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Position Stand

Exercise and Physical Activity for Older Adults

This pronouncement was written for the American College of Sports Medicine by: Robert S. Mazzeo, Ph.D., FACSM (Chair), Peter Cavanagh, Ph.D., FACSM, William J. Evans, Ph.D., FACSM, Maria Fiatarone, Ph.D., James Hagberg, Ph.D., FACSM, Edward McAuley, Ph.D., and Jill Startzell, Ph.D.

SUMMARY

ACSM Position Stand on Exercise and Physical Activity for Older Adults. Med. Sci. Sports. Exerc., Vol. 30, No. 6, pp. 992-1008, 1998. By the year 2030, the number of individuals 65 yr and over will reach 70 million in the United States alone; persons 85 yr and older will be the fastest growing segment of the population. As more individuals live longer, it is imperative to determine the extent and mechanisms by which exercise and physical activity can improve health, functional capacity, quality of life, and independence in this population. Aging is a complex process involving many variables (e.g., genetics, lifestyle factors, chronic diseases) that interact with one another, greatly influencing the manner in which we age. Participation in regular physical activity (both aerobic and strength exercises) elicits a number of favorable responses that contribute to healthy aging. Much has been learned recently regarding the adaptability of various biological systems, as well as the ways that regular exercise can influence them.

Participation in a regular exercise program is an effective intervention/modality to reduce/prevent a number of functional declines associated with aging. Further, the trainability of older individuals (including octo- and nonagenarians) is evidenced by their ability to adapt and respond to both endurance and strength training. Endurance training can help maintain and improve various aspects of cardiovascular function (as measured by maximal V(dot)O_2, cardiac output, and arteriovenous O_2 difference), as well as enhance submaximal performance. Importantly, reductions in risk factors associated with disease states (heart disease, diabetes, etc.) improve health status and contribute to an increase in life expectancy. Strength training helps offset the loss in muscle mass and

strength typically associated with normal aging. Additional benefits from regular exercise include improved bone health and, thus, reduction in risk for osteoporosis; improved postural stability, thereby reducing the risk of falling and associated injuries and fractures; and increased flexibility and range of motion. While not as abundant, the evidence also suggests that involvement in regular exercise can also provide a number of psychological benefits related to preserved cognitive function, alleviation of depression symptoms and behavior, and an improved concept of personal control and self-efficacy.

It is important to note that while participation in physical activity may not always elicit increases in the traditional markers of physiological performance and fitness (e.g., V(dot)O_{2max}, mitochondrial oxidative capacity, body composition) in older adults, it does improve health (reduction in disease risk factors) and functional capacity. Thus, the benefits associated with regular exercise and physical activity contribute to a more healthy, independent lifestyle, greatly improving the functional capacity and quality of life in this population.

INTRODUCTION

Aging is a complex process involving many variables (e.g. genetics, lifestyle factors, chronic diseases) that interact with one another, greatly influencing the manner in which we age. Participation in regular physical activity (both aerobic and strength exercises) elicits a number of favorable responses that contribute to healthy aging. Much has been learned recently regarding the adaptability of various biological systems, as well as the ways that regular exercise can influence them.

Although it is not possible to be all-inclusive regarding the influence of exercise and physical activity on aging, this position stand will focus on five major areas of importance. These topics include: (I) cardiovascular responses to both acute and chronic exercise; (II) strength training, muscle mass, and bone density implications; (III) postural stability, flexibility, and prevention of falls; (IV) the role of exercise on psychological function; and (V) exercise for the very old and frail.

It is estimated that by the year 2030 the number of individuals 65 yr and over will reach 70 million in the U.S. alone; persons 85 yr and older will be the fastest growing segment of the population. Thus, as more individuals live longer, it is imperative to determine the extent and mechanisms by which exercise and physical activity can improve health, functional capacity, quality of life, and independence in this population.

CARDIOVASCULAR FUNCTION

Cardiovascular responses to exercise in older healthy adults. Maximal oxygen consumption (V(dot)O_{2max}), an index of maximal cardiovascular (CV) function, decreases 5 to 15% per decade after the age of 25 yr (89). Decreases in both maximal cardiac output and maximal arteriovenous O_2 difference contribute to the age-associated reduction in V(dot)O_{2max} (66,170,191,225). Maximal heart rate decreases 6 to 10 bpm per decade and is responsible for much of the age-associated decrease in maximal cardiac output

(66,170,180,225). Most, but not all, evidence also indicates that older adults have smaller stroke volumes during maximal exercise (170,225). It is clear, however, that older adults rely on the Frank-Starling mechanism to a great extent to achieve the increase in stroke volume during maximal exercise, as evidenced by their increased end diastolic volumes (66,191). In contrast, plasma, red cell, and total blood volumes are lower in older adults (41). Older adults have reduced early diastolic filling at rest and during exercise compared with young adults, perhaps because of reduced left ventricle compliance (120,153). As a result, older adults rely on late atrial diastolic filling to a greater extent than young adults both at rest and during exercise. End systolic volumes during maximal exercise are also usually larger in older adults, resulting in reduced ejection fractions (66,191,225). In addition, left ventricular contractility appears to be reduced in older adults during maximal exercise compared with young adults (66). Blood pressures and systemic vascular resistance are also higher during maximal exercise in older versus young adults (66). Older men and women generally exhibit qualitatively similar CV responses to maximal exercise. However, older women have lower systolic blood pressure and cardiac, end diastolic, and stroke volume indices, and higher systemic vascular resistance during maximal exercise (66,191).

The CV responses of older adults to submaximal exercise are qualitatively and, in most cases, quantitatively similar to those of young adults. Heart rate at the same relative work rate (same percent of V(dot)O_{2max}) is lower in older versus younger adults (66,170,191). On the other hand, the heart rate responses of young and older adults are similar at the same absolute work rate (the same walking speed or resistance on a stationary ergometer). Cardiac output at the same relative work rate is lower in older adults (66,170). Cardiac output at the same absolute work rate is somewhat lower in older adults, while arteriovenous O_2 difference tends to be somewhat higher (170,225). Older adults also have lower stroke volumes than young adults at the same absolute and the same relative exercise intensities (170,225). Blood pressures are generally higher at both the same absolute and relative work rates in older versus younger adults (170,225). Furthermore, these blood pressure increases with age are more dramatic in women (170). In addition, while total peripheral resistance decreases with progressively more intense exercise in both older and young adults, the total peripheral resistance is generally higher in older versus young adults at the same absolute and relative work rates, especially in older women (170).

Endurance exercise training and the CV system in healthy older adults. Although very early reports indicated otherwise, it is now clear that older adults elicit the same 10-30% increases in V(dot)O_{2max} with prolonged endurance exercise training as young adults (82,83,109,202). As with young adults, the magnitude of the increase in V(dot)O_{2max} in older adults is also a function of training intensity, with light-intensity training eliciting minimal or no changes (83,202,205). The training-induced increase in V(dot)O_{2max} in older adults was originally attributed solely to the widening of the maximal arteriovenous O_2 difference (202). However, while this may be the case in older women (see below), it is now clear that older men elicit central CV adaptations that contribute to the training-induced increase in V(dot)O_{2max} (51,69,198,204,216,225).

Recent cross-sectional and longitudinal intervention studies indicate that exercise-trained older men rely on the Frank-Starling mechanism in the form of an increased left ventricular end-diastolic volume to increase their maximal stroke volume, maximal cardiac output, and V(dot)O_{2max} with exercise training (51,69,198,204,216,225). As in young adults, expanded plasma and total blood volumes may contribute to the training-induced increases in maximal end diastolic volume, stroke volume, cardiac output, and V(dot)O_{2max} in older men (31). A number of studies also report improvements in both rest and exercise diastolic filling characteristics in older men with exercise training (69,120,215). These improvements run counter to the effects occurring with aging, as there is an increased reliance on early diastolic filling as opposed to filling associated with atrial contraction later in diastole. In addition, some studies indicate that the left ventricular inotropic state is improved in men with exercise training, which could also contribute to their increased maximal stroke volume (51,198,225). Furthermore, arterial stiffness is also reported to be lower in older endurance-trained or more fit individuals (239), possibly reducing afterload and helping to increase their maximal stroke volume.

In contrast, while older women elicit the same increases in V(dot)O_{2max} with exercise training as older men, their increased V(dot)O_{2max} appears to be solely the result of a larger arteriovenous O_2 difference, as they have not been shown to obtain training-induced increases in left ventricular mass, cardiac output, stroke volume, or end-diastolic volume during maximal exercise (215-217). In addition, left ventricular diastolic filling characteristics are not improved with exercise training in older women (215). However, some evidence indicates that prolonged and intense exercise training may elicit the same central CV adaptations in women that are evident in older men (145).

Some evidence indicates that maintaining high levels of exercise training results in a diminished rate of loss of V(dot)O_{2max} with age in older adults (105,193,215). These studies generally report a reduced rate of loss expressed as a percentage of the initial V(dot)O_{2max} value, which could be an artifact of the athletes' initially higher V(dot)O_{2max}. On the other hand, the rate of V(dot)O_{2max} decline for endurance-trained athletes over age 70 appears to be similar to that for sedentary adults, probably as a result of their inability to maintain the same training stimulus as when they were younger (180).

Effect of endurance exercise training on CV disease risk factors in older healthy men and women. Because CV disease is the major cause of death in older men and women, the effect of endurance exercise training on CV disease risk factors is of paramount importance. Cross-sectional and intervention studies in older adults consistently indicate that endurance exercise training is associated with lower fasting and glucose-stimulated plasma insulin levels, as well as improved glucose tolerance (if initially impaired) and insulin sensitivity (91,107,201,203,223,236). Older adults do not obtain the same improvements in insulin levels and insulin sensitivity following acute exercise as young adults (38,194). However, this may be due to their decreased exercise capacities and the resulting decreased caloric expenditure during acute exercise, as a number of consecutive days of this same exercise improves insulin levels and insulin sensitivity in older adults (38,194). Improvements in glucose and insulin metabolism are evident in older adults before changes in body weight or body composition occur.

Endurance exercise training appears to lower blood pressure to the same degree in young and older hypertensive adults (79,80), although no studies have directly addressed this question. One study in older hypertensive adults reported that training at 50% $V(dot)O_{2max}$ reduced blood pressure the same or more than training at 70% $V(dot)O_{2max}$ (83). In a second study in older hypertensive adults, training at 40-50% $V(dot)O_{2max}$ decreased blood pressure, although subsequent training at 50-60% $V(dot)O_{2max}$ reduced blood pressure somewhat further (205). Thus, it appears that light- to moderate-intensity training is effective in lowering blood pressure in older hypertensive adults.

The minimal data available generally support the conclusion that older adults improve their plasma lipoprotein lipid profiles with exercise training. However, these changes may be secondary to training-induced reductions in body fat stores (106,200,203,223). The improvements are generally similar to those evident in young adults and include increases in plasma HDL and HDL2 cholesterol levels and reductions in plasma triglyceride levels and the cholesterol:HDL ratio (106,200,203,223).

Body composition is also improved with endurance exercise training in a similar fashion in older and young adults. The most consistent change is a 1-4% reduction in the overall percent of body fat with exercise training in older adults, even if body weight is maintained (82,83,202). Furthermore, one study reported that intraabdominal fat decreased by 25% in older men who lost only 2.5 kg of body weight with exercise training (199). This finding is especially important for older men because intraabdominal fat is the body fat depot that increases the most with age and is associated with other CV disease risk factors.

Impact of age-associated diseases on CV responses to exercise. Most CV pathologies are much more prevalent in older adults. In addition, a number of other comorbidities that increase with age, including diabetes and obesity, can also markedly affect an adult's CV response to exercise. It is now clear that many of the early demonstrations of differences in CV function at rest and during exercise between young and older adults were probably the result of the greater CV disease prevalence in the older subjects (24,181). Older adults with CV disease have further reductions in $V(dot)O_{2max}$ and maximal cardiac output compared with their healthy peers. As a result, older adults with CV disease generally have greater heart rate and blood pressure responses at the same absolute exercise intensity than their healthy peers, while their stroke volume is usually lower and their arteriovenous O_2 difference higher. At maximal exercise, individuals with CV disease also have depressed left ventricular contractility, as indicated by their lower ejection fractions.

Endurance exercise training and the CV system in older adults with CV pathologies. Older patients with CV disease appear to obtain the same beneficial CV adaptations with exercise training as younger patients (1-4,117,243). These changes include decreases in heart rate at rest and during submaximal exercise and decreases in other physiological responses during submaximal exercise at the same absolute exercise intensity. As in younger CV disease patients, all of these changes combine to increase the angina and S-T segment depression thresholds to a higher absolute exercise intensity. It is not known if the high intensity exercise training stimulus that results in central CV adaptations in younger CV disease patients (50,81) has the same effect in older patients. However, such information may have little clinical impact as few older patients would elect or be advised to undertake such a program. The minimal data that are available indicate that older male and female CV disease patients respond to exercise training with similar CV adaptations (3). Older patients with CV disease also appear to improve a number of CV disease risk factors with exercise training, including reductions in body weight, body fat, and plasma LDL cholesterol and triglyceride levels, and increases in plasma HDL cholesterol levels (4,117,243).

