EXERCISE AND AGING

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Contents

Summary

Many factors, including genetic and environmental factors, are involved in the aging process, and the degree of decline in physiological function with aging is attributable to lifestyle-related factors. It is clear that regular exercise is one of the most important lifestyle practices for preventing the overall age-related functional decline. Maximal oxygen uptake (VO_2max) generally begins to decline between ages 25 and 30 and decreases approximately 10% per decade in healthy sedentary individuals. Highly endurance-trained individuals have higher VO_2max than less trained and sedentary individuals regardless of age. Human aging is associated with arterial and cardiac dysfunction and increased risk of clinical cardiovascular disease. The use of aerobic exercise to delay and prevent the development of arterial and cardiac dysfunction is an excellent way to achieve healthy aging. Loss of skeletal muscle mass and strength during aging is inevitable even in healthy elderly people. The skeletal muscle mass decreases by 25–30% from 20 to 80 years of age, and muscle strength decreases by 30–40%; however, age-related changes in skeletal muscle can be prevented or slowed down by exercise training in the very old. Genetics may also influence the aging process. A

decrease in mitochondrial function plays a key role in the aging process and increases the incidence of age-related disorders or phenotypes. Indeed, certain mitochondrial DNA polymorphisms play an important role in age-related phenotypes, and certain mitochondrial haplogroups are related to cardiorespiratory fitness and muscle power. Several nuclear DNA polymorphisms are also associated with age-related phenotypes. Older people can respond favorably to both endurance and strength training. Thus, it is never too late in life to achieve better physical fitness and quality of life by increasing physical activity.

1. Introduction

Every living creature grows old, and humans are no exception. Although the aging process is traditionally considered as an inevitable decline in health and function, it is now known that many factors, including genetic and environmental factors, are involved in the aging process. The degree of decline in physiological function with aging is attributable to lifestyle-related factors.

It is clear that regular exercise is one of the most important lifestyle practices for preventing the overall age-related functional decline. It has been proposed that the decline of functional capacity during aging can be attenuated and perhaps reversed by an increase in daily physical activity and exercise training. This attenuation in functional decline by physical activity and exercise training in old age is extremely important, because these can close the "fitness gap" between active and inactive older people, and can prolong the time to the disability threshold as shown in Figure 1(DiPietro, 2006).

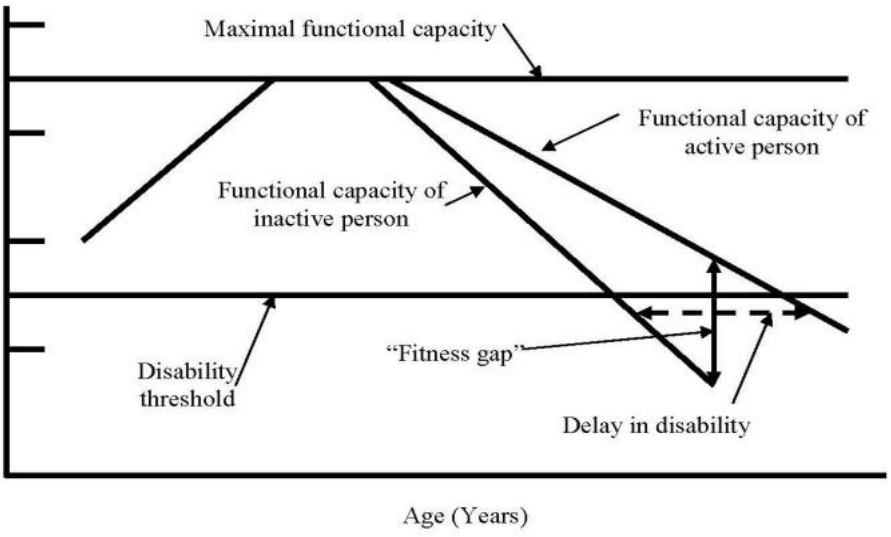

Figure 1. Fitness gap and disability threshold. Data from DiPietro (2006)

