CHAPTER 2

Physical Activity, Cognition, and Aging: A Review of Reviews

Phillip D. Tomporowski, PhD

Questions concerning the relationship between physical activity and mental activity have been posed for centuries. Central to the philosophical framework of Western civilization is the dualistic view that human behavior can be explained in terms of processes of the body and processes of the mind. The specific relationship that exists between the body and mind has been a topic of debate, discussion, and writing for more than two centuries. The questions that have been formulated both by ancient thinkers and by modern scientists reflect the zeitgeist. The questions of contemporary researchers reflect particular epistemological frameworks. Researchers explore the relation between physical activity and cognition from different perspectives. Some researchers use frameworks that emphasize physiological processes, others focus on psychological processes, and others have interests in hormic and motivational processes. Scientists interpret data obtained from studies that examine the relation between physical activity and cognition, and their interpretations reflect these various frameworks or points of view.

This review has two goals. The first is to showcase the historical views of the last two decades of researchers who have examined studies and who have provided interpretations of those studies that assess the impact of physical activity training on mental processing and behavior. A literature search led to the identification of 17 review papers, which were separated into three groups. One group of reviews focuses on the relation between physical activity and mental health; another group focuses on exercise's effects on cognition; and the third group examines the interrelation among exercise, cognition, and aging factors.

The second goal of this review is to highlight two issues deemed critical to any systematic study of physical activity and its impact on aging. The first deals with methodological and research design issues, and the second addresses issues related to theory development. A number of specific research questions are posed and suggestions concerning future directions are then provided.

Critical Reviews

Historians provide numerous examples of the importance that has been placed on physical activity as a method to develop and maintain physical and mental health and mental ability. As early as the fourth century B.C., the Greek philosopher Xenophon promoted the importance of exercise as a means of staving off declines in mental prowess associated with growing older. Socrates and Plato also discussed the merits of vigorous physical activity as a way to maintain a clear mind. During the Renaissance, physical activity was prescribed to ameliorate the extravagant lifestyles of the wealthy. Likewise, Shadrach Ricketson, who is credited in 1806 with the first American text on preventive medicine, devoted an entire chapter to the importance of exercise for maintaining health and vigor throughout the life span. Interestingly, the value of exercise as a health-promoting vehicle had been voiced most vigorously during times when communities experienced wealth and stability and had available leisure time.

The wellness movement in the United States in the 1970s spawned a tremendous interest in physical activity as a method to promote physical and mental health. The merits of running and aerobic activity proselytized by Ken Cooper, Jim Fixx, and others led millions to begin exercise training with the conviction that physical activity is a curative with the potential to offset or postpone the aging-associated deterioration of the body and mind. Since that time, the putative benefits of exercise on mental processing and its ability to offset the impact of aging have been described in more than 1,000 magazine and health-promotion articles written for the general public.

The academic study of the effects of physical activity on mental processing can be traced back to research conducted more than a century ago. The majority of published studies, however, has been conducted over the past three decades, and several reviews of these studies have been conducted (see bibliography on pages 27 and 28). Three reviews stand apart from the others in the manner in which they organize and describe the studies reviewed, address core methodological issues, present theory-based explanations for empirical observations, and propose directions for research and theory development.

Folkins and Sime

Folkins and Sime's (1981) review was published at a time when the aerobic exercise and health movement was gaining momentum; the review was designed to address the impact of physical activity both on nonclinical and on clinical populations. The authors evaluated studies that assessed the effects of aerobic-type exercise on the cognition, perception, affect, behavior (work, sleep, social behavior), and personality of individuals without clinical syndromes. They also evaluated studies that employed

physical fitness training as an intervention for such clinical conditions as depression, anxiety, alcoholism, and mental retardation.

Folkins and Sime concluded that methodological shortcomings and procedural artifacts of many of the studies evaluated made it difficult to make firm conclusions regarding a causal relationship between physical fitness training and cognition or mental health. Only about 15 percent of the studies reviewed met the criteria of a true experiment. Physical fitness training leads to improved mood, self-concept, and work behavior. The effects of exercise on cognition are not clear; however, there are data that suggest that cognitive performance is enhanced during and following physical activity. The Folkins and Sime (1981) review has served as the primary catalyst for much of the academic study of exercise and psychological process that has been conducted over the past two decades. The authors identify three theoretical approaches that researchers take to evaluate the relation between exercise and mental processes:

- A physiological viewpoint. This implies a direct physical causation for the psychological benefits of fitness training.
- A psychological viewpoint. Physical fitness improvements provide people with a sense of mastery and control over their behavior; these changes mediate enhanced cognitive functioning.
- A cognitively oriented viewpoint. Physical fitness training is a self-regulation process that enhances adaptive behaviors.

