Physical Activity and Cognitive Function in the Elderly

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A relationship between physical fitness and cognition, although intuitively believable, has been difficult to document. Barriers to clarifying the relationship are the difficulties in measuring physical fitness and cognitive function, the use of differential research designs, and failures to identify and differentiate cognitive functions as well as to account for cognitive learning. Nevertheless, the fitness–cognition relationship, which continues to be reported and studied, seems compelling. It's precise nature, however, remains to be clarified.

It is not surprising that the study of a relationship between fitness and cognition has received substantial attention from the scientific community over the past 20 years. Any intervention that could be shown to have potential for maintaining cognition throughout the aging process would be of great importance. Adequate cognition is critical for personal function and maintenance of independent living. Even the most mundane actions, such as making a cup of tea, require effective cognition. For example, without adequately functioning attention and memory mechanisms, it is not possible to boil water for tea, get the cup and saucer, answer the telephone, and then remember to return to take the boiling water off the stove and finish making the tea. Without these abilities, social interactions are also impaired. In turn, social experiences are important both because they bring pleasure and increase the quality of life and because they provide an essential component of some coping strategies that adults may use to deal with the many losses that accompany aging. An inability to maintain the personal functions necessary for independent living and social interaction contributes to a loss of self-esteem and dignity and to the subsequent degradation in quality of life.

Adequate cognitive functioning is also a crucial factor in maintaining reasonable health costs in aging, because cognitive awareness and efficiency are necessary (but not sufficient) to maintain good health habits and medication schedules. Absence or deterioration of health habits and medication compliance leads to accidents, falling, and the concomitant pharmacological and physiological emergencies. It is no wonder, then, that in addition to learning more about the relationship of health, fitness, and cognition, as well as the psychophysiology of aging, gerontological study of these relationships have profound implications for the quality of life of aging individuals and for the national economy.

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What Is Cognition?

A prerequisite for understanding the relationship between fitness and cognition is an understanding of cognition. One way to think about cognition is to describe it as three functions: cognitive supports, cognitive mechanics, and cognitive pragmatics (see Figure 1).

Cognitive Supports

Basic to all types of complex cognition are processes that may be described as supports: perceptual processes, information processing speed, working memory, attention, and psychomotor control. Perceptual processes are procedures such as coding visual, auditory, proprioceptive, and tactile information. Information processing speed is the alacrity with which neural impulses travel from neuron to neuron, node to node, or neural network to network. The practical importance of fast processing speed is evident when automobile drivers have to respond quickly to avoid road hazards or other automobiles. Working memory includes holding percep-
tions and memories in contact while operating on them. Unlike short-term or primary memory, working memory is important because it is considered a large contributing factor to success in other cognitive tasks (Salthouse, 1991). An example of working memory is mentally adding or multiplying numbers.

Attention is the process of focusing perceptual-motor systems on specific stimuli or tasks that are to be accomplished. With some tasks, considerable attention is necessary for successful execution, whereas other tasks require minimal attention. Research studies often include dual task assessments, which require high levels of attention by requiring the participant to attend to two tasks at the same time. Psychomotor control is essential to communicate the results of cognition, and even in some cases to enable further cognitive processing on a topic. Psychomotor processing occurs when motor effectors, such as fingers, eye muscles, throat and lip muscles are integrated with cognitive mechanics to reflect information processing and to achieve cognitive pragmatics. An example of how psychomotor control furthers cognitive comprehension is when individuals draw maps to help others understand the location of a building, or when they write a word on paper to determine whether they have spelled it correctly, or when they gesture to assist in verbal communication.

Cognitive Mechanics

Cognitive mechanics along with cognitive pragmatics (described below), was coined by P.B. Baltes and is described in more detail in his Kleeimyer Award Lecture presented at the 1992 Gerontological Society of America annual convention (Baltes, 1993). It is a term others have described as fluid intelligence. Cattell (1963) explains that fluid intelligence reflects the function of neurological structures, which begin to decline after neural maturation (adolescence) unless some kind of intervention takes place. Fluid intelligence (or cognitive mechanics) can be collectively thought of as basic information processing, including cognitive functions such as speed and accuracy of elementary processing, visual and motor short- and long-term memory, discrimination, comparison, and categorization. Information processing speed is the speed and accuracy with which stages of processing are navigated. Visual and motor short-term memory is the process of remembering items and relationships for short periods of time, such as remembering a telephone number long enough to dial. Long-term memory is the process of retrieving information from long-term storage. Discrimination, for example, occurs when a driver determines that a light is green instead of red, and the cognitive process of comparison occurs when a driver determines that the velocity of an oncoming automobile from the right is faster than the velocity of an automobile approaching from the left. Categorizing occurs when people observe a fuzzy, living, moving object and decide that it is a male, pedigreed, poodle, dog, animal.