In the American College of Sports Medicine (ACSM) Position Stand "Exercise and Physical Activity for Older Adults" (Chodzko-Zajko et al, 2009), normal human aging is summarized as follows: (1) physiologic changes that result in reductions in functional capacity and altered body composition, (2) decline in physical activity volume and

intensity, and (3) increased risk of chronic diseases. In addition, the Position Stand of ACSM (2009) summarizes the benefits of exercise and physical activity on health and functional capacity for 2 exercise modalities, aerobic and resistance exercises. The benefits of aerobic exercise training (AET) in previously sedentary individuals are as follows: (1) AET programs of sufficient intensity, frequency, and length can significantly increase cardiorespiratory fitness (CRF) in healthy middle-aged and older adults, (2) three or more months of moderate-intensity AET elicits cardiovascular adaptations, evident at rest and in response to acute dynamic exercise, in healthy middle-aged and older adults, (3) moderate-intensity AET has been shown to be effective in reducing total body fat in overweight middle-aged and older adults, and (4) AET can induce a variety of favorable metabolic adaptations, including enhanced glycemic control, augmented clearance of postprandial lipids, and preferential utilization of fat during submaximal exercise. On the other hand, after resistance exercise training (RET), older adults can also substantially increase their (1) strength, (2) muscular power, and (3) muscle quality, defined as muscular performance (strength or power) per unit muscle volume or mass.

Several evidence-based conclusions relating to exercise and physical activity specifically in the older adult population can also be drawn: (1) a combination of AET and RET activities seems to be more effective than either form of training alone in counteracting the detrimental effects of a sedentary lifestyle on the health and functioning of the cardiovascular system and skeletal muscles; (2) ideally, exercise prescription for older adults should include aerobic and muscle strengthening exercises.

2. Effects of Aging and Exercise on Aerobic Fitness

2.1. Effects of Exercise on Aging-related Decline of Aerobic Capacity

Maximal oxygen uptake (VO_2max), which is the highest rate of oxygen consumption that one can attain while performing an exercise test of progressively increasing intensity requiring a large proportion of the total skeletal muscle mass, is one of the most useful physiological parameters to evaluate CRF in young and older individuals. A progressive decline in VO_2max and capacity for aerobic exercise occurs with aging. VO_2max is determined by the capacity of the cardiovascular system to deliver oxygen to the working muscles and the capacity of the muscles to extract oxygen from the blood and use it to generate adenosine triphosphate (ATP) via oxidative metabolism. VO_2max is also a function of both maximal cardiac output (Qmax), which is the product of maximal heart rate (HRmax) and the stroke volume attained during exercise at VO_2max, and maximal arteriovenous oxygen difference ([Ca - Cv] O_2 difference).

In humans, VO_2max generally begins to decline between ages 25 and 30, and decreases approximately 10% per decade in healthy sedentary people as shown in Figure 2. (A, B) (Holloszy, 1995). The absolute value of VO_2max in terms of L/min is an appropriate parameter to evaluate the changes in aerobic capacity of individuals throughout life. The decline in VO_2max, expressed as mL O_2·kg body weight^{-1}·min^{-1}, is highly associated with body weight gain that usually occurs in sedentary and/or older people.