Contraindications to exercise testing and exercise training. The contraindications to exercise testing and exercise training for older men and women are the same as for young adults (6). The major absolute contraindications precluding exercise testing are recent ECG changes or myocardial infarction, unstable angina, uncontrolled arrhythmias, third degree heart block, and acute congestive heart failure (6). The major relative contraindications for exercise testing include elevated blood pressures, cardiomyopathies, valvular heart disease, complex ventricular ectopy, and uncontrolled metabolic diseases. It is of paramount importance to remember that symptomatic and asymptomatic CV disease and the absolute and relative contraindications precluding exercise testing are much more prevalent in older adults. In addition, there is an increased prevalence of comorbidities in older adults that affect CV function, including diabetes, hypertension, obesity, and left ventricular dysfunction. Thus, adherence to the general ACSM testing guidelines with respect to the necessity for exercise testing and for medical supervision of such testing is imperative (6).

Recommendations. Walking, running, swimming, and cycling are large muscle rhythmic aerobic forms of exercise that were an integral part of the early years of most adults' lives. Maximizing both the quality and quantity of life in older adults is best accomplished by adding these activities to an individual's habitual lifestyle. The initiation of a regular physical activity program elicits numerous changes in the CV system and in certain CV disease risk factors that run counter to the deteriorations normally evident with aging. While the recent CDC/ACSM guidelines recommend light- to moderate-intensity lifestyle physical activities to optimize health (174), moderate or high-intensity exercise may be required to elicit adaptations in the CV system and in CV disease risk factors. The only consistent beneficial CV response to light- to moderate-intensity exercise training in older adults is a reduction in blood pressure in older hypertensive adults. However, the initiation and maintenance of long-term light- to moderate-intensity physical activity programs in older adults may reduce the rate of age-associated deterioration in numerous physiological functions, even if they do not result in absolute increases in these measures, which, in the long-run, should benefit both quantity and quality of life.

STRENGTH TRAINING

Loss of muscle mass (sarcopenia) with age in humans is well documented. The excretion of urinary creatinine, reflecting muscle creatine content and total muscle mass, decreases by nearly 50% between the ages of 20 and 90 yr (238). Computed tomography of individual muscles shows that after age 30, there is a decrease in cross-sectional areas of the thigh, decreased muscle density, and increased intramuscular fat. These changes are most pronounced in women (96). Muscle atrophy may result from a gradual and selective loss of muscle fibers. The number of muscle fibers in the midsection of the vastus lateralis of autopsy specimens is significantly lower in older men (age 70-73 yr) compared with younger men (age 19-37 yr) (121). The decline is more marked in Type II muscle fibers, which decrease from an average of 60% in sedentary young men to below 30% after the age of 80 yr (113), and is directly related to age-related decreases in strength.

A reduction in muscle strength is a major component of normal aging. Data from the Framingham (100) study indicate that 40% of the female population aged 55-64 yr, 45% of women aged 65-74 yr, and 65% of women aged 75-84 yr were unable to lift 4.5 kg. In addition, similarly high percentages of women in this population reported that they were unable to perform some aspects of normal household work. It has been reported that isometric and dynamic strength of the quadriceps increases up to the age of 30 yr and decreases after the age of 50 yr (116). An approximate 30% reduction in strength between 50 and 70 yr of age is generally found. Much of the reduction in strength is due to a selective atrophy of Type II muscle fibers. It appears that muscle strength losses are most dramatic after the age of 70 yr. Knee extensor strength in a group of healthy 80-yr-old men and women studied in the Copenhagen City Heart Study (40) was found to be 30% lower than a previous population study (7) of 70 yr old men and women. Thus, cross-sectional as well as longitudinal data indicate that muscle strength declines by approximately 15% per decade in the 6th and 7th decade and about 30% thereafter (40,84,114,161). While there is some indication that muscle function is reduced with advancing age, the overwhelming majority of the loss in strength results from an age-related decrease in muscle mass.

Strength and functional capacity. The decline in muscle strength associated with aging carries with it significant consequences related to functional capacity. A significant correlation between muscle strength and preferred walking speed has been reported for both sexes (12). A strong relationship between quadriceps strength and habitual gait speed in frail institutionalized men and women above the age of 86 yr supports this concept (63). In older, frail women, leg power was highly correlated with walking speed, accounting for up to 86% of the variance in walking speed (13). Leg power, which represents a more dynamic measurement of muscle function, may be a useful predictor of functional capacity in the very old. This suggests that with the advancing age and very low activity levels seen in institutionalized patients, muscle strength is a critical component of walking ability.

Protein needs and aging. Inadequate dietary protein intake may be an important cause of sarcopenia. The compensatory response to a long term decrease in dietary protein intake is a loss in lean body mass. Using the currently accepted 1985 WHO (242) nitrogen-balance formula on data from four previous studies, the combined weighted averages yielded an overall protein requirement estimate of $0.91 \pm 0.043\ g \cdot kg^{-1} \cdot d^{-1}$. The current Recommended Dietary Allowance (RDA) in the United States of 0.8 $g \cdot kg^{-1} \cdot d^{-1}$ is based on data collected, for the most part, on young subjects. Recent data (29) suggest that the safe protein intake for elderly adults is 1.25 $g \cdot kg^{-1} \cdot d^{-1}$. On the basis of the current and recalculated short-term nitrogen-balance results, a safe recommended protein intake for older men and women should be set at 1.0-1.25 g of high quality $protein \cdot kg^{-1} \cdot d^{-1}$. As discovered in one study, approximately 50% of 946 healthy free-living men and women above the age of 60 yr living in the Boston, Massachusetts area consumed less than this amount of protein, and 25% of the elderly men and women in this same survey consumed less than 0.86 g and less than 0.81 g $protein \cdot kg^{-1} \cdot d^{-1}$, respectively (85). A large percentage of homebound older adults consuming their habitual dietary protein intake (0.67 g mixed $protein \cdot kg^{-1} \cdot d^{-1}$) have been shown (26) to be in negative nitrogen-balance.

Energy metabolism. Daily energy expenditure declines progressively throughout adult life (146). In sedentary individuals, the main determinant of energy expenditure is fat-free mass (185), which declines by about 15% between the third and eighth decade of life, contributing to a lower basal metabolic rate in older adults (37). Twenty-four hour creatinine excretion (an index of muscle mass) is closely related to basal metabolic rate at all ages (238). Nutrition surveys of those over the age of 65 yr show a very low energy intake for men (1400 kcal/d; 23 kcal/kg/d). These data indicate that the preservation of muscle mass and the prevention of sarcopenia can help prevent the decrease in metabolic rate. Body weight increases with advancing age up to 60 yr, and an age-associated increase in relative body fat content has been demonstrated by a number of investigators. The increased body fatness results from a number of factors, but chief among them are a declining metabolic rate and activity level coupled with an energy intake that does not match this declining need for calories (190).

In addition to its role in energy metabolism, age-related skeletal muscle alterations may contribute to such age-associated changes as reduction in bone density (17,209,214), insulin sensitivity (110), and aerobic capacity (67). For these reasons, strategies for preserving muscle mass with advancing age, as well as for increasing muscle mass and strength in the previously sedentary elderly, may be an important way to increase functional independence and decrease the prevalence of many age-associated chronic diseases.

Strength training. Strength conditioning is generally defined as training in which the resistance against which a muscle generates force is progressively increased over time. Muscle strength has been shown to increase in response to training between 60 and 100% of the 1 RM (129). Strength conditioning results in an increase in muscle size, and this increase in size is largely the result of an increase in contractile protein content.

It is clear that when the intensity of the exercise is low, only modest increases in strength are achieved by older subjects (8,115). A number of studies have demonstrated that, given an adequate training stimulus, older men and women show similar or greater strength gains compared with young individuals as a result of resistance training. Two to threefold increases in muscle strength can be accomplished in a relatively short period of time (3-4 mo) in fibers recruited during training in this age population (71,72).

Heavy resistance strength training seems to have profound anabolic effects in older adults. Progressive strength training improves nitrogen-balance, which greatly improves nitrogen retention at all intakes of protein, and for those on marginal protein intakes, this may mean the difference between continued loss or retention of body protein stores (primarily muscle). A change in total food intake or, perhaps, selected nutrients, in subjects beginning a strength-training program can affect muscle hypertrophy (150).

Strength training may be an important adjunct to weight loss interventions in the elderly. Significant increases in resting metabolic rate with strength training have been associated with a significant increase in energy intake required to maintain body weight in older adults (29). The increased energy expenditure included increased resting metabolic rate and the energy cost of resistance exercise. Strength training is, therefore, an effective way to increase energy requirements, decrease body fat mass, and maintain metabolically active tissue mass in healthy older people. In addition to its effect on energy metabolism, resistance training also improves insulin action in older subjects (152).

Regularly performed aerobic exercise has positive effects on bone health in healthy, postmenopausal women (77,163). The effects of a heavy resistance strength training program on bone density in older adults can offset the typical age-associated declines in bone health by maintaining or increasing bone mineral density and total body mineral content (164). However, in addition to its effect on bone, strength training also increases muscle mass and strength, dynamic balance, and overall levels of physical activity. All of these outcomes may result in a reduction in the risk of osteoporotic fractures. In contrast, traditional pharmacological and nutritional approaches to the treatment or prevention of osteoporosis have the capacity to maintain or slow the loss of bone but not the ability to improve balance, strength, muscle mass, or physical activity.

Recommendations. In summary, it is clear that the capacity to adapt to increased levels of physical activity is preserved in older populations. Regularly performed exercise results in a remarkable number of positive changes in older men and women. Because sarcopenia and muscle weakness may be an almost universal characteristic of advancing age, strategies for preserving or increasing muscle mass in the older adult should be implemented. With increasing muscle strength, increased levels of spontaneous activity have been seen in both healthy, free-living older subjects and very old and frail men and women. Strength training, in addition to its positive effects on insulin action, bone density, energy metabolism, and functional status, is also an important way to increase levels of physical activity in the elderly.

POSTURAL STABILITY AND FLEXIBILITY: THE ROLE OF EXERCISE

Postural Stability

There is increasing interest in the role of exercise as a therapeutic modality to improve both postural stability and flexibility in the older adult. Postural stability is a poorly defined term, meant to imply that there is little or no risk of the individual losing balance while standing or falling during a dynamic activity. No single measure of dynamic stability is appropriate for all motions. Postural stability is affected by alterations in both sensory and motor systems, as well as higher level systems, including basal ganglia, the cerebellum, and perceptual systems that interpret and transform incoming sensory information. The vestibular, visual, and somatosensory systems all show changes with aging and may, therefore, provide diminished or inappropriate feedback to the postural control centers. Similarly, the muscle effectors may lack the capacity to respond appropriately to disturbances in postural stability. The assumption that exercise may improve postural stability is based on the assumption that the overall system response can be enhanced despite decrements in individual components.

Evidence that postural stability declines with age has been presented by many authors over the last 60 yr (54,86,90,184,208,247). The assumption underlying the desire to improve postural stability is that this will lead directly to a reduction in falls among older adults. Although early studies stressed this association (171,172), a number of authors have now shown that fall risk is multifactorial and that postural stability is only one component of the overall risk profile (230,231). While this position paper deals only with exercise, it is important that any fall reduction program consider all of the major risk factors, including medication use (particularly sedatives), cognitive status, postural hypotension, environmental hazards, vision, and lower extremity dysfunction. Nevertheless, poor postural stability has been associated with frequent falling (128) and, thus, the improvement of postural stability is clearly a worthwhile goal in fall prevention.

The most definitive measure of postural stability is frequency of falling. However, this is not usually practical in an experimental setting and, although many other indirect measures have been recommended (175), there is no general agreement regarding the optimal approach. Typically, direct measurement of the displacement of some point on the trunk (as measured using a kinematic system) or measures derived from center of pressure movement have been used. Walking is sometimes considered a dynamic stability task both in training and evaluation (126).

It is important to note that many investigators have used broad-based intervention programs (which typically include balance/coordination training, aerobic exercise, and strength training), and it is not always possible to discern which component of the exercise program led to observed changes in postural stability. Specific training in maintaining postural stability in the face of perturbation has also been successfully achieved in isolation from other components (94). Unfortunately, the lack of standardization in methodology makes a "meta-analysis" of the dose-response trends for exercise and improvement in postural stability impossible.

Studies using falls as an outcome measure. While many studies have examined the effect of exercise on postural stability, only a few investigators have followed up to examine the subsequent effect on frequency of falls during daily living. Participation in light-intensity exercise programs has been shown to significantly reduce the number of falls compared with randomly assigned nonexercising control groups, with the exercising group experiencing no fall injuries that required medical attention (130,229,244).

In a meta-analysis of the seven FICSIT trials (182), which examined the role of exercise in the frail elderly, assignment to an exercise group was associated with a decrease in the risk of falling, indicating an overall beneficial effect of exercise treatments. The different treatments were, however, extremely varied in their nature, and some included education and other nonexercise components.

