ANAEROBIC POWER AND PHYSICAL FUNCTION IN STRENGTH TRAINED AND UNTRAINED OLDER ADULTS

by

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CHAPTER I

INTRODUCTION

Sustaining a physical capacity adequate to maintain independence and carry out daily activities is a challenge encountered by many older adults. Declines in muscle mass,[30, 62, 92] strength,[16] and aerobic capacity [10, 14, 27, 42, 53] are associated with the aging process and contribute to a decline in function. Aerobic capacity is important for an older population because oxygen consumption levels have been established to predict dependence [72]. Aerobic capacity for 75-80 year-olds is approximately 1.15 L/min and 1.37L/min for women and men, respectively. Oxygen costs for daily activities have been measured at 0.70 L/min, 0.81 L/min, 0.90 L/min, 1.4 L/min for slow walking (2 mph), showering, using a bedpan, and walking upstairs, respectively[30]. A peak aerobic capacity of <18 ml/kg has been associated with low levels of self reported physical function in daily tasks[72]. A reduction in oxidative capacity may contribute to the increased reliance on another means of energy production. Therefore, functional independence may rely to some extent on the ability to generate short bursts of energy anaerobically. Energy supplied from anaerobic sources may also be important to complete challenging daily tasks such as transferring heavy items, climbing stairs, or rising from the floor.

Anaerobic energy production may also assist with the completion of serial tasks. In order to complete tasks serially, older adults have to maintain a defined level of oxygen consumption. This level required to complete tasks may represent a large proportion of his/her aerobic capacity. Older adults who complete daily tasks at a high percentage of their aerobic capacity are prone to fatigue and are likely to need frequent breaks. These older adults with diminished aerobic capacities may complete tasks and function independently by using energy from anaerobic pathways. Lastly, anaerobic energy production associated with leg power may be important to the success of fall avoidance strategies.

Strength training is effective in changing factors (muscle mass, anaerobic enzymes, muscle force) that affect the anaerobic capacity in older and younger individuals. In addition, in younger adults increases in anaerobic capacity have been reported following strength training[11, 77]. This study has the potential for determining positive benefits strength training may have on anaerobic capacity and possibly physical function. Strength trained individuals may show greater leg strength, as well as anaerobic power when compared to non-strength trained older adults. Women in particular may benefit from an increased anaerobic capacity because physical function status is lower in women than men[9]. In addition, women tend to have lower aerobic capacities, which suggests that they require a higher proportion of the aerobic capacity to complete the same daily activities when compared to older men.

Statement of the Purpose

The primary purpose of the proposed study is to determine the relationship of anaerobic power to physical function. A second purpose is to determine the difference in anaerobic power output and physical function between strength trained and untrained older adults. If anaerobic power is important for completing activities of daily living, interventions that target the anaerobic capacity would be beneficial. Therefore, strength training may benefit older adults through changes in anaerobic power. Strength trained adults may have higher physical function due to higher anaerobic power.

Hypotheses

The hypotheses for the proposed study are:

1) There is a positive relationship between anaerobic power output and physical function.

2) Absolute anaerobic power output will be greater in strength trained (ST) groups vs. untrained (UT) groups. The ST group will have higher mean and peak power relative to fat free mass and lean thigh volume when compared to the UT group. There will be no gender difference in relative mean and peak power (W/kgffm, W/cm^3).

3) ST have higher physical function (whole body-total and lower body function) compared to UT.

Significance of the Study

The proposed study will contribute to the literature by addressing the role of anaerobic power in the performance of daily activities. Studies have investigated anaerobic power output in older adults [64-66, 75] and anaerobic power in younger strength trained adults[44, 50]. Studies have also addressed changes in function following strength training [22, 32, 34]. Anaerobic power in older strength trained adults has not been reported.

Anaerobic power may be an important determinant of physical function. Physical function as defined for this thesis is the ability to perform daily activities independently. At this time, the influence of anaerobic power on physical function has not been reported. The results from the proposed study may support a positive relationship between anaerobic power and physical function. If this is true, an intervention targeting anaerobic power output may also increase physical function. Therefore, if the ST group from the proposed study has higher anaerobic power compared to the UT group, strength-training programs can be recommended to increase anaerobic power and physical function.

Limitations

The study is limited in the following ways:

1) Strength training was not uniform for all participants of the ST group. Differences were apparent within individual training programs (number, type, and intensity of exercises performed). In addition, some subjects participated in strength

training for as short as 3 months while others participated for up to 45 years.

2) Leg circumference may overestimate lean leg volume[75].

CHAPTER II

REVIEW OF THE RELATED LITERATURE

In this section, the following domains of literature relevant to this investigation are reported. The chapter starts with a description of the anaerobic capacity and factors that affect anaerobic power output. Subsequently, data on age related and strength training related changes in components that influence anaerobic power and measured changes in anaerobic work capacity are described. Finally, a brief review on the measurement of physical function and anaerobic capacity is presented.

Anaerobic Power Description

The anaerobic capacity is defined as the capacity to produce energy through high energy phosphagen utilization and anaerobic glycolysis [37]. Anaerobic work capacity (AWC) can be obtained by measuring the total external work performed during a brief maximal or supramaximal bout of exercise [37]. The work produced during a maximal or supramaximal bout of exercise is reflective of the anaerobic capacity and indicates the maximal amount of work that can be done under anaerobic conditions. Anaerobic work capacity values can be expressed as the total work completed in Joules (J), mean power over the work bout in Watts (W), or peak power in Watts. Values from this point forward will only include mean and peak power and will be expressed in Watts. Anaerobic power values may be expressed in relative terms to body weight in kilograms (kg), kilograms of fat free mass (kgffm), and lean leg volume (cm^3).

The capacity to produce energy anaerobically is characterized by the “anaerobic potential.” The level of available fuel sources (ie. resting ATP and phosphocreatine (PC) and anaerobic enzyme functions define the anaerobic potential[37]. High resting levels of ATP and PC and high anaerobic enzyme activity contribute to a larger anaerobic capacity. Thus, anaerobic performance is primarily influenced by the ability to produce lactic acid, quantity of resting phosphate stores, and the buffering capacity of the muscles and blood [93]. Skeletal muscle fiber type [50, 56, 88] and muscle quality (force per unit of muscle) may also influence anaerobic performance. In addition, myoglobin stores, lactate and hydrogen ion efflux, and motivation may play minor roles in anaerobic performance [94]. The factors listed above all influence anaerobic capacity and changes in any of these components may result in changes in the anaerobic capacity.

Anaerobic Power and Physical Function

Anaerobic work capacity expressed as mean power may be important for older adults in completion of serial tasks and difficult daily tasks that last longer than a few seconds (ie. carrying a load of groceries up the steps). Peak power measured during an anaerobic test may be important in more explosive daily activities such as rising from the floor, transferring heavy items, and fall avoidance. For this reason, evaluating peak and mean anaerobic power may be helpful in determining factors that affect daily activities and independent living.

Physical function is described as the integration of physiologic capacity, physical performance, and psychosocial factors and has been used to measure the ability to perform tasks that are important for independent living[23]. An individual's anaerobic work capacity may affect both the physiological capacity and physical performance inclusive in physical function. Strength training may influence physical function by increasing muscle strength and power as well as anaerobic capacity. Physical function becomes particularly important for older adults who experience age related declines in function and performance, and who may also suffer psychosocial declines through limiting environments, withdrawal of role in society, and depression.

Is the anaerobic work capacity related to an individual's ability to complete daily activities? Many daily tasks are short in duration (5 – 45 seconds) and some require quick bursts of energy or powerful movement (i.e. stair climbing, rising from the floor, transferring and carrying heavy items such as groceries or laundry). Completing more challenging daily tasks and completing tasks serially may rely on anaerobic energy. The ability to produce anaerobic energy can be indirectly evaluated through measuring anaerobic work capacity. This capacity may be an important factor contributing to physical function. There is currently no published data that has evaluated the relationship of anaerobic work capacity to physical function.

Age Related Changes

Declines in the levels of anaerobic substrates or anaerobic enzymes (enzyme/given tissue) or enzymatic capacity (rate) would suggest a diminished anaerobic potential in older adults. However, these constituents of anaerobic potential may not be affected by age. The generation of power is also influenced heavily by fiber type composition and phosphocreatine (PCr) turnover. At the cellular level, the fibers associated most often with anaerobic metabolism, type II, tend to decline in size with age [2, 18, 39, 61]. Type II fibers are associated with a high peak power output which in turn is reflective of a high glycogenolytic rate and a high rate of phosphocreatine degredation when compared to type I fibers[49]. The selective atrophy of type II fibers suggests an age related reduced capacity for older adults to perform anaerobic work.

Resting Substrates and Enzymes

Resting energy substrate levels and enzyme activity influence the capacity to generate energy anaerobically. Data show no age-related difference in anaerobic substrates [71]. Anaerobic enzyme capacities have also been shown to remain stable across the adult life span[3]. Little age related change has been observed with resting ATP levels and phosphocreatine[31]. Moller et al. [71] studied substrate and enzyme activity in 14 older males and females and young adults (18 – 36 years old). This research determined a slight drop in resting PCr levels (4%) with no age-related change in the concentration of

ATP. The ATP/ADP ratio was also similar in the young and old adults suggesting the older adults had normal resynthesis of ATP. Feretti et al.[31] examined resting substrate levels in sedentary (age 20 – 65 years) and active groups (26±3 years old). Phosphorus Nuclear Magnetic Resonance Spectroscopy (MRS) is a technique for in vivo quantification of muscle energetics. MRS revealed no difference in resting concentrations of ATP or PC between young and old adults, suggesting there is not an age related decline in resting concentrations between the ages of 20 and 65 years of age. Data from cross sectional research study design have determined that anaerobic enzyme activity of several enzymes (CPK, MK, HK, ATPase, phosphorylase) are similar when comparing young and old groups[2, 18]. These data are based on cross sectional data and should be interpreted cautiously because cross sectional data may be confounded by cohort and period factors. Longitudinal studies to demonstrate true stability within an individual across the life span in these substrates and enzymes have not been done.

<u>Muscle morphology</u>

The age related decline in muscle mass may influence anaerobic capacity. Declines in muscle mass are due to hypoplasia [15, 26, 62] and decreased fiber size[2, 18]. Data from Tzankoff and Norris[92] suggest muscle mass declines by one-third between the ages of 30 and 80 (estimated from 24-hour creatinine excretion). Changes in muscle morphology have also been studied by investigating changes in muscle area. Lexell et al.[62] report a loss of fiber number and size. Data from this cross sectional research suggest a loss of 39% of muscle fibers by age 80 and also indicates a 26% reduction in size of muscle fibers, particularly type II fibers, from age 20 – 80 year old. Longitudinal data from Frontera et al. [33] indicate a 12.5 to 15% decrease in Computed Tomography (CT) measured muscle cross sectional area (CSA) over 12 years. However, other longitudinal data show no age-related change in mean fiber area. Data from middle-aged runners did not show changes in type I or type II fiber area, only an increase in fiber type

I proportion[90]. Recent data from Frontera et al.[33] also show no change in mean fiber area. Others have also found selective fiber type II atrophy,[3, 18, 38] evidence of type I fiber grouping with age [38] and increases in intramuscular connective tissue[61]. Overall, the aging process is associated with a reduction in muscle area through loss of fiber number and size. This reduction influences the ability to generate force and power.