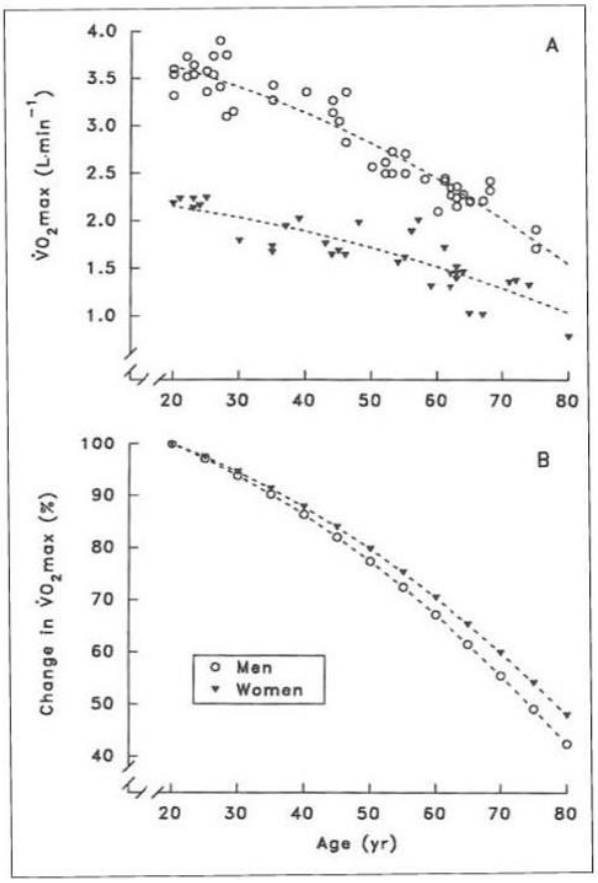

Figure 2. Absolute (A), and relative (B) declines in VO2max expressed as liters/min in healthy, sedentary men and women. Data from Holloszy (1995)

Highly endurance-trained individuals have higher VO_2max than less trained and/or sedentary individuals regardless of age. However, a decrease in the performance in a long-distance race is inevitable with advancing age. It is difficult to determine the exact nature of the effect of aging on the adaptability to physical training. Factors for consideration include: (1) the presence of coronary artery disease, (2) levels of percentage fatness, and (3) the intensity of physical training. All these factors affect the VO_2max to a great degree. To compare athletes across different age groups, it is important that the subjects in the groups be comparable in all respects except age. Well-trained long-distance runners, between 30 and 80 years of age, with similar body composition and training mileage, experienced a 7% decrease in VO_2max/decade (Fuchi et al, 1989). Figure 3 shows the relationships between the age of the runners and their best time and highest average running speed for a 10-km race compared to the world and Japanese Masters records for each age group. Figure 4**.** suggests that decline in VO_2max, HRmax, and Qmax are inevitable events of aging, even in highly trained elite athletes, and that endurance performance is strongly related to the VO_2max associated with aging. This inevitable decline of VO_2max with aging appears to be related to the deterioration of central circulatory functions such as HRmax and Qmax. On the other hand, the (Ca - Cv) O_2 difference, one of the factors that influence the oxygen utilization capacity in peripheral tissues such as skeletal muscles, can be maintained by vigorous AET until old age.

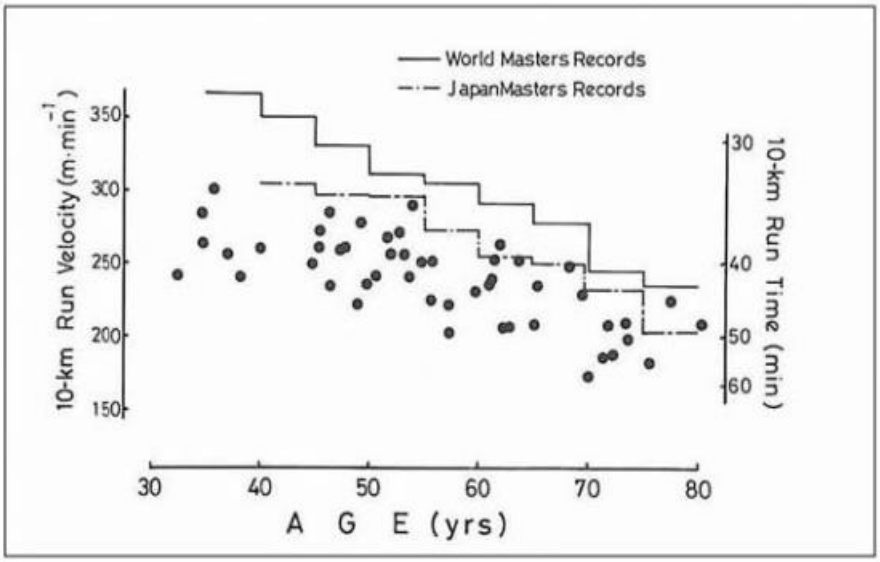

Figure 3. Relationship between the age of the master runners and their run time and run velocity for a 10-km race compared to the world and Japanese masters' records in each age group. Data from Fuchi et al (1989)

