namely, that people who are more mentally active are likely to have had high levels of cognitive functioning throughout their lives. According to this proposal, the differences in performance are preserved across all of adulthood, so it has been termed the *preserved-differentiation* hypothesis (Salthouse et al., 1990).

The key difference between these two perspectives is that the differential-preservation hypothesis views mental activity as a factor that protects against age-related decline in mental ability, whereas the preserved-differentiation hypothesis views an individual's current level of mental activity as at least partly a manifestation of his or her prior level of mental ability. The

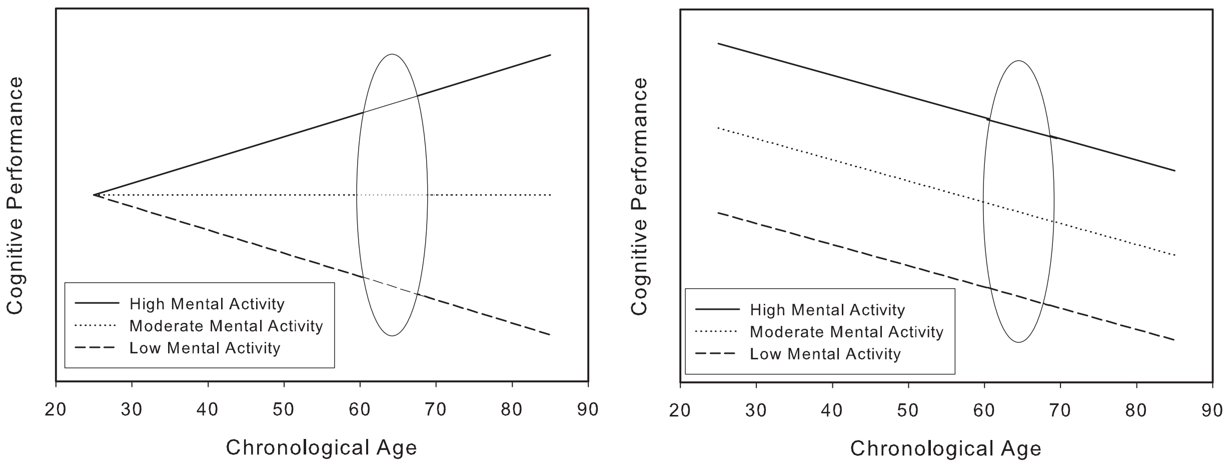

Fig. 3. Schematic representation of two interpretations of variability in cognitive performance at a given age. The left panel portrays the differential-preservation perspective, and the right panel portrays the preserved-differentiation perspective. The ellipses indicate that the two perspectives cannot be distinguished on the basis of a comparison of adults within a narrow age range.

distinction can be elaborated by considering how each perspective would explain a finding that people who play bridge tend to have somewhat higher levels of cognitive functioning than people who do not play bridge (e.g., Clarkson-Smith & Hartley, 1990). The differential-preservation hypothesis would suggest that playing bridge builds mental muscle that prevents atrophy of mental ability, whereas the preserved-differentiation hypothesis would suggest that a minimum level of mental strength is needed for individuals of any age to be capable of playing bridge.

INVESTIGATING THE MENTAL-EXERCISE HYPOTHESIS

It is well recognized that the ideal method of investigating a causal hypothesis is a randomized clinical trial in which one group of individuals is assigned to the experimental treatment (in this case, mental exercise) and another group is assigned to a suitable control activity, and both groups are monitored to determine the effects of the intervention on one or more critical outcome variables. Note that if the outcome of interest is the rate of mental aging, then the individuals must be followed long enough to determine whether the experimental and control groups differ in the relations between age and the relevant measures of mental functioning. Effects immediately after an intervention can be interesting and important, but they are not necessarily informative about age-related changes in mental ability that occur over a period of years or decades. Because large immediate effects could dissipate rapidly, and small immediate effects could accumulate slowly, long-term monitoring is needed to investigate influences on rates of aging.

The ideal study to investigate the mental-exercise hypothesis would therefore possess three critical characteristics. The first is random assignment of individuals to the experimental and control groups to minimize influences associated with preexisting differences such as initial level of cognitive ability and amount of education. The second characteristic is rigorous control of the treatment in terms of the type and amount of mental exercise. And the third critical characteristic is long-term monitoring of the amount of mentally stimulating activity and the level of cognitive functioning to allow influences on the rate of mental aging to be examined. Several aspects of cognition should be monitored during this phase because mental exercise might have different effects on process and product measures of cognitive functioning. (In fact, there have been several suggestions—e.g., Christensen, Henderson, Griffiths, & Levings, 1997; Compton, Bachman, Brand, & Avet, 2000; Gold et al., 1995; Kramer, Bherer, Colcombe, Dong, & Greenough, 2004—that lifestyle may have greater influences on knowledge-sensitive product measures than on measures of processing efficiency.) A study with these critical characteristics would provide support for the mental-exercise hypothesis if, compared with individuals with less mental stimulation, individuals with more mentally stimulating activity had a shallower rate of age-related decline in process measures of cognitive functioning, or a greater age-related gain in product measures of cognitive functioning.

Unfortunately, long-term studies with these characteristics are impractical with humans because it is impossible (and unethical) to randomly assign people to groups who would maintain the same lifestyle for a substantial proportion of their lives. The ideal study might be more feasible in nonhuman animals with short life spans, for whom nearly all aspects of their living conditions can be controlled. However, interventions that might affect mental stimulation, such as enriched environments (e.g., for reviews, see Frick & Fernandez, 2003; Kramer et al., 2004; van Praag et al., 2000), are also likely to alter the amount or variety of social interaction and physical activity, which makes it difficult to isolate the role of mental stimulation on any effects that might be found.

Another major barrier to implementing the ideal study is that no methods are currently available to accurately evaluate an individual's level of mental stimulation. Amount of physical exercise can be quantified with measures such as metabolic expenditure units, but there is no comparable measure of mental exertion. Subjective ratings of mental workload could be obtained, but they are difficult to compare across people, and at the current time, neurobiological assessments, such as rate of glucose metabolism, are available only with activities that can be performed while the individual is in a neuroimaging scanner. A detailed inventory of all of the activities performed by an individual and the cognitive demands of each activity would be extremely valuable, but, unfortunately, very little information on the range of activities in which people engage is currently available, and even less information on the mental demands of those activities is available.

For the reasons just mentioned, all research relevant to the mental-exercise hypothesis has been based on approximations to the ideal, with each category of research lacking one or more of the critical characteristics. Nevertheless, the various approaches differ in their respective strengths and weaknesses, and thus it is informative to examine the findings from all the approaches to determine whether they converge on a similar conclusion.

TRAINING INTERVENTIONS

One category of research considered relevant to the mental-exercise hypothesis consists of training studies in which the researcher provides the participant with the relevant mentally stimulating experience. Training studies have the advantage of controlling the amount and type of experience the individual receives, but they have the disadvantage that the amount of experience is greatly limited in breadth and depth relative to the experience typically acquired in an individual's lifetime.

Many of the training studies involving only older adults were apparently motivated to challenge the cliché that old dogs cannot learn new tricks. This view was worth challenging because it was expressed by no less an authority than William James (1893), arguably the most influential American psychologist, in his classic *Principles of Psychology*, in which he stated that

> outside of their own business, the ideas gained by men before they are twenty-five are practically the only ideas they shall have in their lives. They cannot get anything new. Disinterested curiosity is past, the mental grooves and channels set, the power of assimilation gone. (p. 402)

A great deal of research has clearly established that in this respect James was wrong, because there are now many studies indicating that adults of all ages can benefit from experience (e.g., see reviews by Verhaeghen, Marcoen, & Goossens, 1992, and Willis & Schaie, 1994).

One very impressive training project was conducted in the context of the Seattle Longitudinal Study (Schaie, 2005). The study involved older adults who received 5 hr of training on either series-completion or spatial rotation problems and then took tests on both types of problems immediately after training and again 7 years later. Because the training benefits were ability-specific (e.g., series-completion training led to gains only on series-completion problems and not on spatial rotation problems), the group receiving each type of training can be considered the control group in the comparison testing the effects of the other type of training. For the current purposes, the most relevant results of this project were that the slopes from the immediate posttest to the 7-year follow-up test were very similar for the training and control groups (see Figs. 7.11 and 7.12 in Schaie, 2005). Although the training altered the level of performance on the trained tasks, and although at least some of the training-induced gains appeared to persist over 7 years, the training intervention apparently had little or no effect on the rate of age-related decline on either the reasoning or the spatial variable.