Cognitive Pragmatics

Baltes (1993) described cognitive pragmatics as cultural knowledge. Others have termed this type of cognition crystallized intelligence (Cattell, 1963). It includes the cognitive functions of reading, writing, language comprehension, educational qualifications, professional skills, and life skills. When tests of cognitive supports, mechanics, and pragmatics are combined into test batteries, they are generally called intelligence tests. In the adult population, the two most commonly used intelligence tests are the Wechsler Adult Intelligence Scale (Wechsler, 1981) and the IPAT Culture Fair Intelligence Scale (Cattell, 1957).
Aging Effects on Cognition

Baltes (1993) and Cattell (1963) suggest that aging affects discrete types of cognition differently. Cognitive pragmatics, or intelligence as cultural knowledge, deteriorates very little throughout the life span (Figure 2). Conversely, cognitive mechanics, or intelligence as basic information processing, and the cognitive supports, deteriorate substantially in many individuals. Baltes (1993) suggests that to understand the effects of aging on cognitive mechanics or information processing, it is necessary to study brain functioning at its boundary conditions, or limits of capacity. That is why a test of reaction time, which requires individuals to remember categories or make decisions or comparisons as rapidly as possible, has been a very successful tool for researchers to study aging.

The limits of capacity hypothesis is comparable to Hasher and Zachs’s (1979) hypothesis that cognitive functions can be placed on a continuum from automatic to effortful, and that aging degrades effortful cognitive function more than automatic functions. Tasks that require only automatic functions may be described as self-paced, single tasks, requiring little or no attention. Completion of these tasks can occur without awareness, performance is uninfluenced by other cognitive functions, and these tasks require minimal memory. Conversely, speeded or multitasks, which require intense attention, are influenced by strategy and imagery, and require high memory capacity, are categorized as requiring effortful cognition, and are most affected by aging.

The Fitness–Cognition Relationship Hypothesis

The potential relationship between fitness and cognition has attracted considerable attention over the past 20 years, as is exemplified by the number of review papers that have been published (Chodzko-Zajko, 1991; Chodzko-Zajko & Moore, 1994; Dustman, Emmerson, & Shearer, 1994; Emery & Blumenthal, 1991; Spirduso,
Several suggestions regarding the relationship emerged from these reviews. The most conservative position is that fitness may relate to cognition in the elderly, but only in the case where fitness is entirely absent, as in a diseased state. Thus, Emery and Blumenthal (1991) may be willing to agree that people with severe chronic diseases, such as cardiovascular disease, hypertension, diabetes, or pulmonary disease would also have some impairment in cognitive function, but their work has not supported a relationship between high levels of fitness and increased cognitive function. Another position is that a moderate relationship exists between fitness and cognition, but only for complex rather than simple functions (Dustman et al., 1994), for effortful versus automatic cognitive functions (Chodzko-Zajko, 1991; Chodzko-Zajko & Moore, 1994), or for information processing speed rather than functions such as memory (Spirduso, 1980; Thomas et al., 1993). The most optimistic position is that a low to moderate relationship exists for many types of cognitive mechanics functions (Stelmach & Diewart, 1977; Toole & Abourezk, 1989; Vercruyssen et al., 1990).

Difficulties in Determining the Fitness–Cognition Relationship

Although almost 20 years have passed since one of the earliest formalized studies of the relationship between fitness and a representative of cognitive mechanics—information processing speed—was published (Spirduso, 1975), and in the interim many additional studies have been conducted, the extent and nature of the relationship has eluded researchers. Many factors confuse the issue: (a) The different types of cognition have not been delineated and systematically studied by researchers; (b) cross-sectional and intervention research designs have produced different findings; (c) cognitive task acquisition has not been clearly established and described; (d) fitness has been either inadequately measured or differently measured in various studies; (e) either fitness or cognition has been invalidly measured in most studies; and (f) the age groups across studies have varied markedly, making generalizations difficult at best.

Cognitive Type

No attempt has been made within or across studies to delineate whether the cognitive function being tested is a supportive process, a cognitive mechanic (fluid intelligence), or a cognitive pragmatic (crystallized intelligence). Thus, it is possible that some researchers found a fitness–cognitive relationship because their tests representing "cognition" were loaded more heavily on a cognitive type that is more related to fitness. This issue has not been resolved.

