TANYA A. MISZKO
The Effect of Strength and Power Training on Physical Function in Older Adults
(Under the Direction of M. ELAINE CRESS)

The ability of an older adult to perform daily tasks is influenced by age-associated reductions in the neuromuscular system. Muscle strength, leg extensor power (LEP), and anaerobic power (AP) are highly related to functional task performance. Strength training has improved this performance in older adults, however, the effects of power training have rarely been studied. The neural adaptations associated with power training may make it a more effective modality than strength training for improving physical function, LEP, and AP. The purpose of this study was to determine the effect of strength and power training on physical function, LEP, and AP in older adults. Thirty-nine men and women (mean age ± SD = 72.5 ± 6.3 years) with below average LEP were randomly assigned to control (C, n = 15), strength- (ST, n = 13) and power- (PT, n = 11) training groups. The intervention groups met 3 d/wk for 16 weeks while the control group maintained usual activity and attended three lectures during the 16 weeks. Primary outcome measures included: the Continuous Scale Physical Functional Performance (CS-PFP) test, 1RM strength, LEP, and AP. Secondary outcome measures included individual functional tasks: walking speed, floor-sit time, and stair-power. Using the pre-test as the covariate, a one-way ANCOVA was used to examine differences between the groups on the post-test measures. An effect size (ES) was calculated to examine the standardized magnitude of difference between the groups. Following the intervention, the PT group showed significant improvement compared to the ST (ES = 0.88) and C groups (ES = 0.98) for the CS-PFP total score. The ST group was significantly stronger than the C group (ES =1.63) and exhibited greater average AP ($W \bullet kg^{-1}$). Stair-power was significantly greater ($p = 0.03$) in the PT group than the C group, however, no significant differences were observed between groups for peak AP, LEP, walking speed, or floor-sit time ($p>0.05$). Neither exercise program was superior to the other for improving LEP, AP, or individual functional task performance. Power training was more effective than strength training for improving physical function, as measured by the CS-PFP test, in community-dwelling older adults.

INDEX WORDS: Power training, Leg extensor power, Physical Function

THE EFFECT OF STRENGTH AND POWER TRAINING ON PHYSICAL FUNCTION IN OLDER ADULTS

by

TANYA A. MISZKO

B.S., Springfield College, 1995

M.S., The University of Dayton, 1998

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF EDUCATION

ATHENS, GEORGIA

2001

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TANYA A. MISZKO

Approved:

Major Professor: M. Elaine Cress

Committee: Kirk Cureton
Michael Ferrara
Steve Olejnik
Kathy Simpson

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
December 2001

DEDICATION

This dissertation is dedicated to my family for their continued love, support, and guidance through all my years of schooling and to Carl for his warm heart and patience. The road seemed never ending, but the journey was worth it. I could not have gone this far without any one of you.

ACKNOWLEDGEMENTS

Most importantly, I must thank the undergraduate students in the Exercise Science department who helped me train and test the older adults in my study. Without their help I would not have been able to do it all on my own. Thank you Ashley Carver, Jennith Bernstein, Mandy Blackmon, Rebecca Dockter, Brendan Noggle, and Eric Phillips. Special thanks to Carlton Covey for his help training the older adults, entering data, and editing all versions of the dissertation. I can not forget the generosity of St. Mary's Wellness Center for allowing fifty older adults to train at their facility, free of charge. Steve Olejnik needs to be commended for his patience with me when explaining statistical application in a matter that is most understandable. This study was funded by the Gerontology Consortium Seed Grant.

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CHAPTER 1

INTRODUCTION

The ability of an older adult to perform daily tasks may be affected by age-associated declines in muscle mass, strength, and power (11). Walking can become labored because of inadequate muscle strength. Loss of leg power (net muscle moment* joint angular velocity) produced by lower-extremity extensor muscles may make it difficult to climb stairs or rise from a chair or the floor (6).

Loss of strength and power occurs, in part, because of age-related changes in muscle motor units. The reduction in fast-twitch (Type II) muscle fibers associated with aging (42) reduces total muscle mass, as well as, the force-generating capacity of muscle. Fast-twitch, alpha-motor neurons also undergo some degeneration with age (26, 40). On average, older adults lose approximately 7.5% to 8.5% of their strength per decade (54) and increase reaction time by approximately 5% per decade (77) beginning around age 30. The interaction of these changes contributes to a magnified decline in leg extensor power (LEP) by approximately 35% per decade between 60 to 90 years of age (73), however, the reduction in LEP is largely due to a reduction in contraction velocity (25).

Furthermore, the ability of older adults to complete physically demanding tasks and serial task performance in a timely manner diminishes because anaerobic energy, as measured by anaerobic power, declines with age. Anaerobic power, a measure of metabolic power, is reduced approximately 6% per decade when comparing individuals between the ages of 20 to 75 years (38). Since Type II fiber area is significantly related to anaerobic power (r = 0.59) (50), an exercise intervention that can increase Type II fiber area may improve anaerobic power, as well as, strength and may subsequently improve physical function.

Although strength training can increase muscle strength, it does not necessarily improve physical function. Across a broad range of physical abilities, the relationship between leg strength and physical function, such as self-selected walking speed, has been defined as curvilinear (13). This is true for other measures of function as well (21). Persons with low functional levels realize the greatest gains from an exercise intervention, while those on the flat portion of the curve experience a point of diminishing returns with respect to improved function from gains in capacity. The positive relationship between physical function, LEP, and anaerobic power suggests that improvements in LEP or anaerobic power may also improve physical function.

Both strength- and power-training programs can have a positive effect on power and physical function. Researchers have, in fact, demonstrated significant improvements in LEP (74), anaerobic power (71), and physical function after strength training (33), and improvements in physical function after combined-strength and endurance training (22). They have also shown that older adults participating in a power-training program improved knee-extensor power (72) and LEP (34). No research to date has compared power training to strength training for improving physical function in the older adult population. Because LEP is lost at a faster rate than strength (73), improvements in power may be more important than improvements in strength for improving physical function in older adults.

The faster velocity of power training may offer the potential to improve physical function beyond that of a traditional strength-training intervention. Strength and power training differ in the resistance used and the velocity of the exercise movements. Strength training involves a heavy resistance (80% one-repetition maximum, 1RM) moved at a slow velocity, while power training utilizes a light resistance (40% 1RM) moved at a fast velocity. As evidenced by increased force output and muscle activation, exercises performed at a fast velocity place greater demands on the neuromuscular system than exercises performed at a slow velocity (65).

Advantages of power training have been shown in several studies that demonstrate greater improvements in anaerobic power, rate of force development, and LEP from power training than from strength training (1, 28, 34, 81, 83). Specifically, fast-velocity isokinetic training ($300 \bullet s^{-1}$) resulted in greater improvements in peak torque at both fast ($300 \bullet s^{-1}$) and slow ($60 \bullet s^{-1}$) velocities than slow-velocity isokinetic training ($60 \bullet s^{-1}$) (20). In young adults, power training has significantly increased athletic performance (40-yd dash time, shot put distance thrown) (56) and anaerobic power (37, 55). These results suggest that older adults who train for power in addition to strength may be stronger and faster and may, therefore, be better able to rise from a chair, climb stairs, or catch themselves quickly to avoid a fall.

Similar to the principle of specificity, Rutherford and colleagues have stated that gains in strength may not be transferred to tasks that require different motor patterns than those used during training (68). Therefore, strength training alone may not improve functional tasks that require fast movements, such as crossing a street or climbing stairs, to the extent that power training may. Because the motor patterns in power training mimic the motor patterns used to measure LEP, the fast velocity required of power training may produce substantial gains in LEP. Additionally, anaerobic power may be improved due to greater muscle activation from power training than strength training. Therefore, this study is designed to determine whether strength or power training can increase LEP and anaerobic power and whether physical function can be improved as a result of improved power.

Statement of the purpose

The objectives were to: 1) determine the effect of a 16-week power-training program on physical function, anaerobic power, and LEP compared to a strength-training program and an attention-control group in older adults and 2) determine if there is a significant relationship between changes in physical function and changes in anaerobic power, LEP, and maximal strength.

Hypotheses

I hypothesized that: 1) power training would have a greater effect on whole-body physical function, anaerobic power, and LEP than strength training would and 2) the change in physical function would be significantly related to the change in anaerobic power, LEP, and maximal strength.

Significance of the Study

Data comparing leg extensor and anaerobic power to performance on functional tasks suggests that training to improve power will improve function to a greater extent than will training for strength alone. Such insights are important because of the age-associated changes that can affect an older adult's ability to perform daily tasks. A low level of strength may make it difficult to lift a grandchild, while an impairment in leg power may reduce the ability to climb stairs.

This project investigates changes in physical function resulting from a power-training intervention. It provides scientific knowledge that can guide exercise prescription for older adults, and it has the potential to determine which type of training--strength or power--is more efficacious for improving physical function, anaerobic power, and LEP.

Limitations

The investigator partially responsible for both testing and training was not masked to the group assignment. While this may introduce tester bias, the testing procedures were standardized in such a manner that they were similar for all testers. A conscious effort was made to offer similar encouragement for all subjects. While some participants missed training sessions for medical reasons, vacations, family problems, or other causes, each subject was asked to participate in six training sessions (two weeks) immediately prior to exit testing and to make up sessions when more than three were missed.

Relocation of the training site after the first six weeks may have resulted in an under estimation of strength changes. Maximal strength (1RM) was reassessed at the new facility, and that value served as the baseline strength measure for five subjects in the strength-training group (38%) and five subjects in the power-training group (45%). We may have missed changes in strength that occurred prior to the relocation of the training program.

A small sample size may have interfered with our ability to detect statistically significant differences between groups for anaerobic power and LEP. At the time of planning, we did not have data on the change in LEP or anaerobic power for independent, community-dwelling older men and women. Statistical power was calculated based on the change in physical function. With a larger sample size we may have observed a statistically significant difference between groups.