What is almost certainly the largest cognitive training study conducted with older adults is the ACTIVE (Advanced Cognitive Training for Independent and Vital Elderly) clinical trial (Ball et al., 2002; Jobe et al., 2001). This project involved a total of 2,832 adults between 65 and 94 years of age who were randomly assigned to one of four groups: a no-contact control group and groups receiving 10 sessions of training on memory, reasoning, or speed abilities. All of the participants received the same cognitive assessment at baseline, immediately after the intervention, and again on two annual posttests. The assessment included measures of the trained and untrained cognitive abilities and of outcomes assumed to be relevant to the ability to live independently.

Figure 4 summarizes some of the major results from this project. The values in the figure are the differences from the baseline in the three training groups relative to the differences from the baseline in the control group at three time periods after the completion of training. That is, each data point corresponds to the difference between the performance of a particular training group after subtracting the pretraining score and the performance of the no-training control group after subtracting the pretraining score. As shown in the figure, the training benefits were relatively narrow, as there was very little transfer to untrained abilities, and diminished over time. The diminishing effects indicate that relative to the control group, the training groups experienced greater negative age-related performance change.

Because of its scope, the ACTIVE project has received considerable attention, but some of the interpretations of the findings have been somewhat misleading. For example, one recent report described the results as demonstrating "reduced cognitive declines after cognitive training" (Verghese et al., 2003, p. 2516), even though the pattern apparent in Figure 4 is actually

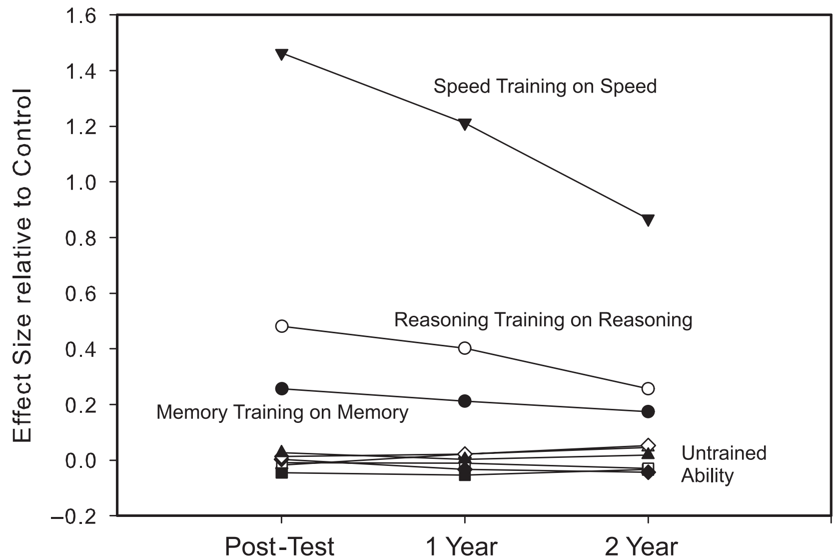

Fig. 4. **Summary results from the ACTIVE (Advanced Cognitive Training for Independent and Vital Elderly) cognitive training intervention (Ball et al., 2002). The three ''training'' functions refer to training-specific performance, and the functions labeled ''untrained ability'' refer to performance on abilities other than what was trained. See the text for details.**

more consistent with the training groups experiencing accelerated declines relative to the control groups. Because the data were collected over a relatively short interval, this pattern likely reflects a loss of the training benefits rather than a faster rate of mental aging, but it is nevertheless inaccurate to claim on the basis of the available results that the training reduced the rate of age-related cognitive decline.

Results from other training studies involving older adults have sometimes been interpreted as providing evidence that age-related mental decline was reversed, and that the mental-exercise hypothesis was confirmed. However, it is important not to confuse equal magnitude of change with equivalent mechanisms of change. That is, merely because the same level of performance can be achieved by some manipulation does not mean that the mechanism involved in that manipulation was responsible for earlier changes in performance. Stated somewhat differently, there is no necessary connection between a discovery that the level of performance can be improved immediately by providing a specific kind of experience and the role of that type of experience in contributing to the changes in performance that occurred over a period of decades.

This point can be elaborated by considering the influence of physical exercise on physical functioning. One common measure of functional physical capacity is maximal oxygen consumption, or VO_2max. A large number of studies have reported that this measure declines with age, dropping approximately 1% per year from the peak (e.g., Fitzgerald, Tanaka, Tran, & Seals, 1997; Pimentel, Gentile, Tanaka, Seals, & Gates, 2003; T.M. Wilson & Tanaka, 2000). There is also considerable evidence that physical exercise can increase VO_2max. For example, a meta-analysis by Green and Crouse (1995) found that after approximately 25 weeks of exercise, older adults can increase their VO_2max by an average of 22.8%.

Both of these sets of findings parallel results reported with measures of mental functioning. However, the key question in this context is whether the relation between VO_2max and age varies according to amount of physical exercise, and that cannot be answered by the type of research cited thus far. Several early studies indicated that the answer to this question might be yes, but more recent reports, including several meta-analyses, suggest that this is not the case. For example, two meta-analyses (Fitzgerald et al., 1997; T.M. Wilson & Tanaka, 2000) categorized people into three levels of physical activity: none, moderate (e.g., two or fewer times a week of walking or using a treadmill-type exercise machine), or vigorous (e.g., three or more times a week of running, swimming, or cycling). Both studies reported large differences in average VO_2max across the three groups, with higher levels of functional capacity among individuals who engaged in more physical activity. Of greatest interest from the current perspective, however, was that the cross-sectional relations between age and VO_2max were either similar across groups (T.M. Wilson & Tanaka, 2000) or more negative for individuals with more exercise (Fitzgerald et al., 1997). Very similar types of patterns have been reported in individual studies with cross-sectional (e.g., Pimentel et al., 2003) or longitudinal (e.g., Eskurza, Donato, Moreau, Seals, & Tanaka, 2002; Hawkins, Marcell, Jaque, & Wiswell, 2001; Katzel, Sorkin, & Fleg, 2001) comparisons.

These studies seem to suggest, therefore, that rather than slowing the rate of aging, exercise might actually accelerate the rate of physical aging. However, this counterintuitive result is probably explained by a decrease with age in the amount of exercise, such that the declines in the high-exercise group represented a mixture of effects of reduced activity and normal aging. There is apparently some controversy about the effects of continued exercise on rates of aging because Tanaka and Seals (2003) claimed that the declines in VO_2max for individuals in the high-exercise group who did not decrease their level of physical activity were similar to those in a sedentary group, but Katzel et al. (2001) reported that the declines for individuals who continued to train vigorously were not significantly different from zero. However, the important point from this discussion of physical functioning is that declines with increasing age and improvements with exercise can both occur, and yet there still may not be evidence that level of activity moderates the rate of aging. Therefore, although mental performance might be improved with training, this does not imply that the same type of stimulation will alter the rate of mental aging.

There are two major limitations of training studies as they apply to the mental-exercise hypothesis. The first is narrow transfer of training. That is, age-related differences have been found in a very broad range of cognitive abilities, but the benefits associated with training are usually quite narrow, and sometimes may not even generalize to other variables representing what appear to be the same construct. Training in a very large number of different domains would therefore be needed to affect all of the cognitive abilities in which age-related differences have been reported.

The second limitation of training research as regards the mental-exercise hypothesis is that there have been very few studies with long-term monitoring. Most training programs have been aimed at improving the level of a specific type of performance immediately after training, and many have been effective at achieving that goal. In some cases, training-related benefits have been detected up to 7 years after the training, which suggests that interventions can have relatively long-lasting consequences. However, from the perspective of the mental-exercise hypothesis, it is the rate of change over a period of years or decades after the beginning of the intervention that is of primary interest, not merely the absolute level of performance immediately after the intervention, or even the difference between trained and untrained groups in absolute level of performance at intervals after the onset of the intervention.