Studies on postural stability. Improvement in "balance related" tests in older community living adults after participation in a program of walking, dancing, resistance exercise, Tai Chi, flexibility, and strengthening exercises has been reported (98,102,244). Subjects performing only flexibility exercises do not show similar improvements. Training on tasks specifically targeted at the sensory systems involved in the maintenance of postural stability also result in improved stability in older populations (93). Further, the trained subjects fell less frequently under conditions of sensory deprivation and stood longer on one leg than the control group. Following a program of walking, flexibility, and strength exercises, improvements in strength, reaction time, and body sway on firm and soft surfaces have been shown (124). No improvements were seen in a nonrandomized, nonconcurrent control group who did not exercise. Other investigators have demonstrated that a number of postural stability measures are improved by a long-term program of exercise (125,127). Within the exercise group, exercise adherers demonstrated significant improvement compared with nonadherers. Improvements in a number of postural stability measures after intensive training (3 times a week for 3 mo) that repeatedly challenged different aspects of balance control have been shown in elderly populations (245). These improvements were maintained for 6 mo using a Tai Chi program. While no studies have reported detrimental effects of training on postural stability, findings of no improvement or inconsistent effects on postural stability exist (39,122).

Recommendations. There are still many questions that remain to be answered regarding the efficacy of different forms of exercise as a fall prevention strategy in different groups of older individuals (34,228). Because of the multifaceted nature of most intervention programs, it is not yet possible to identify the specific mechanisms by which postural stability has been improved. However, it appears that there is sufficient supportive evidence to recommend that a broad-based exercise program that includes balance training, resistive exercise, walking, and weight transfer should be included as part of a multifaceted intervention to reduce the risk of falling. While the optimal frequency and intensity of the program remains to be clearly identified, there are a number of studies that have shown significant positive effects on postural stability with a wide range of interventions.

Flexibility

Flexibility is a general term which encompasses the range of motion of single or multiple joints and the ability to perform specific tasks. The range of motion of a given joint depends primarily on bone, muscle, and connective tissue structure and function, other factors such as pain, and the ability to generate sufficient muscle force. Aging affects the structure of these tissues such that function, in terms of specific range of motion at joints and flexibility in the performance of gross motor tasks, is reduced. The basis for exercise interventions to improve flexibility is that the muscle or connective tissue properties can be improved, joint pain can be reduced, and/or muscle recruitment patterns can be altered. Changes in bone and muscle with aging (addressed in the Strength Training section) indicate that strength training has a protective effect on total body mineral content and promotes an increase in muscle mass and strength. Soft tissue restraints that may affect flexibility include changes in collagen, which is the primary component of the fibrous connective tissue that forms ligaments and tendons. Aging causes an increase in the crystallinity of the collagen fibers and increases the fibers' diameter, thereby reducing extendibility.

It is evident that flexibility declines with age, with the maximum range of motion occurring in the mid- to late twenties for men and women, respectively (15,75,99). Two studies examining both the ankle joint complex and six cervical motions in older adults showed that the ranges of motion declined significantly with age in both sexes (111,166). However, no age-related differences in range of ankle motion have been reported, although gender disparities were observed (206). A study designed to establish population-based normative values indicated losses in the active ranges of motion of the hip and knee that were associated with increasing age in a large cross-sectional subjects' group of mixed gender (189).

Effect of exercise on flexibility in the older adult. In contrast to the interventions described above to improve postural stability, interventions designed to improve flexibility have often lacked large numbers of subjects, randomization, and control. Similar to the postural stability interventions, flexibility interventions have not provided the evidence for clear dose-response effects of exercise.

A flexibility training program is defined as a planned, deliberate, and regular program of exercises intended to progressively increase the usable range of motion of a joint or set of joints. The effect of a flexibility program can be quantified by changes in joint range of motion and mobility assessment scores. Studies have shown both significant positive effects and no significant effects of exercise on the range of motion of joints in the older adult, depending on the duration of the program, the size of the subject group, the rate of attrition, and the measurement technique. Few studies have used direct end range of motion exercise (possibly because it would be difficult to maintain subject interest and compliance with such a program). Most studies have used more indirect approaches, such as walking, dance, aerobic exercise, or "general exercise," often mixed with stretching exercises that were hypothesized to have an effect on flexibility.

Several early reports of interventions were presented in a previous ACSM publication (212). The majority of these and more recent studies have demonstrated significant improvements in the range of motion of various joints (neck, shoulder, elbow, wrist, hip, knee, and ankle) in older adults who participated in a program of regular exercise (95,118,119,157,160). Significant improvement was also noticed in mobility skills (including 26 ambulation skills, proprioception, and balance skills) as a result of exercise. Some authors have speculated that the improvements noted were clinically relevant when compared with the required joint ranges of motion for activities of daily living, such as level and inclined walking, stair negotiation, and rising from a chair. Other investigators found no association between exercise and flexibility, reporting that physical activity as assessed by a questionnaire was not related to range of motion at the shoulder, elbow, hip, and knee in older adult men and women (240). Additionally, a slow therapeutic movement exercise program resulted in no significant improvements in the rotational flexibility of the trunk of older adults (78).

Recommendations. There has been surprisingly little recent research in the area of interventions to increase flexibility in the older adult despite known decrements in joint ranges of motion. Most of the studies conducted their interventions on small groups of healthy older adults for periods of time ranging from 6 wk to 2 yr. The preponderance of evidence is that flexibility can be increased by exercise in the healthy older adult. It is also likely that flexibility exercises could be a useful component of an exercise program for individuals whose overall mobility is reduced. However, the literature does not provide evidence at the present time for the design of systematic and cost effective exercise programs to improve flexibility. We, therefore, recommend that exercises such as walking, aerobic dance, and stretching, which have been shown to increase joint range of motion, be included in a general exercise program for the older adult. It appears likely that many different approaches, with even short program duration, may have a beneficial effect on flexibility. The exact dose-response relationship remains to be determined, as does an understanding of the benefits in the activities of daily life which accrue from increased flexibility.

PSYCHOLOGICAL FUNCTION

There is a considerable amount of literature that suggests physical activity is associated with psychological function (25,68,138,143,179). In this position stand, we choose to limit the examination of this literature to those aspects of psychological function that seem to be more susceptible to declines with aging and that have generated a substantial body of research from which to make consensus statements. These areas are cognitive function, depression, and perceptions of control or self-efficacy. Briefly, cognitive function is highlighted because of the well-documented decline of central nervous system function with aging, changes that have almost universally been accepted as irreversible and inevitable (11). Depression is one of the most frequently reported mental health disorders in the aged, although the prevalence rates are influenced by the criteria employed to assess depressive symptoms (168). The high rate of suicide in the depressed older adult (108) and spiraling public health costs caused by depression (5) make it a condition too important to dismiss. Finally, with advancing age and its attendant declines in physical, sensory, and cognitive function, comes an acceleration in the loss of perceived control (10,154,246). Personal control can be best conceptualized in terms of self-efficacy (9,10) and has been firmly established as declining with age (10,154,192). These three areas of psychological function are subsequently reviewed relative to: (a) the extent to which physical activity can influence these conditions; (b) whether there are both acute and chronic effects; and (c) recommendations for subsequent study.

Physical activity and cognitive function. A number of comprehensive reviews exist that document physical activity and its relation to cognitive function (11,34,48,219,234,235). The primary thrust of this research has been documenting the effect of aerobic fitness on various indices of cognitive function (e.g., memory, attention, reaction time, crystallized and fluid intelligence). The underlying rationale has been that age-related reductions in cardiovascular function lead to brain hypoxia and that aerobic exercise can slow or retard cognitive declines. Early cross-sectional studies comparing active and nonactive older adults consistently report superior performance by the active participants on simple and choice reaction times (14,187,218,220,224), as well as reasoning, short-term recall, memory search, and fluid intelligence (35,42,47,207). The cross-sectional nature of these studies and the inconsistent and often nonexistent assessment of physical fitness, however, make interpretation of the findings difficult.

More definitive examinations of the exercise-cognition relationship are provided by those training studies that exist. However, the findings are equivocal at best. A review of 12 longitudinal studies (49) in which physical fitness increases ranged from 8% (73) to 47% (188) suggests that these interventions resulted in modest or mixed improvements in neuropsychological function with one notable exception (48). This latter study, with a duration of 4 mo and with a small number of subjects, showed impressive changes in reaction times, mental flexibility, and critical flicker fusion, as well as significant improvements in aerobic fitness. Several other studies provided a measure of support for these observations (87,88,97,188), although all could be criticized on issues of design, sample size, or fitness assessment. It should be noted, however, that fitness and cognitive function improvements were not related (48). The majority of studies fail to find aerobic training effects to be associated with improved neuropsychological function (19,20,73,131,132,173,178).

Several limitations exist in the exercise-cognition literature that, if overcome, may shed more light on a complex and equivocal relationship. First, exercise interventions have consisted of widely varying durations and intensities, and it has been suggested that length of exercise intervention and degree of fitness improvement may prove crucial to any neuropsychological improvements brought about by exercise (21,33,34). Second, the age range of participants has been remarkably varied (i.e., 30-83 yr), an important consideration given that several investigators have suggested that the exercise-cognition relationship may well be age-dependent (33,36). Thus, it is imperative that such examinations employ participants of an age where declines in cognitive function are to be expected. Third, if the cardiovascular system's ability to use and transport oxygen is implicated in central nervous system function, then consistent and comprehensive assessments of aerobic fitness are required. Fourth, the adoption of randomized, controlled trials are a necessity if we are to truly identify the effects of exercise on cognitive performance. Finally, subsequent approaches to the study of this relationship should take into consideration the nature of task characteristics and demands. That is, a comparison of the effects of exercise on those cognitive processes that are known to decline with age with those processes that are relatively age-insensitive is necessary.

Physical activity and depression. The effects of physical activity on negative symptomology comprise the majority of the exercise-mental health literature (138). Depressive symptoms are reported by approximately 15% of the older population (108) and, in large population studies, depression has covaried with age, and prevalence rates increase at follow-up (241). Consequently, the study of physical activity effects on depressive symptoms constitutes an important public health issue. Exercise is widely prescribed by physicians for mild depression. Several recent reviews exist (46,134,167,168), with one being a comprehensive documentation of findings in this area relative to the older adult (168). Although some reviewers think that physical activity reduces depression (167), still others argue that such a conclusion is premature given the array of measurement and methodological problems inherent in this literature (46). For example, much of the literature is cross-sectional, measures of physical activity and physical fitness are inconsistent and limited, and the assessment of depression is confounded by employment of measures that are questionably suited to the older adult (248). Perhaps the most convincing data demonstrating a link between physical activity and depression come from the Alameda County Study (28). In a prospective study spanning approximately two decades and three measurement points, baseline depressive symptoms were associated with physical inactivity, even when controlling for other factors known to covary with age. Subsequent increases in activity from baseline indicated subjects were at no greater risk for future depression than those who remained active. Conversely, reductions in activity from baseline levels were predictive of increased likelihood of future depression.

A more recent study (155) employed data from the Iowa 65+ Rural Health Study, a 10-yr longitudinal cohort study of 3,673 men and women 65 yr and older. Findings from this study suggest an inverse relationship between daily walking and the reporting of depressive symptoms. Like the Alameda County Study, the Iowa 65+ data suggest that exercise is a modality suitable for the modification of depression. Subjects with more depressive symptoms at baseline had greater odds ratios for improvement if they were walkers at baseline. The authors further interpreted their findings to suggest that major improvement in depressive symptomology results when one moves from a sedentary lifestyle to a lifestyle of minimal physical activity. These studies, therefore, seem to suggest that physical activity plays a role in the amelioration of depressive symptoms. However, like other survey research (60,222) and cross-sectional studies (33) reporting similar inverse relationships between depressive symptoms and physical activity, measures of both constructs are problematic, and the studies suffer from a host of methodological limitations. Nevertheless, the fact that the relationship is fairly consistent is encouraging. Experimental evidence to support the exercise-depression relationship is not as compelling or illuminating as one would expect (168). In general, exercise effects are small to moderate (16,52,177), samples are small and, more often than not, appropriate comparison groups (e.g., attentional control and placebo groups) are not employed, and careful assessment of adherence/compliance and the potential effects of such adherence/compliance are not considered. Moreover, the majority of these studies are conducted with nondepressed individuals, supporting the suggestion that physical activity can reduce depression in those older individuals who are not clinically depressed (167). Few studies exist that target depressed older subjects. In one that did, both social contact and exercise interventions had marked effects on various aspects of depression, with the exercise group reporting greater reductions (148). Little evidence exists to suggest that acute bouts of physical activity have depression-reducing effects in the older adult. However, a meta-analysis of the exercise-depression literature suggests that the antidepressant effects of exercise may begin with the first session (167). However, this review focused on subjects 55 yr and younger, precluding any definitive statements relative to the older adult.

Information relative to the mechanisms (neurological, biochemical, social, psychological) that underlie the depression-physical activity relationship in the older adult is lacking. Future research efforts must address this issue, as well as the question of optimal exercise dosage for maximal reductions in depression. Further, more recent efforts have focused on older individuals with relatively low levels of depression rather than examining the effects of exercise on those with depressive disorders (168).

Physical activity and perceptions of control. A sense of personal agency or control is vital to both physical and psychological health (192) and, as individuals age, the accompanying deterioration in function and the restriction in performance of activities of daily living (133) serve to reduce their sense of control. In the physical activity and aging literature, this sense of control has typically been conceptualized as self-efficacy beliefs (9,10,137). Efficacy beliefs are a fundamental component of Bandura's (9,10) social cognitive theory and have been broadly demonstrated to influence and be influenced by physical activity in older adults. These relationships hold for both healthy (136,137,195) and clinical populations (57-59,227).