CHAPTER 2

REVIEW OF THE LITERATURE

This literature review provides information on the age-associated changes in human muscle mass, strength, and power. The research data offer compelling evidence of the need for physical interventions to forestall or prevent these changes. Literature on both strength- and power-training interventions is reviewed for the efficacy of the interventions in improving strength, power, and possibly physical function in older adults. Possible reasons why the results are equivocal are discussed, taking into account several instrument limitations. For each outcome measure used in this study, the validity and utility for older adults are examined.

Age-Associated Changes

The ability of an older adult to complete daily tasks may be affected by age-associated changes in the neuromuscular system. Muscle strength is needed to lift a grandchild or to rise from the floor. Leg extensor power is needed to climb stairs or to recover from a fall (7). Anaerobic power is needed for physically demanding tasks or for performance of serial tasks. The following age-related changes are discussed below: changes in muscle mass, changes in strength, and changes in power.

Muscle Mass

According to a recent longitudinal study, total quadriceps muscle cross-sectional area (CSA) declined approximately 15% per decade (192.8 ± 21.1 cm^2 to 168.4 ± 19.1 cm^2) over 12 years (35). Evidence also indicated an increase in the percentage of Type II (fast-twitch) fibers (41.6% per decade), a decline in the percentage of Type I (slow-twitch) fibers (27.8% per decade), and no change in the mean fiber area of either fiber type ($p>0.05$). In contrast, two researchers have reported a decrease in the percentage and number of Type II fibers (29, 54) and an increase in the percentage of Type I fibers (18, 54). Studies using a cross-sectional design have revealed a 24% to 27% (44.1 ± 4.1 cm^2 to 32.3 ± 5.9 cm^2) reduction in muscle CSA between the ages of 30 and 70 years (42, 52). This decline in muscle mass has been attributed to a reduction in Type II fiber area (29, 41, 54) and number (40, 54). Meanwhile, the number and area of Type I fibers remains unaltered (41). This discrepancy between results may be related to the use of a longitudinal vs. a cross-sectional design.

In addition to the decline in the number of Type II fibers (54), there is a reduction in the number of functioning motor units. In a cross-sectional study by Campbell, et al. (14), a reduction in the number of motor units was apparent in adults over the age of 60 years. These authors found a significant increase in the CSA of the remaining motor units, possibly due to reinnervation of the slow-twitch fibers. Thus, a decrease in the number and area of Type II fibers and reinnervation of slow-twitch fibers contributes to a reduction in muscle mass, which subsequently has a negative affect on muscle strength.

Muscle Strength

The ability of skeletal muscle to generate force decreases with age. In the same longitudinal study that observed a reduction in muscle CSA over a 12-year period (35), knee-extensor and -flexor strength decreased approximately 20% to 25% per decade and elbow-extensor and -flexor strength decreased 16% to 22% per decade. These findings are greater than what others have reported (7.5% to 8.5% per decade) for the quadriceps muscles estimated from cross-sectional studies, respectively (16, 54).

The reduction in force referred to above has been attributed to the reduction in muscle CSA and loss of functioning motor units. The high correlation between muscle CSA and force generation (r = 0.79 to 0.82) (2, 42, 52) suggests that the decline in strength may be largely affected by the reduction in muscle mass. Although the two are highly correlated, the rate of decline in strength is faster than that of CSA (20% vs. 15%, respectively). Specific tension, the amount of force per muscle CSA, is reduced approximately 5.1% to 6.5% per decade by cross-sectional analysis (61). When examined longitudinally, however, specific tension remained unchanged from 20 to 80 years of age (61). Specific tension can be thought of as the relative contribution of muscle hypertrophy and neuromuscular factors that contribute to strength (64). Neuromuscular factors are affected by the loss of motor units, 11.8% per decade in the biceps brachii (357 $\pm$ 97 to 189 $\pm$ 77 from 29 to 69 years) (26). A reduction in the number of motor units can also influence force generation.

Considering that the number of motor units is significantly related to the force generated during a maximal voluntary contraction (r = 0.52), the loss of strength with age is also a function of the loss of motor units (26). The relative amount of connective tissue also increases with age, however, it is unlikely that the increase in connective tissue has an effect on strength because the connective tissue occupies only 2% of the muscle CSA (30). While several structural and functional changes in muscle occur with age, the declines in strength are primarily due to the loss of muscle CSA and loss of functioning motor units. These changes in the muscle ultrastructure may contribute to the reduction in power production because the muscle generates less force.

Power

Mechanical power can be defined as the force applied to an object multiplied by the velocity of movement of the object; it is also equivalent to the amount of work per unit time (53). Performing less work in the same amount of time reduces mechanical power. Muscle power, the product of muscle force and contraction velocity, is affected by several age-associated changes. Mechanical power, in turn, is affected by the amount of muscle power an individual can generate.

The reduction in the number of Type II fibers combined with the reduction in the number of functioning motor units leads to a decline in the muscle's maximal force-generating capacity of approximately 7.5% to 8.5% per decade (16, 54). Larsson and colleagues found that maximal knee-extension velocity decreased 7% per decade between the ages of 18 and 65 years (54). This was attributed to the positive relationship between the proportion of Type II fibers and maximal knee-extension velocity. The reduction in the velocity of shortening may also be associated with a change in the time it takes the muscle to relax after each contraction, which affects the timing of the subsequent contraction. This is measured and reported as one-half relaxation time.

A reduced contraction velocity and prolonged one-half relaxation time—time from peak force to one-half force-decay—may affect muscle power (14, 46, 51, 54). A 31% reduction in one-half relaxation time (45 ± 1 ms to 59 ± 2 ms) and in peak rate of relaxation (-5.1 ± 0.1 %/ms to -3.9 ± 0.2 %/ms) in the vastus lateralis was attributed to a 33% decrease in Ca^{2+} uptake by the sarcoplasmic reticulum and 37% decrease in maximal rate of sarcoplasmic reticulum Ca^{2+}-ATPase activity (46). Additionally, evidence from Klein, et al. (51) suggest that time-to-peak-tension is reduced due to a reduction in Type II fiber number and area and a slowing of contractile velocity. Considering that muscle power is the product of muscle force and contraction velocity and that strength decreases 7.5% to 8.5% per decade while contraction velocity decreases 7% per decade, these combined changes compound the loss of mechanical power produced by the leg extensors of 35% per decade (213 $\pm$ 51 W to 80 $\pm$ 49 W over 24 years) (73). The reduction in anaerobic power with age is less dramatic.

Anaerobic power is the maximum rate of adenosine triphosphate (ATP) synthesis by anaerobic metabolism during short duration, maximal exercise (39). Data from cross-sectional studies suggest that anaerobic power declines by 6% per decade (1037 W to 760 W over 45 years) (58, 60) in sedentary individuals. In young adults, the percentage of Type II fibers and fiber area is related to anaerobic power ($r = 0.59$ to 0.84) (50). If these correlations are similar for older adults, the reduction in the percentage of Type II fibers with age would provide support for the age-associated reduction in anaerobic power. Metabolic factors also influence the loss of anaerobic power.

Plausible mechanisms responsible for the reduction in anaerobic power with age may be a decline in anaerobic enzymes [hexokinase (HK), phosphofructokinase (PFK), lactate dehyrdrogenase (LDH), and phosphorylase], anaerobic substrates [creatine phosphate (CP), phosphocreatine (PCr), adenosine triphosphate (ATP)], or a combination of both. Ferretti, et al. (31) found that the decline in anaerobic power was not due to a significant reduction in muscle CSA, ATP, or CP concentration. The authors suggest alterations in the maximal recruitment of motor units as a possible cause for the decline.

Another cross-sectional study supported the maintenance of anaerobic enzymes (phosphorylase and LDH) with age (18). In contrast, Marsh and colleagues attributed the decline in peak and mean anaerobic power to a reduced glycolytic capacity, reflective of blood lactate levels 48% lower in older adults than young adults, and possibly a reduction in PFK activity (60). Additionally, Moller, et al. found a significant reduction in PCr concentration in older adults (63). Most evidence, however, suggests that enzymes associated with glycolytic capacity and anaerobic substrates do not decline with age (29, 31, 41).

Effects of Power Training

Several modalities have been used in power training, such as bicycle- or running-interval training and fast-velocity strength training. Fast-velocity strength training involves fast-velocity movements against a moderate to heavy resistance. These training programs have improved muscle mass, strength, and muscle activation (44, 66), as well as anaerobic power and athletic performance (56, 67). Studies of fast-velocity strength training are the primary focus in this literature review.

Muscle Morphology and Strength Adaptations

Hakkinen, et al. found a 10.8% increase in maximum quadriceps isometric force (4001 ± 1112 N to 4434 ± 1212 N) in young men after 24 weeks of fast-velocity strength training (jumping protocol with and without added weight as fast as possible) (44). Another study by Hakkinen and associates found significant increases in maximal leg-extensor isometric force of 18% in older men (2591 ± 736 N to 3075 ± 845 N) and 37% in older women (1816 ± 427 N to 2483 ± 408 N) following a similar protocol of their prior fast-velocity strength training (43). The increase in strength was associated with an increase in quadriceps CSA of 10.0% and 11.5% for older women and men, respectively. Coyle and colleagues (20) demonstrated a 15% to 24% increase in knee-extensor peak torque at $60°\bullet s^{-1}$, $180°\bullet s^{-1}$, and $300°\bullet s^{-1}$ after six weeks of fast-isokinetic training at $300°\bullet s^{-1}$ in college-age men. After a nine-month combined-strength training and jumping protocol, older men and women increased peak isokinetic strength at $30°\bullet s^{-1}$ an average of 16.5% to 33.3% for hip abduction, knee extension, plantar flexion, and dorsi flexion (71). There was also a significant increase (3.5%) in lean leg mass that explained 10% to 14% of the variance in leg strength. The authors suggested that neural adaptations may have also contributed to the gains in strength.