Declines in type II fibers influence anaerobic capacity because they are highly associated with peak power production. Data from Kaczkowski et al. [56] suggest a significant correlation between percent fast twitch fibers and peak anaerobic power ($r = .59$) and mean power ($r = .81$). Others have suggested moderate to high correlations between percent fast twitch area and peak power ($r = 0.60$)[6], percent fast twitch fibers and peak power ($r = 0.72$)[50], ratio of fast twitch to slow twitch fibers and mean power ($r = 0.63$) [6], and percent fast twitch fibers and mean power ($r = 0.57$)[50]. From these correlations, a loss in number or size of type II fibers without a concomitant loss in type I number and fiber size would suggest a disproportional loss of anaerobic power. Thus, the proportion of type II fibers and the fiber area ratio (II:I) may influence the anaerobic capacity.

Does this fiber area ratio change with age? Most researchers [18, 29, 38, 62] report an age related decline in type II: I fiber area ratio. If this ratio influences anaerobic power production, these data also suggest an age-related decline in anaerobic capacity. The II: I fiber area ratio is much higher in younger males compared to females. However, this difference is reduced at older ages. Older men have larger type I and type II fibers compared to older women[29], but the fiber type ratio (II:I) is essentially the same for men and women [18, 38, 62]. The similarity in fiber type ratio implies no gender differences in relative measures of anaerobic capacity for older adults. Therefore, anaerobic power expressed relative to muscle mass should be similar when comparing older men and women.

Muscular Strength

It is well established that muscular strength declines with age. The decline in muscle mass observed with aging contributes to the decline in muscle strength with age. Chamari et al.[16] estimated a drop in force of 0.75%/yr between the ages of 25 and 65. The cross sectional investigation by Larsson et al. [61] also suggests a similar decline in strength with age (0.82%/yr). Longitudinal data from Frontera et al.[34] suggest a larger annual decline in strength: 1.98±1.22 (±SD) to 2.48±1.91% decline in isokinetic knee extensor strength per year. These data and others[40] indicate that the cross sectional research may underestimate declines in strength associated with aging.

Muscular Power

The declines in maximal force and velocity contribute to changes in power. Leg power has been estimated to decline 3.2% - 4.5% per year [60, 83]. This is an astounding 32-45% per decade. The cross sectional study by Kostka et al.[60] suggests a decline in maximal leg power of 4.5% (relative to body weight) and 3.2% (relative to lean quadriceps mass) per year. Similarly, Skelton et al. [83] used a cross sectional design to examine differences in leg power between groups of older adults aged 65-89. The investigators estimated absolute declines of 3.7% and 3.2% per year in lower extremity power (LEP) for males and females, respectively. Leg power decline relative to body weight was estimated at 3.0% and 1.7% per year for males and females, respectively. The larger decline in males may be attributed to a higher peak power in midlife. Aging is also associated with an age-related increase in body fat[75]. Controlling for body fat is more meaningful for describing changes in power. These studies suggest that the decline in power is significant even after controlling for body mass and lean leg mass.

Qualitative changes (changes in fiber type distribution or neural activation) may contribute to the age related loss in power.

Power production is related to physical function. LEP (instantaneous peak power) is correlated to performance in chair rising, a calculation of stair climbing power, and walking[7]. Lower extremity power (W/kg of both legs) of men and women was significantly related to chair rise time (r =- 0.65), time to climb steps 0.635 meters high (r =-0.81), time to walk 6.1 m (r =-0.80), and stair climbing power (r =0.88). Miszko et al.[70] also studied the relationship between LEP and function. LEP was highly related to stair power (r=0.529), walk power (r=0.632), and floor power (r=0.825). Anaerobic capacity measures (mean and peak power) may also be highly correlated with the completion of daily activities.

<u>Anaerobic capacity in older adults</u>

Do older adults have a diminished AWC when compared to younger adults? Some efforts have been made to investigate peak (instantaneous) power [16, 36] and anaerobic power (mean and peak power) [64-66] in older populations. Anaerobic work capacity in older adults has been measured with short maximal exercise bouts on isokinetic ergometers[64, 65] and electronically[66] or friction braked[82] cycle ergometers. Four studies have addressed AWC in older men,[64-66, 76] while only one group of researches have studied AWC in older women [65].

Cross sectional data have been reported on age related differences in AWC. Makrides et al. [65] measured AWC in 10 adults between age 55-71 using an isokinetic ergometer. Peak power and mean power decreased on average 6% per decade. Peak power was reported 1037 Watts (W) for young and 760 W for old, a difference of 27% between the groups. Mean power averaged 656 W for the young men and 455 W for the older men, a difference of 30% between the groups. Women had similar differences in absolute anaerobic power; older women had 30% lower peak and mean power when compared to younger women. The gender difference in absolute anaerobic capacity was approximately 40% (peak and mean power). Makrides et al.[64] evaluated AWC in young (27.4±2.9) and old (aged 65.0±3.3 years) men using the same 30-second isokinetic test. Data show a difference in AWC of 28 % between the two groups when measured at 110 rpm, an average decline of 7.5% per decade. Mean anaerobic power values were reported at 868 W and 625 W for the young and old groups respectively. Marsh et al. [66] investigated differences in AWC between young (30.6±4.5 years) and old (68.5±2.4 years). Mean power was measured at 765.7±62.6 W and 577.4 ±63 W, in young and old adults, respectively. The older subjects had 24 % lower mean power than the young group, an average decline in mean power of approximately 7.6% per decade. The difference in peak power between the groups was similar (22%) to the decline in mean power. Lastly, Overend et al. [76] measured the AWC in old (mean age 70.7±1.3 years) and young (24.4±1.5) recreationally active men. These investigators report a larger difference (40%) in mean power when comparing young (453.3W) to old (270 W), an average decline of 8.9% per decade. This group used a different testing technique, the y-intercept of critical power, to measure AWC.

Anaerobic power has been reported relative to lean thigh and lean leg volume in 3 of the 4 studies described above. Makrides et al.[64] report no difference between young and old when power is expressed relative to lean thigh volume. Additionally, peak and mean anaerobic power were not different between men and women after expressing power relative to lean thigh volume. The older group (males and females) had relative mean and peak anaerobic power of .0529 W/cm^3 and .0873 W/cm^3, respectively. Although males have higher absolute anaerobic capacity, females perform similarly when values are reported relative to lean thigh volume. Lean thigh volume was highly correlated with peak power (r=0.81) and mean power (r=0.80). These results suggest that age related differences in lean leg volume account for the age-related decline in anaerobic power.

In opposition, Marsh et al.[66] found a significant age related difference in peak and mean anaerobic power after correction for lean leg volume. When values were expressed relative to lean leg volume, a 14% difference in mean power was reported between young and old groups, (0.1021 W/cm^3 vs. 0.0875 W/cm^3). Peak power relative to lean thigh volume also remained significantly different between the groups by approximately 12% (0.1556 W/cm^3 for young and 0.1374 W/cm^3 for old). Results from Makrides et al.[64] suggest a difference (23%) in peak anaerobic power expressed relative to lean thigh volume (0.2359 W/cm^3 in young vs. 0.1817 W/cm^3 in older adults). According to these results, age related change in AWC cannot completely be accounted for by changes in lean leg volume and may be linked to qualitative changes in muscle morphology.

Overall, these studies suggest an age-related decline of 7.5% per decade for mean anaerobic power and 5.9% per decade for peak anaerobic power between the ages of 25 and 75. The declines in AWC are much more modest than declines reported in LEP (32-45% per decade). This may be due to healthier subjects tested for Wingate protocols. Declines in AWC and LEP may also be different due to the mechanism required to perform each power test. LEP is a measure of instantaneous peak power and primarily measures neuromuscular power. Measures of AWC incorporate the neuromuscular system while also heavily relying on metabolic (anaerobic) capacity. As noted earlier, anaerobic potential defined by resting substrates and enzyme capacities appears to remain unchanged across the life span. This may explain in part why AWC experiences moderate age related declines compared to LEP.

Strength Training Adaptations

Interventions influencing anaerobic capacity

Sprint training and strength training affect components of the anaerobic capacity and may influence activities of daily living. Although sprint training can be effective for increasing the anaerobic work capacity, orthopedic issues may render this mode of training impractical for an older population. In addition, some data[64] suggest that sprint training may not be effective in changing AWC for older adults. No significant changes in AWC were reported after 12 weeks of high intensity endurance training (3 hrs/wk). Older subjects (healthy/sedentary) performed 5-minute cycle sprints at 85% of VO_2peak while maintaining a workload at 65% of HRmax in between each sprint. Swensen et al.[86] report that interval training and high intensity strength training both were equally effective for increasing power output in young adults. In addition, large AWC have been measured in young strength trained adults (mean power = 8.0 W/kg) [44], which suggests that strength training may influence AWC for older adults. Furthermore, changes in anaerobic capacity have been measured following strength training programs [11].

Positive effects from strength training protocols that may influence components of the anaerobic capacity are reported in the following pages. Significant changes in older adults following strength training include increases in strength [25, 32, 34, 43, 45, 82, 84] muscle area, [17, 32, 34, 45, 89] cross sectional area, [24, 45, 84, 89, 97]and specific tension[43, 58, 73, 89, 97]. Increases in power have also been shown with resistance training [55, 82, 84]. Investigators have used strength-training programs ranging for 2 – 6 months, and have included males and females ranging from 58 - 95 years old. Although these studies do not directly assess anaerobic capacity, they do report on some of the factors that affect anaerobic capacity and how their response to strength training in older adults.

Substrates and enzymes

The results are mixed regarding the effects of strength training on the anaerobic energy substrates and enzyme measures (components of anaerobic potential). If these do adapt with strength training, after strength training an individual may have a greater potential for anaerobic energy production. Researchers provide positive support for increased anaerobic energy potential after strength training through increased activity of lactate dehydrogenase (LDH) and myokinase (MK), increased intramuscular stores of ATP and (phosphocreatine) PC, increased CPK (creatine phosphokinase, and increased hexokinase (HK)[63, 71, 74, 88, 96]. These substrates and enzymes play key roles in the production of anaerobic energy through the breakdown of PC or through anaerobic glycolysis. MacDougall et al.[63] found a substantial change in resting substrates after 5 months of heavy resistance training in men aged 19 – 22 years; the concentration of CP and ATP increased by 22% and 18% respectively. Data from Orlander and Anainsson[74] revealed an increase in LDH (49%) and PFK (26%) with 12 weeks of static and dynamic physical training in older adults. Meanwhile, Tesch et al.[87] and Costill et al.[20] showed no change in CPK and MK with 6 months and 7 weeks of resistance training, respectively. Goreham et al. [35] did not find a change in resting substrate levels of ATP or PC following 12 weeks of heavy resistance training using loads of 6-8 RM (the highest weight that can be lifted for 6 to 8 repetitions). Houston et al.[48] also showed no change in PFK, HK, and CK with resistance training. At this time, anaerobic enzymes may undergo changes during strength training, but the existing evidence does not consistently support this change.