Research Designs

The findings from cross-sectional studies tend to be supportive of the fitness–cognition relationship, whereas those from intervention studies tend not to support the relationship (Chodzko-Zajko & Moore, 1994; Dustman et al., 1994; Spirduso, 1975). It is probable that a major explanation for these differences is that the fitness levels of participants in these two types of studies are very different. Adults who participate in cross-sectional studies are very different in VO₂max than those who
begin intervention studies. As Figure 3 shows, average $\dot{V}O_2$ values of those who generally participate in cross-sectional studies of highly fit versus sedentary adults average about 45 ml·kg$^{-1}$·min$^{-1}$, whereas the $\dot{V}O_2$ of sedentary adults averages about 22.41 ml·kg$^{-1}$·min$^{-1}$. Conversely, when sedentary adults initiate an exercise program, although they gain on average about 19% in $\dot{V}O_2$, they are still well below the values typical for highly fit life-style exercisers. Thus, researchers employing cross-sectional and intervention designs compare participants with dramatically different levels of fitness.

**Cognitive Task Acquisition**

In some cognitive tasks, performance can be improved remarkably by practice. In others, practice has no effect. Almost no attention has been given to this aspect of differences across studies of the fitness–cognition relationship. Reaction time (RT) is an example of an information processing task that can be greatly improved by practice. For many adults, improvement continues throughout several days (Clarkson & Kroll, 1978; Spirduso, MacRae, MacRae, Prewitt, & Osborne, 1988). Thus, investigators who provided participants with very few RT trials were acquiring evidence of participants’ information processing speed at varying points along their acquisition curve. In intervention studies, the posttests were contaminated by the degree of retention that occurred, and little is known about aging effects on retention of unlearned tasks.

**Fitness Measurement**

Just as cognition has been inadequately defined and measured in many studies of this topic, so has the measurement of fitness been differently, and in almost all cases, inadequately measured. As shown in Figure 1, several aspects of fitness must
be considered when studying the fitness–cognition relationship. The top right side box in Figure 1 includes three measures of health that have been used in studies of health and cognition: a self-report of disease history, a rating by the participant of his or her own health, and a physician or health professional’s rating of the participant. The second box indicates that when exercise is to be related in some way to cognition, the dimensions of acute/chronic, frequency, intensity, and duration of the exercise must be included. The third box indicates that the factors of type of exercise (aerobic or anaerobic), and the level of fitness (low, average, or high) must also be considered when studying the fitness-cognition relationship.

The measurement of fitness in these studies can be placed in three categories: self-report of fitness activities, cardiorespiratory assessment, or physical or physiological assessment. Researchers depending on self-report for their assessment of fitness have generally asked their participants what type of exercise they do, the number of years they have been doing it, and the frequency, duration, and intensity of the exercise. From this, some investigators have calculated the METs (kilocalories per week) or have placed the participants on some type of activity-level ordinal scale. Self-report as a measurement suffers from invalidity and from participants’ biases. Thus, it is likely that many errors in fitness assessment were made in these studies.

Studies that fall into the cardiorespiratory assessment category are those in which \( \dot{V}O_2 \text{max} \) or submax is directly measured, or a stress test is administered to estimate \( \dot{V}O_2 \text{max} \). In some studies, a step test has been employed to estimate fitness. Measuring oxygen consumption in older adults, although accepted as the best single measure of fitness, is fraught with problems. First, most adults over the age of 60 are not able to complete a \( \dot{V}O_2 \text{max} \) or stress test. Thus, the estimates are not accurate. Second, even if they do complete the test, \( \dot{V}O_2 \text{max} \) has a substantial genetic component. Third, \( \dot{V}O_2 \text{max} \) does not continue to increase in parallel with increased training and increased aerobic performance.

The third category includes those studies in which physical assessments are measured or calculated (stature, weight, and body mass index) or in which other physiological measures are taken, such as heart rate, systolic and diastolic blood pressure, blood lipids, blood glucose, or pulmonary function at rest. Chodzko-Zajko and Ringel (1987) have statistically combined these into an Index of Physiological Status (IPS), which they found to be more predictive of cognitive function than a single measure of \( \dot{V}O_2 \text{max} \).