Relative to nonclinical populations, self-efficacy has been consistently identified as a determinant of exercise behavior in older individuals (136,137,139,142,195). In the only randomized trial attempting to influence exercise adherence via an efficacy enhancement treatment, a 12% increase in activity participation in middle-aged adults was reported (141). Almost twice as many participants exercised at desired levels (2 or more days per week) in the treatment group than in the control group. Additionally, acute and chronic activity participation influences beliefs about the control over the physical environment and is related to physiological and biochemical function (140,144,226). Interestingly, in sedentary older adults, there are significant gender differences in control beliefs relative to physical capabilities (92,140). Men are typically more efficacious than women, but these differences are eradicated completely following exposure to exercise training (140,142). Efficacy expectations can reliably mediate the frequently cited relationship between social support and exercise behavior (43-45). Finally, efficacy expectations relative to exercise capabilities influence affective responses to acute bouts of physical activity in middle-aged adults (135,144,151).

In diseased populations (e.g., coronary artery and chronic obstructive pulmonary disease), the exercise-efficacy relationship is perhaps even stronger. Efficacy expectations play an important role in the adoption and performance of and adherence to exercise behavior in postmyocardial infarction patients (57-59,227). Similarly, self-efficacy influences exercise compliance to rehabilitative physical activity and is an important correlate of physiological status (e.g., pulmonary function, exercise tolerance, diffusing capacity) in chronic obstructive pulmonary disease (COPD) patients (104,237). More importantly, this psychosocial variable was recently identified in COPD sufferers as a significant univariate predictor of survival (103).

Efficacy expectations relative to exercise have also proved important correlates of other aspects of physical function in the older adult. After controlling for physical function, exercise self-efficacy is a significant predictor of stair-climbing performance and lifting and carrying ability (186). From a health perspective, and indirectly related to physical activity, efficacy has been consistently identified as a determinant of fall reduction and functional decline in older adult community samples (149,232,233).

Perceptions of personal control can decline dramatically with age and influence important aspects of function (192). However, personal control can be both a determinant and consequence of physical activity participation. How personal control interacts with physiological, social, and biochemical influences in relation to physical activity and aging must be determined.

Recommendations. It is well established that physical activity and psychological function in the older adult are related. To ignore this important element of physical activity's influence on the health of the older adult is contrary to the biopsychosocial model of health and human function (53). However, there remains a need for randomized, controlled trials with close attention paid to the measurement of physical activity and psychological function, the underlying mechanisms influencing the relationship, the time course of psychological change, dose-response issues, and the diversity of populations studied. Such needs present an important future challenge to behavioral, social, and exercise scientists, as well as gerontologists.

EXERCISE FOR THE FRAIL AND VERY OLD

The benefits and contraindications of exercise in the frail and very old. In the past, exercise generally has been considered inappropriate for frail or very aged individuals because of both low expectations of benefit as well as exaggerated fears of exercise-related injury. The past decade has seen an accumulation of data that dispels myths of futility and provides reassurance of the safety of exercise in the oldest adults (61). The benefits are wide-ranging and include physiological, metabolic, psychological, and functional adaptations to physical activity that can substantially contribute to the quality of life in this population. Goals of exercise appropriate to younger adults (74), such as prevention of cardiovascular disease, cancer, and diabetes, and increases in life expectancy (112), are replaced in the oldest adults with a new set of goals, which include minimizing biological changes of aging (62), reversing disuse syndromes (22), the control of chronic diseases (56,164,169), maximizing psychological health (210,211), increasing mobility and function (64,171), and assisting with rehabilitation from acute and chronic illnesses for many of the geriatric syndromes common to this vulnerable population. A targeted exercise prescription offers a benefit that cannot be achieved with any other therapeutic modality. It is important to understand the diverse pathophysiology of frailty in order to use exercise appropriately in this setting.

A combination of biological aging, high burdens of chronic disease, malnutrition, and extreme sedentariness are the primary contributors to a final common pathway that results in the syndrome of physical frailty. Frailty is not specific to the elderly but is increasingly prevalent with aging, particularly after the age of 80 yr (76). Many of the age-related physiological changes described in cross-sectional and longitudinal studies, including decreased aerobic capacity (162,221), muscle strength (63,64), muscle mass (63), and bone density, (213) are modifiable by exercise, even in the oldest adults (55,62). There is also evidence that chronic diseases and syndromes responsible for significant morbidity in the aged, such as arthritis, diabetes, coronary artery disease, congestive heart failure, chronic obstructive pulmonary disease, depression, disorders of gait and balance, falls, and insomnia, respond favorably to exercise (23,174). Exercise has been associated with higher dietary intake in both free-living (27) and institutionalized (64) elderly adults, thus reducing the risk of malnutrition as a contributor to frailty (158). And finally, the atrophy of muscle and bone, cardiovascular deconditioning, postural hypotension, joint stiffness, and diminished neural control of balance reflexes related to inactivity (22) may be the most responsive of all parameters studied to the initiation of an appropriate exercise program in the very sedentary aged adult.

The contraindications to exercise in this population are not different from those applicable to younger, healthier adults (6). In general, frailty or extreme age is not a contraindication to exercise, although the specific modalities may be altered to accommodate individual disabilities (162). Acute illnesses, particularly febrile illnesses, unstable chest pain, uncontrolled diabetes, hypertension, asthma, congestive heart failure, musculoskeletal pain, weight loss, and falling episodes warrant investigation before a new regimen is begun. Sometimes, temporary avoidance of certain kinds of exercise is required during treatment of hernias, cataracts, retinal bleeding, or joint injuries, for example. A very small number of untreatable or serious conditions, including an inoperable enlarging aortic aneurysm, malignant ventricular arrhythmia related to exertion, severe aortic stenosis, end stage congestive heart failure or other rapidly terminal illness, and severe behavioral agitation in response to participation in exercise in dementia and psychological illness, are more permanent exclusions for vigorous exercise. It should be noted, however, that the mere presence of cardiovascular disease, diabetes, stroke, osteoporosis, depression, dementia, chronic pulmonary disease, chronic renal failure, peripheral vascular disease, or arthritis (which may all be present within a single individual) is not by itself a contraindication to exercise. In fact, for many of these conditions, exercise will offer benefits not achievable through medication alone. The literature on exercise training in the frail elderly between the ages of 80 and 100 yr in nursing homes includes no reports to date of serious cardiovascular incidents, sudden death, myocardial infarction, exacerbation of metabolic control or hypertension (18,30,63-65,70,101,123,147,156,159,162,176,197,221). Exercise-related events that have been described include exacerbation of a preexisting hernia (63) and underlying arthritis or other joint abnormalities requiring modification of the exercises prescribed

(64). The fear of excess injurious falls and fractures subsequent to re-mobilization has not been borne out in clinical trials, although large-scale studies are still in progress. Sedentariness appears a far more dangerous condition than physical activity in the very old.

Trainability of the frail and very old. Very large-scale studies of exercise training in the frail elderly remain to be published, but the results from the randomized clinical trials to date indicate that the gain in strength in response to high intensity resistance training is more dependent on the intensity of the stimulus than the characteristics, age, or health status of the individual. As with younger individuals, those with the weakest muscles but the largest reserves of lean tissue seem to have the best response, which is consistent with primarily neural adaptations to training in the first 3 mo. Age, gender, specific chronic conditions, depression, dementia, nutritional status, and functional impairment have not been shown to influence the adaptation to training. The data on aerobic capacity are much less clear, as very little data are available on actual physiological changes occurring after cardiovascular interventions in the very old or frail (221).

The principles of specificity that apply to younger adults are of equal relevance in the frail elderly. Increases in muscle mass and strength are seen following high intensity progressive resistance training (80% of the one repetition maximum) (64), whereas lower intensity regimens (body weight, elastic bands or tubing, resistance to a therapist, or light weights) result in little, if any, significant gains in strength (159). Muscle weakness and atrophy are probably the most functionally relevant and reversible parameters related to exercise in this population. Thus, attempts to reverse these deficits and minimize the clinical consequences (functional decline, immobility, poor balance, falls, and low energy requirements and intake) should focus on scientifically proven strategies rather than nonspecific "movement" programs for the aged. Improvements in gait, velocity, balance, ability to rise from a chair, stair climbing power, aerobic capacity, performance-based tests of functional independence, self-reported disability, morale, depressive symptoms, and energy intake (63-65,165,183,196) are associated with gains in strength after strength training in the frail elderly. In healthier elderly subjects, strength training maintains or increases bone density, resting metabolic rate, insulin sensitivity, gastrointestinal transit time, and decreases pain and disability from arthritis, reduces body fat and central adiposity, and improves sleep quality, but it remains to be seen if these adaptations occur in the very frail as well.

High intensity aerobic training interventions have not been described in frail elderly populations. Lower intensity aerobic activities, such as walking, standing, and stationary cycling at 60% of maximal predicted heart rate, have been associated with modest improvements in cardiovascular efficiency (162,221) and mobility tasks (197) (walking, standing from a chair, etc.). It should be noted, however, that the energy cost of activities for the frail elderly with assistive devices (such as walkers and wheelchairs), joint deformities, and gait disorders, may be significantly higher than standard equations would predict and, therefore, until studies using indirect calorimetry to both monitor effort as well as document change are reported in this population, the exact magnitude of the physiological benefits of aerobic training remain unclear. It is likely, however, that, like younger adults, lower intensity aerobic activities may provide benefits in terms of quality of life, psychological outcomes, and relief of pain and disability without changing cardiovascular conditioning substantively.

Recommendations. Many common geriatric syndromes contributing to frailty are responsive to increased levels of appropriate physical activity. The major physiological deficits that are relevant and reversible include muscle weakness, low muscle mass, low bone density, cardiovascular deconditioning, poor balance, and gait. The most evidence for benefit exists with programs that include strength training, and higher intensity training is more beneficial and just as safe as lower intensity training. Therefore, all exercise programs for the frail elderly should include progressive resistance training of the major muscle groups of the upper and lower extremities and trunk. Regimens of at least 2, but preferably 3, d per week are recommended, with 2-3 sets (1 set may be sufficient; however, studies are lacking in this population) of each exercise performed on each training day. If possible, some standing postures with free weights should be used to simultaneously enhance balance and muscle coordination. Clinically relevant muscle groups include hip extensors, knee extensors, ankle plantar flexors and dorsiflexors, biceps, triceps, shoulders, back extensors, and abdominal muscles.

Balance training should also be incorporated, either as part of strength training or as a separate modality. Training and supervision (especially for the very frail) is mandatory for safety and progression to occur. The optimal series of exercises for improvements in balance cannot be defended with scientific data at this time but, in general, progressively more difficult postures that gradually reduce the base of support (one-legged stand), require dynamic movements that perturb the center of gravity (tandem walk, circle turns), stress posturally important muscle groups, such as the dorsiflexors (heel stands), and reduce other sensory input (vision) conform to the accepted theories of balance control and adaptation.

The most difficult prescription for the frail elderly is that of aerobic training. Severe gait disorders, arthritis, dementia, cardiovascular disease, podiatric and orthopedic problems, visual impairment, and incontinence are only some of the conditions that make the usual recommendation of walking for aerobic fitness difficult, or even impossible, in the frail elderly. Before one can walk, it is necessary to be able to get out of a chair (requiring muscle power) and maintain an erect posture while moving through space (requiring balance). Therefore, aerobic conditioning should follow strength and balance training, which is, unfortunately, the converse of what is done today. The tolerance to weight-bearing activity, such as walking, may be significantly improved by first improving muscle strength, joint stability, and balance. At that point, moderate intensity aerobic training can begin, first by reaching a target frequency (at least 3 d per wk), then duration (at least 20 min), and finally, appropriate intensity (40-60% of heart rate reserve, or 11-13 on the Borg scale). Walking intensity should be increased by adding hills, inclines, steps and stairs, pushing a weighted or occupied wheelchair, or adding arm and dance movements rather than increasing velocity or changing to jogging. Higher intensities are unlikely to be feasible in this population. Assistive devices increase safety as well as the energy costs of an activity, so there is little benefit to attempt to exercise without them.

Although walking is a preferred mode because of its direct functional nature, in some individuals only arm and leg ergometry, seated stepping machines, and water exercises may be possible because of a variety of disabilities, and these are suitable alternatives if available.

Most of the frail elderly live in environments and among caregivers for whom exercise is still an unfamiliar and perhaps frightening concept. There is a great need to change the physical surroundings, recreational programming options, and staff training to allow these recommendations to be instituted in private homes, senior apartment complexes, life care communities, and nursing homes. By eliminating unnecessary barriers to optimal mobility and fitness among the oldest adults, substantial health benefits may be realized via both prevention of new disabilities as well as rehabilitation from chronic conditions.

CONCLUSIONS

Based upon available evidence, several conclusions can be made. Participation in a regular exercise program is an effective intervention/modality to reduce/prevent a number of functional declines associated with aging. Further, the trainability of older individuals (including octo- and nonagenarians) is evidenced by their ability to adapt and respond to both endurance and strength training. Endurance training can help maintain and improve various aspects of cardiovascular function (as measured by maximal V(dot)O_2), cardiac output, and arteriovenous O_2 difference, as well as enhance submaximal performance. Importantly, reductions in risk factors associated with disease states (heart disease, diabetes, etc.) improve health status and contribute to an increase in life expectancy. Strength training helps offset the loss in muscle mass and strength typically associated with normal aging. Together, these training adaptations greatly improve the functional capacity of older men and women, thereby improving the quality of life in this population. Additional benefits include improved bone health and, thus, reduction in risk for osteoporosis; improved postural stability, thereby reducing the risk of falling; and increased flexibility and range of motion. While not as abundant, the evidence also suggests that involvement in regular exercise can also provide a number of psychological benefits related to preserved cognitive function, alleviation of depression symptoms and behavior, and an improved concept of personal control and self-efficacy. There is an obvious need for more properly controlled and conducted research addressing several important issues related to the interaction of exercise and physical activity on healthy aging. This includes studies ranging from clinical investigations to those examining molecular and cellular mechanisms.