Muscular strength changes

The effects of strength training on muscular strength in older adults have been investigated by many groups. Eight select studies will be briefly described below to illustrate studies focusing on men, women, men and women, and frail older adults, which demonstrate changes in strength following strength training. These studies also show that different strength training programs increase strength. Frontera et al.[34] trained 12 males (60 – 72 years old) for 12 weeks using a “thigh-knee” dynamic machine. Training was done 3 days/wk at 80% 1RM using 3 sets of 8 repetitions. Results show a 5% per training day increase in 1RM strength resulting in a 100 – 190% increase in strength over 12 weeks and a 6.4 – 14.2% increase in isokinetic strength (60 degrees/sec and 240 degree/sec). Hakkinen et al. [45] studied 10 older men (61±4 years old) before and after 10 weeks of strength training. The periodized, progressive resistance training program included 3- 6 sets of exercises 3 day/wk (one day using 8-10 RM loads, one day with 15 RM loads, and the third day with 3 –5 RM loads). After 10-weeks maximal isometric knee extensor strength increased by 16.5%. Older women have also been shown to be responsive to increases in strength following strength training. Skelton et al. examined changes in isometric knee extensor strength after 12 weeks of progressive resistance training (3 day/wk) in older women aged 75 – 90 years old[84]. Resistance was provided by body weight, weighted back-packs, rice bags, and elastic tubing for 3 sets of 4 - 8 repetitions. Isometric knee extensor strength (absolute and relative to body mass in kg) increased 27%. Shaw and Snow investigated changes in strength in 44 women (aged 62.6±6.6 years) after a 9-month weighted vest training program which included stepping, squats, chair raises, lunges, and toe raises [82]. After 9-months, peak isokinetic force increase ranged from 16.6±16.5% – 33.3±21.8% for hip abduction, knee flexion, and ankle plantar flexion. Cress et al.[25] trained older women (72±6 years old) for 50 weeks using a combined endurance and resistance protocol. The isokinetic dynamic strength index (DSI) from the knee flexors/extensors increased by 9.4% while the control group declined in DSI by 5.3%. Pyka et al. [79] studied men and women (age 68.2±1 SEM) for one year using a 12-exercise circuit training program 3 days/wk (load = 75%1RM, 3 sets of 8 repetitions). After 8 weeks of circuit training exercisers significantly increased strength and continued to increase strength slowly over the next 42 weeks. The exercise group increased strength (ranging from an increase of 32.0±5.2% to 96.8±12.4 %) while the non-exercise control group experienced a loss of strength (ranging from -2.9±1.3% to -4.5±2.6%). Hakkinen and Hakkinen[43] investigated changes in strength, cross sectional area, and integrated electromyographic activity (IEMG) (to determine muscle activation) after explosive strength training in older male and females (64 – 73 years old). The repetitions during the training were done as quickly or explosively as possible. Maximal isometric leg strength increased over the 12-week training period ($p<0.001$). Inferring from the graphed data, the mean increase in maximal force was approximately 16% and 33% for older men and women, respectively. Muscular strength adaptations have also been shown in frail older adults following strength training. Fiatarone et al. [32] used a high intensity strength training protocol in frail older adults (mean age 90.1±1 years). Eight weeks of progressive resistance training (3 day/wk) included 3 sets of 8 repetitions at 50 – 80% 1RM. The average dynamic strength gains were 174±31% after eight weeks. These data suggest that various protocols for strength training are useful for increasing muscular strength. The evidence to suggest that strength can be increased in older men and women through a variety of strength training programs is overwhelmingly.

<u>Muscle morphology changes</u>

Strength training in older adults has also shown to increase muscle size through increases in muscle area or muscle fiber cross sectional area. Charette et al. [17] found a 20.1±6.8% increase in mean type II fiber CSA in older women after a 12-wk-resistance training program. Frontera et al. [34] reported increases in muscle area of 10 – 11% after 12 weeks of resistance training. Fiber CSA of type I and type II also increased significantly by 33.5% for fiber type I and 27.6% for fiber type II. In Fiatarone et al.'s [32] study on frail older women, total mid-thigh muscle area increased 9.0± 4.6% after 8 weeks of high-intensity strength training. Cress et al.[24] report changes in myofibrillar area following a year long endurance and strength training combined program with older women (73.3±7.0 years old). The change in myofibrillar area was 6.2% greater when compared to the control group change after one-year. The older men in Hakkinen et al.'s[45] strength training study described earlier increased type I CSA from 4091±1354 to 5044±832 μm^2 (23% increase) and type IIa CSA 3879±323 to 5337±851 μm^2 (38% increase) following training. According to data from Tracy et al., [89] training resulted in a 12% increase in quadriceps volume for males and females after 9 weeks. Results from Pyka et al. [79] reveal an increase in type I fiber CSA (3872±259 to 5742±187 μm^2) and type II fiber CSA (3245±183 to 5246±264 μm^2) after 30 weeks of resistance training. The existing data suggest that strength training can cause increases in muscle fiber size and muscle area for older males and females. It appears that increases in muscle size result from changes in fiber type I and type II.

Neural adaptations

The force produced per unit of muscle (specific tension) also increases with strength training. Increases in specific tension suggest that increasing muscle size alone does not account for the entire increase in strength evident after strength training. Rat data suggest that specific tension is increased after strength training in old rats (24 –29 mos.) [59]. The investigation by Tracy et al. [89] noted previously also demonstrated increases in specific tension for older adults. Specific tension (N/cm^3) in the trained and untrained leg increased by 14±4 and 8±3% in men and 16±4 and 10±3% in women. Welle et al. [97] also examined the effect of strength training on specific tension (3RM-strength/muscle CSA) in older adults. Older subjects showed a 32% increase in specific tension after 3 months of training. Results from Klitgaard et al.[58] show a 54% greater specific tension of the quadriceps for strength trained (~69 N/cm^2) vs. sedentary older adults (~46N/cm^2). These strength trainers had lifted for 12 or more years (ranging from 12 to 17 years).

Neural adaptations may be observed by recording integrated electromyogram (IEMG). Moritani and deVries [73] reported increased IEMG activity after progressive resistance training two days/wk for eight weeks. The progressive resistance training increased strength by 22.6% in the trained arm. Muscle activation increased approximately 23% after the training without increases in cross sectional area (measured by skin fold technique)($p=0.10$). Hakkinen and Hakkinen [43] noted increases in strength ($p<0.01$), CSA ($p<0.05$), and IEMG ($p\leq 0.05$) in the quadriceps femoris after 12 weeks of explosive strength training. The increase in strength was accounted for by both increases in muscle CSA and IEMG. Changes in muscle size as well as changes in neural components (synchronization, increased recruitment, or decreased antagonistic muscle activity) account for improvements in strength. In addition to strength, these adaptations in muscle activation may also contribute to peak and mean power. Therefore, neural changes associated with strength training may also influence anaerobic power.

Power changes

Can strength-training interventions change power production? Data suggests that power may be increased through training[55, 82]. Jozsi et al. [55] investigated arm pull power and leg extensor power of older men and women (mean age = 60.3±0.8) after 12 weeks of resistance training. Both arm pull power (resistance at 40 and 60% 1RM) and leg extensor power (resistance at 80%1RM) increased after training. Shaw and Snow[82] trained older women (mean age = 64.2±5.8) using a 9-month weighted vest exercise program and found an increase in peak power for the exercise group. Results from an abbreviated Wingate anaerobic test showed a significant increase in absolute power of 13±12% (3.5±3.3% increase relative to lean leg mass) after 9-months. Although this weighted vest protocol is not a typical strength training program, it is reported here because the program was designed to add resistance in which the body was forced to overcome and therefore it can be compared to strength training. These data suggest that power can be increased following training in an older adult population.

Physical Function

Increases in strength are important because they may be reflected as increases in function[32, 83]. Data from Fiatarone et al. [32] show an increased tandem gait and 6 m walk time, while data from Skelton et al.[84]showed increases in chair rise time and step height with resistance training. Researchers[13] however, failed to show significant differences in other functional measures, possibly due to training protocol (elastic tubing) or inappropriate functional measures. Cress et al.[22] showed significant changes in function in older adults with a 6-month combined endurance and strength-training program. Physical function, as measured using the Continuous Scale Physical Function Performance Test (CS-PFP) increased by 14% following the training. Individuals in the exercise group carried 14% more weight while moving 10% faster after the training program.

Leg power may be more important than strength alone in performing activities such as chair rising and stair climbing. The studies above support a change in function with strength training. Is this change in function associated with strength training due to changes in anaerobic capacity? Currently data are not available on the relationship between anaerobic capacity and physical function or how increases in strength may influence anaerobic capacity, which may in turn influence physical function.

Strength Training and Anaerobic Work Capacity

Does strength training affect the ability to produce anaerobic energy in older adults? After a thorough search of the literature, few data were found on the measured AWC of older strength trained individuals. Shaw and Snow report a 13% increase in absolute peak anaerobic power, measured a 15-second abbreviated cycle test, following 9 months of weighted vest training. Data have been reported on the effect of strength training in younger adults following training. The following data reveal significant changes in the anaerobic capacity with strength training in young adults. Results from Inbar[50] using the Wingate anaerobic test reveal a mean power of 8.6 ± 0.2 W/kg for a combined group of elite male Israeli wrestlers and weight lifters. Inbar[50] also reports results from healthy untrained males ages 16-45 years old ranging in relative mean power ranging from 4.29 ± 0.78 to 4.72 ± 0.65 W/kg, a difference of 50% between ST and UT men. In agreement, elite weight lifters in Hakkinen's investigation averaged 8.45 W/Kg for mean power[44]. This maximal effort test lasted 60 seconds (compared to the standard 30 seconds). Therefore, mean power was examined over a longer duration. Weight lifters in this study are likely to have even higher mean power with the standard 30-second test. Anaerobic tests longer than 45 seconds may not be appropriate for measuring anaerobic power because anaerobic energy production can only be maintained for short durations.

Others have reported increases in AWC following strength training [1, 11, 77, 85, 88]. Peterson et al. [77]studied the change in anaerobic work capacity in 12 elite swimmers after a five-week high-velocity weight-training program. Swimmers trained 4 times a week using circuit training for the first 15 sessions (including exercises emphasizing leg extension/flexion, ankle plantar flexion) and variable resistance machines for the last six sessions. The Wingate test was used to measure anaerobic power. Absolute and relative mean power significantly changed from 601.0 ± 15.6 (pre) to 636.8 ± 17.2 W (post) and 8.4 ± 0.02 W/kg (pre) to 8.8 ± 0.2 W/kg (post) ($p<0.001$). Bishop and Jenkins[11] investigated the effect of six weeks of strength training on the AWC in moderately active young males (18-24 years old). Participants trained 3-4 times/wk with 2 sets per station using incline leg press, squats, horizontal leg press, and calf raises. The training program was periodized to result in high load sets to failure**.** Following training the AWC (measured by the y-intercept of critical power) significantly increased by 25.9% ($p<0.05$), with no change in the control group. Thorstensson et al. [88] studied the effects of eight weeks of strength training and jumping on fiber characteristics and functional tasks. Training included 3 days/wk completing 3 sets at 6 RM of exercises loading the knee extensors and 3 sets of 6 vertical and broad jumps. The Sargent jump test was used to estimate changes in anaerobic capacity. After 8 weeks, jump height increased 22% ($p<0.001$). Unfortunately, no control group was used for comparison.

In summary, these data suggest that strength and jump training can increase the anaerobic capacity in younger populations. Older adults have similar abilities to make the same relative adaptations to strength training compared to younger adults and therefore may also show increases in anaerobic work capacity after strength training. The data above on AWC in younger trained adults have not been reported relative to fat free mass or lean leg volume. Therefore data on young strength trained adults will be difficult to compare to values from older adults.

Measurement of Physical Function

Description

Several tests have been established to measure or estimate physical function[23, 41, 80]. The Continuous Scale Physical Functional Performance (CS-PFP) test developed by Cress et al. is a unique, valid, and reliable test of physical function[23]. The continuous scaled nature of the CS-PFP detects a broad range of function, involving 16 everyday tasks ranging from low to high effort. The score from each task contributes to 2 or more of the five physical domains (upper body strength, lower body strength, balance and coordination, endurance, and upper body flexibility) allowing total body physical function to be evaluated. The original version of the CS-PFP was evaluated with 148 older adults from different living status (community dweller, long-term care residents living independently and long term care residents living with some dependence) [23]. Differences in physical function were detected between the three groups, demonstrating construct validity. High test-retest reliability was shown in all domains and total CS-PFP score (r = .85 - .97). The CS-PFP is scaled from 0-to-100 with 100 reflecting higher function[21]. The test is sensitive in detecting changes in function following training[22].