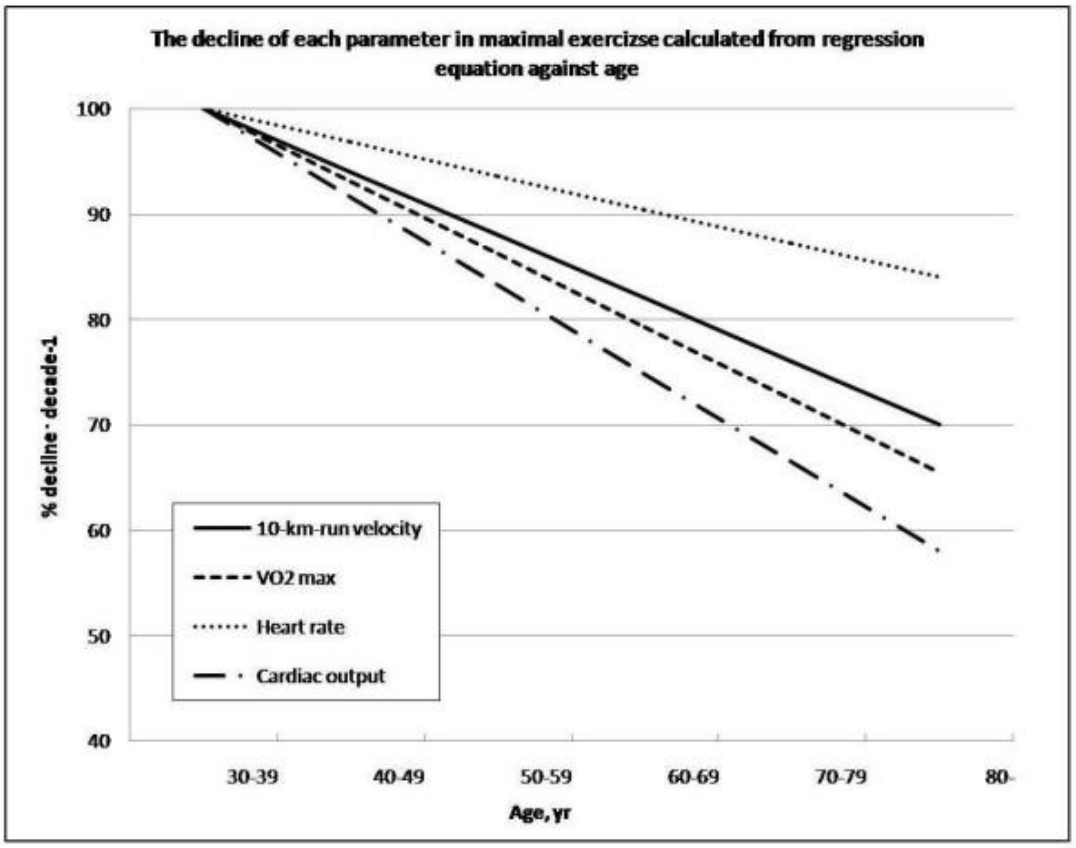

Figure 4. Decline of each physiological parameter in maximal exercise calculated from regression equation against age. Data from Fuchi et al (1989)

Rowing was one of the oldest organized sports and has been very popular among young and older individuals in Europe and North America. Rowing involves almost all the muscles in the body, and consists of rhythmic muscle contractions that demand a high aerobic capacity. VO_2max, expressed as L/min, and rowing performance in 2000 m ergometer rowing were evaluated in older rowing-trained men, and the results were compared to those obtained in older and young sedentary men and young rowing-trained men (Yoshiga, 2007). The older oarsmen had a lower rowing performance than the young oarsmen did (489 ± 16 vs. 451 ± 12 s). The VO_2max of the older rowing-trained men was lower than that of the young oarsmen (3.0 ± 0.4 vs. 4.1 ± 0.3 L/min), but similar to that of the young sedentary men (3.1 ± 0.5 L/min) and higher than that of the older sedentary men (2.2 ± 0.3 L/min) (Figure 5-A). The association between performance time (s) to row 2000 m on an ergometer and VO_2max (L/min) suggests that high levels of CRF may play an important role in rowing performance even in the older rowers (Figure 5 -B).