Neural Adaptations

The effect of fast-velocity strength training on electromyographic characteristics of the leg-extensor muscles was examined in 10 young men (44). Various jumping exercises were performed with little or no additional weight as fast as possible three days per week for 24 weeks. Following this protocol, the rate of force production in the leg extensors increased 24.0%, maximal isometric force increased 10.8%, and maximal isometric muscle activation increased significantly - yet there was only slight hypertrophy of the quadriceps muscles. In another fast-velocity strength training study by Hakkinen, et al. (43), middle-aged and older men and women performed three to four sets of three to eight repetitions of leg-extensor exercises (leg press and leg extension) at 40% to 80% of 1RM, as quickly as possible, for 12 weeks. Maximal isometric strength, specific tension, integrated electromyogram, and muscle CSA increased significantly for both men and women. These studies suggest that power may be positively influenced by the improvements made not only in maximal strength, but also in the rate of force production.

Effects of Power Training on Lower Extremity and Anaerobic Power

Older women with self-reported disability significantly improved LEP after 16 weeks of fast-velocity training (34). After participation in a fast-velocity isokinetic ($270°\bullet s^{-1}$) knee-extensor strength-training program for 12 weeks, older women significantly improved knee-extensor peak torque and average power (72). Earles, et al. (28) found a 140% improvement in leg-press power performed at a load of 70% of the subject's body mass. Anaerobic power was significantly improved in older women after 12 weeks of fast-velocity isokinetic ($270°\bullet s^{-1}$) training (15). Certain short duration, high intensity athletic performances may also be improved as a result of power training.

Effects of Power Training on Athletic Performance

Power training significantly improves athletic performance in young adults and single-item functional tasks in older adults. Lyttle and colleagues (56) found significant improvements in performance of the shot put and medicine ball throw, 1RM bench press, 1RM squat, and vertical jump for college-aged men after eight weeks of power training using the squat exercise. Counter-movement vertical-jump height has also been found to increase after a power-training intervention (81). Carmel and colleagues investigated the difference between fast-velocity ($270°\bullet s^{-1}$) and slow-velocity ($60°\bullet s^{-1}$) isokinetic training on performance of individual functional tasks in older women (age range = 61 to 75 years) (15). After exercising three days per week for 12 weeks, both groups significantly improved gait speed, agility, and small object lifting. The fast-velocity group also significantly improved anaerobic power and functional reach.

Thus far, studies have demonstrated significant improvements in LEP (74), anaerobic power (71), and arm pull power (48) for older adults, however, these results were measured after three to nine months of strength training, not power training. A few fast-velocity strength-training studies have examined changes in muscle strength and/or power (34, 43), but there have been no power-training interventions examining the effect on whole-body physical function (15). In summary, power-training programs consisting of fast-velocity exercises for 6 to 12 weeks can significantly improve strength, integrated electromyogram, and anaerobic power in older adults (70 to 95 years).

Effects of Strength Training

Strength-training interventions have elicited increases in muscle mass, muscle strength, power, and physical function in older adults. In a thorough review of the morphological adaptations in human skeletal muscle following strength training, MacDougall suggested that total muscle CSA increased (57). This was due to an increase in the CSA of myofibrils resulting from an increase in sarcomere diameter. These morphological changes, as well as the large neural contribution to strength gains, are documented for older adults (32, 36). Strength-training interventions have also improved power and physical function for older adults.

Muscle Morphology and Strength Adaptations

Strength-training interventions have been shown to be effective for altering both muscle ultrastructure and strength. Frail older men and women (mean age $\pm$ SD = 90 $\pm$ 1 years) who participated in a high-intensity strength-training program (three sets of eight repetitions at 80% knee extensor 1RM) for eight weeks significantly increased knee-extensor strength 174% and mid-thigh CSA 9% (32). In another study by Fiatarone and colleagues (33), 10 weeks of progressive-resistance training resulted in a 113.0% increase in muscle strength and 2.7% increase in thigh CSA. Frontera and colleagues (36) found a 107% increase in knee-extensor (20 ± 1 kg to 40 ± 2 kg) and 226% increase in knee-flexor (8 ± 1 kg to 23 ± 2 kg) strength following a strength-training protocol (three sets of eight repetitions at 80% knee extensor 1RM) three days per week for 12 weeks. Total thigh CSA also increased by 4.8%, Type II fiber area by 27.6%, and Type I fiber area by 33.5%. Older women (mean age ± SD = 69.9 ± 1 years) participating in a 12-week lower-body strength-training program three days per week performed three sets of six repetitions at 65% to 75% of 1RM on seven lower-body exercises (17). Results indicated a 28% to 115% increase in strength and 20% increase in Type II mean fiber area. These studies collectively suggest that neural adaptations were primarily responsible for the improvements in strength.

Neural Adaptations to Strength Training

In addition to gains in muscle strength, specific tension has also increased after strength training. Older adults participating in a progressive-resistance training program (three sets of eight repetitions at 80% 3RM) three days per week for 12 weeks significantly improved knee-flexor specific tension by 64% (80). In another study, older men and women performed heavy-resistance knee-extensor strength training three days per week for nine weeks (79). Maximal dynamic strength increased an average of 27% and muscle volume increased 12%, which contributed to a 14% increase in specific tension. Once again, the improvement in strength greater than that of muscle volume implies a neural contribution to strength gains. Possible neuromuscular mechanisms explaining the increase in specific tension include an increase in motor-unit-firing rate and recruitment and an increase in activation of synergistic muscles (64, 70). These neural adaptations may also influence power.

Effects of Strength Training on Leg Extensor and Anaerobic Power

Anaerobic power is increased after a strength-training program in young men (9). To date, however, few studies have examined the effect of a strength-training intervention on anaerobic power or LEP in older adults. Shaw and Snow (71) investigated the effect of a nine-month resistance-training program on lower-body strength and power in older women (mean age ± SD = 62.5 ± 6.6 years for control, 64.2 ± 5.8 years for exercise group). Subjects performed three to five sets of 10 to 15 repetitions for four to six exercises (squats, stepping, chair raises, forward lunges, lateral lunges, and toe raises). Resistance was applied with a weighted vest totaling 5% to 20% of the subject's body mass. In order to increase power, subjects performed jumps in place and depth jumps from an 8-inch step. After nine months, the exercise group increased dynamic strength by 16.0% to 33.0% and lean leg mass by 3.5%. Additionally, peak anaerobic power relative to body mass ($W \bullet kg^{-1}$), as measured using the Wingate anaerobic test, increased 13%. Jozsi, et al. (48) found similar results when older and younger adults resistance trained two days per week for 12 weeks. The investigators compared the changes in power and strength between the old (mean age ± SD = 60.3 ± 0.8 years) and young (mean age ± SD = 26 ± 0.8 years) men and women after a progressive-resistance training (PRT) program or no exercise control protocol. The subjects in the PRT group performed two sets of eight repetitions at 80% 1RM and one set to volitional fatigue on five upper- and lower-body exercises. Following the 12-week program subjects increased arm pull power and LEP at 40% and 60% of the 1RM.

Effects of Strength Training on Physical Function

Leg extensor power and anaerobic power are significantly related to physical function (15, 75). An intervention that increases LEP or anaerobic power could potentially improve physical function. Recent studies have shown that strength training can improve the ability of an older adult to perform daily tasks and live independently. When Cress and colleagues (22) utilized a combined-strength and endurance-training program for older adults to perform three days per week for six months, an 11% increase in VO_{2max}, 33% increase in dynamic strength, and a 14% increase in whole-body physical function was observed. After one year of functional-strength training (stair climbing with a weighted backpack), older women (age range = 65 to 83 years) significantly increased Type IIb fiber area and mean fiber area (24). These changes in the muscle ultrastructure were responsible for an increase in thigh strength, which explained 60% of the variance in stair performance. Skelton and colleagues (74) found an improvement by their participants for step-up height after 12 weeks of strength training. Ten weeks of high-intensity strength training in frail nursing home residents improved gait velocity by 11.8 % (from 0.51 ± 0.04 $m{\bullet}s^{-1}$ to 0.04 ± 0.02 $m{\bullet}s^{-1}$) and stair climb power by 28.4% (from 39.1 ± 3.4 W to 11.1 ± 2.5 W) (33).

Yet, others have not found significant improvements in function after a strength-training program. Although Skelton and colleagues (74) found a significant improvement in step-up height, no significant changes were detected in self-selected gait velocity, step rate, time to rise from a chair, functional reach, or time to rise from the floor. Knee-extensor strength increased 62% after 13 weeks of resistance training, but there was no improvement in the time to rise from a chair (49). In another study, no change in stair-climb speed or gait velocity was evident after a six-month strength-training intervention (12). This lack of improvement may be partly explained by the curvilinear relationship between function and strength (11). An individual's improvement would depend upon his or her initial point on this curve. Additionally, improvements demonstrated in serial-task performance would have been missed by only evaluating an individual task (10, 22).

In summary, strength-training interventions with older adults have been conducted for lengths of 8 to 52 weeks at frequencies of two to three days per week using intensities ranging from 40% to 80% of the 1RM. These training protocols have resulted in statistically significant increases in muscle mass (32, 79, 80), Type II fiber area (17, 24), strength (32, 36, 74), specific tension (79, 80), power (48, 71), and improvements in physical function (22, 33). Several other studies, however, have not found significant improvements in physical function (12, 22, 49, 74). In a later section, some potential explanations for these conflicting findings are presented. These varying results leave the practitioner, clinician, and researcher to question, which type of exercise is best for improving physical function and which functional assessment instrument is best.

Power Training vs. Strength Training

Both power- and strength-training programs have produced improvements in muscle strength, athletic performance, power and physical function. Whether or not one type of training is more efficacious than the other type has only briefly been addressed in the literature. Strength training is typically performed at slow velocities with heavy resistance, whereas power training is performed at fast velocities with light to moderate resistance. In this section, the research performed with young adults is followed by research with older adult participants. Then, several possible mechanisms responsible for the physiological differences between the two exercise modes is reviewed.