Together, the benefits associated with regular exercise and physical activity contribute to a more healthy, independent lifestyle, greatly improving the functional capacity and quality of life for the fastest growing segment of our population.

This pronouncement was reviewed for the American College of Sports Medicine by members-at-large, the Pronouncements Committee, and by John Lawler, Ph.D., and Christian Leeuwenburg, Ph.D.

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REFERENCES

1. Ades, P. and M. GRUNVALD. Cardiopulmonary exercise testing before and after conditioning in older cardiac patients. *Am. Heart J.* 69:1442-1446, 1990.
2. Ades, P., J. Hanson, and J. GUNTHER. Exercise conditioning in the elderly coronary patient. *J. Am. Geriatr. Soc.* 35:121-126, 1987.
3. Ades, P., M. Waldmann, and D. POLK. Referral patterns and exercise response in the rehabilitation of coronary patients > 62 years. *Am. J. Cardiol.* 69:1442-1446, 1992.
4. Ades, P., M. Waldmann, and E. POEHLMAN. Exercise conditioning in older coronary patients: submaximal lactate response and endurance capacity. *Circulation* 69:273-278, 1988.
5. Agency for Health Care Policy and Research. Depression in primary care: detection and diagnosis, Vol. 1, Washington, DC: U.S. Government Printing Office 93:0551, 0-176 1993.
6. American College of Sports Medicine. *Guidelines for Exercise Testing and Prescription*, 5th Ed. Baltimore: Williams and Wilkins, 1995, pp. 1-373.
7. Aniansson, A., G. Grimby, M. Hedberg, and M. KROTKIEWSKI. Muscle morphology, enzyme activity and muscle strength in elderly men and women. *Clin. Physiol.* 1:73-86, 1981.
8. Aniansson, A. and E. GUSTAFSSON. Physical training in elderly men with special reference to quadriceps muscle strength and morphology. *Clin. Physiol.* 1:87-98, 1981.
9. Bandura, A. *Social Foundations of Thought and Action: A Social Cognitive Theory*, Englewood Cliffs, NJ: Prentice-Hall, 1986, pp. 1-617.
10. Bandura, A. *Self-Efficacy: The Exercise of Control*, New York: W. H. Freeman and Company, 1997, pp. 1-601.
11. Bashore, T. R. and P. H. GODDARD. Preservative and restorative effects of aerobic fitness on the age-related slowing of mental processing speed. In: *Adult Information Processing: Limits on Loss*, J. Cerella, J. Rybash, W. Hoyer, and M. L. Commons (Eds.). New York: Academic Press, 1993, pp. 205-227.
12. Bassey, E. J., M. J. Bendall, and M. PEARSON. Muscle strength in the triceps surae and objectively measured customary walking activity in men and women over 65 years of age. *Clin. Sci.* 74:85-89, 1988.
13. Bassey, E. J., M. A. Fiatarone, E. F. O'Neill, M. Kelly, W. J. Evans, and L. A. LIPSITZ. Leg extensor power and functional performance in very old men and women. *Clin. Sci.* 82:321-327, 1992.
14. Baylor, A. M. and W. W. SPIRDUSO. Systematic aerobic exercise and components of reaction time in older women. *J. Gerontol.* 43:121-126, 1988.
15. Bell, R. D. and T. B. HOSHIZAKI. Relationships of age and sex with range of motion of seventeen joint actions in humans. *Can. J. Appl. Sport Sci.* 6:202-206, 1981.

16. Bennett, J., M. A. Carmack, and V. J. GARDNER. The effect of a program of physical exercise on depression in older adults. *Physiol. Educ.* 39:21-24, 1982.
17. Bevier, W. C., R. A. Wiswell, G. Pyka, K. C. Kozak, K. M. Newhall, and R. MARCUS. Relationship of body composition, muscle strength, and aerobic capacity to bone mineral density in older men and women. *J. Bone Miner. Res.* 4:421-432, 1989.
18. Blankfort-Doyle, W., H. Waxman, F. Naso, et al. An exercise program for nursing home residents. In: *Aging and Motor Behavior,* A. C. Ostrow (Ed.). Indianapolis: Brown and Benchmark, 1989:201-206.
19. Blumenthal, J. A., C. F. Emery, D. J. Madden, L. K. George, R. E. Coleman, M. W. Riddle, D. C. McKee, J. Reasoner, and R. S. WILLIAMS. Cardiovascular and behavioral effects of aerobic exercise training in healthy older men and women. *J. Gerontol.* 44:M147-M157, 1989.
20. Blumenthal, J. A., and D. J. MADDEN. Effects of aerobic exercise training, age, and physical fitness on memory-search performance. *Psychol. Aging* 3:280-285, 1988.
21. Blumenthal, J. A., C. F. Emery, D. J. Madden, S. Schniebolk, M. Walsh-Riddle, L. K. George, D. C. McKee, M. B. Higginbotham, F. R. Cobb, and R. E. COLEMAN. Long-term effects of exercise on psychological functioning in older men and women. *J. Gerontol. Psychol. Sci.* 46:P352-P361, 1991.
22. Bortz, W. M. Disuse and aging. *JAMA* 248:1203-1208, 1982.
23. Bouchard, C., R. J. Shepherd, and T. STEPHENS (EDS.). *Physical Activity, Fitness, and Health.* International Proceedings and Consensus Statement. Champaign, IL: Human Kinetics, pp 1-1055:1994.
24. Brandfonbrener, M., M. Landowne, and N. SHOCK. Changes in cardiac output with age. *Circulation* 12:557-566, 1955.
25. Brown, D. R. Physical activity, ageing, and psychological well-being. *Can. J. Sports Sci.* 17:185-193, 1992.
26. Bunker, V., M. Lawson, M. Stansfield, and B. CLAYTON. Nitrogen balance studies in apparently healthy elderly people and those who are housebound. *Br. J. Nutr.* 57:211-221, 1987.
27. Butterworth, D., D. Nieman, R. Perkins, et al. Exercise training and nutrient intake in elderly women. *J. Am. Diet Assoc.* 93:653-657, 1993.
28. Camacho, T. C., R. E. Roberts, N. B. Lazarus, G. A. Kaplan, and R. D. COHEN. Physical activity and depression: evidence from the Alameda County Study. *Am. J. Epidemiol.* 134:220-230, 1991.
29. Campbell, W. W., M. C. Crim, G. E. Dallal, V. R. Young, and W. J. EVANS. Increased protein requirements in the elderly: new data and retrospective reassessments. *Am. J. Clin. Nutr.* 60:167-175, 1994.
30. Carl, C. A. The effects of an exercise program on self-care activities for the institutionalized elderly. *J. Gerontol.* 8:282-285, 1982.
31. Carroll, J., V. Convertino, C. Wood, J. Graves, D. Lowenthal, and M. POLLOCK. Effect of training on blood volume and plasma hormone concentrations in the elderly. *Med. Sci. Sports Exerc.* 27:79-84, 1995.
32. Chandler, J. M. and E. C. HADLEY. Exercise to improve physiologic and functional performance in old age. *Clin. Geriatr. Med.* 12:761-784, 1996.

33. Chodzko-Zajko, W. J. Physical fitness, cognitive performance, and aging. *Med. Sci. Sports Exerc.* 23:868-872, 1991.
34. Chodzko-Zajko, W. J. and K. A. MOORE. Physical fitness and cognitive functioning in aging. *Exerc. Sport Sci. Rev.* 22:195-220, 1994.
35. Clarkson-Smith, L. and A. A. HARTLEY. Relationships between physical exercise and cognitive abilities in older adults. *Psychol. Aging* 4:183-189, 1989.
36. Clarkson-Smith, L. and A. A. HARTLEY. Structural equation models of relationships between exercise and cognitive abilities. *Psychol. Aging* 5:437-446, 1990.
37. Cohn, S. H., D. Vartsky, S. Yasumura, A. Savitsky, I. Zanzi, A. Vaswani, and K. J. ELLIS. Compartmental body composition based on total-body potassium and calcium. *Am. J. Physiol.* 239:E524-E530, 1980.
38. Cononie, C., A. Goldberg, E. Rogus, and J. HAGBERG. Seven consecutive days of exercise lowers plasma insulin responses to an oral glucose challenge in sedentary 60-80 yr olds. *J. Am. Geriatr. Soc.* 42:394-398, 1994.
39. Crilly, R. G., D. A. Willems, K. J. Trenholm, K. C. Hayes, and L. F. DELAQUERRIERE-RICHARDSON. Effect of exercise on postural sway in the elderly. *Gerontology* 35:137-143, 1989.
40. Danneskoild-Samsoe, B., V. Kofod, J. Munter, G. Grimby, and P. SCHNOHR. Muscle strength and functional capacity in 77-81 year old men and women. *Eur. J. Appl. Physiol.* 52:123-135, 1984.
41. Davy, K. and D. SEALS. Total blood volume in healthy young and older men. *J. Appl. Physiol.* 76:2059-2062, 1994.
42. Del Rey, P. Effects of contextual interference on the memory of older females differing in levels of physical activity. *Percept. Mot. Skills* 55:171-180, 1982.
43. Duncan, T. E. and E. MCAULEY. Social support and efficacy cognitions in exercise adherence: a latent growth curve analysis. *J. Behav. Med.* 16:199-218, 1993.
44. Duncan, T. E., E. McAuley, M. Stoolmiller, and S. C. DUNCAN. Serial fluctuations in exercise behavior as a function of social support and efficacy cognitions. *J. Appl. Soc. Psychol.* 23:1498-1522, 1993.
45. Duncan, T. E. and M. STOOLMILLER. Modeling social and psychological determinants of exercise behaviors via structural equation systems. *Res. Q. Exerc. Sport* 64:1-16, 1993.
46. Dunn, A. L. and R. K. DISHMAN. Exercise and the neurobiology of depression. *Exerc. Sport Sci. Rev.* 19:41-98, 1991.
47. Dustman, R. E., R. Y. Emmerson, R. O. Ruhling, D. E. Shearer, L. A. Steunhaus, S. C. Johnson, H. W. Bonekat, and J. W. SHIGEOKA. Age and fitness effects on EEG, ERPs, visual sensitivity and cognition. *Neurobiol. Aging* 11:193-200, 1990.
48. Dustman, R. E., R. Y. Emmerson, and D. E. SHEARER. Electrophysiology and aging: slowing, inhibition, and aerobic fitness. In: *Cognitive and Behavioral Performance Factors in Atypical Aging*, M. L. Howe, M. J. Stones, and C. J. Brainerd (Eds.). New York: Springer-Verlag, 1984, pp. 103-149.
49. Dustman, R. E., R. Emmerson, and D. SHEARER. Physical activity, age, and cognitive- neuropsychological function. *J. Aging Phys. Act. 2:143-181, 1994.*

50. *Ehsani, A., G. Heath, J. Hagberg, B. Sobel, and J. HOLLOSZY. Effects of 12 months of intense exercise training on ischemic ST-segment depression in patients with coronary artery disease. Circulation* 64:1116-1124, 1981.
51. Ehsani, A., T. Ogawa, T. Miller, R. Spina, and S. JILKA. Exercise training improves left ventricular systolic function in older men. *Circulation* 83:96-103, 1991.
52. Emery, C. F. and M. GATZ. Psychological and cognitive effects of an exercise program for community-residing older adults. *Gerontologist* 30:184-188, 1990.
53. Engel, G. L. The need for a new medical model: a challenge for biomedicine. *Science* 196:129-136, 1977.
54. Era P. and E. HEIKKINEN. Postural sway during standing and unexpected disturbance of balance in random samples of men of different ages. *J. Gerontol.* 40:287-295, 1985.
55. Evans, W. and W. CAMPBELL. Sarcopenia and age-related changes in body composition and functional capacity. *J. Nutr.* 123:465-468, 1993.
56. Evans, W., V. Hughes, C. M. Ferrara, R. A. Fielding, M. A. Fiatarone, E. C. Fisher, and D. ELAHI. Effects of training intensity on glucose homeostasis in glucose intolerant adults (Abstract). *Med. Sci. Sports Exerc.* 23:S152, 1991.
57. Ewart, C. K., K. J. Stewart, R. E. Gillilan, and M. H. KELEMAN. Self-efficacy mediates strength gains during circuit weight training in men with coronary artery disease. *Med. Sci. Sports Exerc.* 18:531-540, 1986.
58. Ewart, C. K., K. J. Stewart, R. E. Gillilan, M. H. Keleman, S. A. Valenti, J. D. Manley, and M. D. KALEMAN. Usefulness of self-efficacy in predicting overexertion during programmed exercise in coronary artery disease. *Am. J. Cardiol.* 57:557-561, 1986.
59. Ewart, C. K., C. B. Taylor, L. B. Reese, and R. F. DEBUSK. Effects of early postmyocardial infarction exercise testing on self-perception and subsequent physical activity. *Am. J. Cardiol.* 51:1076-1080, 1983.
60. Farmer, M. E., B. Z. Locke, E. K. Moscicki, A. L. Dannenberg, D. B. Larson, and L. S. RADLOFF. Physical activity and depressive symptoms: the NHANES I epidemiologic follow-up study. *Am. J. Epidemiol.* 128:1340-1351, 1988.
61. Fiatarone, M. A. and W. J. EVANS. Exercise in the oldest old. *Top. Geriatr. Rehabil.* 5:63-77, 1990.
62. Fiatarone, M. A. and W. J. EVANS. The etiology and reversibility of muscle dysfunction in the aged. *J. Gerontol.* 48(Special Issue):77-83, 1993.
63. Fiatarone, M. A., E. C. Marks, N. D. Ryan, C. N. Meredith, L. A. Lipsitz, and W. J. EVANS. High-intensity strength training in nonagenarians: effects on skeletal muscle. *JAMA.* 263:3029-3034, 1990.
64. Fiatarone, M. A., E. F. O'Neill, N. D. Ryan, K. M. Clements, G. R. Solares, M. E. Nelson, S. B. Roberts, J. J. Kehayias, L. A. Lipsitz, and W. J. EVANS. Exercise training and nutritional supplementation for physical frailty in very elderly people. *N. Engl. J. Med.* 330:1769-1775, 1994.
65. Fisher, N., D. Pendergast, and E. CALKINS. Muscle rehabilitation in impaired elderly nursing home residents. *Arch. Phys. Med. Rehabil.* 72:181-185, 1991.