**Balance of Fitness–Cognition Measurement**

Yet another source of error in fitness–cognition studies is that fitness and cognition have not been measured with equal rigor. These fitness–cognition relationship studies tend to be directed either by exercise physiologists or psychologists. When exercise physiologists are principal investigators, the measurements of fitness tend to be rigorous, sophisticated, and comprehensive. The measurements of cognition—in terms of validity, reliability, and logic—are less well planned and administered. Conversely, in studies by psychologists, the cognitive measurements are exquisite, and the fitness measures are sketchy and poorly planned. Consequently, most studies of this genre are unbalanced in the treatment of the two major variables, an imbalance that limits the usefulness of the conclusions.
Age Groups

A final complicating design factor that undermines the conclusiveness of studies on this topic is the great disparity of ages within groups labeled young and old, as shown in Figure 4. In almost all cross-sectional studies, the age range is not equal in the young and old groups. In some studies, the old group ranges in age from 50 to 75 or 80, a grouping that clusters individuals of very different abilities. Similarly, in three of these studies, the young group includes participants from 20 to 55, whereas the old groups include participants from 60 or 70 to 80. Not one of the cross-sectional studies has equivalent age ranges and sufficiently old participants.

In general, the old participants in intervention studies are older than those in cross-sectional studies. In Figure 5, only the exercise group ages are shown; control groups were comparable ages, but are not shown. Many of these studies also included groups with age ranges that were much too large.

Current Status of the Fitness–Cognition Relationship

Clearly, the complexity of the subject and the multitude of confounding factors indicate that the state of this topic is not ready for a formal meta-analysis. The studies that have been completed thus far are too few, too mixed in design and variables, and too varied in terms of ages and genders studied. In order to make some sense out of the area, and to provide some information regarding the relationship between fitness and cognition, however, studies can be categorized on some factors and then compared in terms of whether they found or did not find a statistically significant relationship between fitness and cognition. We deliberately did not do

![Figure 4](image_url) — Age ranges of participants for 19 cross-sectional studies assessing cognitive function related to fitness. The Total Group category represents single-group studies. The other studies described young and old groups, as designated in the legend. Studies represented include Baylor and Spirduso (1988); Chodzko-Zajko, Schuler, Solomon, Heiml, and Ellis (1992); Chodzko-Zajko and Ringel (1987); Clarkson (1978); Clarkson-Smith and Hartley (1989, 1990); Dustman et al. (1990); Elsayed, Ismail, and Young (1980); Emmerson, Dustman, Shearer, and Turner (1990); Era, Jokela, and Heikkinen (1986); Era, Pärrssinen, and Suominen (1991); Kroll and Clarkson (1978); Offenbach, Chodzko-Zajko, and Ringel (1990); Powell and Pohndorf (1971); Shay and Roth (1992); Sherwood and Selder (1979); Spirduso (1975); Spirduso and Clifford (1978); Spirduso, MacRae, MacRae, Prewitt, and Osborne (1988).
Figure 5 — Age ranges and means of participants for 18 intervention studies assessing the effects of exercise on cognitive function. Only the exercise group age ranges are shown here, as the control or nonexercise group ages had similar ranges. Studies represented include Barry, Steinmetz, Page, and Rodahl (1966); Blumenthal et al. (1989); Blumenthal and Madden (1988); Dustman et al. (1984); Elsayed, Ismail, and Young (1980); Emery and Gatz (1990); Hassmen, Ceci, and Bäckman (1992); Hawkins, Kramer, and Capaldi (1992); Hill, Storandt, and Malley (1993); Ismail and El-Nagger (1981); Madden, Blumenthal, Allen, and Emery (1989); Molloy, Richardson, and Crilly (1988); Panton, Graves, Pollock, Hagberg, and Chen (1990); Pierce, Madden, Siegel, and Blumenthal (1993); Rikli and Busch (1986); Rikli and Edwards (1991); Roberts (1990); VanFraechem and VanFraechem (1977).

a meta-analysis or any type of statistical analysis of category differences that we found because we do not wish to attribute the kind of importance that statistical quantification can confer to the observations that we made in this very complicated area of study.

Analysis Categories

Thirty-eight research reports were studied and were sorted according to the following categories: type of cognition (support, function, or combined/index scores), research design (cross-sectional, intervention), task acquisition status (practiced, unpracticed), and assessment of fitness (self-report, aerobic capacity measurement or estimate, or physiological assessment). The total number of statistical tests that we used from these studies was 296; that is, in some studies several statistical tests—either t tests, F tests, or tests of correlational significance—were made of several variables, (e.g., simple reaction time, choice reaction time, and the Stroop test of attention). Thus, the dependent variable of our analysis was the percentage of significant statistical tests found for each category.