Evidence from Research with Young Adults

For young adults, power training has resulted in greater gains in athletic performance and strength than has strength training. Wilson and colleagues (81) examined the effect of training load on counter-movement vertical-jump height and peak anaerobic power of college-aged men. These men were randomly assigned to one of three training groups: power training (30% 1RM), typical-weight training (80% 1RM), or plyometric training (depth jumps). Peak anaerobic power achieved during a 6-sec-cycle ergometer test increased within the exercise groups, but no differences were found between the groups. Participation in the power-training program resulted in a 12% larger increase in counter-movement vertical-jump height, but less isokinetic peak torque than the strength-training protocol. In this experiment, certain performance variables were more affected by the type of training than others were. This result supports the principle of specificity.

In another study, 18 college-aged men participated in a maximum-strength (90% 1RM) or a maximum-power (30% to 80% 1RM) training program for seven weeks (83). The power-training group increased the rate of force production (68.7%) during an isometric squat exercise more than the strength-training group did (23.5%) ($p<0.05$). The strength-training group, however, increased isometric force production (31%) more than the power-training group did (12.4%).

In contrast, some authors have found no difference between the two training protocols (56, 81). Thirty-nine young men participated in a power-training program, a heavy weight plus plyometrics-training program, or a no exercise control group (56). The two exercise groups met two days per week for eight weeks. The power-training group performed fast-velocity exercises for two to six sets of eight repetitions at 30% 1RM. The heavy weights plus plyometrics-training group performed similar exercises with a resistance that enabled each subject to perform 6 to 10 repetitions as fast as possible. Both groups increased athletic performance on selected fast-velocity exercises more than the control group, but there was no significant difference between the two training programs. This indicates that both methods of training were equivalent in their ability to increase power and athletic performance in young male athletes, although the heavy resistance strength-training exercises utilized in this study were performed as fast as possible and were similar to power training rather than to strength training. The training programs may not have been as clearly differentiated as is necessary for detecting differences between the two programs. Therefore, caution needs to be used when interpreting the results from this study. Nonetheless, evidence from the studies discussed in this section suggest that power training is more effective for improving athletic performance (81), while strength training is more effective for improving strength (83).

Evidence from Research with Older Adults

Researchers have found that LEP is reduced at a faster rate than muscle strength in older adults when examined cross-sectionally (73). Uncovering this fact has prompted interest in determining whether power training is more efficacious than strength training for preserving or improving these muscle qualities in older adults. Fielding and colleagues (34) examined the effects of a 16-week fast- vs. slow-velocity resistance-training program on community-dwelling older women (age range = 70 to 95 years) with self-reported disability. Women in the fast-velocity resistance-training group increased isokinetic LEP by 140%, while those in the slow-velocity resistance-training group increased only 40% ($p<0.0001$). Isokinetic peak knee-extensor torque improved 40% and 25% in the fast-velocity and slow-velocity groups, respectively. The results of this study demonstrate that the most positive changes occur after a power-training program rather than a strength-training program.

Additionally, Signorile, et al. (72) demonstrated that older women who participated in a fast-velocity ($270°\bullet s^{-1}$) isokinetic knee-extensor training program improved average power at $180°\bullet s^{-1}$ and $300°\bullet s^{-1}$ significantly more than those who participated in a slow-velocity ($60°\bullet s^{-1}$) isokinetic knee-extensor training program. The difference in results between the two training programs may be due to the physiological mechanisms involved in this type of training.

Mechanisms Responsible for the Observed Differences Between Training Modalities

Several plausible mechanisms have been suggested to explain improvements specific to power and strength training. First, the nature of power training itself may recruit more fast-motor neurons than strength training (82). Yessis (82) has suggested that the fast-velocity movements performed during power training are necessary for the training adaptations to the fast-motor units. Secondly, motor-unit-firing rate and frequency may be faster after power training than after strength training. Hakkinen and colleagues (44) provide evidence for increased motor-unit-firing frequency and recruitment patterns in young men after a fast-velocity strength-training program. Sale (69) suggests that motor-unit-firing rates and patterns are influenced by the velocity of contraction; increasing velocity will increase firing rate. Training at a fast velocity is an inherent characteristic of power training. In another review, Sale (70) summarizes evidence from other researchers to support an increase in synchronization of discharge and firing rate of motor units after strength training. He also suggests that the adaptations are specific to the type of training performed. This is supported by evidence from Hakkinen, et al. (44). Slow-velocity, heavy-weight training resulted in a 27.0% increase in knee-extensor peak force and 0.4% increase in maximal rate of force development, whereas fast-velocity, light-resistance training resulted in an 11.0% increase in peak force and 24.0% increase in rate of force production. In accordance with these results, the fast velocity inherent to power training may increase the motor-unit-firing rate more than the slow velocity employed during strength training. Finally, more muscle activation may contribute to more neural adaptations after power training than after strength training (44). Power training may recruit more fast-motor neurons, increase motor-unit-firing rate and frequency, and help develop increased muscle activation. These neural adaptations resulting from power training may have a greater effect on physical function than strength training would. The conflicting results from strength-training interventions on their ability to improve physical function may be due to several instrument limitations.

Assessment of Physical Function

Traditional measurement of physical function has some limitations. Physical function has been defined as the integration of physiological capacity and physical performance capability mediated by psychosocial factors (23). With the increasing older adult population wanting to age in place, physical function is important for independent living.

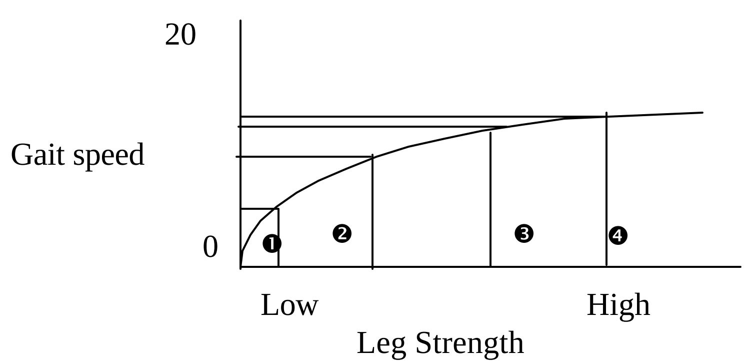
Recently, attention has been paid to the relationship between strength and physical function for older adults. Several investigators have examined the efficacy of a strength-training program to improve physical function in older adults. Results indicate improvements in rising from a chair (8), time to climb stairs (33), step-up height (24), and whole-body physical function (22), while some studies have failed to demonstrate significant improvements in physical function (12, 49, 74).

Lack of consistency between the results may be due to several instrument issues. First, the type of scaling used to evaluate an individual's physical function may be a reason for the discrepancies. Two types of scaling are discussed, ordinal and continuous. Ordinal scaling may limit the sensitivity of the instrument to detect small changes in function. For example, if a task is scored by time (sec) and the ordinal scaling is divided into four 3-sec time intervals, an improvement of 1 sec may not necessarily correspond to an improvement on the instrument. Thus, an individual's score would not change. Continuous scaling, on the other hand, may be more sensitive to detecting change because it allows an individual to demonstrate improvements in his or her score even with small changes on the scale. Most ordinal scales are set up with the assumption of a linear relationship between function and a physiological measure. Buchner and colleagues (13), however, have argued that the relationship between leg strength, a physiological measure, and gait velocity, a functional measure, is non-linear.

Secondly, ceiling effects (scores that cannot exceed a certain value) limit the detection of an individual's improvement in function. Using the timed-tandem stance as an example of a measure of function that is scored on a continuous scale, a score of 10 sec corresponds to the best possible maximum value. Therefore, an individual who stands for 10 sec prior to a strength-training intervention and 15 sec after a strength-training intervention is assigned the same score. The individual's improvement went undetected, statistically, because the top score was 10 sec.

Finally, the reliability and validity of an instrument needs to be demonstrated. As there is not a 'gold standard' measure of physical function, it is impossible at this time to establish criterion validity. Nevertheless, logical, construct, and convergent validity can be examined. Logical validity refers to the ability of an instrument to measure what it purports to measure. For example, if physical function is to be evaluated, tasks such as vacuuming, walking, or climbing stairs should be incorporated into the measurement, not tests of memory. Construct validity refers to the ability of a test to discriminate between different levels of physical function, and convergent validity refers to the ability of different functional measures to be related to each other. Inter-rater and test-retest reliability also need to be established. The instrument chosen should also be valid and reliable when used with older adults.

The correct sample of participants must be targeted when evaluating changes in functional status. This is done to maximize the potential benefits of a physical intervention. Using the non-linear relationship between function and a physiological measure established by Buchner, et al. (13), this point can best be demonstrated by the graph below.



The y-axis represents gait velocity (function) and the x-axis represents knee-extensor strength (physiological measure). An individual who is strong at baseline, point ❸, and improves his or her strength, point ❹, will not demonstrate a concomitant increase in function. This individual will improve his or her reserve of strength, however, function will not be significantly improved. On the other hand, an individual with low strength at baseline, point ❶, who improves his or her strength, point ❷, will demonstrate a concomitant increase in function. The individual with low initial strength is on the linear portion of the curve, therefore, his or her improvement in function will be similar to the improvement in strength. The individual with high initial strength is on the flatter portion of the curve, therefore, improvements in strength can appear without similar improvements in function. To satisfy the purpose of the study, the sample targeted should be the one most affected by the intervention.

Measures of physical function range from single- to multi-item assessments. A single-item measurement, e.g., time to climb a flight of stairs, evaluates only one dimension of function, such as strength or power, whereas a multi-item measurement is a combination of tasks, e.g., the 16 tasks in the Continuous Scale Physical Functional Performance (CS-PFP) test. Scores for single-item measurements may be less sensitive to change in value with an intervention because they evaluate only one dimension of function that may change with an intervention. Multi-item measurements evaluate several different domains of function. In this instance, a summary score is usually created to represent overall physical function. This summary score is more reflective of daily tasks than a single measure is. To illustrate the difference in sensitivity between single- and multi-item measurements, it was recently demonstrated that a significant improvement in whole-body physical function (multi-item) occurred, but no significant change was detected for 6-minute walk distance (single-item) after six months of combined-strength and endurance training (22).