The critical question in the current context is therefore not the magnitude, nor the durability, of training effects, but rather the influence of the relevant experience on the rate of change in measures of cognitive functioning over time. The mental-exercise hypothesis would be supported only if there was a smaller age-related decline in the relevant measure of cognitive performance over time in the training group than in the control group, such that differences between the groups increased as a function of age. Failure to appreciate this point has led to confusion regarding the relation between the finding of immediate benefits of an intervention and causes of age-related cognitive decline. For example, Kramer and Willis (2002) claimed that "age-related decline in cognition can sometimes be reduced through experience, cognitive training, and other interventions such as fitness training" (p. 173). However, this assertion of a connection between the short-term intervention findings and age-related decline in cognition may be too strong because Kramer and Willis did not mention any studies that monitored the relation of age to cognition over a period of decades to determine whether there were any effects on rate of decline.

COMPARISONS OF PREEXISTING GROUPS

Most of the remaining research relevant to the mental-exercise hypothesis has involved comparisons of people of different ages who are assumed to vary in their amount of cognitively stimulating activity. Research of this type has the advantage that relations between age and measures of mental functioning can be examined across a wide age range in individuals with different levels of mental activity. However, the lack of control over the "treatment" means that there could be variation in the nature and amount of relevant activity, and because the individuals are not randomly assigned, they may differ in characteristics other than level of mental activity. Nevertheless, this type of research can still be used to examine the critical prediction of the mental-exercise hypothesis, namely, differential aging in the form of an interactive effect of age and amount of mental activity on measures of cognitive performance.

There are two categories of nonexperimental research relevant to the mental-exercise hypothesis. One category consists of studies of people from special groups who are assumed to differ from other people in the amount and type of mental activity they engage in. The other major category consists of studies in which people are administered questionnaires to evaluate their level of mental activity.

Special Groups

Experts

A particularly interesting special group consists of experts in domains such as chess, music, or Go. By definition, experts have a very high level of performance in a particular domain, and that level of performance is assumed to be largely achieved by extensive practice and not simply innate talent. Because of experts' extensive experience, it is natural to ask whether they differ from nonexperts with respect to the effects of aging on performance within their domain.

Before attempting to address this question, it is important to distinguish between experts, who are defined on the basis of their very high level of performance in a specific domain, and people who merely have considerable experience with an activity. From the current perspective, only a small number of people should be considered experts, and thus research based on people categorized according to their amount of experience, regardless of their level of skill in a domain, is examined in a later section.

Chess is the most frequently studied domain of expertise because of the availability of an objective measure of skill based on performance in competitions. The most commonly used measure of chess proficiency is the Elo score, which takes into consideration the quality of a player's opponents, as well as the player's success rate in competitions. A plausible prediction from the mental-exercise hypothesis is that the relation between age and chess performance among highly skilled chess players would not exhibit the same type of age-related declines found with other measures of cognitive functioning because these players continue to engage in mentally stimulating activity.

Figure 5 portrays results from two types of comparisons relevant to this prediction. The cross-sectional data are based on 46,888 rated players whose birth dates were included in the International Chess Association (FIDE) file as of January 2005, and the longitudinal data are based on 14 masters whose ratings between the ages of 21 and 60 were reported by Elo (1965). The vertical scales for the two comparisons are different, and thus it is not possible to compare the absolute level of performance across the two functions. Nevertheless, it is clear that the relation between age and performance is qualitatively similar in the cross-sectional data of competitive players and in the longitudinal data of very elite players. At least in the field of chess, therefore, it appears that relevant measures of cognitive functioning decline with increased age even among experts in the domain.

There is much less empirical evidence on the relations between age and expertise in other domains, and most comes from experimental studies with very small samples. For example, a study of musical expertise by Krampe and Ericsson (1996) was based on only 12 adults in each of four groups (i.e., young amateur and professional pianists and old amateur and professional pianists). It is difficult to draw conclusions from this study because the small sample sizes meant the power to detect effects as statistically significant was low, and because the large number of significance tests conducted on data from the same individuals without any adjustment for chance outcomes may have led to some results being significant merely by chance. For example, in Krampe and Ericsson's Table 4 alone, separate Age × Expertise analyses of variance were reported for 10 variables. The critical Age × Expertise interaction was significant for three measures of finger-movement efficiency, but it was not significant for what might be the most interesting measure—musical interpretation, which was described as reflecting "the ability to control timing and force variation in interpreting a musical piece" (p. 334).

Another domain of expertise in which age-performance relations have been examined is the Japanese game of Go. Masunaga and Horn (2000, 2001) reported several comparisons of speed and memory in amateur and professional Go players. The sample included 243 amateurs between 18 and 78 years of age, and 20 professionals from 19 to 48 years of age. The professionals might be considered experts, but their small number and limited age range resulted in low power to detect any age-performance relations that might have existed within this group. Separate Age × Go Skill analyses of variance were conducted on each of seven cognitive variables in the data from the amateurs. The interaction was significant for two of the variables, but the pattern was complicated because the relations between age and cognitive performance were not very systematic in any of the groups categorized on the basis of Go skill.

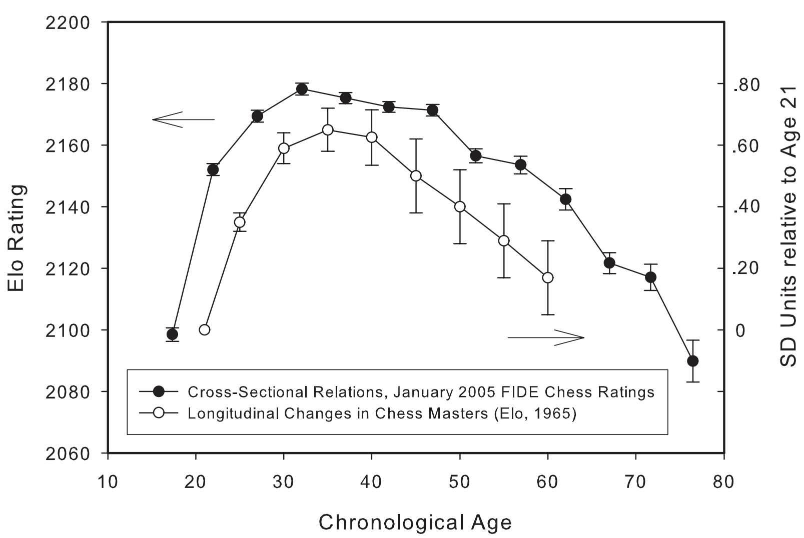

Fig. 5. Chess performance as a function of age in a large cross-sectional sample of rated players and in a small longitudinal sample of chess masters. Note that the cross-sectional relations (filled circles) refer to the left vertical axis, and the longitudinal age relations (open circles) refer to the right vertical axis.

Research with experts has a number of limitations as it applies to the mental-exercise hypothesis. First, the number of true experts in any domain is very small, which means that the comparisons have low power to detect any differences that might exist. Second, there is almost certainly a high degree of selectivity in who survives to become an expert, and thus experts are likely to differ from nonexperts in many respects other than performance in the relevant domain. And third, expertise is highly specific to select domains, and therefore even if there is differential preservation, it would exist only in very limited aspects of mental functioning, and not in all aspects in which age-related differences have been reported.

The little information that is available about the relations between age and expert performance in the domain of chess suggests that age-related declines are often found among experts even in their specialized domains. In a discussion of age and expertise, Ericsson (2000) claimed, "Much of the decline in performance attributed to aging results from reduced levels of deliberate practice among older individuals" (p. 370). The evidence relevant to this speculation is still quite limited, but if it does turn out to be true, it would then raise the question of why so many people reduce their level of activity as they get older. Are the incentives to excel no longer as attractive, or is the activity more demanding because of age-related declines in relevant cognitive abilities? It is not very satisfying to attribute the phenomenon of age-related cognitive decline to a reduction in level of activity without explaining what is responsible for that reduction.