Plante and Rodin

This review was designed specifically as an update of Folkins and Sime's (1981) review. It focused primarily on studies that examined the effects of exercise among nonclinical populations. The researchers evaluated 38 studies that did not suffer from extensive methodological shortcomings. These studies were grouped into four areas: well-being and mood, personality and self-concept, physiological stress responsivity, and cognition.

Plante and Rodin (1990) concluded that exercise improves mood and psychological well-being (especially immediately following exercise), and it improves self-concept and self-esteem. Exercise appears to do little for personality functioning. There is little evidence that exercise alters stress responsivity or cognitive functioning.

The Plante and Rodin (1990) review stresses the need to evaluate separately the effects of acute bouts of exercise and the effects of chronic exercise interventions. The authors reiterate Folkins and Sime's (1981) views on the lack of methodological rigor that exists in many of the studies that have been conducted. However, there is a need to conduct research aimed at addressing the importance of engaging in exercise activity relative to factors that motivate someone to become an exerciser. It is difficult to

determine if exercise improves psychological functioning, or if exercisers as a group tend to be more psychologically fit than nonexercisers. There is also a need to conduct follow-up evaluations to determine if psychological improvements attributed to exercise are maintained.

Morgan

A significant contribution to the study of the mental health benefits of physical activity was provided by William Morgan (1997) in the form of an edited, uniquely organized text. It provided a series of comprehensive reviews of empirical studies that assessed the effects of physical activity on such factors as depression (Martinsen & Morgan, 1997), anxiety (Raglin, 1997), self-esteem (Sonstroem, 1997), and overtraining (O'Connor, 1997). The text also included a series of reviews that addressed potential explanations for observed relations between physical activity and mental health. Exercise-produced changes in endorphin (Hoffmann, 1997), serotonin (Chaouloff et al., 1987), norepinephrine (Dishman, 1997), and thermogenic (Koltyn, 1997) levels on affect were evaluated. However, issues that relate specifically to the relation between physical activity and cognition were not addressed.

The contributions of Morgan's book, including the questions raised for future research, include a cogent overview of methodological issues that is particularly relevant to the assessment of physical activity and its effects on psychological variables, the evaluation of effects of exercise from the perspective of both basic and applied research. Attention is paid to the potential of exercise to produce both positive and negative outcomes. The book postulates that the consequences of exercise on mental health depend on the parameters of the training program.

The "dose-effect" relation between exercise and mental health is not known. It is unclear if there is a "threshold" effect; that is, does the dose-effect relation require a specific level of improvement to elicit a change in psychological functioning? Future research should address issues related to exercise mode, intensity, duration, preferred versus prescribed exercise, personalized prescription, and lifestyle versus traditional exercise prescription.

Physical Activity and Cognition

The hypothesis that aerobic exercise can serve as a vehicle to promote positive changes in affective states has received considerable empirical support. Indeed, Morgan (1997) suggests that "there is no further need for research or reviews dealing with the question of whether or not physical activity results in improved mood. There is compelling evidence supporting the efficacy of physical activity in the prevention and treatment of both physical and mental disorders" (p. 230). However, the evidence in favor

of the effectiveness of exercise programs on changing cognitive functioning was less clear.

Two reviews, Gutin (1972) and McMorris and Graydon (2000), address directly the relation between exercise-induced arousal and cognitive performance. The notion that performance is associated with arousal level has long been a part of psychological research. The formulation of the Yerkes-Dodson law (1908), which hypothesizes an inverted U-shaped function between arousal and performance, figured prominently in early learning theory and has had an impact on modern theories of human performance.

Both of these reviews examined studies that were designed based on *a priori* predictions derived from theories that were grounded in the Yerkes-Dodson law. These studies are characterized by the repeated assessment of an individual's cognitive performance as his or her level of physical arousal increases as a direct function of exercise. Typically, exercise protocols include bouts of aerobic and anaerobic exercise that are relatively brief; most protocols last less than 20 minutes. Demonstration of an initial improvement in performance, followed by a decline in performance as arousal increases from a resting state, is taken as support for the Yerkes-Dodson law.