66. Fleg, J., F. O'Connor, G. Gerstenblith, L. Becker, J. Clulow, S. Schulman, and E. LAKATTA. Impact of age on the cardiovascular response to dynamic upright exercise in healthy men and women. *J. Appl. Physiol.* 78:890-900, 1995.
67. Fleg, J. L. and E. G. LAKATTA. Role of muscle loss in the age-associated reduction in VO_{2max}. *J. Appl. Physiol.* 65:1147-1151, 1988.
68. Folkins, C. H. and W. E. SIME. Physical fitness training and mental health. *Am. Psychol.* 36:373-389, 1981.
69. Forman, D., W. Manning, R. Hauser, E. Gervino, W. Evans, and J. WEI. Enhanced left ventricular diastolic filling associated with long-term endurance training. *J. Gerontol.* 47:M56-M58, 1992.
70. Friedman, R. and R. TAPPEN. Effect of planned walking on communication in Alzheimer's disease. *J. Am. Geriatr. Soc*. 39:650-654, 1991.
71. Frontera, W. R., C. N. Meredith, K. P. O'Reilly, and W. J. EVANS. Strength training and determinants of VO_{2max} in older men. *J. Appl. Physiol.* 68:329-333, 1990.
72. Frontera, W. R., C. N. Meredith, K. P. O'Reilly, H. G. Knuttgen, and W. J. EVANS. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J. Appl. Physiol.* 64:1038-1044, 1988.
73. Giltlin, L. N., M. P. Lawton, L. A. Windsor-Landsberg, M. H. Kleban, L. P. Sands, and J. POSNER. In search of psychological benefits. *J. Aging Health* 4:174-192, 1992.
74. Goldberg, T. and S. CHAVIN. Preventive medicine and screening for older adults. *J. Am. Geriatr. Soc.* 45:344-354, 1997.
75. Greey, C. W. *A Study of Flexibility in Selected Joints of Adult Males Ages 18-72.* Doctoral dissertation, University of Michigan, 1955.
76. Guralnik, J., A. LaCroix, R. D. Abbott, et al. Maintaining mobility in late life: I--demographic characteristics and chronic conditions. *Am. J. Epidemiol.* 137:845-857, 1993.
77. Gutin, B. and M. J. KASPER. Can vigorous exercise play a role in osteoporosis prevention? a review. *Osteoporos. Int*. 2:55-69, 1992.
78. Gutman, G. M., Herbert, C. P., and S. R. BROWN. Feldenkrais versus conventional exercises for the elderly. *J. Gerontol.* 32:562-572, 1977.
79. Hagberg, J., S. Blair, A. Ehsani, N. Gordon, N. Kaplan, C. Tipton, and E. ZAMBRASKI. Position stand: physical activity, physical fitness, and hypertension. *Med. Sci. Sports Exerc.* 25:i-x, 1993.
80. Hagberg, J. Exercise, fitness, and hypertension. In: *Exercise, Fitness, and Health: A Consensus of Current Knowledge*, Champaign, IL: Human Kinetics, 1990, pp. 455-466.
81. Hagberg, J., A. Ehsani, and J. HOLLOSZY. Effects of 12 months of intense exercise training on stroke volume in patients with coronary artery disease. *Circulation* 67:1194-1199, 1983.
82. Hagberg, J., J. Graves, M. Limacher, D. Woods, C. Cononie, S. Leggett, J. Gruber, and M. POLLOCK. Cardiovascular responses of 70-79 year old men and women to exercise training. *J. Appl. Physiol.* 66:2589-2594, 1989.

83. Hagberg, J., S. Montain, W. Martin, and A. EHSANI. Effect of exercise training on 60 to 69 year old persons with essential hypertension. *Am. J. Cardiol.* 64:348-353, 1989.
84. Harries, U. J. and E. J. BASSEY. Torque-velocity relationships for the knee extensors in women in their 3rd and 7th decades. *Eur. J. Appl. Physiol.* 60:187-190, 1990.
85. Hartz, S. C. *Nutrition in the Elderly: The Boston Nutritional Status Survey*, S. C. Hartz, R. M. Russell, and I. H. Rosenberg (Eds.). London: Smith-Gordon, 1992, pp. 1-287.
86. Hasselkus, B. R. and G. M. SHAMBES. Aging and postural sway in women. *J. Gerontol.* 30:661-667, 1975.
87. Hassmen, P., R. Ceci, and L. BACKMAN. Exercise for older women: a training method and its influences on physical and cognitive performance. *Eur. J. Appl. Physiol.* 64:460-466, 1992.
88. Hawkins, H. L., A. F. Kramer, and D. CAPALDI. Aging, exercise, and attention. *Psychol. Aging* 7:643-653, 1992.
89. Heath, G., J. Hagberg, A. Ehsani, and J. HOLLOSZY. A physiological comparison of young and older endurance athletes. *J. Appl. Physiol.* 51:634-640, 1981.
90. Hellebrandt, F. A. and G. L. BRAUN. The influence of sex and age on the postural sway of man. *Am. J. Phys. Anthropol. 24:347-360, 1939.*
91. *Hersey, W., J. Graves, M. Pollock, R. Gingerich, R. Shireman, G. Heath, F. Spierto, S. McCole, and J. HAGBERG. Endurance exercise training improves body composition and plasma insulin responses in 70-79 yr old men and women. Metabolism* 43:847-854, 1994.
92. Hickey, M. L., S. V. Owen, and R. D. FROMAN. Instrument development: cardiac diet and exercise self-efficacy. *Nurs. Res.* 41:347-351, 1992.
93. Hu, M-H. and M. H. WOOLLACOTT. Multisensory training of standing balance in older adults: I--postural stability and one-leg stance balance. *J. Gerontol.* 49:M52-M61, 1994.
94. Hu, M-H. and M. H. WOOLLACOTT. Multisensory training of standing balance in older adults: II--kinematic and electromyographic postural responses. *J. Gerontol.* 49:M62-M71, 1994.
95. Hubley-Kozey, C. L., J. C. Wall, and D. B. HOGAN. Effects of a general exercise program on passive hip, knee, and ankle range of motion of older women. *Top. Geriatr. Rehabil.* 10:33-44, 1995.
96. Imamura, K., H. Ashida, T. Ishikawa, and M. FUJII. Human major psoas muscle and sacrospinalis muscle in relation to age: a study by computed tomography. *J. Gerontol.* 38:678-681, 1983.
97. Ismail, A. H. and A. M. EL-NAGGAR. Effect of exercise on cognitive processing in adult men. *J. Hum. Ergol.* 10:83-91, 1981.
98. Jarnlo, G. B. Hip fracture patients: background and function. *Scand. J. Rehabil. Med.* 24(Suppl):1-31, 1991.
99. Jervey, A. *A Study of Flexibility of Selected Joints in Specified Groups of Adult Females.* Doctoral dissertation, University of Michigan, 1961.
100. Jette, A. M. and L. G. BRANCH. The Framingham disability study: II--Physical disability among the aging. *Am. J. Public Health* 71:1211-1216, 1981.

101. Jirovec, M. The impact of daily exercise on the mobility, balance, and urine control of cognitively impaired nursing home residents. *Int. J. Nurs. Stud.* 28:145-151, 1991.
102. Judge, J. O., Lindsey, C., Underwood, M., and D. WINSEMIUS. Balance improvements in older women: effects of exercise training. *Phys. Ther.* 73:254-265, 1993.
103. Kaplan, R., A. Reis, L. Prewitt, and E. EAKIN. Self-efficacy expectations predict survival for patients with chronic obstructive pulmonary disease. *Health Psychol.* 13:366-368, 1994.
104. Kaplan, R. M., C. J. Atkins, and S. REINSCH. Specific efficacy expectation mediate exercise compliance in patients with COPD. *Health Psychol.* 3:223-242, 1984.
105. Kasch, F., J. Boyer, S. Van Camp, L. Verity, and J. P. WALLACE. Effect of exercise on cardiovascular ageing. *Age Ageing* 22:5-10,1993.
106. Katzel, L., E. Bleecker, E. Colman, E. Rogus, J. Sorkin, and A. GOLDBERG. Effects of weight loss vs. aerobic exercise training on risk factors for coronary disease in healthy, obese, middle-aged and older men. *JAMA* 274:1915-1920, 1995.
107. Kirwan, J., J. Kohrt, D. Wojta, and J. HOLLOSZY. Endurance exercise training reduces glucose-stimulated insulin levels in 60-to 70-year-old men and women. *J. Gerontol.* 48:M84-M90, 1993.
108. Koenig, H. G. and D. G. BLAZER. Epidemiology of geriatric affective disorders. In: *Clinics in Geriatric Medicine*, G. S. Alexopoulos (Ed.). Philadelphia: Saunders, 1992, pp. 235-252.
109. Kohrt, W., M. Malley, A. Coggan, R. Spina, T. Ogawa, A. Ehsani, R. Bourey, W. Martin III, and J. HOLLOSZY. Effects of gender, age, and fitness level on response of VO2max to training in 60-71 yr olds. *J. Appl. Physiol.* 71:2004-2011, 1991.
110. Kolterman, O. G., J. Insel, M. Saekow, and J. M. OLEFSKY. Mechanisms of insulin resistance in human obesity: evidence for receptor and postreceptor defects. *J. Clin. Invest.* 65:1272-1284, 1980.
111. Kuhlman, K. A. Cervical range of motion in the elderly. *Arch. Physiol. Med. Rehabil.* 74:1071-1079, 1993.
112. LaCroix, A., S. Leveille, and J. A. HECHT, et al. Does walking decrease the risk of cardiovascular disease, hospitalizations and death in older adults? *J. Am. Geriatr. Soc.* 44:1113-1220, 1996.
113. Larsson, L. Histochemical characteristics of human skeletal muscle during aging. *Acta. Physiol. Scand.* 117:469-471, 1983.
114. Larsson, L. Morphological and functional characteristics of the aging skeletal muscle in man. *Acta. Physiol. Scand. Suppl.* 457(Suppl):1-36, 1978.
115. Larsson, L. Physical training effects on muscle morphology in sedentary males as different ages. *Med. Sci. Sports Exerc.* 14:203-206, 1982.
116. Larsson, L. G., G. Grimby, and J. KARLSSON. Muscle strength and speed of movement in relation to age and muscle morphology. *J. Appl. Physiol.* 46:451-456, 1979.