In summary, the inability of studies to reproduce results demonstrating improvements in physical function following a strength-training program may be due partially to characteristics of the measurement instruments used. Improvements in physical function may be better detected by utilizing an instrument that is valid, reliable, continuously scaled, and comprised of multiple measures of function.

Review of Outcome Measures

When designing a research study, the criteria for appropriate outcome measures are validity, reliability, and application to the sample being studied. Using these criteria, physical function measured by the Continuous Scale Physical Functional Performance (CS-PFP) test, LEP measured on the Nottingham leg power rig, and anaerobic power measured by the Wingate anaerobic performance test are discussed. Because measures of power from the Wingate anaerobic performance test have been expressed relative to lean leg volume, the methods for estimating lean leg volume are also evaluated.

Assessment of Physical Function

One functional assessment tool that may potentially serve as a criterion measure of physical function is the Continuous Scale Physical Functional Performance (CS-PFP) test. This test is comprised of 16 daily tasks to measure whole-body physical function and five physical domains: upper-body strength, upper-body flexibility, lower-body strength, balance and coordination, and endurance. This measure is both valid and reliable (23). Physical function as measured by the CS-PFP is highly correlated with an established physiological measure for each functional domain (e.g., $r = 0.93$ between upper-body strength domain and biceps strength), is highly discriminating between levels of physical function and living statuses ($F = 24.09$, $p<0.0001$), and is correlated to other measures of function ($r = 0.68$ to 0.77). These features of the CS-PFP test demonstrate its logical, construct, and convergent validity (23). The CS-PFP has high inter-rater and test-retest reliability, $r = 0.92$ to 0.98 and $r = 0.85$ to 0.97, respectively. The CS-PFP is continuously scaled, which allows small changes in function to be detected (22). After six months of a combined-strength- and endurance-training program, whole-body physical function was shown to improve 14%, whereas a single-item measure of function, e.g., the 6-minute walk, demonstrated no significant change (22). Other advantages of the CS-PFP include limited ceiling effects, continuous scale measure, representation of different functional domains, multiple task performance, and sensitivity to change.

Assessment of Leg Extensor Power

Development of the Nottingham leg power rig (University of Nottingham, U.K.) has improved the measurement of LEP by making the test portable and easy to use (5). Leg extensor power is a measure of peak instantaneous power produced by the leg-extensor muscles. This method of measuring LEP has been validated and reliability has been established by Bassey and Short (5). Measures of peak power calculated from the leg power rig (watts, W) were highly correlated with isokinetic (4 $rads{\bullet}s^{-1}$) knee-extensor peak power ($r = 0.80$) and peak power on a force plate ($r = 0.86$). Test-retest reliability of measuring LEP on the Notthingham leg power rig is high ($r = 0.97$) (5). This test is able to discriminate LEP between persons with neurological or musculoskeletal diseases and healthy persons (6). A high correlation between LEP and functional tasks has previously been confirmed with older adults through measures of stair-power (r = 0.88), chair rise velocity (r = 0.65), and floor-rise power (r = 0.79) (6, 62). After 12 weeks of strength training, LEP expressed relative to body mass ($W \bullet kg^{-1}$) increased 18% in older men and women (74), thus establishing the instrument's ability to detect change in LEP. The Nottingham leg power rig is a valid and reliable measure of LEP for older adults.

Wingate Anaerobic Performance Test

The Wingate anaerobic performance test was first developed in the 1970s at the Wingate Institute for Physical Education and Sport in Israel. This test was designed to be portable, inexpensive, and feasible for persons of different functional levels. The Wingate anaerobic performance test is a 30-sec maximal sprint on a cycle ergometer against a constant resistance, which is based on a percentage of the subject's body mass, 8.5% body mass (kg) (27). In studies with older adults, the resistance has also been based on a percentage of the individual's lean body mass (71, 75). Peak and mean power are quantified while a fatigue index can be calculated. The primary energy contribution during the Wingate anaerobic performance test comes from glycolysis (56%) and the phosphagen system (28%), with the least energy provided by aerobic metabolism (16%) (76)--hence the anaerobic nature of the test. Results of this test are unaffected by climate and hydration status, but are affected by warm-up, circadian rhythms, and motivation in the form of rewards and/or punishment (3). High test-retest reliability of the Wingate was shown (r = 0.95 to 0.97) (4).

The Wingate protocol requires a familiarization warm-up prior to the start of the test. This warm-up involves pedaling at a low resistance interspersed with brief sprints.

Research studies with older adults performing the Wingate have utilized this protocol (60, 75).

Although there is no known gold standard measure of anaerobic power, the Wingate has been compared to physiological and performance measures to examine validity. Kaczkowksi, et al. (50) found a high correlation between fast-twitch fiber area and peak (r = 0.84) and mean (r = 0.83) power measured by the Wingate test. In a review by Bar-Or (3), mean and peak power from the Wingate were significantly correlated to performance measures such as the vertical jump and 40-meter run speed (r = 0.69 to 0.92). Recently, Shaw and Snow (71) demonstrated that peak power ($W \bullet kg^{-1}$) obtained from the Wingate anaerobic performance test increased 13% in older women after nine months of resistance training. Evidence from these studies suggests that the training stimulus needs to be of an anaerobic nature to elicit the observed changes in anaerobic power. Based on past research, the Wingate anaerobic performance test is a valid and reliable measure of anaerobic power and can detect change in anaerobic power.

Lean Leg Volume

Lean leg volume (LLV) is an anthropometric estimation of muscle plus bone area. Anthropometric methods of estimating muscle plus bone area have been highly correlated with computed tomography scans (r = 0.98) (19). However, the estimated values for young adults are approximately 12.5% to 13.7% higher than the measured values (19, 78). This overestimation may be due to the assumption that the limb is circular, which would result in the largest thigh area (78). An anthropometric estimation of LLV developed by Jones and Pearson was validated against the water displacement method (r = 0.98) (47). Housh and colleagues cross-validated an anthropometric estimate of total thigh muscle plus bone area with magnetic resonance imaging (r = 0.85) (45). While anthropometric estimates of LLV appear to be valid, they overestimate the actual area of the muscle plus bone.

Values of anaerobic power have been expressed relative to LLV in the literature (58, 59, 60). Estimates of LLV have been significantly related to peak (r = 0.81) and mean power (r = 0.80) (58), which would suggest that an individual with more LLV would have more anaerobic power.

Summary

The ability of an older adult to complete daily tasks is dependent upon the physiological reserve of the neuromuscular and cardiovascular systems. The loss in muscle mass with age is primarily due to the loss of Type II fibers and the denervation of fast-twitch, alpha-motor neurons. A reduced force-generating capacity of aged muscle and slower contraction velocity parallels these changes. Muscle power subsequently declines. Participating in either strength- or power-training interventions has significantly improved the above mentioned systems of older adults in defense of facultative aging.

Strength-training interventions have proven successful with older adults by positively altering the neuromuscular physiology. Results have indicated an increase in muscle mass, strength, power, and possible improvements in physical function. Power training, on the other hand, has rarely been performed with older adults. Athletes and young adults have demonstrated significant improvements in strength, rate of force development, muscle activation, and athletic performance measures. Although researchers are now concerned with how an older adult can utilize the gains in strength from a strength-training intervention, little research has examined the effect of power training on whole-body physical function, anaerobic power, or LEP in older adults.

Where strength is concerned, some studies have demonstrated improvements in physical function following a strength-training intervention, but others have not. The reasons for these discrepancies may be related to several issues concerning the instrument used to measure function, such as ceiling effects, validity, reliability, and the type of scaling used.

Several different outcome measures can be used to assess physical function and power. The Continuous Scale Physical Functional Performance (CS-PFP) test, the Nottingham leg power rig, and Wingate anaerobic performance test are the most appropriate tests for physical function, LEP, and anaerobic power, respectively, for older adults. The measures chosen have demonstrated validity, reliability, and an ability to detect improvements after an exercise intervention.

Older adults can benefit from a strength-training intervention and possibly improve physical function. The effect of a power-training intervention on whole-body physical function, anaerobic power, or LEP has yet to be examined in this population. The greater neural adaptations resulting from power training may make it a more effective exercise modality than strength training for improving physical function in older adults. It is important to examine the efficacy of a power-training intervention to improve physical function in older adults and to see whether the effect of power training is greater than the effect of strength training.

CHAPTER 3

EFFECT OF STRENGTH AND POWER TRAINING ON PHYSICAL FUNCTION IN COMMUNITY-DWELLING OLDER ADULTS[1]

[1] Miszko, T.A., M.E. Cress, C.J. Covey, J.M. Slade, S.K. Agrawal, and C.E. Doerr. To be submitted to the *Journal of Gerontology: Medical Sciences.*

Abstract

Background. The performance of daily tasks, such as stair climbing or lifting an object, requires both muscle strength and power. Age-associated reductions in the neuromuscular system can affect an older adult's ability to complete daily tasks and live independently. Strength training has improved the functional performance of older adults, however, greater neural adaptations from power training may make power training a more effective modality than strength training for improving physical function.

Methods. The purposes of this study were 1) to determine the effect of strength and power training on physical function and anaerobic power in older adults and 2) to examine the relationship between the change in anaerobic power and muscle strength and the change in physical function. Thirty-nine 65-90-year-old men and women (mean age ± SD = 72.5 ± 6.3 years) with below-average leg extensor power were randomly assigned to attention-control (C, n = 15), strength- (ST, n = 13) and power- (PT, n = 11) training groups. The intervention groups met three days per week for 16 weeks, while the control group maintained usual activity and attended three lectures during the course of the study. Primary outcome measures included: the Continuous Scale Physical Functional Performance (CS-PFP) test, a performance-based measure of 16 common daily tasks; capacity measures of strength using the maximal weight lifted through one repetition; and the Wingate measure of anaerobic power (AP). An analysis of covariance was used to examine differences between the groups on the post-measure, with the pre-test as the covariate. Pearson correlation coefficients were calculated to examine the relationship

between the change in physical function and the change in anaerobic power. An effect size (ES) was calculated to examine the magnitude of difference between the groups.