Twenty-three men and women ($\geq$ 70 years old) participated in an exercise program designed to load muscle groups recruited during daily tasks (stair stepping, leg press machine, Gravitron machine for upper body training, and free weight exercises). After the 6-month intervention, the physical function score was increased by 14% (p = .004) and increases were also reported in the lower body strength, upper body strength, and endurance domains.

Measurement of Anaerobic Power

The Wingate anaerobic test

A number of tests exist that have been designed to measure anaerobic ability [94]. The Wingate test is a maximal effort performance on a friction braked cycle ergometer [50]. The Wingate anaerobic test determines AWC by counting the number of revolutions completed during a 30-second period with a known resistance. The following equation can be used to determine AWC: # of revolutions X 6 meters per pedal revolution X resistance (kp) X 2. Total work (Joules), peak power (Watts), mean power (Watts), and fatigue index can be measured during the test.

The Wingate test has been used extensively in past research to measure anaerobic work capacity. The 30-second Wingate anaerobic test [4, 66] and the abbreviated Wingate test (15-sec) [4, 82] have been used to study older adults (aged $\geq$ 65 years). Abbreviated tests (15 seconds) may be appropriate to measure peak anaerobic power, but may not be appropriate to measure mean anaerobic power due to the short duration. In these studies measuring AWC in older adults, a friction or electronically braked bike was used for testing. Makrides et al.[64, 65] have also tested older adults using a 30-second isokinetic Wingate test. Typically, Wingate resistances are set relative to body weight [50] or relative to body weight plus lean leg volume [30]. The above studies have used resistance settings between 0.075 kp/kg - 0.085 kp/kg. For younger populations, the test load is typically set at 0.085kp/kg body weight for the average male (70kg, 18% body fat). The following equation may be used to determine the load in an older population based on the lean mass in an average young male (57.4 kg) and the typical load set for a young male during the Wingate test (load = 0.085 kp/kg bodyweight).

$$\frac{\text{Load average for young male (0.085)}}{\text{Load other (older adult)}} = \frac{\text{Lean body weight for average male (57.4kg)}}{\text{Lean body weight for older adult}}$$

$$\frac{0.085}{X} = \frac{57.4}{LBM}$$

$$\text{Load (kp)} = (57.4 * \text{LBM}) / 0.085$$

This equation may be helpful in considering the optimal resistance for testing older adults who typically have higher percentages of body fat than young adults.

Reliability and validity of the Wingate anaerobic test

The Wingate test has been shown to be reliable with mean power test-retest correlations ranging between r = .89 - .97[4, 50, 56]. Older patients with chronic obstructive pulmonary disease were tested for reliability with the abbreviated Wingate test, suggesting good reliability in Wingate testing for older adults. At this time, no other data on test-retest reliability have been published for older adult.

Presently there is not a gold standard for measuring anaerobic capacity. However, the Wingate test has been compared to anaerobic performance tasks to examine validity. The review by Inbar et al. [50] shows significant correlations (r = ± 0.69 - 0.92) between the mean power calculated from the Wingate test and performance measures such as a vertical jump and short swimming, skating, running, and cycling tests.

Gender differences in anaerobic capacity

Gender differences are present when anaerobic capacity values are expressed in absolute terms or relative to total body mass in younger populations. Researchers report gender differences in anaerobic capacity measures even after controlling for body weight[50] and fat-free mass [68, 81]. The proportion of type II fibers is higher in younger males compared to females and may be directly related to differences in anaerobic capacity between the genders. The high correlations reported between the proportion of type II fibers and anaerobic capacity [6, 50, 56] suggest that an average young man should have a higher anaerobic capacity (relative to body weight and fat-free mass) when compared to a young woman. Inbar and colleagues[50] reported significant gender differences in anaerobic work capacity measured from a 30-second Wingate anaerobic test. A significant gender difference remained in anaerobic work capacity values after correcting for body weight. Mayhew et al. [68] used several performance measures (vertical jump, standing long jump, Margaria step-running test) to examine anaerobic power in a large group of untrained young adults (n = 181). Gender differences persisted in the measures of anaerobic power after controlling for lean body mass, leg strength, and nueromuscular function. However, data from Maud and Schultz suggest no difference in anaerobic capacity in active young males and females (aged 18 – 28) after correcting for fat-free mass [67]. Data from Vandewalle [94] also suggest no gender difference in AWC when values were expressed per lean body mass. Despite opposing findings in gender differences when examining relative anaerobic power, the high correlation between anaerobic capacity and type II fibers would suggest a pronounced gender difference in anaerobic capacity measures in younger populations. The gender difference in the fiber area ratio diminishes with advancing age and most studies report no gender difference in fiber area ratio in older adults. Therefore, if the proportion of type II fibers is responsible for the difference in anaerobic capacity (relative to fat-free mass) in a younger population, a gender difference in the anaerobic work capacity measured relative to fat-free mass or lean leg volume would not be present in older ages.

Anaerobic metabolism during maximal exercise

Blood lactate is measured following an anaerobic test to ensure that energy was derived at least partially from anaerobic metabolism. Although muscle blood lactate concentrations are higher than blood lactate concentrations, blood lactate is used as a validation of anaerobic capacity tests including the Wingate test[5]. Lactate levels have shown to be highly correlated with relative peak anaerobic power (W/kg). A correlation of r = 0.87 (wet weight) and r = 0.76 (dry weight) was found between peak power and change in concentration of muscle lactate (mmol/kg)[50]. For younger populations, blood lactate normally peaks between 3-to-5 minutes post exercise[91]. However, older adults may have a longer lactate diffusion time, with peak blood lactate for older adults peaking between 7-to-9 minutes [91]. Based on this, it appears that peak blood lactate should be measured 7-to-9 minutes following maximal testing for older adults.

Normalizing anaerobic work capacity values

Anaerobic capacity values can be normalized to fat free mass or lean leg volume to eliminate some differences in body size and gender and to examine neuromuscular contributions. Lean leg volume can be determined using the methods of Jones and Pearson[54]. In an older population, this is important because it should remove gender differences. Lean thigh volume may be more appropriate to use for normalizing anaerobic power for stationary cycling because the upper leg muscles (quadriceps and hamstrings) contribute most of the power compared to the lower limb musculature (triceps surae). This method involves circumference, skin fold and height measures of the leg. Seven circumference measures are made at the following sites: gluteal furrow, one-third of the subischial height up from the tibial-femoral joint space, the minimum circumference above and below the knee, the maximum circumference around the knee joint space, the maximum calf circumference, and the minimum ankle circumference. Height from the floor is measured at each site. Skin folds are done with a Lange caliper at four sites: the anterior and posterior thigh, mid line at the one-third subischial height level, and medial and lateral skinfolds of the calf. Volume (in liters or cm^3) is calculated from the 6 truncated cones using the following equation.

$$V = 1/3h\ (a + (ab)^{1/2})\ + b$$

In this equation, (a) and (b) are the areas of the two parallel surfaces and (h) is the height measured between the two parallel surfaces. This procedure has been shown to overestimate lean leg volume[19, 47, 86] however, equations have been developed in attempt to correct for the overestimation [86]. A strong relationship is detected between anthropometric measures (estimated) and computed tomography (actual) (r = .94 - .98)[19, 86] and magnetic resonance imaging (actual) (r = .85-.88)[47].

<u>Warm-up for Wingate testing</u>

Unfamiliar or maximal exercise may require a warm-up and familiarization bout of exercise. Presently, there is no standard warm-up prior to the Wingate test. A warm-up period may be essential to data collection if subjects become injured without warming up or if values increase when subjects perform a warm-up period prior to the Wingate test. In young boys (7-9 years old) a 15-minute intermittent warm-up increased mean power by 7%, suggesting that a warm-up may alter measures of anaerobic work capacity [50]. Studies involving older adults have included warm-ups prior to Wingate testing. Marsh et al. [66] used a five-minute warm-up targeting low heart rate (100-120 beats/min) interspersed with several all out 5 second sprints before testing older adults. The subjects in the research by Shaw and Snow performed five minutes of warm-up at a low load (0.5 kg) at 40 – 60 RPM prior to completing the abbreviated Wingate test[82]. These groups did not examine the effect of the warm-up period on performance, but the information can be useful in designing warm-up protocols for an older adult population.

Aerobic training and the anaerobic capacity

Aerobic capacity does not influence anaerobic performance. Medbo and Burgers compared the anaerobic capacities in untrained, endurance trained, and sprint trained athletes using the maximal accumulated oxygen deficit test[69]. No difference was measured between the anaerobic capacity of the endurance trained and untrained groups, whereas sprinters had a 30% greater anaerobic capacity than both groups. Likewise, Keren and Epstein found no change in anaerobic capacity after endurance training young adults (25±1 years old), 4 hours of running/jogging per day for three weeks[57]. A significant increase in aerobic capacity (19-33%) without changes in the anaerobic capacity was reported after three weeks. Most reported findings suggest no effect of aerobic training on AWC, which suggests that aerobic capacity doe not confound measures of AWC.

Climate, hydration, motivation, and circadian rhythm

Other factors that may effect the Wingate test are climate, hydration, motivation, and circadian rhythms. Climate and hypohydration do not seem to affect performance during the Wingate test[50]. Motivation in the form of cognitive information (ie. presence of an audience) during the Wingate test has been shown to be ineffective on Wingate tests [50]. Inbar has found that reward and punishment motivation may have positive effects on the outcome of the test[50]. The effects of the circadian rhythm on the heart rate and temperature may influence the test [46]. According to Hill and Smith[46], as temperature and resting heart rate increase from 0300 hours to 2100, the results of the Wingate test may increase. In this study, 6 men (22±3 years old) performed Wingate tests. Conflicting results presented from Inbar suggest that the AWC test is not affected by circadian rhythm[50]. Wingate tests performed every 4 hours for 24 hours revealed no difference in measured anaerobic work capacity. In summary, investigators should organize testing sessions during the same hours for all participants in order to avoid confounding factors from circadian rhythm. Although motivation may not influence results in young population, it may be important to provide motivational support for older adults during Wingate testing.

CHAPTER III

ANAEROBIC POWER AND PHYSICAL FUNCTION IN STRENGTH TRAINED AND UNTRAINED OLDER ADULTS[1]

[1] Slade, J.M., T.A. Miszko, J.H. Laity, S.K. Agrawal, M.E. Cress. To be submitted to Journal of Gerontology: MEDICAL SCIENCES

Abstract

The purpose of this study was to determine the relationship between anaerobic capacity and performance-based physical function. In order to examine a broad range of ability in anaerobic capacity, a strength trained (ST) and untrained (UT) group of older adults were recruited. Using a cross sectional design, measures of anaerobic power (Wingate anaerobic test), physical function (Continuous Scale Physical Functional Performance Test), lower body strength, and lean thigh volume were obtained in 35 older men and women (mean age = 71.5±6.4 yr.). Mean and peak anaerobic power were significantly related to whole body physical function ($r=0.642$, $r=0.521$, respectively $p<0.05$) and lower body physical function ($r=0.692$, $r=0.611$, respectively $p<0.05$). There was no significant difference between groups for lean thigh volume. The ST group had greater leg strength, anaerobic power, and physical function when compared to the UT group ($p<0.05$). We conclude that strength trained older adults have higher anaerobic capacity, which in turn contributes to higher physical function.

INDEX WORDS: **Anaerobic capacity, physical function, Wingate anaerobic test, strength training, lean leg volume, aged, activities-of-daily-living**

Introduction

Sustaining a physical capacity adequate to maintain independence and carry out daily activities is a challenge encountered by many older adults. Declines in muscle mass (1-4), strength (2,5-7), and aerobic capacity (8-11) are associated with the aging process and contribute to the loss of physical function. Data also support an age-related decline in anaerobic capacity (~7.5% decline per decade) (12-15). Aerobic capacity is an important determinant of function (8,16). Oxygen costs for daily activities have been measured at 0.70 L/min, 0.81 L/min, 0.90 L/min, and 1.4 L/min for slow walking (2 mph), showering, using a bedpan, and walking upstairs, respectively (1). A peak aerobic capacity of <18 ml-O_2kg^{-1}min^{-1} has been associated with low levels of self reported physical function in daily tasks (16).