Occupational Groups

Another special group relevant to the mental-exercise hypothesis consists of people in particular occupations, because members of different occupations are assumed to vary in the amount of specific types of mental activity they engage in. There has been considerable interest in the age-cognition relations among academics, because professors like to believe that they live in a constant state of mental stimulation, and therefore if the mental-exercise hypothesis is correct, they might be able to look forward to less pronounced age-related declines in cognitive functioning than people in less stimulating occupations. Unfortunately, most of the empirical evidence has not been consistent with this optimistic expectation.

One of the earliest, and still among the most impressive, studies involving college professors was reported by Sward (1945). Not only did he match young and old professors on many characteristics, but he administered a broad variety of cognitive tasks of which only a few had time limits. In this sample of college professors, Sward found age differences in reasoning, memory, and speed that were very similar to those reported in other types of samples. Numerous studies since Sward's have also found typical patterns of age-related differences in samples of college professors (e.g., Christensen, 1994; Christensen & Henderson, 1991; Christensen et al., 1997; Compton et al., 2000; Compton, Bachman, & Logan, 1997; Macht & Buschke, 1984; Perlmutter, 1978; Thomas & Charles, 1964; Traxler, 1973). The project by Christensen and her colleagues is particularly noteworthy because although many of the older academics in this project were officially retired, a substantial proportion reported that they were still engaged in scholarly work for 60 hr a week or more. Nevertheless, significant age-related differences in measures of cognitive functioning were reported among the academics in both cross-sectional (Christensen, 1994; Christensen & Henderson, 1991) and longitudinal (Christensen et al., 1997) comparisons.

A study by Shimamura, Berry, Mangels, Rusting, and Jurica (1995) is sometimes mentioned as finding only small age-related differences in mental functioning among college professors, but a careful reading of that report reveals that this study may not be as encouraging as occasionally believed. These researchers found typical age-related differences in measures of reaction time, paired-associates learning, and working memory, and only in a measure of prose recall did they report no age-related difference. However, as the authors noted, other studies have reported little or no age-related differences in measures of prose recall in samples of nonacademics (e.g., Johnson, 2003), and thus this finding is not unique to college professors.

Relations between age and various measures of cognitive functioning have also been examined in samples of pilots (e.g., Hardy & Parasuraman, 1997) and physicians (e.g., Powell & Whitla, 1994), and both of these groups have been found to exhibit typical age-related differences in a variety of cognitive variables. Even the assumption that older physicians are superior to young ones in the quality of their medical practice, or with respect to the breadth or depth of their relevant knowledge, has been challenged by empirical studies (e.g., Choudhry, Fletcher, & Soumerai, 2005; Leigh, Young, & Haley, 1993).

Although research with people from different occupations is interesting, it would likely be more relevant to the mental-exercise hypothesis if there were a closer linkage between the type of activity performed by the individuals in their occupations and the aspect of cognitive functioning that is assessed. This argument was the motivation for a project (Salthouse et al., 1990) in which practicing architects were compared with nonarchitects on several measures of spatial visualization. The major finding was that although architects performed at higher levels than nonarchitects, the age-related trends in performance of the spatial tasks were parallel. For example, the cross-sectional relations between age and paper-folding accuracy were identical in a sample of architects and in a sample of nonarchitects of nearly the same educational level, with a decrease in accuracy of 4.4% per decade in both groups.

Reliance on occupational membership as the basis for inferring level of mental activity has at least two major limitations. One is that people in different occupations may differ in many respects, and not simply in the extent of engagement in particular types of activity. Even if differences were to be found in the rates of mental aging across occupational groups, therefore, the causes of those differences might not be easily specified. The second limitation is that individuals within the same occupation likely exhibit considerable variation in the amount of mental activity they engage in. For example, there may be a decrease with age in the frequency of engaging in a particular type of activity, and in fact, my colleagues and I (Salthouse et al., 1990) found lower levels of self-reported spatial visualization activity with increasing age in a sample of architects.

Change in Work and Leisure Activities

Schooler and his colleagues (e.g., Schooler & Mulatu, 2001; Schooler, Mulatu, & Oates, 1999) have published a number of reports on a unique project in which the same individuals were interviewed about work and leisure activities, and assessed for "intellectual flexibility," in 1964, 1974, and 1994. The availability of longitudinal data allowed simultaneous estimates of the influence of mentally demanding activity on intellectual flexibility and of the influence of intellectual flexibility on activity. The major finding in each study was that the relations are reciprocal, such that higher intellectual flexibility appears to contribute to higher levels of mentally stimulating activity, and greater amounts of mentally stimulating activity appear to contribute to higher levels of intellectual flexibility.

These results have been interpreted as supporting the mental-exercise hypothesis because engaging in intellectually demanding activities seems to have an effect on level of cognitive functioning. However, although these results clearly could be relevant to the hypothesis, interpreting them is complicated by the unusual measure of cognitive functioning used in this project. The measure of intellectual flexibility was based on five variables, three measurements derived from ratings by the examiner and two objective measurements. However, unlike most measures of process cognition, the intellectual-flexibility measure was not significantly related to age in 1964 ($r = .00$), 1974 ($r = -.01$), or 1994 ($r = .04$), and therefore it may not reflect the same phenomenon of mental aging apparent with more traditional cognitive measures. Another complication is that the patterns of longitudinal change from 1964 to 1994 differed across the individual variables used to form the intellectual-flexibility factor, as there were large declines in the two objectively measured variables, but substantial increases in the three rating variables. This overall pattern raises the possibility that the meaning of the composite intellectual-flexibility variable formed by combining the individual variables may have changed from one measurement occasion to the next, and that some of what was interpreted as a change in intellectual flexibility may have actually reflected a change in what was being assessed.

Schooler and his colleagues were sensitive to some of these measurement concerns, and they reported a moderately high correlation between the intellectual-flexibility measure and a composite measure based on a combination of more traditional cognitive measures. However, the correlations between the variables belonging to the intellectual-flexibility factor and the correlations between the variables belonging to the general cognitive factor were relatively weak, and thus it is difficult to determine exactly what each factor represents.

For the reasons just mentioned, it is probably premature to summarize the findings of this project, as Fillit et al. (2002) did, by stating that "complex intellectual work increases the cognitive functioning of older workers" (p. 685). Schooler's project is extremely intriguing, but the available results are quite complex, and the extent to which they should be considered as providing support for the mental-exercise hypothesis is not yet clear.

Self-Reports of Mental Activity

Specific Mental Activities

Another category of research relevant to the mental-exercise hypothesis has relied on individuals' self-reports as the basis for categorizing their level of mental activity. In several studies, researchers asked people about their experience with a set of specific similar activities and examined performance in cognitive tasks selected to be relevant to that kind of experience.

In one study of this type, Mitchell and I examined a sample of 383 adults who ranged from 20 to 83 years of age (Salthouse & Mitchell, 1990). All of the participants were administered a questionnaire asking about their experience with activities presumed to involve spatial visualization ability (e.g., following instructions for the assembly of furniture or models, solving piece-assembly games). As expected, people reporting more experience with these types of activities performed better on a variety of spatial visualization tasks, including paper folding and surface development. However, contrary to the prediction from the mental-exercise hypothesis, there were no interactions between age and experience, as the performance differences between people reporting different amounts of spatial visualization activity were as large among adults in their 20s and 30s as among adults in their 60s and 70s.

Because attempting to solve crossword puzzles is often mentioned as a mentally stimulating activity, my colleagues and I investigated whether crossword-puzzle experience might moderate the relations between age and measures of reasoning (process cognition) or knowledge (product cognition; Hambrick, Salthouse, & Meinz, 1999). We conducted four separate studies, each with 200 or more adults and multiple measures of reasoning and knowledge. All of the participants answered questions about their crossword-puzzle experience and performed tests of crossword puzzles, vocabulary, general knowledge, and reasoning.