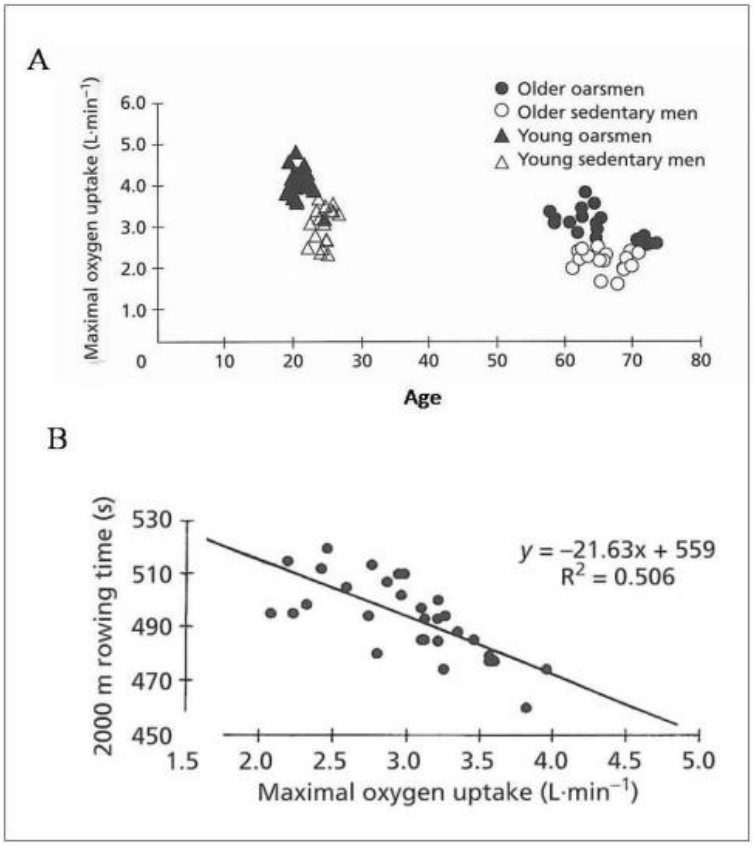

Figure 5. **A**: Maximal oxygen uptake in rowing-trained and sedentary men related to age.
B: Relationship between 2000m rowing performance and maximal oxygen uptake in older rowing-trained men. Data from Yoshiga (2007)

Based on the above-mentioned studies and many other reports, regular performance of endurance exercises increases the CRF involved in aerobic metabolism of skeletal muscles.

The (Ca - Cv) O_2 difference at maximal level of exercise in older and younger runners, matched on the basis of training and performance, was the same, indicating that there is no significant reduction in the oxygen extraction capacity of aged skeletal muscles. Furthermore, although the VO_2max in endurance-trained older athletes was 11% lower than that in young training- and performance-matched runners, activities of mitochondrial citrate cycle enzymes, such as citrate synthase (CS) and succinate dehydrogenase (SDH), and an enzyme involved in fatty acid oxidation, 3-hydroxyl-acyl CoA dehydrogenase (HAD), were 25 to 30% higher in the older runners, indicating enhanced muscle respiratory capacity (Table 1) (Rogers and Evans, 1993). Additionally, the capillary/fiber ratio and number of capillaries with respect to each fiber were significantly greater in the older runners than in the matched young runners.

These findings suggest that elderly humans retain the ability to adapt to endurance exercise with an increase in the aerobic metabolic capacity of skeletal muscles.

	Master Athletes (N = 8)	Matched Young Runners (N = 8)	Δ
SDH	2.6 ± 0.6	2.0 ± 0.4*	30%
CS	6.0 ± 1.5	4.7 ± 0.8	28%
β-HAD	10.0 ± 1.8	8.0 ± 1.91*	25%
Capillaries/mm^2	388 ± 93	367 ± 60	6%
Capillaries/fiber	2.4 ± 0.4	1.9 ± 0.4*	31%
Capillaries in contact with each fiber	5.9 ± 0.9	4.8 ± 0.8*	23%
SDH = succinate dehydrogenase; CS = citrate synthase; β-HAD = β-hydroxylacyl=coA dehydrogenase. Values are means ± SD in mol.kg protein^{-1}. h^{-1}. *($p<0.05$) vs master athletes. Adapted from Coggan et al (1990) Rogers and Evans, 1993Coggan et al (1990)			