117. Lavie, C., R. Milani, and A. LITTMAN. Benefits of cardiac rehabilitation and exercise training in secondary coronary prevention in the elderly. *J. Am. Coll. Cardiol.* 22:678-683, 1993.
118. Leslie, D. K. and G. A. FREKANY. Effects of an exercise program on selected flexibility measures of senior citizens. *Gerontologist* 4:182-183, 1975.
119. Lesser, M. The effects of rhythmic exercise on the range of motion in older adults. *Am. Correct. Ther. J.* 32:118-122, 1978.
120. Levy, W., M. Cerqueira, I. Abrass, R. Schwartz, and J. STRATTON. Endurance exercise training augments diastolic filling at rest and during exercise in healthy young and older men. *Circulation* 88:116-126, 1993.
121. Lexell, J., K. Henriksson-Larsen, B. Wimblod, and M. SJOSTROM. Distribution of different fiber types in human skeletal muscles: effects of aging studied in whole muscle cross sections. *Muscle Nerve* 6:588-595, 1983.
122. Lichtenstein, M. J., S. L. Shields, R. G. Shavi, and C. BURGER. Exercise and balance in aged women: a pilot controlled clinical trial. *Arch. Physiol. Med. Rehabil.* 70:138-143, 1989.
123. Lindemuth, G. and B. MOOSE. Improving cognitive abilities of elderly Alzheimer's disease patients with intense exercise therapy. *Am. J. Alzheimer's Care Rel. Disord. Res. 5:31-33, 1990.*
124. *Lord, S. R. and S. CASTELL. Physical activity program for older persons: effect on balance, strength, neuromuscular control, and reaction time. Arch. Physiol. Med. Rehabil.* 75:648-652, 1994.
125. Lord, S. R., D. G. Lloyd, M. Nirui, J. Raymond, P. Williams, and R. A. STEWART. The effect of exercise on gait patterns in older women: a randomized controlled trial. *J. Gerontol.* 51:M64-M70, 1996.
126. Lord, S. R., J. A. Ward, and P. WILLIAMS. Exercise effect on dynamic stability in older women: a randomized controlled trial. *Arch. Physiol. Med. Rehabil.* 77:232-236, 1996.
127. Lord, S. R., J. A. Ward, P. Williams, and M. STRUDWICK. The effect of a 12-month exercise trial on balance, strength, and falls in older women: a randomized controlled trial. *J. Am. Geriatr. Soc.* 43:1198-1206, 1995.
128. Lord, S. R., P. N. Sambrook, C. Giblert, P. J. Kelly, T. Nguyen, and I. W. WEBSTER. Postural stability falls and fractures in the elderly: results from the Dubo Osteoporosis Epidemiology Society. *Med. J. Aust.* 160:684-685, 1994.
129. MacDougall, J. D. Adaptability of muscle to strength training-a cellular approach. In: *Biochemistry of Exercise,* Vol. 5, B. Saltin (Ed.). Champaign, IL: Human Kinetics, 1986 pp. 501-513.
130. MacRae, P. G., M. E. Feltner, and S. REINSCH. A 1-year exercise program for older women: effects on falls, injuries, and physical performance. *J. Aging Phys. Act. 2:127-142, 1994.*
131. *Madden, D. J., J. A. Blumenthal, P. A. Allen, and C. EMERY. Improving aerobic capacity in healthy older adults does not necessarily lead to improved cognitive performance. Psychol. Aging* 4:307-320, 1989.
132. Madden, D. J., J. A. Blumenthal, and C. EMERY. Improving aerobic capacity in healthy adults does not necessarily lead to improved cognitive performance. *Psychol. Aging* 4:307-320, 1986.

133. Maddox, G. L. and D. O. CLARK. Trajectories of functional impairment in later life. *J. Health Hum. Behav.* 33:114-125, 1992.
134. Martinsen, E. W. Benefits of exercise of the treatment of depression. *Sports Med.* 9:380-389, 1990.
135. McAuley, E. Efficacy, attributional, and affective responses to exercise participation. *J. Sport Exerc. Psychol.* 13:382-393, 1991.
136. McAuley, E. The role of efficacy cognitions in the prediction of exercise behavior in middle-aged adults. *J. Behav. Med.* 15:65-88, 1992.
137. McAuley, E. Self-efficacy, physical activity, and aging. In: *Activity and Aging,* J. Kelly (Ed.). London: Newbury Park, 1993, pp. 187-205.
138. McAuley, E. Physical activity and psychosocial outcomes. In: *Physical Activity, Fitness, and Health*: *The Consensus Knowledge,* C. Bouchard, R. J. Shephard, and T. Stephens (Eds.). Champaign, IL: Human Kinetics, 1994, pp. 551-568.
139. McAuley, E. and K. S. COURNEYA. Adherence to exercise and physical activity as health promoting behaviors: attitudinal and self-efficacy influences. *Appl. Prev. Psychol.* 2:65-77, 1993.
140. McAuley, E., K. S. Courneya, and J. LETTUNICH. Effects of acute and long-term exercise on self-efficacy responses in sedentary, middle-aged males and females. *Gerontology* 31:534-542, 1991.
141. McAuley, E., K. S. Courneya, D. L. Rudolph, and C. L. LOX. Enhancing exercise adherence in middle-aged males and females. *Prev. Med.* 23:498-506, 1994.
142. McAuley, E., C. Lox, and T. E. DUNCAN. Long-term maintenance of exercise, self-efficacy, and physiological change in older adults. *J. Gerontol.* 48:P218-P224, 1993.
143. McAuley, E. and D. RUDOLPH. Physical activity, aging, and psychological well-being. *J. Aging Physiol. Activ.* 3:67-96, 1995.
144. McAuley, E., S. Shaffer, and D. RUDOLPH. Self-efficacy and affective responses to exercise testing in older males. *Int. J. Aging Hum. Dev.* 41:13-27, 1995.
145. McCole, S., M. Brown, G. Moore, J. Zmuda, J. Cwynar, and J. HAGBERG. Maximal exercise cardiovascular hemodynamics in postmenopausal women are independent of hormone replacement therapy (Abstract). *Med. Sci. Sports Exerc.* 29:S11, 1997.
146. McGandy, R. B., C. H. Barrows, A. Spanias, A. Meredith, J. L. Stone, and A. H. NORRIS. Nutrient intake and energy expenditure in men of different ages. *J. Gerontol.* 21:581-587, 1966.
147. McMurdo ME and L. M. RENNIE. Improvements in quadriceps strength with regular seated exercise in the institutionalized elderly. *Arch. Phys. Med. Rehabil.* 75:600-603, 1994.
148. McNeil, J. K., E. M. Leblanc, and M. JOYNER. The effect of exercise on depressive symptoms in the moderately depressed elderly. *Psychol. Aging* 6:487-488, 1991.
149. Mendes de Leon, C. F., T. E. Seeman, D. I. Baker, E. D. Richardson, and M. E. TINETTI. Self- efficacy, physical decline, and change in functioning in

community-living elders: a prospective study. *J. Gerontol. B. Psychol. Sci. Soc. Sci.* 51:S183-S190, 1996.
150. Meredith, C. N., W. R. Frontera, and W. J. EVANS. Body composition in elderly men: effect of dietary modification during strength training. *J. Am. Geriatr. Soc.* 40:155-162, 1992.
151. Mihalko, S. L., E. McAuley, and S. M. BANE. Self-efficacy and affective responses to acute exercise in middle-aged adults. *J. Soc. Behav. Personal.* 11:375-385, 1996.
152. Miller, J. P., R. E. Pratley, A. P. Goldberg, P. Gordon, M. Rubin, M. S. Treuth, A. S. Ryan, and B. F. HURLEY. Strength training increases insulin action in healthy 50- to 65-yr-old men. *J. Appl. Physiol.* 77:1122-1127, 1994.
153. Miller, T., S. Grossman, K. Schectman, D. Biello, P. Ludbrook, and A. EHSANI. Left ventricular diastolic filling and its association with age. *Am. J. Cardiol.* 58:531-535, 1986.
154. Mirowsky, J. Age and the sense of control. *Soc. Psychol. Q.* 58:31-43, 1995.
155. Mobily, K. E., L. M. Rubenstein, J. H. Lemke, M. W. O'Hara, and R. B. WALLACE. Walking and depression in a cohort of older adults: the Iowa 65+ rural health study. *J. Aging Physiol. Activ.* 4:119-135, 1996.
156. Molloy, D., L. D. Richardson, and R. G. CRILLY. The effects of a three-month exercise programme on neuropsychological function in elderly institutionalized women: a randomized controlled trial. *Age Ageing* 17:303-310, 1988.
157. Morey, M. C., P. A. Cowper, J. R. Feussner, R. C. Dipasquale, G. M. Crowley, and R. J. SULLIVAN, JR. Two-year trends in physical performance following supervised exercise among community-dwelling old veterans. *J. Am. Geriatr. Soc.* 38:549-554, 1991.
158. Morley, J. Anorexia in older persons: epidemiology and optimal treatment. *Drugs Aging* 8:134-155, 1996.
159. Mulrow, C., M. Gerety, D. Kanten, et al. A randomized trial of physical rehabilitation for very frail nursing home residents. *JAMA* 271:519-524, 1994.
160. Munns, K. Effects of exercise on the range of joint motion in elderly subjects. In: *Exercise and Aging: The Scientific Basis*. E. L. Smith, and R. C. Serfass, (Eds.). Short Hills, NJ: Enslow, 1981, pp. 1-191.
161. Murray, M. P., E. H. Duthie, S. T. Gambert, S. B. Sepic, and L. A. MOLLINGER. Age-related differences in knee muscle strength in normal women. *J. Gerontol.* 40:275-280, 1985.
162. Naso, F., E Carner, W. Blandfort-Doyle, et al. Endurance training in the elderly nursing home patient. *Arch. Physiol. Med. Rehabil.* 71:241-243, 1990.
163. Nelson, M. E., F. A. Dilmanian, G. E. Dallal, and W. J. EVANS. A one-year walking program and increased dietary calcium in postmenopausal women: effects on bone. *Am. J. Clin. Nutr.* 53:1304-1311, 1991.
164. Nelson, M. E., M. A. Fiatarone, C. M. Morganti, I. Trice, R. A. Greenberg, and W. J. EVANS. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. *JAMA* 272:1909-1914, 1994.

165. Nelson, M., J. Layne, A. Nuernberger, et al. Home-based exercise training in the frail elderly: effects on physical performance (Abstract). *Med. Sci. Sports Exerc.* 29:S110, 1997.
166. Nigg, B. M., V. Fisher, T. L. Allinger, J. R. Ronsky, and J. R. ENGSBERG. Range of motion of the foot as a function of age. *Foot Ankle* 13:336-343, 1992.
167. North, T. C., P. McCullagh, and Z. V. TRAN. Effect of exercise on depression. *Exerc. Sport Sci. Rev.* 18:379-415, 1990.
168. O'Connor, P. J., L. E. Aenchenbacher, and R. K. DISHMAN. Physical activity and depression in the elderly. *J. Aging Physiol. Activ.* 1:34-58, 1993.
169. Oddis, C. New perspectives on osteoarthritis. *Am. J. Med.* 100:10S-15S, 1996.
170. Ogawa, T., R. Spina, W. Martin III, W. Kohrt, K. Schechtman, J. Holloszy, and A. EHSANI. Effects of aging, sex and physical training on cardiovascular responses to exercise. *Circulation* 86:494-503, 1992.
171. Ory, M., K. Schechtman, J. P. Miller, et al. Frailty and injuries in later life: the FICSIT trials. *J. Am. Geriatr. Soc.* 41:283-296, 1993.
172. Overstall, P. W., A. N. Exton-Smith, F. J. Imms, and A. L. JOHNSON. Falls in elderly related to postural imbalance. *BMJ* 1:261-264, 1977.
173. Panton, L. B., J. E. Graves, M. L. Pollock, J. M. Hagbert, and W. CHEN. Effect of aerobic resistance training on fractionated reaction time and speed of movement. *J. Gerontol.* 45:M26-M31, 1990.
174. Pate, R., M. Pratt, S. N. Blair, et al. Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 273:402-407, 1995.
175. Patla, A. E., J. S. Frank, and D. A. WINTER. Assessment of balance control in the elderly: major issues. *Phys. Ther. Can.* 42:89-97, 1990.
176. Perkins, K., S. Rapp, C. R. Carlson, and C. E. Wallace. Behavioral interventions to increase exercise. *Gerontologist* 26:479-481, 1986.
177. Perri, S. and D. TEMPLAR. The effects of an aerobic exercise program on psychological variables in older adults. *Int. J. Hum. Dev.* 20:162-172, 1985.
178. Pierce, T. W., D. J. Madden, W. C. Siegel, and J. A. BLUMENTHAL. Effects of aerobic exercise on cognitive and psychosocial functioning in patients with mild hypertension. *Health Psychol.* 12:286-291, 1993.
179. Plante, T. E. and J. RODIN. Physical fitness and enhanced psychological health. *Curr. Psychol. Res. Rev*. 9:3-24, 1990.
180. Pollock, M., L. Mengelkoch, J. Graves, D. Lowenthal, M. Limacher, C. Foster, and J. WILMORE. Twenty-year follow-up of aerobic power and body composition of older track athletes. *J. Appl. Physiol.* 82:1508-1516, 1997.
181. Port, S., F. Cobb, R. Coleman, and R. JONES. The effect of age on left ventricular function at rest and during exercise. *N. Engl. J. Med.* 303:1133-1137, 1980.
182. Province, M. A., E. C. Hadley, M. C. Hornbrook, L. A. Lipsitz, J. P. Miller, C. D. Mulrow, M. G. Ory, R. W. Sattin, M. E. Tinetti, and S. L. WOLF. The effects of exercise on falls in elderly patients: a preplanned meta-analysis of the FICSIT Trials--Frailty and Injuries: Cooperative Studies of Intervention Techniques. *JAMA* 273:1341-1347, 1995.