Eleven different measures of recent and cumulative experience with crossword puzzles were obtained in each of the four studies, but none of the 44 interactions of age and experience were significant for the composite measures of reasoning or knowledge. In order to provide a more powerful test of the interaction, I created average *z* scores from the two to six scores on the reasoning or knowledge tests in each study, and combined the data across these four studies (Hambrick et al., 1999), as well as a study reported in Salthouse (2001). This aggregate sample included a total of 1,021 individuals, and the expected pattern of age-cognition relations was obtained: The correlations were −.55 for the composite reasoning variable and +.16 for the composite knowledge variable. However, even with this relatively large sample, there were no statistically significant interactions of age and crossword-puzzle experience for either the measure of reasoning or the measure of knowledge. The results are illustrated in Figure 6, which shows *z* scores for reasoning and knowledge for individuals in the top 25% (averaging 10.2 hr per week) and in the bottom 25% (averaging 1.1 hr per week) of the overall distribution of crossword-puzzle experience. The graph shows that the age-related trends were very similar in these groups with quite different amounts of crossword-puzzle experience. The results of these studies therefore provide no evidence of a slower rate of age-related decline in reasoning, or a greater age-related increase in knowledge, for individuals who spend more time working crossword puzzles.

Studies in the domains of music (e.g., Halpern, Bartlett, & Dowling, 1995; Meinz, 2000; Meinz & Salthouse, 1998), pilot communication (e.g., Morrow, Menard, Stine-Morrow, Teller, & Bryant, 2001; Morrow et al., 2005; Taylor, O'Hara, Mumenthaler, Rosen, & Yesavage, 2005), and baseball (Hambrick & Engle, 2002) have also generally failed to find Age × Experience interactions with measures of domain-relevant performance. In each of these studies, there was a positive relation between amount of experience in the relevant activity and measures of domain-relevant cognitive performance, but few if any interactions with age that would indicate that experience moderates the relations between age and cognition. People with more experience generally performed better on many cognitive tests assumed to be relevant to the experience in question than did people with less experience, but the advantage was as large for people in their 20s and 30s as for people in their 60s and 70s.

Although the results of the studies investigating effects of specific experience have not been very consistent with the mental-exercise hypothesis because few of the interactions of age and experience have been statistically significant, it is important to note that many of the studies reported a positive relation between age and amount of cumulative experience. It is therefore possible that if people continue to accumulate relevant experience with increasing age, they may perform better on domain-relevant cognitive tasks than they would have performed without that experience. To the extent that continuously increasing experience serves to maintain performance that would decline in the absence of that experience, one might predict the relations between age and measures of cognitive functioning would be more negative if the amount of experience was controlled by statistical procedures. In fact, Meinz (2000) reported some evidence supporting this prediction in a study of musical experience, and Stanovich, West, and Harrison (1995) found that the positive correlation between age and word knowledge was reduced after controlling the variation in amount of experience with printed words.

There is still only limited evidence for the hypothesis that increasing experience compensates for age-related declines,

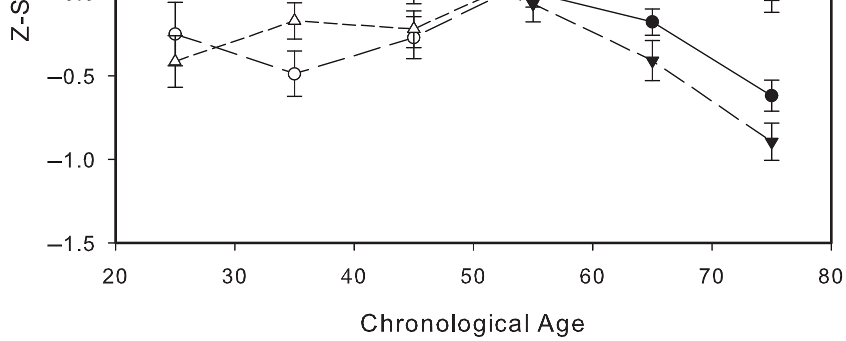

Fig. 6. Means (and standard errors) of *z* scores of composite reasoning and knowledge variables as a function of age for individuals with high and low amounts of crossword-puzzle experience.

and this evidence may primarily apply to product measures of knowledge and not to measures of processing efficiency. Furthermore, there may be practical limitations on the applicability of this interpretation to the mental-exercise hypothesis because if progressively greater amounts of mentally stimulating activity are required at each successive age to maintain the same level of performance, eventually nearly all of one's waking hours might have to be devoted exclusively to the prevention of cognitive decline. Nevertheless, this interpretation should be pursued in future research because it offers an intriguing alternative perspective on the relations among age, experience, and cognitive performance.

General Activity Questionnaires

The most frequently used approach to investigate the mental-exercise hypothesis has consisted of asking people questions about their amount of engagement in different types of activities assumed to be mentally stimulating, and then examining relations between each individual's inferred level of mental activity and his or her performance on a variety of measures of cognitive functioning. Although many questionnaires have been designed to assess level of mental activity, this category of research has shown little consistency in assessment, or in the outcome variables and analytical methods used (e.g., Hertzog, Hultsch, & Dixon, 1999; Hultsch, Hertzog, Small, & Dixon, 1999; Salthouse, Berish, & Miles, 2002; R.S. Wilson et al., 1999). Because each of these factors could influence results, they need to be considered when evaluating these studies.

One important issue concerns how mental activity should be assessed. Some questionnaires base their evaluations of mental activity at least in part on status variables such as education and occupation, which are at best very indirect indications of an individual's current lifestyle. One questionnaire (Arbuckle, Maag, Pushkar, & Chaikelson, 1998) even included napping and personal care as activities contributing to the assessment of engaged lifestyle. Other questionnaires have included social activities, gardening, and dancing, which may be indicative of an active lifestyle, but do not necessarily involve much mental stimulation.

Several questionnaires have asked about 10 or more activities, but some questionnaires have evaluated lifestyle with as few as four activities. For example, Kliegel, Zimprich, and Rott (2004) based their assessment of lifestyle on whether the individuals reported that at any time in their lives they had balanced a checkbook, tried to learn a foreign language, traveled within their country, or traveled outside their country.

Another issue concerning self-reports of activities is how the cognitive demands of the activities are assessed. Some researchers have relied on judges' ratings of cognitive demands (e.g., Arbuckle, Gold, & Andres, 1986; Arbuckle et al., 1998; Christensen & Mackinnon, 1993; Hultsch et al., 1999; Singh-Manoux, Richards, & Marmot, 2003; R.S. Wilson et al., 1999, 2002, 2003). However, because most of these judges were likely of high cognitive ability, they may not have an accurate perception of the difficulty of the activities for lower-ability individuals.

Research with self-report questionnaires has also differed with respect to how the information is aggregated and analyzed. For example, Bosma et al. (2002) asked respondents how many hours per week they engaged in "mentally active sports (e.g., chess, puzzles)," and classified anyone reporting at least 1 hr per week as mentally active. Richards, Hardy, and Wadsworth (2003) asked individuals whether they had participated in any of seven activities, and then coded each person's activity level as 0 if he or she reported no activities, and as 1 if he or she reported one or more activities regardless of the nature of, or degree of involvement in, the activity. Responses to the questionnaires have also been summarized in many different ways, such as the total duration of all reported activities, the intensity of selected activities, or, in some cases, merely the number of different activities.

Finally, a wide range of analytical methods has been used to examine the relation between self-reported activity and level of cognitive functioning. For example, simple correlations, partial correlations controlling for other potential influences such as education or physical activity, complex structural equation models, correlations of level of activity with change in cognition, and correlations of change in activity with change in cognition have all been used to investigate the mental-exercise hypothesis. However, only a few of these analytical procedures test whether the relation between age and cognitive performance varies according to the level of mentally stimulating activity, and thus not all are directly relevant to the mental-exercise hypothesis.

Many of the issues just discussed were taken into consideration in the design and analysis of a new self-report activity inventory (Salthouse et al., 2002). The questionnaire was constructed by specifying 22 common activities, and then asking research participants for a rating of the cognitive demand of each activity and an estimate of the number of hours devoted to performing each activity in a typical week. Table 1 summarizes responses obtained from more than 1,200 adults, ranging from 18 to 97 years of age, who participated in the original and subsequent studies in my lab. This sample of participants can be considered to be high functioning because they had completed an average of 15.8 years of education, and their scores on standardized tests averaged about two thirds of a standard deviation above the average in a nationally representative normative sample (see Salthouse et al., 2002).