Table 1. Skeletal muscle enzyme activities and capillarization in master athletes and performance-matched young runners. Data from Rogers and Evans (1993)

2.2. Effects of Aerobic Exercise and Aging on Glucose Metabolism

Older people usually exhibit a progressive deterioration in glucose tolerance with advancing age. Type 2 diabetes, previously called non-insulin-dependent diabetes mellitus (NIDDM) or adult-onset diabetes, is highly prevalent in the elderly. In fact, many elderly people have type 2 diabetes or impaired glucose tolerance. Insulin, a hormone produced by the islets of Langerhans in the pancreas, regulates the amount of glucose secreted in the blood. Age-related decline in glucose tolerance is usually associated with a higher level of blood insulin.

Physically active people are protected against the development of abdominal obesity associated with NIDDM, and exercise results in preferential loss of abdominal fat. After AET for a period of time long enough to lose a considerable amount of abdominal fat in some insulin-resistant elderly individuals, the decrease in insulin resistance was

substantial enough to result in an improvement in glucose tolerance despite the marked blunting of the insulin response (Figure 6 -A, B) (Holloszy, 1995). In addition, in endurance-trained older runners, plasma glucose responses to an oral glucose tolerance test (OGTT) were similar to those in young runners and young sedentary men, despite a plasma insulin response.

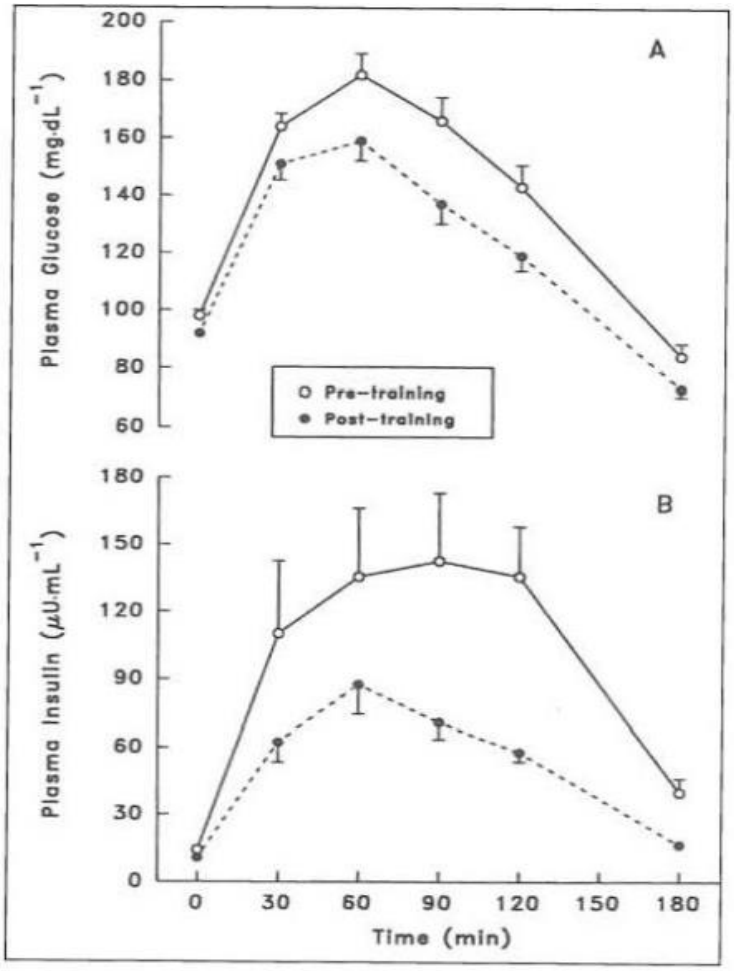

Figure 6. Pre- and post-training plasma glucose (A) and insulin (B) responses toa 75 g OGTT in older people. Data from Holloszy (1995)

These results suggest that AET and a higher VO_2max can induce enhanced insulin sensitivity and better glucose tolerance in older individuals with obesity and/or type 2 diabetes.

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