The authors concluded that the results of laboratory studies that attempt to link cognitive performance to specific levels of exercise-produced arousal are ambiguous. There are studies that provide clear evidence for an inverted U-shaped relation between arousal and cognitive performance, studies that provide only partial support for the relation, and still other studies that provide no support for the relation. Gutin (1972) concluded that the relation between exercise and performance may be negative, positive, or curvilinear, depending on the kind of task used. McMorris and Graydon (2000) concluded that exercise-induced arousal is limited to information-processing speed and has little influence on complex decision making.

Based on the review, Gutin proposed the implementation of research strategies that incorporate physiological, neuropsychological, and behavioral measures of exercise's effects on cognition. Also suggested were the utilization of the measures of participants' fitness status and the reevaluation of the concept of arousal and the incorporation of new theories of mental processing.

Three reviews focused on studies that examined the effects of acute bouts of exercise on cognitive performance. Acute exercise protocols result in the activation of the entire body and produce systemic changes in physiological functions such as cardiorespiration, endocrine function, and body temperature. In these studies, measures of cognitive performance are taken while an individual is in the process of exercising or shortly following the termination of exercise.

Weingarten

This review focused on studies that examined mental performance during and immediately following exercise. Weingarten (1973) concluded that physically fit individuals have a definite advantage over nonfit individuals when mental tasks are administered during or immediately after physiological stress. The advantage of physical fitness is not evidenced under normal conditions.

Tomporowski and Ellis

These authors classified 27 studies into three groups on the basis of the duration and intensity of the exercise protocol. Tomporowski and Ellis (1986) concluded that the data obtained from the studies reviewed failed to support the notion that exercise influences cognition.

Tomporowski

A review of 43 studies examined the effects of acute bouts of exercise on cognitive functioning. Studies were separated into one of three groups on the basis of the focus of the intensity and duration of the exercise protocols employed. One group focused on the construct of fatigue and studies that employed brief, maximal exercise protocols. A second group focused on the construct of arousal and studies that employed both maximal and submaximal exercise protocols of short duration. The third group focused on the effects of submaximal exercise protocols of relatively long duration.

Tomporowski (2003) concluded that moderate levels of aerobic, steady-state exercise facilitate specific stages of information processing. Exercise does not influence directly those operations involved in the initial stage of processing. Studies consistently fail to find systematic exercise effects on tasks that measure perceptual and sensory processing. However, exercise does influence the decision-making stage of information processing. Faster choice responses have been observed both on simple and complex tasks during and following exercise. In most cases, response speeds increase with no accompanying increase in error rates, suggesting that exercise is not simply altering participants' response criterion. Rather, exercise produces a condition during which individuals are able to perform both simple and complex tasks rapidly and efficiently.

Studies that employ tasks that measure response inhibition provide compelling evidence for exercise's influence on working memory. Acute bouts of exercise improve the ability to block irrelevant information and to select and respond to task-relevant information. Although exercise alters working-memory processes, it does not influence retrieval of information from long-term memory. Furthermore, exercise has clear effects on the response-preparation stage of information processing. The capacity to

mobilize and to time movement patterns is enhanced during and following bouts of steady-state aerobic exercise. Intense anaerobic exercise does not impair cognitive function significantly; however, submaximal aerobic exercise that leads to dehydration does compromise both information processing and memory functions.

The author made three other conclusions regarding the effects of exercise on cognition. First, acute bouts of moderately intense exercise are hypothesized to function in a manner similar to that of psychostimulant drugs, which do not influence directly the computational processes that are involved in information processing. Rather, they produce changes in state processes that are responsible for the allocation of attentional resources. Second, the magnitude of acute exercise's effects on cognitive function is expected to interact with a variety of individual difference variables. Several of the studies reviewed reported that exercise's impact on performance depended on the participants' level of physical fitness or their level of experience. Finally, the conclusions drawn from empirical studies evaluated can be explained in the context of contemporary energetic models of cognition. These theories attempt to capture the relation among the components of the information-processing system, the allocation of energy that is involved in mental operations, and the guidance functions of executive processes.

Etnier, Salazar, Landers, Petruzzello, Han, and Nowell

This review examined the roles of both acute exercise interventions and chronic exercise interventions on cognitive functioning. Etnier and colleagues (1997) conducted a meta-analysis of 134 studies that evaluated the relation between exercise and cognitive function. They separately examined studies that examined exercise's acute effects and chronic effects on exercise. The results of the meta-analysis were used to test nine hypotheses generated from previous literature reviews.

The authors concluded that exercise has a small positive effect on cognition ($ES = 0.25$). However, the importance of this finding must be judged in light of subsequent analyses, which suggest that the impact of single bouts of aerobic exercise is limited only to improvements in participants' simple reaction time. The analysis identified a negative relation between acute exercise and participants' performance on tasks that measured either choice or discriminant reaction time.