183. Pu, C., M. Johnson, D. Forman, L. Piazza, and M. FIATARONE. Performanced-based functional changes after strength training in elderly women with heart failure. *J. Am. Geriatr. Soc.* (in press).
184. Pyykkö, I., H. Aalto, M. Hytonen, J. Starck, P. Jantti, and H. RAMSAY. Effect of age on postural control. In: *Posture and Gait: Development, Adaptation and Modulation*. B. Amblard, A. Berthoz, and F. Clarac (Eds.). New York: Elsevier Science, 1988, pp. 95-104.
185. Ravussin, E., S. Lillioja, T. E. Anderson, L. Cristin, and C. BOGARDUS. Determinants of 24-hour energy expenditure in man. *J. Clin. Invest.* 78:1568-1578, 1986.
186. Rejeski, W. J., T. Craven, W. H. Etiinger Jr., M. McFarlane, and S. SHUMAKER. Self-efficacy and pain in disability with osteoarthritis of the knee. *J. Gerontol.* 51:P24-P29, 1996.
187. Rikli, R. E. and S. BUSCH. Motor performance of women as a function of age and physical activity level. *J. Gerontol.* 41:645-649, 1986.
188. Rikli, R. E. and D. J. EDWARDS. Effects of a three-year exercise program on motor function and cognitive processing speed in older women. *Res. Q. Exerc. Sport* 62:61-67, 1991.
189. Roach, K. E. and T. P. MILES. Normal hip and knee active range of motion: the relationship to age. *Phys. Ther.* 70:656-665, 1991.
190. Roberts, S. B., V. R. Young, P. Fuss, M. B. Heyman, M. A. Fiatarone, G. E. Dallal, J. Cortiella, and W. J. EVANS. What are the dietary energy needs of adults? *Int. J. Obes.* 16:969-976, 1992.
191. Rodeheffer, R., G. Gerstenblith, L. Becker, J. Fleg, M. Weisfeldt, and E. LAKATTA. Exercise cardiac output is maintained with advancing age in healthy human subjects: cardiac dilatation and increased stroke volume compensate for a diminished heart rate. *Circulation* 69:203-213, 1984.
192. Rodin, J. Aging and health: effects of the sense of control. *Science* 233:1271-1276, 1986.
193. Rogers, M., J. Hagberg, W. Martin, A. Ehsani, and J. HOLLOSZY. Decline in VO_{2max} with aging in master athletes and sedentary men. *J. Appl. Physiol.* 68:2195-2199, 1990.
194. Rogers, M., C. Yamamoto, D. King, J. Hagberg, A. Ehsani, and J. HOLLOSZY. Improvement in glucose tolerance after 1 wk of exercise in patients with NIDDM. *Diabetes Care* 11:613-618, 1988.
195. Sallis, J. F., M. F. Hovell, C. R. Hofstetter, et al. A multivariate study of determinants of vigorous exercise in a community sample. *Prev. Med.* 18:20-34, 1989.
196. Sauvage L. R., B. M. Mykelbust, J. Crow-Pan, et al. A clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents. *J. Phys. Med. Rehabil.* 71:333-342, 1992.
197. Schnelle, J., P. MacRae, and J. G. OUSLANDER, et al. Functional Incidental Training, mobility performance, and incontinence care with nursing home residents. *J. Am. Geriatric. Soc.* 43:1356-1362, 1995.
198. Schulman, S., J. Fleg, A. Goldberg, J. Busby-Whitehead, J. Hagberg, F. O'Connor, G. Gerstenblith, L. Becker, L. Katzel, L. Lakatta, and E. LAKATTA.

Continuum of cardiovascular performance across a broad range of fitness levels in healthy older men. *Circulation* 94:359-367, 1994.

199. Schwartz, R., W. Shuman, V. Larson, K. Cain, G. Fellingham, J. Beard, S. Kahn, J. Stratton, M. Cerqueira, and I. ABRASS. The effect of intensive endurance exercise training on body fat distribution in young and older men. *Metabolism* 40:545-551, 1991.

200. Seals, D., W. Allen, B. Hurley, G. Dalsky, A. Ehsani, and J. HAGBERG. Elevated high-density lipoprotein cholesterol levels in older endurance athletes. *Am. J. Cardiol.* 54:390-393, 1984.

201. Seals, D., J. Hagberg, W. Allen, B. Hurley, G. Dalsky, A. Ehsani, and J. HOLLOSZY. Glucose tolerance in young and older athletes and sedentary men. *J. Appl. Physiol.* 56:1521-1525, 1984.

202. Seals, D., J. Hagberg, B. Hurley, A. Ehsani, and J. HOLLOSZY. Endurance training in older men and women: I--cardiovascular responses to exercise. *J. Appl. Physiol.* 57:1024-1029, 1984.

203. Seals, D., J. Hagberg, B. Hurley, A. Ehsani, and J. HOLLOSZY. Effects of endurance training on glucose tolerance and plasma lipid levels in older men and women. *J. Am. Med. Assoc.* 252:645-649, 1984.

204. Seals, D., J. Hagberg, R. Spina, M. Rogers, K. Schechtman, and A. EHSANI. Enhanced left ventricular performance in endurance trained older men. *Circulation* 89:198-205, 1994.

205. Seals, D. and M. REILING. Effect of regular exercise on 24-hr arterial pressure in older hypertensive humans. *Hypertension* 18:583-592, 1991.

206. Sepic, S. B., M. P. Murray, L. A. Mollinger, G. B. Spurr, and G. M. GARDNER. Strength and range of motion in the ankle in two age groups of men and women. *Am. J. Physiol. Med.* 65:75-84, 1986.

207. Shay, K. A. and D. L. ROTH. Association between aerobic fitness and visuospatial performance in healthy older adults. *Psychol. Aging* 7:15-24, 1992.

208. Sheldon, J. H. The effect of age on the control of sway. *Gerontol. Clin.* 5:129-138, 1963.

209. Sinaki, M., M. C. McPhee, and S. F. HODGSON. Relationship between bone mineral density of spine and strength of back extensors in healthy postmenopausal women. *Mayo Clin. Proc.* 61:116-122, 1986.

210. Singh, N. A., K. M. Clements, and M. A. FIATORNE. A randomised controlled trial of the effect of exercise on sleep. *Sleep* 20:95-101, 1997.

211. Singh, N. A., K. M. Clements, and M. A. FIATORNE. A randomized controlled trial of progressive resistance training in depressed elders. *J. Gerontol.* 52A:M27-M35, 1997.

212. Smith, E. L. and R. C. SERFASS (EDS.) *Exercise and Aging: The Scientific Basis*. Short Hills, NJ: Enslow Publishers, 1981, pp. 1-191.

213. Smith Jr., E. L., W. Reddan, and P. E. SMITH. Physical activity and calcium modalities for bone mineral increase in aged women. *Med. Sci. Sports Exerc.* 13:60-64, 1981.

214. Snow-Harter, C., M. Bouxsein, B. Lewis, S. Charette, P. Weinstein, and R. MARCUS. Muscle strength as a predictor of bone mineral density in young women. *J. Bone Miner. Res.* 5:589-595, 1990.

215. Spina, R., T. Miller, W. Bogenhagen, K. Schechtman, and A. EHSANI. Gender-related differences in left ventricular filling dynamics in older subjects after endurance exercise training. *J. Gerontol.* 51:B232-B237, 1996.
216. Spina, R., T. Ogawa, W. Kohrt, W. Martin III, J. Holloszy, and A. EHSANI. Differences in cardiovascular adaptations to endurance exercise training between older men and women. *J. Appl. Physiol.* 75:849-855, 1993.
217. Spina, R., T. Ogawa, T. Miller, W. Kohrt, and A. EHSANI. Effect of exercise training on left ventricular performance in older women free of cardiopulmonary disease. *Am. J. Cardiol.* 71:99-104, 1993.
218. Spirduso, W. W. Reaction and movement time as a function of age and physical activity level. *J. Gerontol.* 43:18-23, 1975.
219. Spirduso, W. W. *Physical Dimensions of Aging*, Champaign, IL: Human Kinetics, 1995.
220. Spirduso, W. W. and P. CLIFFORD. Replication of age and physical activity effects on reaction time movement time. *J. Gerontol.* 33:23-30, 1978.
221. Stamford, B. Effects of chronic institutionalization on the physical working capacity and trainability of geriatric men. *J. Gerontol.* 28:441-446, 1973.
222. Stephens, T. Physical activity and mental health in the United States and Canada: evidence from four population surveys. *Prev. Med.* 17:35-47, 1988.
223. Stevenson, E., K. Davy, and D. SEALS. Hemostatic, metabolic, and androgenic risk factors for coronary heart disease in physically active and less active postmenopausal women. *Arterioscler. Thromb.* 15:669-677, 1995.
224. Stones, M. and A. KOZMA. Physical activity, age, and cognitive/motor performance. In: *Cognitive Development in Adulthood: Progress in Cognitive Development Research*. M.L. Howe and C.J. Brainerd (Eds.). New York: Springer-Verlag, 1988, pp. 273-321.
225. Stratton, J., W. Levy, M. Cerqueira, R. Schwartz, and I. ABRASS. Cardiovascular responses to exercise effects of aging and exercise training in healthy men. *Circulation* 89:1648-1655, 1994.
226. Talbot, H. M., E. McAuley, J. A. Woods, and M. A. CEDDIA. Self-efficacy and cortisol response to maximal exercise in older adults (Absract). *Med. Sci. Sports Exerc.* 29:S119, 1997.
227. Taylor, C. B., A. Bandura, C. K. Ewart, N. H. Miller, and R. F. DEBUSK. Exercise testing to enhance wives' confidence in their husbands' cardiac capability soon after acute myocardial infarction. *Am. J. Cardiol.* 55:635-638, 1985.
228. Tinetti, M. E. Prevention of falls and fall injuries in elderly persons: a research agenda. *Prev. Med.* 23:756-762, 1994.
229. Tinetti, M. E., D. I. Baker, G. McAvay, E. B. Claus, P. Garrett, M. Gottschalk, M. L. Koch, K. Trainor, and R. I. HORWITZ. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. *N. Engl. J. Med.* 331:821-827, 1994.
230. Tinetti, M. E., Doucette, J. T., and E. B. CLAUS. The contribution of predisposing and situational risk factors to serious fall injuries. *J. Am. Geriatr. Soc.* 43:1207-1213, 1995.

231. Tinetti, M. E., J. Doucette, E. Claus, and R. MAROTTOLI. Risk factors for serious injury during falls by older persons in the community. *J. Am. Geriatr. Soc.* 43:1214-1221, 1995.
232. Tinetti, M. E., C. F. Mendes de Leon, J. T. Doucette, and D. I. BAKER. Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. *J. Gerontol.* 49:M140-M147, 1994.
233. Tinetti, M. E., M. Speechley, and S. F. GINTER. Risk factors for falls among elderly persons living in the community. *N. Engl. J. Med.* 319:1701-1707, 1988.
234. Tomporowski, P. D. The effects of physical and mental training on the mental abilities of older adults. *J. Aging Physiol. Act.* 5:9-26, 1997.
235. Tomporowski, P. D. and N. R. ELLIS. Effects of exercise on cognitive processes: a review. *Psychol. Bull.* 99:338-346, 1986.
236. Tonino, R. Effect of physical training on the insulin resistance of aging. *Am. J. Physiol.* 256:E352-E356, 1989.
237. Toshima, M. T., R. M. Kaplan, and A. L. RIES. Experimental evaluation of rehabilitation in chronic obstructive pulmonary disease: short-term effects on exercise endurance and health status. *Health Psychol.* 9:237-252, 1990.
238. Tzankoff, S. P. and A. H. NORRIS. Longitudinal changes in basal metabolic rate in man. *J. Appl. Physiol.* 33:536-539, 1978.
239. Vaitkevicius, P., J. Fleg, J. Engel, F. O'Connor, J. Wright, L. Lakatta, F. Yin, and E. LAKATTA. Effects of age and aerobic capacity on arterial stiffness in healthy adults. *Circulation* 88:1456-1462, 1993.
240. Walker, J. M., D. Sue, N. Miles-Elkousy, G. Ford, and H. TREVELYAN. Active mobility of the extremities in older subjects. *Phys. Ther.* 64:919-923, 1994.
241. Wallace J. and M. W. O'HARA. Increases in depressive symptomatology in the rural elderly: results from a cross-sectional and longitudinal study. *J. Abnorm. Psychol.* 101:398-404, 1992.
242. FAO/WHO/UNU. Report of a joint FAO/WHO/UNU Expert Consultation: energy and protein requirements. *World Health Organ Tech. Rep. Ser*. 724:1-206, 1985.
243. Williams, M., C. Maresh, and D. ESTERBROOKS. Early exercise training in patients older than age 65 years compared with that in younger patients after acute myocardial infarction or coronary artery bypass grafting. *Am. J. Cardiol.* 55:263-269, 1985.
244. Wolf, S. L., H. X. Barnhart, N. G. Kutner, E. McNeely, C. Coogler, and T. XU. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training--Atlanta FICSIT Group: Frailty and Injuries--Cooperative Studies of Intervention Techniques. *J. Am. Geriatr. Soc.* 44:489-497, 1996.
245. Wolfson, L., R. Whipple, C. Derby, J. Judge, M. King, P. Amerman, J. Schmidt, and D. SMYERS. Balance and strength training in older adults: intervention gains and tai chi maintenance. *J. Am. Geriatr. Soc.* 44:498-506, 1996.
246. Wolinsky, F. D. and T. E. STUMP. Age and the sense of control among older adults. *J. Gerontol.* 51:S217-S220, 1996.

247. Woollacott, M. H. and A. SHUMWAY-COOK. Changes in posture control across the life span: a systems approach. *Phys. Ther.* 70:799-807, 1990.
248. Yesavage, J. A. The use of self-rating scales in the elderly. In: *Handbook for Clinical Memory Assessment of Older Adults*, L.W. Poon (Ed.). Washington: American Psychological Association, 1986, pp. 213-217.

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