The sum of the average number of hours reported for the 22 activities was 100.5, which corresponds to about 14 hr per day. This value suggests that the activities included in the questionnaire account for a large proportion of the average respondent's nonsleeping time during the week. It is also worth noting that certain relations in these data were consistent with those reported elsewhere. For example, the correlation between

TABLE 1
Perceived Cognitive Demands and Hours per Week Devoted to 22 Activities in a Sample of Approximately 1,200 Adults

Activity	Rated cognitive demands Mean	Rated cognitive demands *SD*	Hours/week Mean	Hours/week *SD*
Teaching, attending class	4.0	1.0	3.8	8.2
Working on crossword puzzles	3.9	1.1	1.5	3.4
Handling finances	3.7	1.1	1.9	2.6
Playing chess or other strategy games	3.7	1.2	0.7	1.7
Reading nonfiction	3.6	1.0	4.0	4.5
Using a computer	3.5	1.4	14.3	14.3
Writing	3.5	1.1	2.8	4.3
Supervising other people	3.4	1.1	8.4	17.6
Attending meetings	3.3	1.0	2.0	2.5
Participating in musical or other artistic activities	3.2	1.2	2.2	4.8
Playing bridge or other card games	3.2	1.2	0.9	2.1
Driving a car	3.1	1.2	8.5	8.0
Reading novels	3.0	0.8	4.0	5.0
Volunteering	3.0	1.1	1.7	3.5
Reading newspapers, magazines	2.9	0.8	5.3	4.8
Participating in hobbies and crafts	2.8	1.0	2.0	3.5
Socializing with friends	2.7	1.0	8.9	10.3
Preparing meals	2.6	1.0	5.8	4.7
Shopping	2.4	1.0	2.7	3.7
Gardening	2.1	0.9	2.4	4.8
Doing housework	2.1	1.0	5.3	5.8
Watching television	2.0	0.9	11.4	9.9

Note. Ratings of cognitive demands were on a scale ranging from 1, *low* (corresponding to sleeping), to 5, *high* (corresponding to working on a tax form).

the number of hours per week spent watching television and the score on a vocabulary test in this sample was −.14, which is similar to the correlation of −.19 reported by Glenn (1994) on the basis of analyses of data from a nationally representative sample.

Inspection of the entries in Table 1 reveals that the activities differ in the average cognitive-demand ratings, which indicates that the activities are perceived to vary in their degree of mental challenge. The standard deviations of the ratings are also moderately large, which means that people do not all have the same perceptions of the cognitive demands of the activities. One factor that may be associated with some of the variability in the cognitive-demand ratings is the cognitive ability of the individual. This possibility was examined by creating a cognitive-ability composite by averaging the scores for vocabulary, digit-symbol, paired-associates, and spatial relations tests, and then computing correlations between this composite score and the rated cognitive demands for each activity. (The patterns were very similar when the correlations were computed with each cognitive variable separately, rather than with the composite variable—see Salthouse et al., 2002.)

The correlations between composite cognitive-ability score and cognitive-demand ratings were statistically significant for all but four of the activities. The correlations were greater than .20 for reading nonfiction, working on crossword puzzles, playing chess or other strategy games, reading novels, teaching or attending class, and writing, but less than −.20 for watching television and doing housework. These results suggest that the same activities are perceived to differ in their cognitive demands according to the individual's level of cognitive ability. An implication of the results of this study is that researchers need to be careful in selecting the activities used to represent mental stimulation and to be sensitive to individual differences in the perceived mental demands of the activities.

In the physical domain, an estimate of overall physical activity level is often obtained by combining the duration of each activity with its intensity to estimate metabolic expenditure and then summing metabolic expenditure across different activities (e.g., Ainsworth et al., 2000). My colleagues and I attempted to create a mental analogue of this physical activity measure by multiplying the number of hours engaged in each activity included in the activity inventory by its rated cognitive demand and then summing these products across all activities (Salthouse et al., 2002). However, this cognitive-stimulation index was only weakly related to cognitive performance, and it was not involved in any interactions with age.

In order to emphasize activities with the greatest potential for mental stimulation, I created an index by summing the number of hours per week each individual devoted to the seven activities with average rated cognitive demands greater than or equal to 3.5. This index averaged 28.3 hr, which still represents a sizable proportion of a week. The correlation between age and this index was −.27, which indicates that increased age was associated with a decrease in the frequency of performing this set of mentally stimulating activities.

Of greatest interest from the perspective of the mental-exercise hypothesis are the interactive effects of age and level of mentally stimulating activity on measures of cognitive functioning. The interaction was statistically significant only for the knowledge measure of vocabulary and not for cognitive process measures, and the statistical outcomes were unchanged after controlling for amount of education. The patterns can be illustrated by dividing the sample into quartiles on the basis of the reported number of hours devoted to activities with high cognitive demands (i.e., the seven activities with cognitive-demand ratings greater than or equal to 3.5). The age-related trends in the groups with the highest and lowest amounts of high-cognitive-demand activity are portrayed in Figure 7. Notice that with the exception of the vocabulary variable, the trends were nearly parallel for these two groups.

To the extent that self-reports of activities provide valid assessments of an individual's lifestyle, the results just summarized suggest that people who engage in high amounts of cognitively stimulating activities exhibit the same relation between age and performance on a variety of cognitive tasks as do people who engage in low amounts of cognitively stimulating activities. Only with the knowledge measure of vocabulary is there any evidence for the mental-exercise hypothesis, and that may simply reflect differential opportunities to acquire relevant information rather than differential preservation of mental ability.

Although studies based on self-reports of activity constitute the largest category of research considered relevant to the mental-exercise hypothesis, the results of these studies may be distorted because of positive self-presentation or desirability bias, or because the relevant information cannot be retrieved from memory or is inaccessible for other reasons. One indication that the self-report estimates are not always accurate is that when asked to estimate the durations of the 22 activities in the