Functional independence may rely to some extent on the ability to generate short bursts of energy anaerobically. Energy supplied from anaerobic sources may be important to complete challenging daily tasks such as transferring heavy items, climbing stairs, or rising from the floor. As peak aerobic power declines, daily tasks require a higher relative oxygen consumption, which in turn may necessitate a greater reliance on anaerobic means of energy production. Older adults with diminished aerobic capacities who complete daily tasks at a high percentage of their aerobic capacity, are prone to fatigue and are likely to need frequent breaks. These older adults who function independently may intermittently require energy from anaerobic pathways to complete daily tasks.

If anaerobic power is related to completing tasks of daily living, exercise programs that increase the anaerobic power output would be beneficial. Strength training may influence anaerobic power in older adults as it has been reported in younger adults (17-23). We hypothesized that strength trained older adults (ST) would have higher mean and peak anaerobic power when compared to untrained older adults (UT). Also, the ST group would have higher physical function and anaerobic power would be positively correlated with physical function, as measured by the Continuous Scale Physical Functional Performance Test (CS-PFP score). The primary objective of this study was to determine the relationship of anaerobic power to physical function across a range of strength trained and untrained older adults.

Methods

Subjects. Thirty-five older adults (aged 60 to 90) were recruited from the Athens community to meet requirements for two distinctly different groups: ST (n=10 males, 7 females) and UT (n=8 males, 10 females). Current participation in a strength training program (≥ 2 days/wk) for 12 or more weeks consisting of whole body strength training (≥ 8 exercises) was used to determine eligibility for the ST group. Strength training programs included leg extension, leg press, or squat exercises. Participation in a strength-training program was an exclusion criterion for the UT group. Aerobic training was not an exclusionary criterion. Exclusion criteria for both groups included uncontrolled diabetes, diseases with variable disorders, recent bone fracture or hip replacement (within 12 months), severe osteopenia, and severe hypertension. Written physician clearance and participant consent as approved by the Institutional Review Board at the University of Georgia was obtained prior to testing.

Design. A cross sectional design examining older adults (ST and UT) was used to determine differences in anaerobic power and physical function. The independent variable was training and the dependent variables were anaerobic power, physical function, lower extremity power, and leg strength. Subjects performed tests of anaerobic power, leg strength, and physical function on three separate days.

Lower extremity physiological measures.

Anaerobic power (mean and peak power) was measured during a cardiologist-supervised Wingate test. The Wingate test is a valid (20) and reliable (20,24,25) measure of anaerobic power. The 30-second Wingate test was performed on a Monark friction-braked bike (Varberg, Sweden model 814E). Fat free mass (FFM) was used to determine the load applied during the Wingate test.

$$\text{Load (kp)} = (57.4 * \text{FFM}) / 0.085$$

This equation is based on a 70 kg person with 18% body fat (FFM = 57.4 kg) and a load of 0.085 kp/kg body weight. Prior to the test, resting 12-lead electrocardiograph (ECG) and blood pressure were recorded. Each subject performed a 5-minute warm-up at a low resistance, interspersed with 5-second sprints at various resistance settings. After the warm-up, a 7-second countdown was given after which the subject increased to maximal pedal frequency and the total load was applied to the flywheel. Throughout the test, subjects were verbally encouraged. An optical sensor was used to detect reflective markers on the flywheel of the cycle ergometer. The sensor was interfaced with a PC with software from Sports Medicine Industries (St. Cloud, MN) to calculate power indices. Measures obtained included absolute peak power (highest five-second average), mean power (average power output over 30 seconds) and the fatigue index (the difference between the highest and lowest five-second interval of power output). Results are expressed in Watts, and in Watts relative to body weight, FFM, and lean thigh volume. Following completion of the test, the subjects either sat quietly on the bike or pedaled slowly against 0.5 kp resistance for 3 minutes or until heart rate returned to resting. Rating of perceived exertion (RPE) was assessed immediately after the test using the Borg scale (26) and heart rate was recorded. A whole blood sample was obtained 7.5 minutes post exercise from a pre-warmed finger. Duplicate heparinized samples were processed immediately using the YSI 2300 Stat Plus lactate analyzer (Yellow Springs, OH). Both ECG and heart rate were monitored throughout warm-up, exercise, and recovery.

Lower extremity power (LEP) can be reliably measured using the Nottingham Power Rig (Nottingham, UK) (27). Peak instantaneous power was determined from the velocity (RPM) of the flywheel measured with an optoswitch timed by a microcomputer, as previously described (27). Each subject was familiarized to the Power Rig by performing five practice pushes on each leg. The subject performed trials until he/she reached a plateau where LEP did not increase over 2 consecutive trials. The highest power output from a single push was used as the peak LEP. LEP is reported as the sum of the peak push from the right and left leg.

Leg strength was determined from a one-repetition maximum (1 RM) using the Alliance Rehab double leg press (Chattanooga, TN). 1 RM is defined as the maximal weight that can be lifted one time holding to good form (28). Participants were familiarized with the leg press on a day prior to the 1 RM test. Familiarization included 2 sets of 5 to 10 repetitions at a moderate resistance (40 to 80 lbs). Upon returning to the lab, each subject performed a warm-up set of five repetitions at a moderate resistance. Higher loads were attempted until reaching 1 RM. Rest intervals between each trial were $\geq$ 3 minutes. Maximal strength was measured to the nearest 5-lb increment.

Body composition. Percent fat was estimated from the sum of 7 skin folds using Lange calipers (Cambridge, MD) and valid gender-specific equations (29,30). Lean leg volume was determined using anthropometric procedures according to Jones and Pearson as previously described (31). This procedure includes seven circumference measures, height of the leg, and 4 skinfolds (anterior/posterior thigh and medial/lateral calf) to yield lean leg volume and lean thigh volume. For body composition, the same tester measured each site and recorded values to within 2 mm and 0.25 cm for the skinfolds and circumferences, respectively.

Physical Function. The Continuous Scale Physical Functional Performance Test (CS-PFP) is a valid and reliable measure of physical function (32). Ceiling effects are not present for this performance-based measure making it ideal for evaluating function in adults with higher levels of fitness. The CS-PFP is comprised of 16 everyday tasks including making a bed, getting down and up from the floor, stair climbing, and transferring laundry (32). The test was administered in a standardized environment with standardized instructions as explained on the World Wide Web (http://www.coe.uga.edu/csp-pfp/). Each of the 16 tasks contributes to one or more of 5 domains to comprise the CS-PFP score. The domains of the CS-PFP are lower body strength (LBST), upper body strength (UBST), upper body flexibility (UBFL), balance and coordination (BALC), and endurance (ENDU). A range of functional abilities in older adults has been tested to establish the 0-to-100 scale (1 = low, 100 = high) (33).

Statistical analysis. Statistical analyses were performed using SPSS for windows, version 10 (SPSS Inc. Chicago, IL). A two-way (training X gender) analysis of covariance was used to determine differences in anaerobic power output and physical function. A one-way analysis of covariance was used to evaluate main effects for training group. The covariate used for these analyses was age. Pearson's r was used to determine the relationship between physical function and power output (anaerobic and lower extremity). Linearity and best model were examined for all correlations. Fisher's Z was used to determine differences between correlations. An alpha level of 0.05 for statistical significance was used for all analyses.

Results

Fifty-two older men and women were recruited from the Athens, GA community. Of the 52 recruited, 33% were excluded; 17 were not medically cleared (n = 4) or did not complete the study due to personal reasons (n=13). The final sample of 35 older adults (17 males and 18 females) reflected a 67% completion rate.

Selected physical characteristics are listed in Table 1. There was a significant age difference between UT and ST groups. There were no significant differences in FFM or lean thigh volume between the ST and UT groups. Males were heavier, taller, and leaner than women and had greater absolute and relative (W/kg) anaerobic power ($p<0.05$). Leg strength and specific tension (1 RM/ thigh volume) were significantly higher in the ST groups ($p \leq 0.004$ and $p \leq 0.003$, respectively). The average period of time involved in strength training for the ST group ranged from 3 months to 40 years (mean = 4.89 years, median = 5.5 months, mode = 3 months).

Results for the two-way ANCOVA revealed no significant interactions between training group and gender for all dependent variables. A significant effect for gender, but not training, was found for mean and peak power (both absolute and relative to body weight). However, when expressed relative to lean thigh volume, there was no effect of gender on mean and peak power. Based on the results of this analysis, males and females were analyzed together with a one-way ANCOVA using age as the covariate. Significant differences between the training groups for mean power ($p=0.047$) and peak power ($p=0.016$) relative to lean thigh volume were confirmed with an analysis of covariance (Figure 1). Following the Wingate test, RPE was equivalent for both groups and averaged 19 for ST and 18 for UT subjects. Heart rate immediately after the Wingate test averaged 151 and 139 beat per minute for the ST and UT groups, respectively. Blood lactate was highly correlated with absolute mean ($r = .857$) and peak ($r = .800$) anaerobic power ($p<0.01$). The load applied during the Wingate anaerobic test, based on FFM, averaged 0.077 kp/kg body weight and 0.067 kp/kg for males and females, respectively.

A two-way ANCOVA revealed no significant main effect for gender when evaluating differences in physical function. The CS-PFP total and domain scores were compared with a one-way ANOVA using training group as the independent variable. Physical function (CS-PFP total) was significantly different between the ST and UT groups ($p = 0.001$) (Table 2). The ST group demonstrated greater CS-PFP total scores (74.24 ± 7.87) when compared to the UT group (61.18 ± 13.14). The ST group also had higher LBST domain scores (70.94±7.91) when compared to the UT group (54.12±16.64) ($p=0.001$). The female ST group attained LBST domain scores that were 50% higher than UT females ($p=0.002$). The other four domains were also significantly different between ST and UT groups ($p=0.046$) (Figure 2). Differences were not attributable to gender or age in CS-PFP total or domain scores. Inter-rater reliability for the CS-PFP test was $r^2 = 0.976$ ($p<0.01$).

Absolute peak power and mean power (W) were significantly correlated to CS-PFP total score ($r = 0.521$ and 0.642, respectively) and the LBST domain ($r=0.611$ and $r=0.692$, respectively) (Figure 3 & 4). Similarly, peak and mean power relative to thigh volume were significantly correlated with CS-PFP total score ($r=0.592$ and $r=0.648$, respectively) and the LBST domain ($r=0.500$ and $r=0.608$) (Figure 5 & 6). The linearity was tested using $r^2_{yx} = R^2_{y.x}$ yielding significant F values ($p<0.05$) for linearity in the correlations reported above. In addition, calculating the squared multiple correlation for a second-degree polynomial did not significantly increase the variance compared to a linear correlation. Despite mean power having a stronger relationship to physical function, Fisher's Z revealed that there was no significant difference between Pearson's correlation of mean power and peak power to physical function. (Figures 3 - 6). Mean power was highly correlated with peak power and LEP ($p<0.01$) (Table 3). Peak power was also correlated with LEP ($p<0.01$).

Discussion

This study demonstrated that ST adults have greater anaerobic power output compared to UT adults and that anaerobic power is correlated to functional performance. Mean and peak anaerobic power were both significantly higher for the ST group compared to the UT group after normalizing data for lean thigh volume and age. Although the ST and UT groups had similar lean thigh volume, the ST group produced more power relative to estimated lean thigh volume.