Also, exercise appears to have a meaningful impact on cognition when it is administered as a chronic treatment to produce fitness gains. Further, the impact of exercise increases with training duration. However, the importance of this finding needs to be judged in light of numerous methodological flaws that exist in many studies. Furthermore, Etnier and

colleagues (1997) determined that the age of the participants did not have a significant impact on the effect size generated by the meta-analysis.

In recent years, controversy has shifted from the question of whether there is a link between mind and body to the question of what the precise causal relationship is between the two components. Exercise's impact on cognition may be explained in terms of its impact on cerebral blood flow, modification of neurotransmitter systems, or structural changes in the brain.

Physical Activity, Cognition, and Aging

Throughout history, numerous methods have been proposed to stave off age-related declines in mental abilities. One method that has been consistently suggested to have ameliorative effects on mental processing is physical activity. In today's popular culture, involvement in physical activity is believed to offset declines in abilities associated with advancing age; articles in popular literature tout the beneficial effects of exercise. Some articles encourage older adults to participate in such physical activities as walking, swimming, and cycling. The commonsense belief that physical activity maintains one's general health has led to the development of various programs designed to improve abilities, prevent the onset of decline of abilities, and restore lost abilities.

Reviews of studies that examine the relation among exercise, cognition, and aging tend to fall on a continuum. At one end are reviews that address basic research questions, and at the other end are reviews that address applied research questions.

Spirduso

This classic review article focused on age-related changes in psychomotor speed and the impact that physical fitness has on psychomotor speed. The author evaluated a number of studies within several research domains considered to be relevant to understanding age-related changes in psychomotor speed. The areas reviewed included psychomotor performance of young and older adults who differed in level of physical fitness, the influence of physical fitness training on psychomotor speed, psychomotor speed with supplemental oxygenation, and psychomotor speed and cardiovascular disease.

The author concluded that many of the studies reviewed possessed methodological or design weakness. However, it appears that the psychomotor speed of fit young and older adults is faster than the speeds of their less fit age-mates, and that physical training programs result in the improvement of participants' response speeds. Furthermore, cardiovascular diseases compromise older adults' psychomotor speed, and supplemental oxygen can improve psychomotor functioning in some individuals.

Spirduso (1980) stated that the basis for fitness-related differences in psychomotor speed may be caused by such physiological mechanisms as cerebral blood flow, maintenance of the neural integrity of motor and somatosensory brain areas, and enhancement of brain neurotransmitter production. Furthermore, empirical evidence and theoretical supposition suggest that exercise modifies the brain structures that are involved in age-related slowing. Exercise may postpone psychomotor decline and have a significant impact on older adults' daily activities. Advances in the field will be spurred when greater attention is paid to physical and cognitive measurement.

Stones and Kozma

The main thrust of the review was to present various models that might explain the relation between physical activity and cognition. The authors contrasted the merits of three models. The health mediation model suggests that the prevention of ill health through exercise will help postpone disease states that have debilitating impacts on mental cognitive abilities. The moderator variable model suggests that lifelong exercising postpones or arrests age changes by maintaining processes that underlie performance ability (e.g., brain systems). The functional age model suggests that chronic exercise has generalized benefits for the organism, but it does not assume that the aging process itself is affected by exercise. The effects of chronic exercise can be described as tonic, meaning that vigor and vitality are restored to the performance of a range of functions. Health activities, such as exercise, contribute independently to overall capability to function.

The authors assess the empirical support for each of these models by drawing on published research and an extensive evaluation of two of their own studies designed to test the validity of the functional age model. They concluded that there was minimal support for either the mediation model or the moderator model. Furthermore, the studies reviewed provide support for the functional age model and the hypothesis that chronic exercise has a generalized effect across both physical and psychological domains. Exercise helps compensate for age deterioration by bolstering functional capability (e.g., vigor and vitality). Also, the improvement in cognitive performance is probably due to changes in brain oxygen transport capabilities brought about by exercise.

Stones and Kozma (1988) also asserted that physical activity can influence cognitive performance in two ways. Chronic exercise produces a generalized, or tonic, effect on functional capability that can be engendered at any point throughout the life span. Second, the repetitive nature of exercise leads to overpractice of specific motor movement patterns that are resistant to aging effects. The tonic and overpractice effects (TOPE) model provides a framework for assessing the dual nature of chronic exercise training.