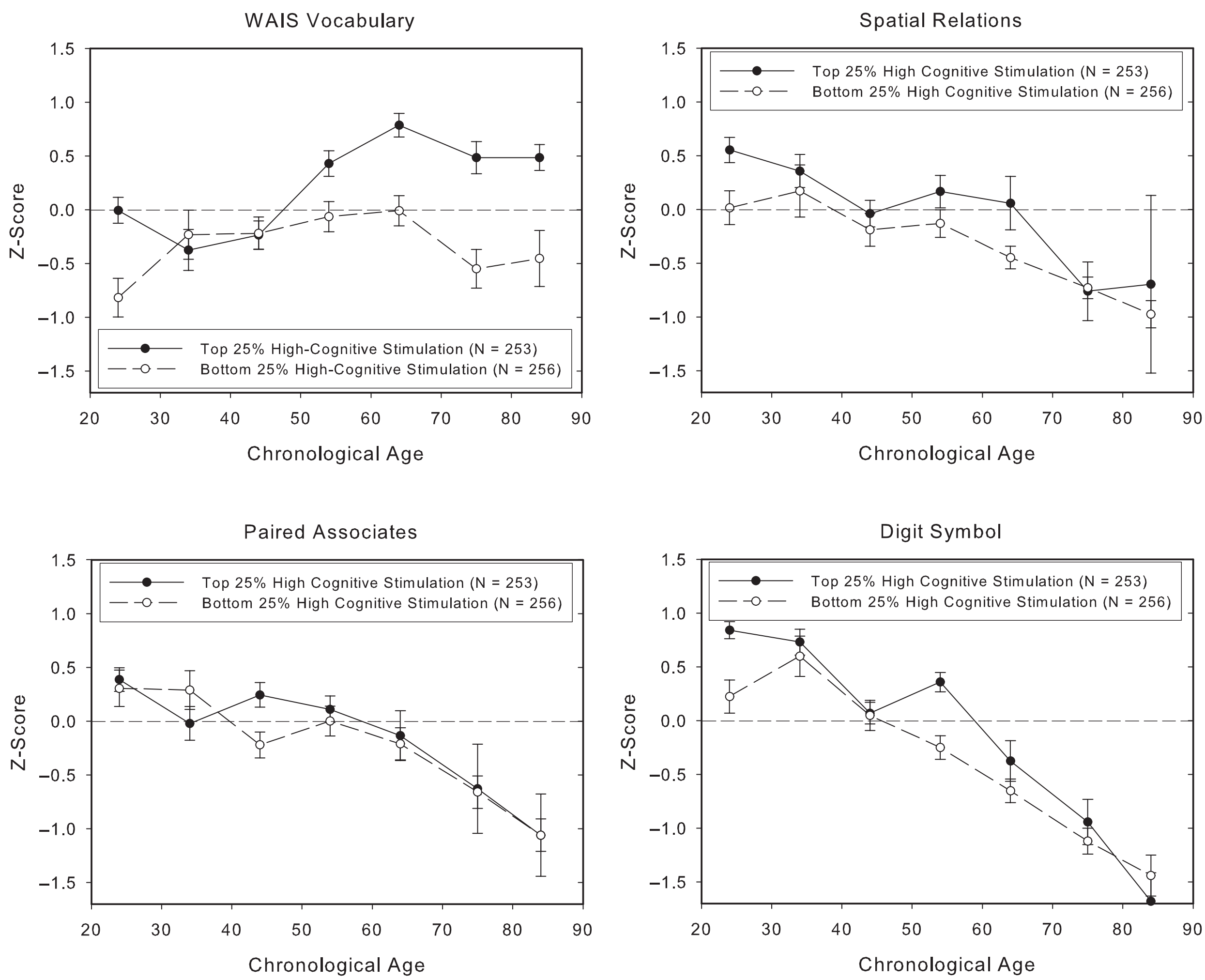

Fig. 7. Means (and standard errors) of *z* scores for four cognitive variables as a function of age for individuals with high and low amounts of engagement in cognitively stimulating activities. WAIS = Wechsler Adult Intelligence Scale.

new self-report activity questionnaire (Salthouse et al., 2002), several individuals reported a total of more than 168 hr per week. Even if one allows for the possibility that some activities might be performed concurrently, it is unlikely that all of the time estimates were realistic.

Because many of the studies with self-report questionnaires involved only older adults, they were limited to examining relations between mental activity and mental performance over a restricted age range. These studies may therefore have had low power to test the primary prediction of the mental-exercise hypothesis—that the rate of age-related cognitive change varies according to the individual's level of mental activity.

Another major limitation of this category of research is that there has been little consistency in the methods used to assess either mental activity or mental performance, or in the analytical procedures used to examine the relationship. As a consequence, few true replications have been reported, and there is a risk that some of the published findings are a positively selected subset of the results from studies with mixed outcomes.

Inferred Dispositions

A final category of research relevant to the mental-exercise hypothesis is based on assessment of individuals' dispositions or tendencies derived from personality or intellectual-style questionnaires. The rationale of such research is that people's reports of what they like and dislike, and how they describe themselves, may reflect aspects of their lifestyles.

The personality trait of openness is sometimes considered to represent intellectuality, and there are several reports of significant correlations between the level of openness and a variety of cognitive measures (e.g., Hultsch et al., 1999; Schaie, Willis, & Caskie, 2004). Studies conducted in my laboratory showed that openness had significant correlations with four measures of cognitive performance: .32 for vocabulary, .21 for paired associates, .14 for spatial relations, and .10 for digit symbol. However, none of the cognitive variables exhibited significant interactions between age and openness, and thus these studies provide no evidence that people who are more open to novel experiences exhibit shallower rates of age-related cognitive decline than people who are less open.

Another self-report instrument, the Need for Cognition questionnaire, was specifically designed to assess an individual's tendency to seek out cognitive stimulation (Cacioppo, Petty, Feinstein, & Jarvis, 1996). The questionnaire contains items such as "I prefer life to be filled with puzzles that I must solve" and "I prefer tasks that are difficult, intellectual, and important." Respondents use a scale from 1 to 5 to indicate how characteristic each statement is of themselves. In studies conducted in my laboratory, almost 1,200 research participants completed the 18-item version of the Need for Cognition questionnaire. As one might expect, the Need for Cognition score correlated significantly with the personality trait of openness (.36) and with the self-reported number of hours spent in activities with high cognitive demands (.22), and it was also positively correlated with each cognitive variable (i.e., vocabulary: .22, digit symbol: .13, paired associates: .16, and spatial relations: .22). However, the interaction of age and Need for Cognition score was not significant for any cognitive variable, and this pattern was unchanged after controlling for amount of education. Figure 8 indicates that there were nearly parallel age-related trends for individuals in the top and bottom 25% of each age group in the Need for Cognition score.

The results summarized in Figure 8 indicate that for each cognitive task, performance was better among individuals who characterized themselves as high in the tendency to seek out intellectual stimulation than among individuals who characterized themselves as lower in the tendency to seek out intellectual stimulation. However, the magnitude of the difference between individuals who scored high and low for stimulation seeking was similar at all ages, and thus there was no evidence that the age-cognition relations were moderated by self-reported preference for engaging in intellectual stimulation, at least as that construct is measured by the Need for Cognition scale. If responses to this questionnaire are considered valid reflections of lifestyle, then the findings are inconsistent with the view that more mental engagement is associated with better preservation of cognitive functioning.

CONCLUSION

There have been many reports of a significant positive association between engagement in mentally stimulating activity and level of cognitive performance. There is also convincing evidence that cognitive training and other interventions can have an immediate beneficial effect on the level of performance in the trained tasks in adults of all ages. Results such as these have led to widespread acceptance of the view that continued engagement in mentally stimulating activities will maintain one's cognitive abilities, and may also prevent age-related cognitive decline.

Unfortunately, the research reviewed here is not very consistent with this optimistic interpretation. A variety of different types of findings have been interpreted as supporting the mental-exercise hypothesis, but there are very few examples of what I have argued is the most convincing type of evidence—demonstration that the differences in mental performance associated with varying levels of mental exercise increase with increased age.

Before reaching a conclusion about the validity of the mental-exercise hypothesis, it is important to consider a number of reasons that might account for the failure to find stronger support for it. For example, one possibility is that the hypothesis might be applicable primarily among individuals below a certain level of cognitive ability. In fact, there are several reports of significant relations between mental activity and cognitive func-