Both ST and UT groups reported high levels of exertion (RPE) and also achieved age-predicted maximal heart rate (220-age ± 1 SD) during the Wingate anaerobic test indicating an equivalent and near-maximal effort. As expected, the ST group had higher levels of blood lactate than the UT group following the Wingate test (20,34). Due to the relationship between lactate production and anaerobic glycolysis, we expected to find higher levels of lactate production with greater levels of anaerobic power.

Several possible mechanisms may account for the differences in anaerobic power. Strength trained adults may achieve greater mean and peak power output due to several mechanisms including increased recruitment of motor units, synchronization, increased synergistic activation of other musculature, or decreased activation of antagonistic muscle groups. Data from both rat (35) and human studies (36-38) have found increased specific tension (strength/unit area) following strength training. Increases in reported EMG activity following 8-12 weeks of strength training (39) may account for increased strength associated with increased specific tension. Muscle composition may also contribute to higher anaerobic power output. Several studies have reported significant correlations between percent fast twitch fibers and anaerobic power ($r = 0.57$-$.80$) in younger adults (20,25,34). The ST group may have a higher proportion of type II fibers compared to the untrained group. The ST group may also have higher anaerobic enzyme activities or substrates, which have been reported (40) to increase with strength training (41). These data suggest that strength-trained adults may differ in ability to activate muscle or differ in muscle composition. Due to the design of this study we are unable to determine which, if any, of these mechanisms contributes to higher power output for the ST group.

Similarly, Shaw and Snow report increases in peak anaerobic power that were not explained by increases in muscle mass following training (42). They report significant increases in peak anaerobic power relative to lean leg mass (13.2±12%) following 9 months of weighted vest training (lunges, squats, step-ups, toe raises) combined with jumping. Weighted vests added 11 to 14 kg to the body weight (16-20% of body weight). Peak anaerobic power was measured using an abbreviated Wingate test (15-sec) and leg mass was quantified using dual-energy x-ray absorptiometry. Increases in leg mass accounted for only 7.5 – 8.0 % of the variance in anaerobic power changes. These data support this notion that strength trained adults may be able to activate their muscle better than the untrained older adult.

Results of this study indicate that anaerobic power production and LEP are related to the ability to complete daily activities. Higher anaerobic power and LEP scores are associated with higher total function scores and higher LBST domain scores. Others (43,44) have also reported positive relationships between physical function and LEP. LEP is highly related to stair power (r=0.529), walk power (r=0.632), and floor power (r=0.825) for community dwellers (aged 72±8 years) (44). Bassey et al. (43) reports the relationship between LEP relative to body weight and chair rising speed (r =0.65), stair-climbing speed (r =0.81), walking speed (r =0.80), and stair-climb power (r=0.88) for very old (mean age = 87 yr.) chronic care patients. In the current investigation, significant correlations were found between relative LEP and stair-climbing speed (r = 0.397), walking speed (r =0.619), and stair-climb power (r = 0.976). These tasks contribute to the lower body strength domain of the CS-PFP. Collectively, these data suggest that LEP is a valuable research tool that is predictive across a broad range of abilities and is associated with function across living statuses.

Mean anaerobic power was correlated with the LBST domain, as was peak anaerobic power. Weaker relationships were found between peak anaerobic power and function. Examining the average power output over 30 seconds (mean power, r^2=0.482) was more related to physical function compared to examining peak power output (r^2=0.371). We were unable to detect significantly different relationships, possibly due to the low subject number. Although mean anaerobic power output is highly correlated with peak anaerobic power and LEP, the anaerobic power test requires substantially more effort to complete the entire 30 seconds and reflects a sustained effort whereas peak anaerobic power and LEP are measures of instantaneous or peak power (1-to-5 sec). The measure of mean anaerobic power output requires a sustained effort and similarly many daily activities necessitate a sustained effort. Many daily tasks, such as stair climbing, transferring laundry, and transferring heavy items between rooms, are between 5 and 65 seconds in duration and require a sustained power output to complete the task. Although we were unable to show that the Pearson's r differed between mean and peak power in relation to physical function, these data imply that a sustained measure of work, such as mean anaerobic power, may be more reflective of physical function. These findings indicate that near maximal measures that capture a sustained effort may be more appropriate for evaluating physical function than peak measures that offer a snapshot view of capacity.

In the ST group, CS-PFP total scores and lower body physical function were 20% and 31% higher in the ST group compared to the UT group. While neither group had individual participants with functional limitation, the CS-PFP was still capable of discriminating between the groups. The UT group had two-thirds the power output compared to the ST group. The larger difference between the groups in anaerobic power (48% for peak power, 61% for mean power) than in CS-PFP (20% for total, 31% for lower body) may be reflective of a higher physical reserve in the ST group. Improvements in physical function may occur with increases in anaerobic power up to a particular level or threshold after which further increases in anaerobic power do not increase physical function. Examining the female groups, the LBST scores from the ST group suggest that physical functional performance may be greatly enhanced through strength training. Strength trained females produced equivalent power and attained similar function scores compared to strength trained men. Although women have less muscle mass, according to these data their physical function is not compromised. Strength training can improve physical function (tandem gait, chair rise time, step height, and total physical function) (45-47). Although power training in older adults is rare, one study suggests it can be increased in as few as 12 weeks (46). Future studies are needed to determine if power training can increase physical function.

This study shows positive support for strength training in older adults. However, there were some limiting factors. This design was not longitudinal and therefore does not represent direct evidence for changes in anaerobic power. Strength training differed within the ST group in the training frequency, intensity, and volume, as well as the type of exercises regularly completed. In addition, the length of time that individual subjects were involved in a strength-training program ranged from 3 months to 45 years. The anthropometric procedure used to determine lean leg volume may be associated with error resulting in an overestimation of lean leg volume, especially for older populations (15). However, the procedure is highly correlated with other measures of leg volume (magnetic resonance imaging, computed topography) (31,47-49). In addition, we assumed that the overestimation was consistent across the groups, therefore lean leg volume was overestimated for all subjects. Lastly, although we attempted to recruit a representative sample of older adults, 35% of the initially recruited sample were excluded or did not complete the study. Results from this study may not apply to unhealthy or unmotivated older adults.

In conclusion, strength-trained older adults have higher anaerobic power than untrained adults independent of age differences between groups. Strength training may be associated with qualitative changes in skeletal muscle, which enhance anaerobic power. Although the strength-trained group did not have larger thigh volume compared to the untrained group, the strength trained group's anaerobic performance was significantly greater. Anaerobic power is positively related to physical function. Increases in function following strength training may be due to increased anaerobic power. Therefore, a strength-training program is an appropriate mode of exercise for enhancing anaerobic power production in an older adult population. From these data, it appears that older adults who strength train 2 days/week using a full body strength-training program may benefit in terms of increased anaerobic power output and physical function. In addition, these data also imply that high intensity sustained performance measures, such as mean power output, may be more appropriate than maximal capacity measures when investigating determinants of physical function.

Table 1. Physical characteristics

Measure	Male ST (n=10)	Male UT (n=7)	Female ST (n=8)	Female UT (n=10)
Age (yr)	70.90±5.40*	76.00±2.56	66.00±2.56*	73.2±6.63
Height (cm)	174.47±5.87†	177.11±9.56†	158.36±4.48	161.09±6.16
Weight (kg)	81.82±7.67†	82.00±7.67†	71.61±11.33	63.89±7.71
% fat	24.96±2.46†	24.4±3.91†	35.79±6.18	33.03±6.56
FFM (kg)	61.08±6.33†	61.65±6.8†	45.44±4.00	42.5±3.19
Lean thigh volume (cm^3)	3711.33±593†	4023.56±445†	2513.80±377	2792.10±411
Leg press strength (kg/cm^3)	.045±0.023*	.032±0.006†	.0400±0.010*	.023±0.20

Table 1. Physical characteristics. Values are means ± SD. * = Significant differences between training groups, †= Significant difference between genders. $p < 0.05$. ST= strength trained, UT= untrained. FFM = fat-free mass, leg strength is 1 RM expressed relative to lean thigh volume.

Table 2. Anaerobic power, leg extensor power, and physical function

Measure	Male UT (n=7)	Female UT (n=10)	UT Group (n=17)	Male ST (n=10)	Female ST (n=6)	ST group (n=16)
Anaerobic Power						
Peak Power						
Absolute (W)	357.00±55.5†	244.60±96.7	282.09±99.5	467.73±91.3†	297.13±47.6	391.92±114
W/kg	4.66±1.98†	3.76±1.13	4.13±1.58	5.73±1.05†	4.18±0.65	5.04±1.18
W/kgffm	5.38±1.37	5.74±2.06	5.60±1.79	7.58±1.21*	6.56±1.05	7.13±1.22
W/cm^3	.08206±0.012	.0871±0.028	.0852±.0.024	.1296±0.035*	.1216±0.030*	.1260±0.003*
Mean Power						
Absolute (W)	271.20±72.4†	164.80±62.4	208.61±84.1	357.10±81.4†	231.25±31.4	301.22±90.1
W/kg	3.41±1.23†	2.55±0.83	2.90±1.11	4.35±0.90†	3.28±0.56	3.89±0.89
W/kgffm	4.02±0.87	3.87±1.38	3.93±1.18	5.84±1.22*	5.11±0.71*	5.51±1.07*
W/cm^3	.0613±0.011	.0589±0.020	.0598±0.0165	.0980±0.026*	.094±0.021*	.0963±0.023*
Fatigue Index	43.00±8.96	48.00±12.65	45.94±11.25	41.93±10.50	36.88±9.10	39.68±9.96
Lactate (mmol/l)	5.39±1.29†	4.01±1.55	4.56±1.57	6.36±1.14*†	5.03±.91	5.77±1.23
LEP (W)	419.8±92†	226.2±73	305.9±126	497.2±116*†	317.6±67	417.4±132
Physical function						
CS-PFP-TOT	66.57±14.37	58.0±12.06	61.18±13.14	73.67±8.72	75.38±7.67*	73.72±7.89*
CS-PFP-LBST	62.57±16.54	48.20±14.67	54.12±16.64	70.44±8.82*	71.50±7.31*	70.94±7.91*

Table 2. Anaerobic power, leg extensor power, and physical function. Values are means ± SD. * = Significant differences between training groups, †= Significant difference between gender $p < 0.05$. ST=strength trained, UT=untrained, W/kg = watts relative to body weight, W/kgffm = watts relative to fat free mass, W/cm^3 = watts relative to lean thigh volume, CS-PFP-TOT=total score for the CS-PFP, CS-PFP-LBST=lower body strength domain of CS-PFP.

Table 3. Correlations between absolute power and physical function

	CS-PFP TOT	CS-PFP-LBST	Peak power (W)	Mean power (W)	LEP (W)	AGE
CS-PFP-TOT	1.00	.944**	.521*	.642**	.610**	-.418*
CS-PFP-LBST		1.00	.611*	.692**	.622**	-.446**
Peak Power			1.00	.953**	.866**	-.320
Mean Power				1.00	.898**	-.401*
LEP					1.00	-.292
AGE						1.00

Table 3. Correlations between absolute power and physical function using Pearson's r product correlation. * = Significant correlation $p<0.05$, ** = $p<0.01$. CS-PFP-TOT=total physical function score, CS-PFP-LBST=lower body strength domain of CS-PFP, Mean and peak power=anaerobic power from the Wingate test, LEP=lower extremity power (both legs).