Emery, Burker, and Blumenthal

This review reports the results of studies selected from a number of research domains. Emery, Burker, and Blumenthal (1991) assessed the impact of acute bouts of aerobic exercise on mood and cognitive functioning and the impact of chronic exercise on older adults' personality, mood, and cognitive functioning. The authors concluded that data from studies that examined the acute effect of exercise are scarce, and those that are available are difficult to interpret because of methodological problems. Also, the few studies that are available suggested that chronic exercise influences personality functioning.

The results of several studies conducted to evaluate the impact of chronic exercise on older adults' mood states are inconsistent. A number of studies were conducted during the 1980s and early 1990s that examined the effects of chronic exercise programs on older adults' cognitive performance (Blumenthal & Madden, 1988; Blumenthal et al., 1989; Blumenthal et al., 1991; Dustman et al. 1984; Dustman, Emmerson, Ruhling, et al. 1990; Madden, Blumenthal, Allen, & Emery, 1989; Panton et al. 1990). The results of these studies are mixed. Comparisons among these studies are made difficult by the differences that exist in research methodology, statistical analyses, and outcome measures. No intervention studies have been conducted that assess the impact of physical fitness training on neuropsychological performance of older adults following an acute bout of exercise. Furthermore, there have been no studies conducted of cardiovascular reactivity among older adults, which is a promising area for research in aging.

Therefore, more systematic studies need to be conducted; however, the boundaries of these studies should be expanded. Researchers should incorporate measures of self-perceptions of both emotional and physical status, indices of psychosocial functioning, self-esteem, and personal efficacy. Researchers will also need to address the issue of noncompliance or participant dropout.

Dustman, Emmerson, and Shearer

The authors examined studies investigating animal research that involved physical activity training of rodents and dogs, cross-sectional research that compared measures of the cognitive and neuropsychological processes of individuals who exercise with those of sedentary individuals, and intervention research that assessed the effects of aerobic exercise training on older adults' cognitive and neuropsychological processes.

Dustman, Emmerson, and Shearer (1994) concluded that research conducted with animals provided compelling evidence that improvements in aerobic fitness are linked to enhanced behavioral and neurobiological functioning. Aerobically fit animals differ from less fit animals on measures of acetylcholine, dopamine, norepinephrine, serotonin, and gamma-

aminobutyric acid (GABA). Exercise participation beginning in middle age and continuing into old age can offset declines in neural integrity that typically occur during aging, both in animals and in humans.

Cross-sectional research indicated a strong positive association between physical activity level and cognitive performance. Physically active individuals consistently perform better on tests that demand speeded performance than those who are sedentary. The benefits of physical fitness are seen most clearly on cognitive tasks that provide measures of mental flexibility. However, intervention studies have not consistently demonstrated cognitive–neuropsychological improvements following exercise training.

The authors further concluded that converging evidence taken from three areas of research suggested that physical activity is associated with fundamental changes in the brain function, and that these improvements have an impact on age-related changes in mental processing. The results obtained from studies involving animal research, although compelling, must be evaluated with caution. It is not known if the exercise-based neuroanatomical changes found in animals generalize to the functioning of older adults. Research in the field will benefit from taking a life span approach.

The role of response inhibition across the life span may provide a way to assess physical fitness effects on adaptive behavior. Response inhibition involves the control of thought and action. It is known that inhibitory efficiency decreases with aging. The brain's capacity to benefit from physical activity is reduced with aging. Thus, the sooner exercise interventions are made a part of one's lifestyle, the greater the impact they will have on forestalling age-related changes in cognition.

Chodzko-Zajko and Moore

Chodzko-Zajko and Moore (1994) reviewed cross-sectional studies that examined the differences between highly fit and less fit older adults' cognitive performance and reviewed intervention studies that examined the effect of physical fitness training on older adults' cognitive functioning. These studies were evaluated in terms of a resource theory of attention that hypothesizes that cognitive processes can be distributed along an automatic-to-effortful continuum. Tasks that require the allocation of attentional resources are viewed as effortful, while tasks that are only minimally dependent on attentional resources are viewed as automatic. Theorists who employ resource models of cognition suggest that aging is associated with a reduction of attentional reserve.

The authors concluded that data obtained in cross-sectional research suggested that the cognitive functions of physically fit older adults are more efficient than those of their less fit peers. The relation between fitness and cognitive performance appears to be task dependent. Data obtained from intervention studies failed to support the view that physical activity training

results in clinically significant improvements in cognition. Physical fitness effects are most likely to be observed in tasks that require rapid or effortful cognitive processing and are less likely to occur in self-paced tasks. There are several potential mechanisms by which physical activity may directly or indirectly influence older adults' cognitive processes. These include improvements in cerebral oxygenation, neurotrophic stimulation, and neural efficiency.