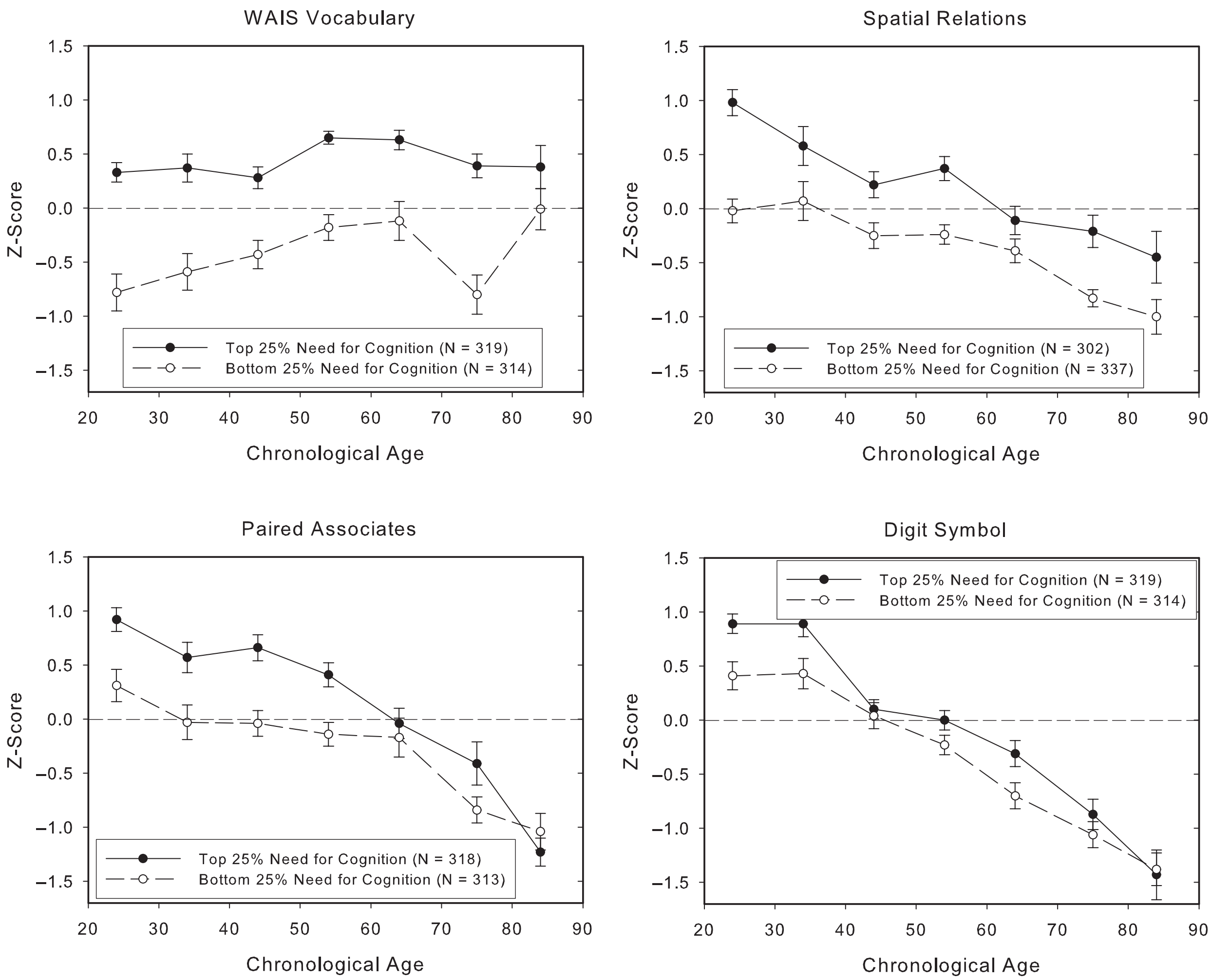

Fig. 8. Means (and standard errors) of *z* scores for four cognitive variables as a function of age for individuals with high and low scores on the Need for Cognition scale. WAIS = Wechsler Adult Intelligence Scale.

tioning among individuals with low levels of education (e.g., Arbuckle et al., 1998; Christensen & Mackinnon, 1993; Gold et al., 1995). It is clearly conceivable that stimulating mental activities are beneficial only among individuals with a very low baseline level of cognitive ability, but if this is the case, then it would severely limit the applicability of the mental-exercise hypothesis. That is, because moderate to large age differences in many measures of cognitive functioning have been reported in samples with relatively high levels of ability (and likely high levels of mental activity), lack of mental exercise is presumably not the primary factor contributing to those age-related declines.

Furthermore, a point that is often overlooked is that the same activities may become more challenging, and potentially more stimulating, as an individual's cognitive abilities decline. It is therefore somewhat paradoxical that to the extent that the amount of mental challenge increases as an individual's abilities decline, then according to the mental-exercise hypothesis the abilities might be expected to never decline. In other words, no decline might be predicted if the decline is attributable to a low level of mentally challenging activities, because the level of challenge for the same activities would likely increase as the cognitive abilities decline. Of course, an individual undergoing cognitive decline may cut back on the most demanding activities, but there may be a limit on the number of activities that can be abandoned while still maintaining an independent and productive life.

Another factor that might account for the lack of stronger evidence for the mental-exercise hypothesis is that the impact of mental exercise may differ across different periods of adulthood. For example, engaging in mentally stimulating activity might have the greatest impact at older ages, when the declines are becoming more serious and effects of lifestyle have had the greatest opportunity to accumulate. This possibility was examined in the data from my laboratory by repeating the analyses involving the number of hours of high-demand activities and the Need for Cognition score in the 256 adults between 65 and 97 years of age. However, none of the interactions of these variables with age were significant in any analyses of cognitive performance, and consequently there is no support for this age-specific interpretation in the results from these studies.

The differential-impact interpretation could still be true, but if so, it would again limit the generalizability of the mental-exercise hypothesis because the mental-aging phenomenon occurs across a wide range of adulthood and is not restricted to the period of old age. For example, inspection of Figure 1 reveals that for several cognitive variables the total difference between individuals in their 20s and those in their 80s ranges from 1.38 to 2.23 standard deviation units, but an average of about 55% of this difference is apparent by age 65.

Because many of the results considered relevant to the mental-exercise hypothesis have consisted of failures to find interactions of age and mental activity, there is a risk of basing conclusions on acceptance of the null hypothesis. This is a particular concern when the statistical power is low, either because of a small sample size or because of narrow ranges of mental activity or of age. The sample sizes in most of the studies cited in this review were moderately large (i.e., typically 100 to 1,000 or more) compared with the sample sizes in many behavioral studies, and significant effects of both mental activity and age were often found. Nevertheless, it is conceivable that small interactions did exist but were not detected because of limited statistical power.

Still another possibility is that the effects of lifestyle may be very small relative to effects associated with other individual difference characteristics, and hence they may be detectable only in longitudinal studies. However, before the validity of this speculation can be examined, the type of information from longitudinal studies that would be most relevant to the mental-exercise hypothesis must be specified. For example, one might expect a significant relation between the longitudinal change in amount of mentally stimulating activity and the longitudinal change in cognitive functioning, but a finding of this type would not be definitive because both changes could be attributable to a third factor, such as health status. A potentially more powerful prediction is that the change in mentally stimulating activity will occur before the change in cognitive functioning, but such a prediction will be very difficult to test without detailed information about the magnitude of change in activity needed to induce a noticeable change in cognitive performance, and about the interval from the time of activity change until effects should be expected in the measures of cognitive functioning. Some researchers analyzing longitudinal data seem to assume that causal effects are instantaneous, but it seems more likely that influences related to one's lifestyle accumulate over a period of years or decades, such that there would be moderate to large lags between the lifestyle "causes" and any effects they might have on cognitive functioning.

Although the ideal study based on a randomized critical trial is not feasible with humans, tests of the mental-exercise hypothesis more definitive than those that have been conducted thus far will require closer approximation to the critical characteristics of that type of design. Of particular importance will be improved assessment of activities, as well as specific hypotheses about the mechanisms responsible for a relation between activity and cognition, and about the timing between critical events, so that lead-lag relations can be tested. Long-term monitoring over a period of decades will also be necessary to examine effects of activity on rates of mental aging.

Given what appears to be a general lack of empirical support, it is worth considering why the mental-exercise hypothesis seems to be so well accepted. Among the likely reasons are a plethora of anecdotal observations, what seems to be a compelling analogy to the effects of physical exercise on physical functioning, and a commitment to the assumption that humans can exert control over their own destiny by choice of lifestyle. Still another reason for an optimistic perspective on the role of mental exercise may be related to a particular conceptualization of mental functioning in which there is some absolute threshold for functioning, perhaps related to a diagnosis of dementia or ability to live independently. If a threshold of this type exists, then anything, perhaps including increased mental activity, that will increase the distance of one's level of functioning from that threshold will likely prolong the interval until the critical level of performance is reached. For example, if an individual is 6 units away from the threshold and is declining at a rate of 3 units per year, then he or she will reach the threshold in 2 years. However, if the individual's level of functioning could be increased by 3 points, then even without affecting the rate of age-related decline, the time until the threshold is reached will be increased from 2 to 3 years. Under these circumstances, therefore, an increase in the individual's level of functioning would have the effect of slowing the progression to the critical level of functioning. Although an outcome of this type would not be considered evidence for the mental-exercise hypothesis according to the argument developed here, the practical benefits of this kind of finding could be enormous and might lead to an understandable lack of concern about the theoretical issue of whether there is an effect on the rate of age-related change.

Despite frequent assertions of the mental-exercise hypothesis, its intuitive plausibility, and an understandably strong desire to believe that it is true, the results and interpretations discussed here suggest that there is currently little scientific evidence that differential engagement in mentally stimulating activities alters the rate of mental aging. All of the available research has limitations, and thus it is conceivable that future studies that overcome some of the weaknesses will yield more positive results. Although my professional opinion is that at the present time the mental-exercise hypothesis is more of an optimistic hope than an empirical reality, my personal recommendation is that people should behave as though it were true. That is, people should continue to engage in mentally stimulating activities because even if there is not yet evidence that it has beneficial effects in slowing the rate of age-related decline in cognitive functioning, there is no evidence that it has any harmful effects, the activities are often enjoyable and thus may contribute to a higher quality of life, and engagement in cognitively demanding activities serves as an existence proof—if you can still do it, then you know that you have not yet lost it.

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