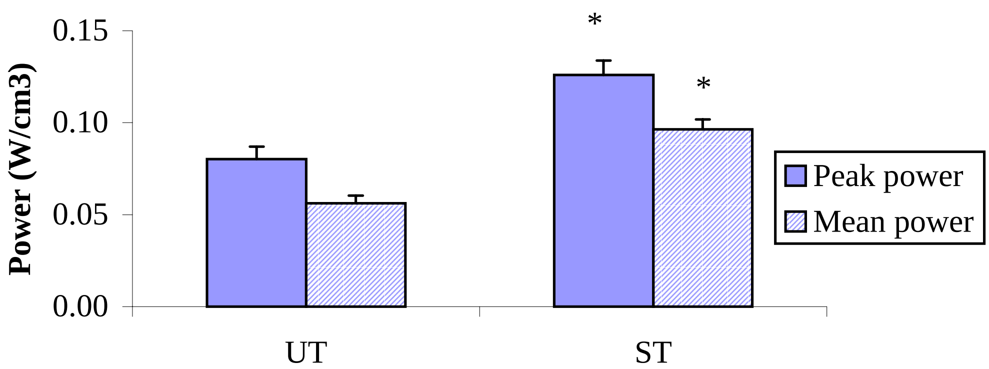

Figure 1. Anaerobic power relative to lean thigh volume. Power is ± standard error of the measure (SE). * = Significant difference between groups, p<0.05. ST=strength trained, UT=untrained.

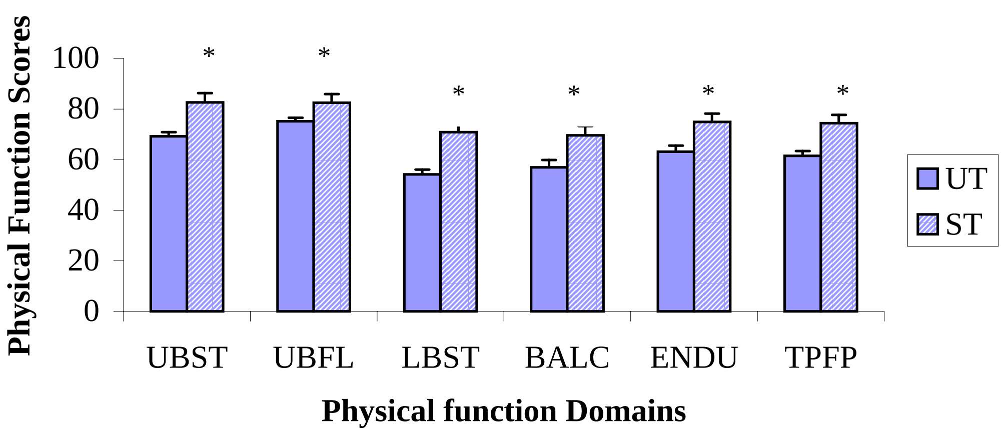

Figure 2. Physical function scores (±SE) from CS-PFP in ST and UT groups.
* = Significant difference between groups, p<0.05. ST=strength trained, UT=untrained, UBST=lower body strength, UBFL=upper body flexibility, LBST=lower body strength, BALC=balance and coordination, ENDU=endurance domains of CS-PFP, TPFP= total CS-PFP score.

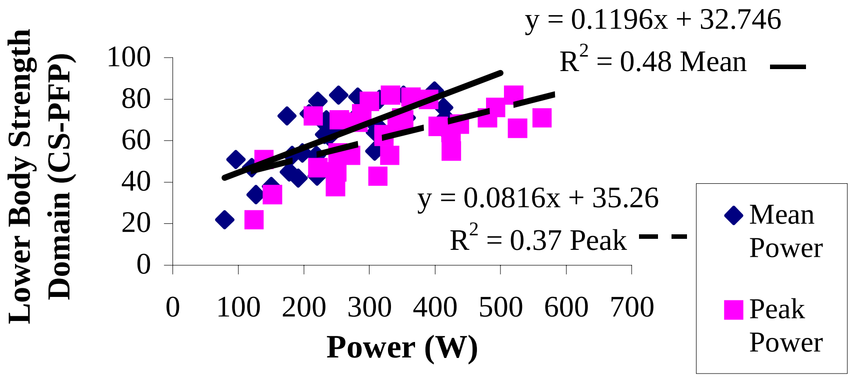

Figure 3. Anaerobic power output vs. lower body physical function, $p < 0.05$.

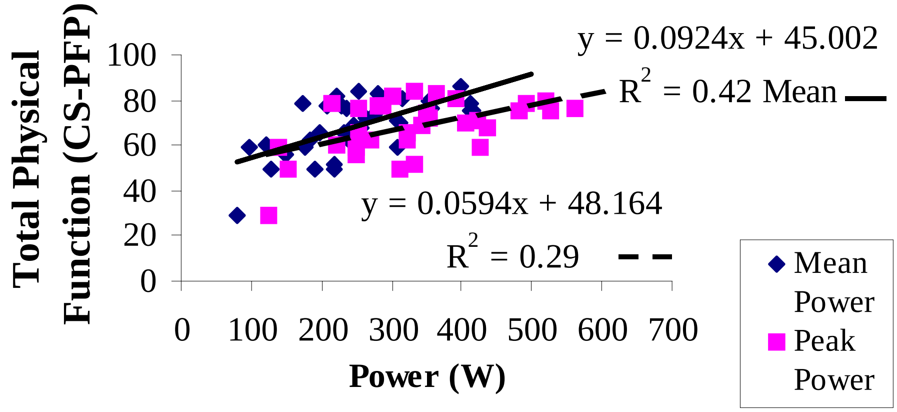

Figure 4. Anaerobic power output vs. total body physical function, $p < 0.05$.

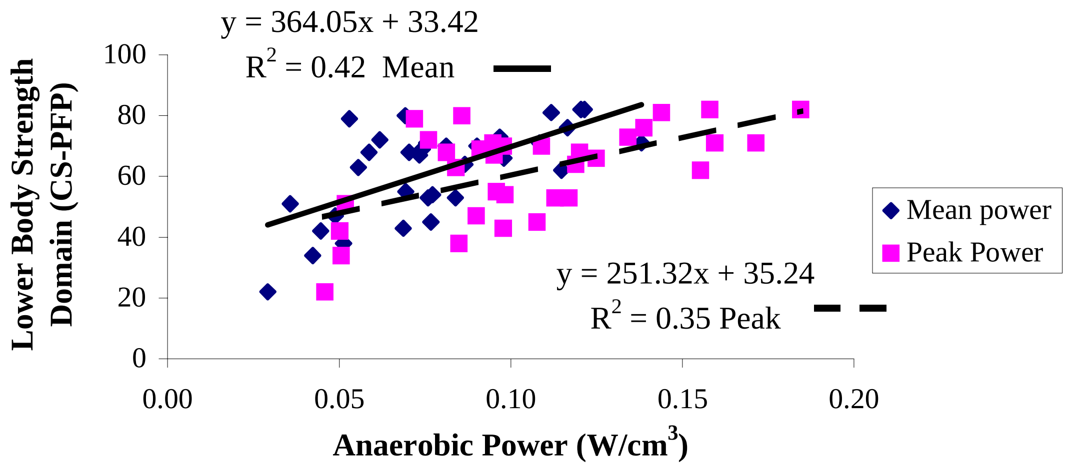

Figure 5. Anaerobic power relative to lean thigh volume vs. lower body strength domain, $p<0.05$.

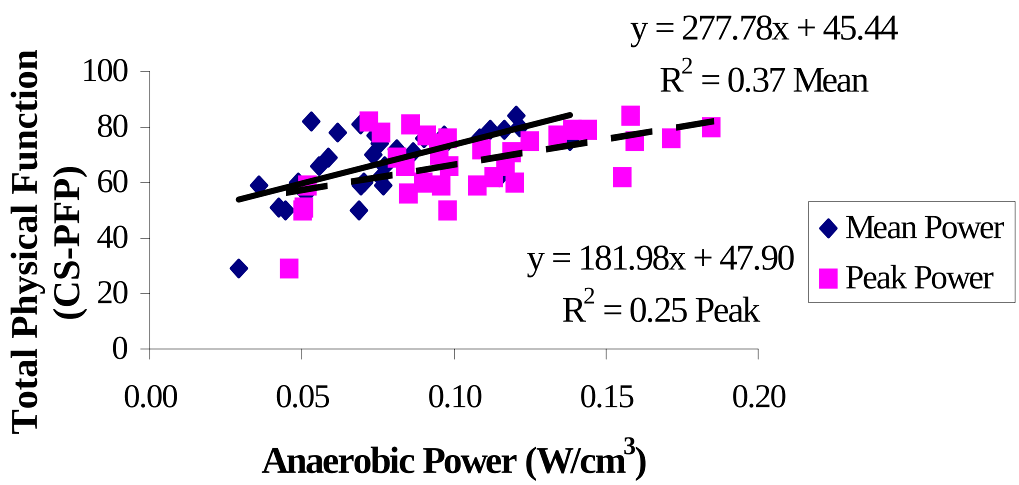

Figure 6. Anaerobic power relative to lean thigh volume vs. total physical function, $p<0.05$.

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CHAPTER IV

SUMMARY AND CONCLUSIONS

Multiple factors influence the aging process and physical function. In order to provide the best quality of life for older adults, the determinants of physical function must be ascertained. Upon determining these factors that contribute to independence, programs can be designed and implemented to maintain or increase physical function. The demand for programs that target functional impairments is expected to increase with the proportion of older adults in the population.

The aging process is associated with declines in muscle mass, strength, aerobic capacity, and anaerobic power. Whereas muscle mass, strength, and aerobic power have been examined for their influence on physical function in older adults, little research has been reported on anaerobic power in older adults or its influence on physical function. As maximal aerobic power declines, anaerobic power may be an important energy source for completing challenging tasks such as rising from the floor, transferring heavy items, or ascending stairs. Brief tasks may be completed with bursts of energy supplied from anaerobic power. Therefore, anaerobic power may become more essential in daily function for the elderly.

If anaerobic power does influence physical function, interventions that increase anaerobic power would contribute to higher physical function. Few researchers have attempted to investigate changes in anaerobic power following training in older adults. Strength training has shown to increase anaerobic power following strength training in younger adults but has not been investigated in an older population. In the present investigation, we assessed anaerobic power and it's relations to physical function in order to determine if strength trained older adults had higher anaerobic power output compared to untrained adults. These data indicate that anaerobic power was related to physical function with strength trained older adults having higher anaerobic power and function. Mean power, an average power output, was more related to function compared to peak power suggesting that examining sustainable, near-maximal workloads such as mean power may be more reflective of physical function. Although the strength trained and untrained groups had equal lean leg volume, the strength-trained group produced significantly more anaerobic power compared to the untrained group. This suggests that the strength-trained adults were able to activate their muscles better than untrained adults, perhaps as a result of strength training. From these data, it appears that strength training may increase physical function through increases in anaerobic power. Longitudinal studies are needed to confirm this inference. Other interventions including power training may also be effective for increasing anaerobic capacity, in turn, increasing physical function.