Kramer and Colleagues

Presented as a chapter in an edited text, and while not developed as a review of the literature, this work provided a significant contribution to the literature. Kramer, Hahn, and colleagues (2002) described a major research study that involved the assessment of the effects of a six-month physical fitness training program on 124 sedentary but healthy older adults. A cognitive test battery was constituted on the basis of the hypothesis that improvements in aerobic fitness would be associated with selective improvements in cognitive functions that involve executive control processes such as coordination, inhibition, schedule planning, and working memory. The exercise program resulted in improvements on the majority of cognitive tasks predicted to reflect executive control processes.

The authors concluded that the data obtained do not support the resource allocation hypothesis. Physical activity produces its beneficial effects on cognition through its impact on executive control processes. It was observed that the performance of subjects who exercised improved on tasks that require the capacity to retain and manipulate information in working memory, to perform two or more tasks concurrently, to switch rapidly between two tasks, and to inhibit prepotent responses. No attempts have been made to examine the relation among aerobic fitness, cognition, and brain function and structure. There is strong support from data obtained from neuroimaging studies that implicate the role of frontal-lobe processes and executive control. The development of nonintrusive neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), provides a unique opportunity to examine fitness effects on both the brain and mind.

Two reviews, Shephard and Leith (1990) and Boutcher (2000), have examined the exercise literature with a view toward its application to health programs that are designed for older adults. Shephard and Leith (1990) provided a description of age-related changes in physiological, psychological, and emotional systems. They then addressed the impact that physical activity training has on each of these systems. The effects of habitual exercise's impact on normal and pathological aging processes were also assessed.

The authors concluded that physical activity training modifies anxiety and depression states. Habitual exercise may result in physiological and psychological hardiness. The effects of physical training programs on

individuals with pathology are unclear. There is increasing evidence that habitual physical activity can improve cognitive function in older adults.

Exercise training programs must be designed to meet the needs of the individual. This is particularly true given possible interactions between medication and exercise. Particular efforts must be made to better understand compliance and adherence issues. This is especially true of individuals with pathological disorders.

Boutcher (2000) placed the major emphasis of his review on the effect that aerobic fitness has on the cognitive performance of older adults from nonclinical populations. The organization, presentation, conclusions, and discussion of the studies reviewed were similar to those presented by Chodzko-Zajko and Moore (1994). Boutcher concluded that the beneficial effects of habitual physical activity can be linked to changes in cerebral circulation, neurotrophic stimulation, and neural efficiency. Psychosocial processes linked to performance in exercise programs may facilitate older adults' level of motivation and contribute to cognitive-task improvement. There is a need for exercise scientists to collaborate with gerontological researchers. Randomized controlled trials must ensure that exercise training is sufficient to produce measurable improvements in physiological function.

ADDITIONAL REVIEWS

The following is a bibliography of reviews on exercise, activities, cognition, and aging not covered in this chapter. The reviews are clustered as published up to 1981, in the 1980s, and in the 1990s.

Reviews up to 1981

- Browman, C.P. (1981). Physical activity as a therapy for psychopathology: A reappraisal. *Journal of Sports Medicine, 21,* 192-197.
- Clarke, H.H. (1958). Physical fitness benefits: A summary of research. *Education, 78,* 460-466.
- Ismail, A.H. (1972). Integrated development. In J.E. Kane (Ed.), *Psychological aspects of physical education and sport.* London: Routledge.
- Layman, E.M. (1972). The contribution of play and sports to emotional health. In J.E. Kane (Ed.), *Psychological aspects of physical education and sport.* London: Routledge.
- Morgan, W.P. (1974). Exercise and mental disorders. In A. Ryan & F. L. Allman, Jr. (Eds.), *Sports medicine.* New York: Academic Press.
- Powell, R.R. (1975). Effects of exercise on mental functioning. *Journal of Sports Medicine & Physical Fitness, 15,* 125-131.