Results. After controlling for baseline, the CS-PFP total score was significantly greater for the PT group than the ST (ES = 0.88) and C group (ES = 0.98). Maximal strength and mean AP ($W \bullet kg^{-1}$) were significantly greater for the ST group than for the C group (ES = 1.63). There was no significant difference between groups for peak AP.

Conclusions. Power training was more effective than strength training for improving physical function in community-dwelling older adults.

Introduction

The performance of daily tasks requires muscle strength and power, though both may be compromised because of age-associated changes in the neuromuscular system (30). A low level of strength may make it difficult to lift a grandchild, while stair climbing may be difficult with a low level of leg power. Loss of anaerobic power, needed for physically demanding tasks and serial task performance, can also impose limitations on older adults. These age-associated changes are largely due to a reduction in muscle mass, which is mediated by the loss of Type II fibers (23). Numerous studies of older adults with and without disease have demonstrated the ability of strength-training programs to attenuate these losses (11, 20, 31).

Declines in strength are well documented (23), and these have been addressed through strength-training programs (5, 11). Traditional strength training may also address the loss in velocity of movement that occurs with advancing age (23). This type of training, however, does not focus on increasing the velocity of movement. By improving strength with two different protocols, one fast velocity and one slow velocity, the declines in both strength and velocity of movement may be attenuated.

While strength training incorporates a heavy resistance moved at a moderate to slow velocity, power training utilizes a light resistance moved at a fast velocity. Participation in a strength-training intervention has been shown to significantly improve strength (5, 11) and some functional tasks in older adults (11), but older adults who train for muscle power may be stronger and more powerful than those who do not. These individuals may have a greater ability to rise from a chair, climb stairs, and possibly avoid a fall.

Power training has significantly improved leg extensor power in older adults (12). Power training may improve physical function beyond that of a traditional strength-training intervention because it involves a high velocity of movement. High-velocity movements, in turn, can improve motor-unit-firing rate and frequency, synchronization of discharge, and muscle activation more than strength training can (14, 26, 27).

Furthermore, older adults who strength trained had higher anaerobic power than non-strength-trained older adults (32). This study found a significant correlation between physical function and anaerobic power ($r = 0.55$ to 0.61). Considering this relationship, one would expect to see an improvement in physical function resulting from increased anaerobic power. A nine-month strength-training study with older women, in fact, has already shown significant improvements in anaerobic power (29). Furthermore, physical function can be improved after a strength-training intervention (8). Power training, however, may have a greater effect on anaerobic power than strength training because of the increased neural adaptations resulting from power training.

Both strength and power training improve anaerobic power (4, 29), and strength training improves physical function (3, 8), yet a study evaluating the effect of power training on anaerobic power and physical function has not been done. The purposes of this study were 1) to determine the effect of strength and power training on physical function and anaerobic power in older adults and 2) to examine the relationship between the change in anaerobic power and muscle strength and the change in physical function. We hypothesized that, because individuals would be able to perform the tasks faster, the combination of the low resistance and the fast velocity of movement necessary for power training would lead to a greater improvement in whole-body physical function than strength training. We further hypothesized that power training would improve anaerobic power more than strength training would because of the increased neural adaptations associated with power training (14). Additionally, we hypothesized that the change in physical function would be significantly related to the change in anaerobic power and maximal strength.

Methods

Subjects and Procedures

Sixty-five men and women between the ages of 65 and 90 were recruited from the Athens, GA community. Subjects were included in the study if their leg extensor power was less than 140 W for women and 210 W for men. This level of leg extensor power was chosen because unpublished data from our lab suggested that it corresponded to a low level of physical function (Continuous Scale Physical Functional Performance total score < 55). Subjects were excluded from the study if they met any of the following criteria: poorly controlled or unstable cardiovascular disease or diabetes, recent unhealed bone fracture (within the past 12 months), severe hypertension (> 160/90 mmHg) while resting quietly in the supine position, leg or arm amputation, severe psychiatric illness that limits cooperation in general and the ability to follow directions or keep appointments, excessive alcohol intake (more than three drinks per day), a classic anterior compression fracture, terminal illness (life expectancy less than one year), neuromuscular disorders, non-ambulatory, or current or recent (< six months) involvement in a strength-training or running/jogging program. All subjects signed a written informed consent approved by the Human Subjects Institutional Review Board at the University of Georgia.

Out of the 65 subjects recruited, 50 older adults were stratified by sex and randomized into one of three groups: strength training (ST, n = 17), power training (PT, n = 18) or attention control (C, n = 15). Subjects were evaluated on physical function, maximal strength, and anaerobic power at baseline and after 16 weeks. Make-up sessions were required for those who missed more than three sessions.

Training Interventions

Subjects in the strength- and power-training groups met three days per week for 16 weeks.

Strength training: The following four upper- and lower-body exercises were performed for three sets of six to eight repetitions: seated row, chest press, biceps curl, triceps extension, leg press, leg extension, plantar flexion, and seated leg curl (Keiser Inc., Fresno, CA). The squat exercise was performed for three sets of six repetitions. Each session began with a 5-minute dynamic warm-up utilizing the major joints and muscles to be exercised that day. Muscle-specific stretches were performed after each set. The intensity progressed from 50% to 70% of the one-repetition maximum (1RM) by week eight, then remained at 80% of the 1RM for weeks 9 through 16. The 1RM was re-tested every four weeks to properly adjust the resistance. The concentric action was performed in approximately 4 sec and the eccentric action was slow and controlled.

Power training: The power-training program consisted of the same eight exercises as the strength-training program, with the addition of jump squats. Because research suggests building a strength base prior to power training (28), the first eight weeks were the same as in the strength-training program. After eight weeks, the program was designed to increase muscle power. Each subject performed three sets of six to eight repetitions at

40% of the 1RM value as fast as possible. The concentric action was performed in approximately 1 sec and the eccentric action was performed in approximately 2 sec.

Attention Control: Subjects in the C group maintained their usual activity without engaging in any strength training, jogging and/or running, and without beginning a new exercise program during the study. Subjects met for an educational presentation three times during the 16 weeks. At the conclusion of the 16 weeks, these subjects had the opportunity to participate in a strength-training program.

Anthropometric Measures

Percent fat was estimated from the sum of three skinfold measurements and using sex-specific generalized equations (17, 18). Skinfold measurements were taken with Lange® calipers (Cambridge, MA) and measured to the nearest 1mm. Lean thigh volume was estimated by the anthropometric procedures according to Jones and Pearson to normalize anaerobic power (19). Circumference measurements were taken at the gluteal fold, at mid-thigh, and just above the knee. Skinfold measurements were taken at the anterior and posterior mid-thigh. Each circumference and skinfold site was recorded twice and the average value was calculated.

Physical Function

The Continuous Scale Physical Functional Performance (CS-PFP) test was used to measure physical function. The CS-PFP test is both valid and reliable across a range of functional levels (9). This test consists of a battery of 16 everyday tasks measured by the distance moved, the time to complete each task, and/or the amount of weight carried. Tasks quantified by distance include the 6-minute walk and maximal reach height. Tasks quantified by time include transfer of laundry from washer to dryer, putting on and removing a jacket, sweeping a section of a floor, vacuuming, making a bed, climbing a flight of stairs, sitting down and rising from the floor, opening a fire door, putting a Velcro® strap across a shoe, and picking scarves off the floor. Tasks that are quantified by weight carried and time include carrying of weight, pouring water from a jug into a cup, carrying a weighted bag up and down a bus platform, and carrying groceries a specified distance. The CS-PFP test yields a total score and five physical domain scores: lower-body strength (LBS), upper-body strength (UBS), upper-body flexibility (UBF), balance and coordination (BALC), and endurance (END). Each task is adjusted to a scale of 0 to 100 based on older adults with a broad range of abilities (7). The CS-PFP total is the average of all adjusted scores, and the domain scores are the average of the tasks in that domain. A detailed description of the tasks performed has been reported previously (9). A detailed dialogue can be obtained on the World Wide Web at http://www.coe.uga.edu/cspfp/.

Maximal Strength

Maximal strength was measured for the chest press (Cemco Physical Fitness Products, S. El Monte, CA) and leg press (Alliance Rehabilitation System, Chattanooga Group, Inc., Hixson, TN) using the maximal strength procedure. The one-repetition maximum (1RM) is the maximal amount of weight that can be lifted once through the full range of motion while holding to good form (34). One warm-up set of approximately four to six repetitions was performed. Resistance was gradually increased so that the subject reached a maximal value in less than five trials. No less than 3 minutes was allowed between each trial. Each subject performed two familiarization trials before the

1RM test. This testing protocol has been used previously with older adults and was reliable (r = 0.85) (11, 16, 20).

Anaerobic Power

The Wingate anaerobic cycle test is a 30-sec maximal cycle sprint against a constant resistance. This is a valid test of anaerobic power (21) that has demonstrated high test-retest reliability (1). This test quantifies peak and mean anaerobic power. Peak power is the highest average power in any 5-sec interval, and mean power is the average power over the total 30 sec. The pedal resistance was based on a percentage of the subject's lean body mass by using the following equation (32):

Load (kp) = [(57.4/LBM)*0.085] * BM

A 12-lead electrocardiogram recording (Quinton, Inc., Bothell, WA) was taken during rest, throughout the test, and for 3 minutes post-test. A 5-minute warm-up on a Monarch cycle ergometer (Varberg, Sweden: Model 814E) interspersed with four brief sprints was performed in order to familiarize the subject with the protocol and to look for signs of cardiovascular insufficiency. After a 7-sec countdown, the subject proceeded to pedal as fast as possible for 30 sec. The subject or the physician was able to terminate the test if he or she determined it unsafe. Upon completion of the test, the subject remained seated on the bike and pedaled at a low resistance (0.5 kp) until heart rate returned to baseline. A rating of perceived exertion (RPE) was recorded at the conclusion of the bike test (2). During the test, an optical sensor was used to determine the number of revolutions of the cycle flywheel from the reflective markers. This sensor was interfaced with computer software (Sports Medicine Industries, St. Cloud, MN) to calculate mean and peak power.