CHAPTER V

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APPENDIX A

RAW DATA AND PLOTS

SUBJID	SEX	GROUP	AGE YR	HEIGHT CM	BODYWT KG	%FAT	LEANMASS KG	THIGHVOL CM^3	1RM KG
101	M	UT	84	161	64.70	18.6	52.67	4170	109.1
103	M	ST	68	176	84.55	26.0	62.60	4548	134.1
105	M	ST	73	171	95.70	28.0	68.90	3546	197.7
106	M	ST	77	181	81.36	23.3	62.40	4212	145.5
107	F	UT	76	165	62.30	33.6	41.37	2399	77.3
110	F	UT	76	160	59.10	29.5	41.67	3003	61.4
111	M	UT	79	173	75.70	22.9	58.36	4436	177.3
112	M	UT	65	175	69.32	21.7	54.28	3601	136.4
113	F	ST	66	160	79.78	37.4	49.95	3098	100.0
114	F	ST	68	155	59.10	34.0	39.01	2074	90.9
115	M	ST	74	177	72.95	27.6	52.80	3680	140.9
116	F	ST	70	154	59.10	29.5	41.67	2815	70.5
117	M	ST	75	175	71.14	22.5	55.13	3567	113.6
118	F	UT	72	156	60.70	39.0	37.03	2321	65.9
119	F	UT	70	147	84.10	44.4	46.76	3637	88.6
122	F	UT	78	163	60.91	27.4	44.72	2708	63.6
123	F	UT	78	166	61.60	34.8	40.16	2457	63.6
124	M	UT	77	173	86.30	27.8	62.30	4209	109.1
125	M	UT	83	183	90.00	23.1	69.21	4286	154.6
126	M	UT	73	189	92.73	29.8	65.10	3210	100.0
127	F	UT	71	161	67.70	37.3	42.45	2922	50.0
129	F	UT	84	164	56.80	21.8	44.42	2684	36.4
130	F	UT	71	186	95.22	26.9	69.60	4252	118.2
132	F	ST	64	164	82.50	41.7	48.10	2523	77.3
138	M	ST	65	180	81.82	23.5	62.59	3284	131.8
139	M	UT	66	160	60.70	34.7	39.64	2564	54.6
141	M	ST	67	167	74.77	26.8	51.74	3012	186.4
143	M	ST	63	167	90.23	21.2	71.10	4510	277.3
146	M	ST	68	169	80.20	23.3	61.51	2816	154.6
147	F	ST	68	151	72.95	37.2	45.80	2101	109.1
148	F	ST	62	159	78.60	42.2	45.43	2148	95.5
149	F	UT	61	170	65.00	27.8	46.90	3227	81.8
150	M	ST	79	183	85.50	27.4	62.07	3938	154.6
151	F	ST	65	161	83.60	39.8	50.33	2754	136.4
152	F	ST	65	163	57.27	24.5	43.24	2597	109.1

* = missing data   ** = outlier

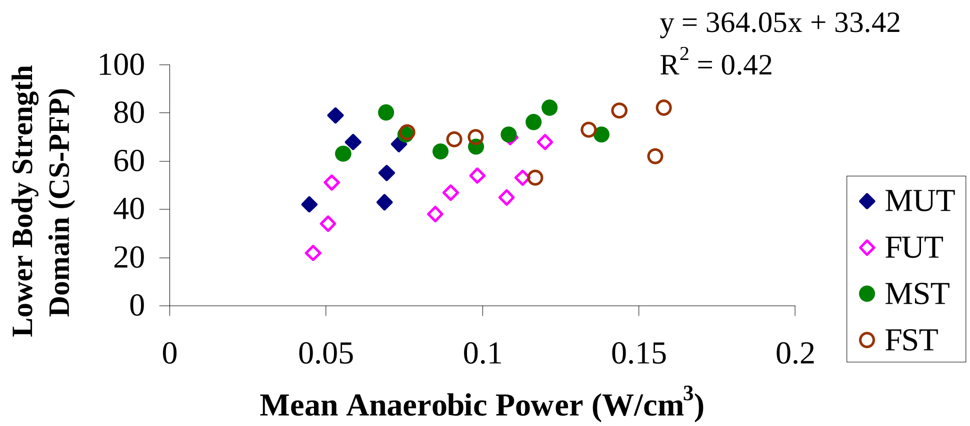
SUBJID	PPRELTHI W/CM^3	FATIGUE INDEX %	LACTATE MMOL/L	HRMAX BPM	RPEBIKE BORG	LEPR W	LEPL W	LEPDIFF W	LEPBOTH W
101	.0719	44	4.79	139	19	182	161	21	343
103	.0857	35	5.14	165	18	301	268	13	569
105	.1388	31	5.70	166	19	305	260	45	565
106	.1249	41	5.94	156	17	246	233	13	479
107	.1129	47	3.80	143	19	143	147	4	290
110	.0506	24	1.62	89	*	65	69	4	134
111	.0958	44	5.91	140	17	248	199	49	447
112	.1640**	56	9.85**	154	17	275	233	42	508
113	.0910	29	4.39	144	19	221	154	108	375
114	.1553	39	5.44	151	19	143	147	4	290
115	.0948	35	5.20	166	20	167	195	28	362
116	.0760	32	3.52	145	19	95	112	17	207
117	.1189	54	6.19	125	17	191	172	19	363
118	.1077	50	4.65	90	19	126	114	12	240
119	.1200	62	6.36	167	19	157	144	13	301
122	.0458	57	*	160	17	88	73	15	161
123	.0899	67	2.27	124	17	142	134	8	276
124	.0813	45	7.09	159	19	179	260	81	439
125	.0502	26	4.59	134	19	145	177	32	322
126	.0978	46	3.60	102	19	159	167	8	326
127	.0849	53	4.62	144	19	108	117	9	225
129	.0518	42	2.64	122	19	52	57	5	109
130	.0952	40	6.37	170	19	238	316	115	554
132	.1439	45	6.28	168	19	221	190	31	411
138	.1714	56	7.35	174	20	272	268	4	540
139	.0983	38	5.10	170	19	112	94	18	206
141	.1594	29	6.61	151	17	235	251	16	486
143	.1337	34	7.97	160	20	404	347	57	751
146	.1845	50	8.24	152	18	214	219	5	433
147	.1580	43	6.11	136	20	164	144	20	308
148	.1341	46	4.76	137	20	125	129	4	254
149	.1090	40	5.03	150	18	166	154	12	320
150	.0840	54	5.29	146	17	219	205	3	424
151	.1169	41	5.04	148	19	166	169	14	335
152	.0978	20	4.67	133	19	195	166	29	361

*** = missing data** **** = outlier**

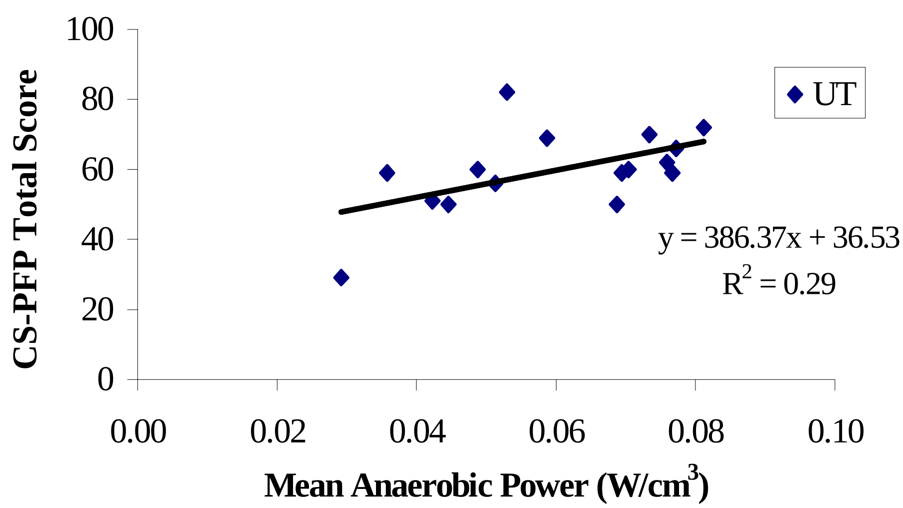
SUBJID	1RM KG/KGBW	SPECTENS 1RM/THI	MEANPOW W	MPREL W/KG	MPREL W/KGFFM	MPREL W/CM^3	PEAKPOW W	PPREL W/KG
101	1.69	.0262	221	3.42	4.20	.0530	300	4.60
103	1.59	.0295	315	3.70	5.03	.0693	390	4.60
105	2.07	.0558	413	4.30	5.99	.1165	492	5.10
106	1.79	.0345	413	5.08	6.62	.0980	526	6.46
107	1.24	.0322	182	2.92	4.40	.0759	271	4.35
110	1.04	.0204	127	2.15	3.05	.0423	152	2.57
111	2.34	.0400	308	4.07	5.28	.0694	425	5.61
112	1.98	.0379	399	5.76	7.351**	.1108**	591**	8.530**
113	1.25	.0323	230	2.88	4.60	.0742	282	3.54
114	1.38	.0438	238	4.03	6.10	.1148	322	5.45
115	1.93	.0383	278	3.81	5.26	.0755	349	4.78
116	1.19	.0250	174	2.94	4.18	.0618	214	3.62
117	1.60	.0319	309	4.35	5.60	.0866	424	5.96
118	1.09	.0284	178	2.93	4.81	.0767	250	4.11
119	1.05	.0244	256	3.04	5.48	.0704	437	5.20
122	1.04	.0235	79	1.30	1.72	.0292	124	2.04
123	1.03	.0259	120	1.95	2.99	.0488	221	3.59
124	1.26	.0259	247	2.86	3.96	.0587	342	3.96
125	1.72	.0361	191	2.12	2.76	.0446	*	2.39
126	1.06	.0312	220	2.37	3.42	.0687	313	3.30
127	.74	.0171	150	2.20	3.53	.0513	248	3.66
129	.64	.0135	96	1.69	2.16	.0358	139	2.45
130	1.24	.0278	312	3.28	4.48	.0734	405	4.25
132	.94	.0306	282	3.42	5.86	.1118	363	4.40
138	1.61	.0401	356	4.35	5.69	.1084	563	6.88
139	.90	.0213	198	3.30	4.99	.0772	252	4.20
141	2.49	.0619	416	5.56	8.04	.1381	480	6.48
143	3.07	.0615	500	5.54	7.03	.1109	603	6.68
146	1.93	.0549	352	4.26	5.56	.1215	520	6.48
147	1.49	.0519	253	3.47	5.52	.1204	332	4.55
148	1.21	.0444	208	2.65	4.58	.0968	288	3.66
149	1.26	.0254	262	4.00	5.59	.0812	352	5.40
150	1.81	.0392	219	2.56	3.53	.0556	331	3.86
151	1.63	.0495	231	2.76	4.59	.0839	322	3.85
152	1.90	.0420	234	4.10	5.41	.0901	254	4.40

* = missing data, ** = outlier

SUBJID	RPE PFP	UBST PFP	UBFL PFP	LBST PFP	BALC PFP	ENDU PFP	TPFP PFP
101	14	83	82	79	85	81	82
103	10	91	78	80	76	81	81
105	13	90	81	76	73	79	79
106	11	83	82	66	76	75	75
107	14	64	85	53	60	64	62
110	12	54	87	34	45	53	49
111	12	82	83	55	46	57	59
112	10	95	89	84	82	86	86
113	12	83	87	69	74	80	77
114	12	80	81	62	49	60	62
115	12	76	74	71	70	78	74
116	12	72	94	72	78	83	78
117	11	80	89	64	66	71	71
118	*	50	81	45	63	66	59
119	12	76	61	68	62	67	68
122	12	40	46	22	24	28	29
123	11	68	75	47	53	65	60
124	11	94	81	68	53	66	69
125	13	70	49	42	43	50	50
126	15	72	61	43	39	49	50
127	12	56	85	38	55	62	56
129	15	62	83	51	56	61	59
130	13	71	66	67	71	72	70
132	11	95	84	81	80	81	83
138	12	91	77	71	71	74	76
139	13	66	81	54	64	72	66
141	11	78	86	71	73	76	75
143	*	*	*	*	*	*	*
146	12	92	79	82	71	79	80
147	13	83	82	82	83	88	84
148	15	78	78	73	75	80	77
149	9	74	83	70	68	75	72
150	12	76	74	53	37	47	52
151	13	78	90	63	58	64	66



Mean anaerobic power vs. lower body physical function, divided by gender and training groups, $p < 0.05$.



Mean anaerobic power vs. CS-PFP total score for the untrained group, $p < 0.05$.