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Reviews of the 1980s

- Doan, R.E., & Scherman, A. (1987). The therapeutic effect of physical fitness on measures of personality: A literature review. *Journal of Counseling & Development, 66,* 28-36.
- Hale, R.E., & Travis, T.W. (1987). Exercise as a treatment option for anxiety and depressive disorders. *Military Medicine, 152,* 299-302.
- Martinsen, E.W. (1989). The role of aerobic exercise in the treatment of depression. *Stress Medicine, 3,* 93-100.
- Oberman, A. (1984). Healthy exercise. *Western Journal of Medicine, 141,* 884-871.
- Phelps, J.R. (1987). Physical activity and health maintenance: Exactly what is known? *Western Journal of Medicine, 146,* 200-206.
- Ransford, C.P. (1982). A role for amines in the antidepressant effect of exercise: A review. *Medicine & Science in Sports & Exercise, 14,* 1-10.
- Rippe, J.M., Ward, A., Porcari, J.P., & Freedson, P.S. (1988). Walking for health and fitness. *Journal of the American Medical Association, 259,* 2720-2724.
- Sachs, M.L. (1982). Exercise and running: Effects on anxiety, depression, and psychology. *Humanistic Education & Development, 21,* 51-57.
- Simons, A.D., McGowan, C.R., Epstein, L.H., Kupfer, D.J., & Robertson, R.J. (1985). Exercise as a treatment for depression: An update. *Clinical Psychology Review, 5,* 553-568.
- Sonstroem, R.J. (1984). Exercise and self-esteem. *Exercise & Sports Science Review, 12,* 123-155.
- Taylor, C.B., Sallis, J.F., Needle, R. (1985). The relation of physical activity and exercise to mental health. *Public Health Reports, 100,* 195-202.

Reviews of the 1990s

- Arent, S.M., Landers, D.M., & Etnier, J.L. (2000). Effects of exercise on mood in older adults: A meta-analytic review. *Journal of Aging & Physical Activity, 8,* 407-430.
- Kramer, A.F., Hahn, S., & McAuley, E. (2000). Influence of aerobic fitness on the neurocognitive function of older adults. *Journal of Aging & Physical Activity, 8,* 379-385.
- Thomas, J.R., Landers, D.M., Salazar, W., & Etnier, J. (1994). Exercise and cognitive function. In C. Bouchard, R.J. Shephard, & T. Stephens (Eds.), *Physical activity, fitness, and health: Consensus statement* (pp. 521-529). Champaign, IL: Human Kinetics.

Inplications for Aging Research

Advances in understanding the effect that exercise training has on older adults' cognitive function will be realized when investigators employ research designs that avoid the methodological and procedural shortcomings that plague prior studies.

Methodological Issues

Virtually every review evaluated made a plea for more studies with adequate research design. Folkins and Sime (1981) reported that only about 15 percent of the studies they reviewed met the standards of a true experiment. Similar percentages are reported in other reviews. More recently, Etnier and colleagues (1997) identified 200 studies that examined exercise's effects on cognitive function, and they also addressed the serious design flaws present in many studies. They pointed out that support for the view that exercise benefits cognitive function comes primarily from cross-sectional and correlational studies, which do not provide a basis for establishing a causal relationship between exercise and cognition. The results obtained in these studies may be due to a wide variety of factors other than exercise, such as lifestyle choice, level of education, and socioeconomic status. Further, intervention studies are not immune to methodological problems. Their meta-analysis revealed that the effect sizes for chronic exercise studies were greater when participants were allowed to self-select a treatment condition than when participants were randomly assigned to a treatment.

Morgan (1997) provided an excellent review of issues that are central to physical activity research. He described how research outcomes can be influenced by such variables as participant and experimenter expectancies, demand characteristics, and the Hawthorne effect. Addressed also are several design issues that can make difficult the interpretation of research outcomes, such as sample size, statistical analysis approaches, and test selection. Test selection was identified by many reviewers as a particularly vexing problem. For example, Etnier and colleagues (1997) reported that 106 different cognitive tests were used in the studies they evaluated.

Procedural Issues

A number of factors either mediate or moderate the effect of exercise on older adults' cognitive function. It will important for researchers to isolate and evaluate the interactive effects of these variables.

Chronic Versus Acute Exercise Interventions

Reviewers tend to categorize exercise interventions into two types: acute and chronic. There are reviews that examine only acute effects or only

chronic effects of exercise on mental processing. The separation of these two research approaches may make sense when conducting a review of the exercise literature. At some point, however, it will be essential to evaluate the impact of acute bouts of exercise within the context of chronic exercise interventions. Researchers who examine exercise's acute effects on cognition tend to recruit participants, conduct a few sessions during which the level of exercise intensity and duration is manipulated, then release the participant to the wild, never to be seen again. Researchers who examine exercise's chronic effects tend to recruit a sample of participants, obtain preexercise measures of psychological and physiological function, turn the participants over to exercise leaders for a prescribed duration, then obtain postexercise measures of physical and mental function. Presently, there are no studies that examine the impact of individual exercise bouts that take place in the context of long-term training.