Fitness Category Differences

The percentage of significant statistical tests of cognitive differences between fit and sedentary adults was different, depending upon how fitness was measured. The differences are shown in Figure 6. The first observation that can be made is that in all types of studies, more than one third of the tests of relationships were significant. The relationships were greater (75%), however, in those studies in which self-report of fitness was used and were least in those studies in which \( \text{VO}_2\max \) was directly or indirectly measured. In most cases, direct measurement of \( \text{VO}_2\max \)
occurred in intervention studies, whereas self-report occurred in cross-sectional studies. This large difference may very well reflect the great difference in characteristics of fit and sedentary adults in these different types of studies, but it may also reveal that VO\textsubscript{2} assessment does not measure those exercise-related fitness, physical, or physiological characteristics most related to cognition.

The difference between cross-sectional and intervention designs is clearly shown in Figure 7. These differences are enhanced because participants in exercise groups also tend to have better health habits, to have a genetic predisposition to optimize all aspects of their lives, and to self-select themselves into studies that
offer tests related to health and physical prowess. The intervention studies have tended to have severe sampling problems, poor cognitive assessment, inadequate practice provided, and participants with low fitness levels.

Practice is a factor that complicates the issue (see Figure 8). In more than half of the studies in which performance (practiced) rather than learning (unpracticed) was assessed, fitness was shown to relate to some aspect of cognition.

Finally, when only those studies that were categorized as being the most rigorous in terms of an idealized experimental design (directly testing fitness level, using an intervention design, and providing practice) were compared to those categorized as least rigorous (self report for level of fitness, using a cross-sectional design, and not providing practice), a huge difference was seen in the percentage of significant statistical tests of the fitness-cognition relationship (Figure 9). This result might be interpreted to mean that when participants are categorized as “exercisers,” and no statistical disassociation from related behaviors is conducted, the exercise variable has a much larger component of other related variables in it, such as abstinence from smoking, abstinence from drinking, adequate sleep, high socioeconomic status, high education level, and other optimizing factors.

Cognitive Functions and Fitness

In Figure 10, the percentages of significant statistical tests found are shown for each cognitive function. Because some types of cognitive function were tested by the researchers many more times and in more studies, the percentages shown at the end of each bar cannot be interpreted without also noting the thickness of the bar. Those functions such as psychomotor ability and attention were tested more times (65 to 90 tests) than others. Comparing the percentages while simultaneously considering the number of tests made suggests that cognitive supports such as speed of processing, psychomotor control, attention, and perceptual processing are related to physical fitness. Cognitive mechanics such as spatial manipulation and abstract reasoning may also be related.
Conclusions

An analysis of the literature on fitness and cognition suggests that researchers’ understanding of this topic is not as clear as is desired. In the past 20 years this issue has been addressed by many investigators, but the relationship of specific cognitive functions to specific measures of fitness has not been high. Yet, although these relationships have not been robust, they continuously appear. A minimum of
one third of the statistical tests analyzed among the many research reports supported a relationship between fitness and cognition, a fraction too high to occur by chance alone. Correlation coefficients between fitness–cognitive measurements are not zero, they are usually low to moderate. There have also been human studies in which the effect of exercise on brain mechanisms has shown positive effects that support a fitness–cognition relationship. These studies include evidence that exercise significantly changes cerebral blood flow (Hedlund, Nylin, & Regnström, 1962; Kleinerman & Sokoloff, 1953; Thomas, Schroeder, Secher, & Mitchell, 1989). In animal studies, significant exercise-related changes have been seen in increased blood flow to the motor-sensory cerebral cortex (Gross, Marcus, & Heistad, 1980), increases brain capillaries (Black, Isaacs, & Greenough, 1991), and effects on brain neurotransmitter function (Brown et al., 1979; Fordyce & Farrar, 1991a, 1991b; Gilliam et al., 1984; MacRae, Spirduso, Walters, Farrar, & Wilcox, 1987).

Part of the failure to find a robust relationship may be due to serious and plentiful errors and inadequacies in the research designs and measures employed to test these relationships in humans. But part of the failure may also be due to the prospect that the contribution of exercise alone is insufficient to maintain cognitive function throughout aging. Rather, it may be that it is the constellation of good health habits, exercise, and high socioeconomic and educational status that are robustly related to cognition in the elderly.

References