Statistical Analysis

The sample size calculation was based on the effect size (d = 0.74) for the change in physical function published by Cress, et al. (8). This effect size was converted to an effect size for an analysis of covariance (d') using the procedures established by Glass, et al. (13). Using Cohen's power charts with statistical power based on one-half of d', an alpha level of 0.05, and power of 0.80, seven subjects per group (N = 21) were needed (6).

All statistical analyses were performed using SPSS® (Chicago, IL, v10). An analysis of covariance (ANCOVA) was used to examine differences between population means on the post measure while using the pre-test as the covariate. Even though there were no significant differences between groups at baseline, an ANCOVA was chosen because it reduces the error variance. Three pairwise comparisons were done to test the hypothesis. An effect size (ES) was calculated according to the procedures of Glass, et al. (13). Pearson correlation coefficients were calculated to evaluate the relationship between the change in physical function, strength, and anaerobic power. An alpha level of 0.05 was required to establish significance.

Results

Participants

Fifteen of the sixty-five recruited volunteers did not participate in the study for the following reasons: unable to obtain medical clearance, disinterested in study due to the length of the program, or failed to meet eligibility criteria. Eleven of the fifty volunteers (22%) did not complete the study due to family and/or personal medical reasons, injuries, or relocations (ST, n = 4; PT, n = 6; C, n = 1). Six women (ST, n = 5;

C, n = 1) fell during the course of the study. The falls resulted in two broken ankles, a torn rotator cuff, a sprained finger, a cracked rib, and a fractured lumbar vertebra. Three of the falls occurred outside of the exercise sessions and three occurred during the exercise sessions. Fourteen participants (93.3%) in the C group participated in the strength-training program at the conclusion of the 16 weeks. There was no significant difference between groups at baseline for any physical characteristic shown in Table 3.1.

Table 3.2 includes the pre- and post-test data for the outcome variables.

Physical Function

After controlling for baseline, the PT group was significantly different from the ST group for CS-PFP total (ES = 0.88), BALC (ES = 1.02), END (ES = 0.91), and UBF (ES = 0.84) (Table 3.3, Figure 3.1). Additionally, the PT group was significantly different from the C group for CS-PFP total (ES = 0.98), BALC (ES = 0.99), and END (ES = 1.09). There was not enough statistical evidence to indicate a significant difference between groups for the LBS or UBS domains of the CS-PFP test ($p > 0.05$). The change in physical function was not significantly correlated to the change in peak anaerobic power ($r = 0.29$) or leg press strength ($r = 0.16$).

Strength

After controlling for baseline, the ST group was significantly stronger than the C group for the leg press and chest press (Table 3.3). There was no significant difference between the two exercise groups for either measure of strength.

Anaerobic Power

The ST group had significantly more relative mean power ($W \bullet kg^{-1}$) than the C group on the post-test measure. There was no significant difference between groups for peak power expressed as absolute (W), relative to LTV ($W \bullet l^{-1}$), or relative to body mass ($W \bullet kg^{-1}$).

Discussion

The major finding of this study was that power training was more effective than strength training for improving whole-body physical function on the CS-PFP test in community-dwelling older adults. Additionally, power training was more effective than strength training for improving specific domains of physical function on the CS-PFP test. These findings support previous work that demonstrated a significant improvement in CS-PFP total following a six-month strength-training program (3) and a combined-strength and endurance-training program (8). The 15% improvement in CS-PFP total after power training was similar to the 14% improvement previously observed in healthy older adults (8), but less than the 24% found in older women with disability (3).

We found that the increase in CS-PFP total was due to a reduction in performance time rather than an increase in the amount of weight carried. The reduction in performance time of the eight CS-PFP tasks by the PT group increased the balance and coordination, upper-body flexibility, and lower-body strength domains. The ST group improved the weight carried on one task, which improved the upper-body strength domain but did not improve whole-body physical function. Plausible physiological mechanisms responsible for the reduction in performance time observed for the PT group include increased muscle activation, motor-unit-firing rate, and synchronization of discharge (15, 26). Although we did not measure these physiological mechanisms, the literature has suggested that these adaptations are greater after power training than strength training.

The fact that power training and strength training improved two different functional strength domains raises the issue of specificity of training. The PT group significantly improved the lower-body strength domain, whereas the ST group significantly improved the upper-body strength domain. The lower-body strength domain consists of seven time-dependent tasks, five of which the PT group significantly reduced. The ST group increased the amount of weight carried during one task in the upper-body strength domain but did not perform the tasks any faster. Power training increased the velocity at which the individuals could perform tasks while carrying the same amount of weight, whereas strength training increased the amount of weight individuals could carry. The fact that the strength-training group improved upper-body strength without a change in whole-body physical function or any other physical domain supports Rutherford, et al. (25), who suggest that strength gains may not be transferred to tasks that require different motor patterns than those used during training. With respect to function, this may be thought of as training at a velocity of movement similar to the joint angular velocity of the hip and knee when walking. Improvements in training include the muscles trained and the joints used, but are also dependent upon the velocity of movement. When the goal of training is to improve physical function, then power training can be a modality that maximizes the training efforts.

Our results did not support previous research that found greater gains in maximal strength after strength training than power training (22). While our ST group was significantly stronger than the control group following training, there was no significant difference between the ST and PT groups. Similarly, Hortobagyi, et al. (16) found comparable improvements in strength after 10 weeks of strength or power training.

Therefore, both programs are equally effective for improving strength. Our findings for anaerobic power were similar to those found for muscle strength.

Anaerobic power may be needed to complete daily tasks such as stair climbing or lifting and carrying an object (24). These tasks are short in duration and may require a supra-maximal effort. Anaerobic power is positively correlated with CS-PFP total in strength-trained and untrained older adults (r = 0.55 to 0.61) (32). Slade, et al. (32) found that older adults who strength trained had significantly higher anaerobic power than non-strength-trained older adults. To further test this relationship, we examined longitudinal changes in anaerobic power after a strength- and power-training program. We hypothesized that power training would improve anaerobic power more than strength training because of the increased neural adaptations expected from power training. This hypothesis was not supported by our results, though participants in the PT group significantly improved performance time while carrying the same amount of weight during the functional tasks. This suggests that adaptations did occur after power training and that the lack of significant findings for anaerobic power may be due to factors unrelated to the strength- and power-training programs.

The Wingate anaerobic performance test is a cycle ergometer test. Since many older adults do not cycle regularly, inadequate familiarity with cycling may have confounded our results on the Wingate test. Although the subjects performed a warm-up according to the established procedures (1), this may have been an inadequate amount of time to maximally recruit the fast-twitch motor units and muscle fibers needed for a maximal effort test. In another study performed in our laboratory, older adults have performed the Wingate test using the same procedures (32). From our experience, we suggest that older adults receive familiarization on two separate visits and a demonstration of the test protocol prior to the maximal test. Since blood lactate was not measured, there was no direct physiological measure to ensure that anaerobic metabolism was elicited on either the pre- or post-test Wingate. This may also explain why we failed to find a significant improvement in anaerobic power.

While anaerobic power did not increase, physical function, as measured by the CS-PFP test, did show marked improvement for the PT group. Since physical function is an integration of physiological capacities and physical performance (9), it may be a better measure than a capacity measure to capture changes on multiple levels such as strength, power, confidence, and flexibility. This study does provide evidence of an individual's ability to effectively use his or her strength or power to complete daily tasks.

The strength- and power-training interventions resulted in different improvements in the lower-body and upper-body functional domains. Our data show that upper-body tasks, e.g., carrying groceries, are performed more slowly or possibly with more extended periods of contraction than lower-body tasks. In order for an individual to carry a large bag of groceries, the individual must walk more slowly than if he or she were to carry a small bag of groceries. Lower-body tasks require different velocities of movement, e.g., climbing stairs and crossing a street. The velocity in this case is variable because the individual is not limited by carrying additional weight. This reasoning and a non-significant observation of the data indicate that perhaps exercise prescriptions for functional improvements should be written for strength training the upper body while power training the lower body.

Regardless if the exercise prescription is for strength or power training, the risk of injury must be considered. This study had a 22% dropout rate with 36% due to injuries. Twelve percent of our subjects fell and 6% fell while exercising. Although the study was only 16 weeks in duration, our fall rate was less than the average 30% of older adults who experience a fall per year (33). Turning too quickly, tripping over the base of a machine, and falling backwards during the downward phase of the squat caused the three falls that occurred during the strength-training program. In the beginning of the strength-training program, one participant strained a hamstring during the leg curl exercise. This prompted a reduction in the intensity of the exercises during the first four weeks and a more gradual progression of the resistance. Although there were no major injuries resulting from participation in the strength- and power-training programs, additional data are needed to determine if one type of training program is safer than another.

Limitations

Although we found a significant improvement in physical function, there were limitations to our study. First, the trainer and tester were not blinded to the group assignment. To counter any bias, motivation and testing procedures were the same for all groups. Second, the absolute total work performed during the exercise sessions was different between the two exercise groups. The PT group had to apply less force to start movement of the resistance lever of the machine and less force throughout the range of motion (ROM) of the movement. The impulse generated to initiate the movement may have created more momentum of the resistance load to carry it through the ROM without applying much more force. Conversely, the strength-training program required the participants to apply higher levels of force throughout the ROM. Thus, the load each group was moving was different throughout the ROM. Last, the location of the training site was moved during the initial four to six weeks of training. Maximal strength was re-evaluated at the new facility and that value served as the baseline score. For some subjects, however, that occurred at the fourth or sixth week of training. During the earlier weeks, strength changes may have occurred that we were unable to detect. This relocation, which was not under our control, may have diluted our strength results and hindered our ability to detect differences between the groups.

In conclusion, power training improved whole-body physical function more than strength training in community-dwelling older adults. The improvement in physical function was significantly different between groups in spite of a lack of significant difference between groups for anaerobic power and strength. These results suggest that functional measurements may be more sensitive than capacity measures for detecting change after an exercise intervention, because physical function is the sub-maximal integration of these physiological systems. Further evidence is needed to support the efficacy of a power-training program over a strength-training program to improve physical function, along with qualitative measures to address other outcomes that affect life satisfaction. Physiological mechanisms, such as motor-unit-recruitment patterns and discharge rates, responsible for the change in physical function should also be investigated.