There is compelling evidence that brief bouts of exercise enhance affect and cognitive function. Little is known, however, about how repeated bouts of exercise affect these variables. Researchers who track the impact of individual exercise sessions within long-term exercise programs may provide data that are critical to understanding the relation not only between exercise and cognition but also between exercise and participant compliance and attrition.

Follow-Up Evaluations

The study reported by Kramer, Hahn, and colleagues (2002) provided clear evidence for the positive effect of aerobic exercise training on the specific cognitive functions of older adults. It is hoped that studies designed to replicate the findings of this study will include follow-up evaluations to assess the long-term benefits of aerobic exercise training.

Issues of Individual Differences

Once over the hurdle of establishing that chronic physical activity has a salutary effect on cognition, we can begin to examine individual differences and the effects of exercise on cognition. These individual difference factors include: initial level of physical fitness, history of exercise training, history of skill development and expertise, personality, and presence of disease states (e.g., Alzheimer's disease and Parkinson's disease).

Theoretical Issues

The observations made by Folkins and Sime (1981) continue to hold true. The explanations provided by researchers for exercise's effects tend to be of three types: physiological, psychological, and cognitive. The review of reviews conducted here suggests that considerable progress has been made in each of these areas over the past two decades.

Physiological Approach

It is clearly the case that the zeitgeist has shifted toward physiological explanations for exercise's effects on human behavior. The roles of brain structures and functions have been discussed in relation to mental health, affect, and cognition. Many reviewers look forward to the application of technological advances to elucidate the mechanisms that account for cognitive and behavioral changes that accompany improvements in fitness and health.

Psychological Approach

Several researchers suggest that we not lose sight of the fact that exercise's impact on mental health and cognition will ultimately depend on an interaction between the individual and his or her environment. Progress in the field will be made through multidisciplinary research studies that evaluate the impact of lifestyle changes in health-promoting behaviors, only one of which is physical activity.

Cognitive Approach

Several theory–based reviews of studies have been published recently. These theories include attentional resource theory (Chodzko-Zajko & Moore, 1994), executive control theory (Kramer, Hahn, et al., 2002) and cognitive-energetics theory (Tomporowski, 2002). Several reviewers note that theory-driven research will lead to a better understanding of body–mind connections than the atheoretical approach that typifies much of the research in the field. However, some have expressed words of caution. It will be important for theories of cognition to fit into more general theories of human behavior that address life span issues.

Spirduso provides a framework for evaluating the complex relations that exist among health, fitness, and cognitive function. As noted in chapter 11 of *Physical Dimensions of Aging* (Spiriduso, 1995), cognitive function is the result of both primary aging factors and secondary aging factors. Primary aging factors that affect cognition include cerebrovascular change, neurotransmitter depletion or malfunction, brain morphological changes, and neuroendocrine function deterioration. Secondary aging factors include disease, accident, and environmental hazards. Health behaviors that can modify both primary and secondary aging factors include diet, absence of drug abuse, controlled stress, sleep, and exercise.

Future Directions

If the question, "Does physical activity influence cognitive function?" were posed to researchers only a few years ago, the answer would have been a weak "maybe." If the question were "Does physical activity influence older adults' cognitive function?" the answer would have been an even weaker

"maybe" (Thomas, Landers, Salazar, & Etnier, 1994). Indeed, a meta-analysis conducted by Etnier and her associates, published as recently as 1997, suggests that acute bouts of exercise may impede cognitive performance, and the impact of chronic exercise training is modest.

Recent research and evaluation of the exercise literature lead to a different interpretation of the relation between exercise and cognitive function. Today it can be stated firmly that yes, indeed, exercise, both acute and chronic, facilitates specific aspects of cognitive functioning, and exercise interventions do facilitate specific aspects of older adults' cognitive functioning. Further, the specific cognitive processes that are enhanced by exercise play important roles in one's daily life and are critical to adaptive functioning.

Supporting the basic assumption that physical activity influences cognitive function leads to a number of important questions (Bouchard, Shephard, & Stephens, 1994; Boutcher, 2000). Some of these questions are:

- What is the dose-response relationship between exercise and cognition? Is there a threshold of physical fitness change that is required to promote improvements in cognitive function?
- Are there specific types of cognitive processes that are more sensitive than others to exercise's effects?
- Are the benefits engendered by exercise similar across the life span?
- What happens to the cognitive performance of those individuals who stop exercising?
- What are the mechanisms by which exercise influences cognitive functions?
- What types of exercises are most effective in promoting improvements in cognitive function?