Acknowledgments

This project was funded by the Georgia Gerontology Consortium Seed Grant. The authors would like to acknowledge the diligent efforts of the undergraduate students who helped train and test the participants. Great appreciation is extended to St. Mary's Wellness Center in Athens, GA for allowing us to use their facility for this training program.

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Table 3.1: Physical characteristics (Mean ± SD) of the participants at baseline

Variable	Control (n=15)	Strength (n=17)	Power (n=18)
% Female (%)	60	58	50
Age (yrs)	72.4 ± 7.2	72.7 ± 5.4	72.2 ± 6.7
Height (cm)	169.9 ± 10.0	170.9 ± 9.8	170.4 ± 11.3
Body mass (kg)	68.22 ± 13.5	80.20 ± 24.0	79.73 ± 15.6
LBM (kg)	19.25 ± 2.9	19.71 ± 4.1	20.13 ± 3.1
Body Fat (%)	26.77 ± 6.2	31.24 ± 9.9	29.16 ± 7.5

LBM = lean body mass.

Table 3.2: Descriptive data (Mean ± SD) for outcome variables

	Control (n=15)		Strength (n=13)		Power (n=11)	
Variable	Pre	Post	Pre	Post	Pre	Post
1RM Strength						
Chest Press (kg)	29.36 ± 12.2	29.18 ± 13.6	30.25 ± 15.8	34.62 ± 17.7	31.01 ± 12.9	34.81 ± 14.6
Leg Press (kg)	75.61 ± 38.9	79.71 ± 37.5	85.61 ± 45.2	105.27 ± 53.1	95.45 ± 33.2	107.65 ± 32.2
Anaerobic Power						
Peak Power (W)	263.0 ± 81	248.4 ± 83	262.2 ± 117	294.5 ± 117	310.2 ± 105	334.7 ± 137
Peak Power ($W \bullet l^{-1}$)	88.04 ± 32.3	83.01 ± 27.1	68.90 ± 22.6	81.84 ± 26.5	91.49 ± 35.6	91.45 ± 34.0
Mean Power (W)	199.8 ± 64	176.0 ± 54	216.7 ± 100	234.1 ± 107	233.1 ± 80	247.5 ± 119
Mean Power ($W \bullet l^{-1}$)	66.31 ± 24.9	58.71 ± 17.0	57.02 ± 20.1	65.38 ± 26.6	68.36 ± 25.0	66.49 ± 27.6
Physical Function						
CS-PFP total	55.5 ± 14	57.0 ± 18	55.5 ± 10	57.7 ± 10	58.2 ± 13	67.1 ± 13
Lower-body strength	47.9 ± 17	50.7 ± 5	49.8 ± 10	50.8 ± 13	54.1 ± 16	61.3 ± 16

Upper-body strength	64.3 ± 15	66.0 ± 4	62.8 ± 13	67.9 ± 13	70.7 ± 16	74.6 ± 4
Upper-body flexibility	67.5 ± 15	69.3 ± 11	66.3 ± 13	68.1 ± 13	65.7 ± 15	76.3 ± 3
Balance / Coordination	52.4 ± 15	52.6 ± 19	53.4 ± 13	53.2 ± 11	52.9 ± 11	63.2 ± 4
Endurance	56.2 ± 14	57.3 ± 18	55.5 ± 11	58.2 ± 11	57.4 ± 12	68.0 ± 14

CS-PFP = Continuous Scale-Physical Functional Performance test.

Table 3.3: Results of the planned comparisons adjusted for baseline scores

Variable	Control (N=15)	Strength (N=13)	Power (N=11)	F-value
1RM Strength				
Chest Press (kg)	30.51 ± 1.0	34.23 ± 1.0†	33.59 ± 1.1	3.72
Leg Press (kg)	87.86 ± 3.7	104.98 ± 3.9†	97.59 ± 4.2	4.69
Anaerobic Power				
Peak Power (W)	262.5 ± 18.1	309.4 ± 16.5	302.8 ± 18.3	2.06
Peak Power ($W \bullet l^{-1}$)	78.73 ± 6.3	91.09 ± 5.8	84.64 ± 6.3	1.01
Mean Power (W)	193.0 ± 15.6	233.9 ± 14.1	230.7 ± 15.6	2.20
Mean Power ($W \bullet l^{-1}$)	56.51 ± 5.4	70.20 ± 5.0	62.92 ± 5.5	1.70
Physical Function				
CS-PFP total	57.9 ± 1.9	58.6 ± 2.0*	65.4 ± 2.2†	3.68
Lower-body strength	53.1 ± 2.2	51.3 ± 2.4	57.3 ± 2.6	1.50
Upper-body strength	68.0 ± 1.6	71.8 ± 1.7	70.8 ± 1.9	1.38
Upper-body flexibility	68.9 ± 2.5	68.3 ± 2.7*	76.6 ± 2.9	2.65
Balance / Coordination	53.0 ± 2.5	52.8 ± 2.7*	63.1 ± 2.9†	4.39
Endurance	57.3 ± 2.2	59.0 ± 2.3*	67.0 ± 2.5†	4.58

Values are reported as mean ± SE, CS-PFP = Continuous Scale-Physical Functional Performance test, † Significantly different from control, * Significantly different from power training, $p<0.05$.

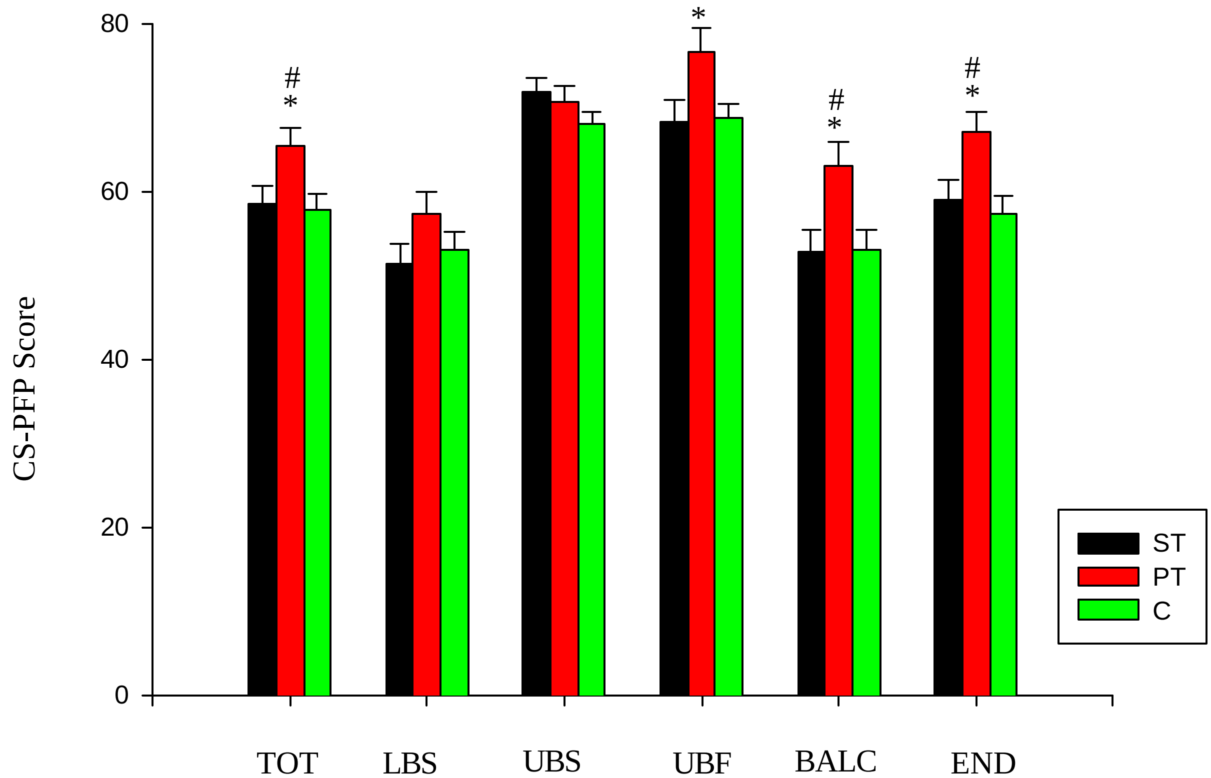

Figure 3.1 Post-test adjusted means for CS-PFP scores between groups

TOT = CS-PFP total score, LBS = lower-body strength, UBS = upper-body strength, UBF = upper-body flexibility, BALC = balance and coordination, END = endurance, * Significantly different from strength-training group, # Significantly different from control, p<0.05

CHAPTER 4

EFFECT OF STRENGTH AND POWER TRAINING ON LEG EXTENSOR POWER AND FUNCTIONAL TASK PERFORMANCE IN COMMUNITY-DWELLING OLDER ADULTS[1]

[1] Miszko, T.A., M.E. Cress, J.M. Slade, S.K. Agrawal. To be submitted to the *Journal of the American Geriatric Society*.

Abstract

Objective: To determine the effect of strength and power training on task performance and to examine the contribution of change in power to the change in task performance.

Design: Randomized controlled intervention trial of older adults (65 to 90 years of age, mean age ± SD = 72.5 ± 6.3 years) to a strength (ST), power (PT) or an attention-control (C) group.

Setting: Community hospital wellness center, Athens, GA.

Participants: Fifty community-dwelling older adults were recruited from the local area. Ten subjects from the exercise groups and one subject from the control group dropped out during the study. Pre- and post-training measurements were obtained from 13 subjects in the ST group, 11 in the PT group, and 15 in the C group.

Intervention: The ST (16 weeks of strength training) and PT (8 weeks each of power and strength training) groups performed three sets of six to eight repetitions at 80% maximal strength (slow) and 40% maximal strength (fast), respectively. Training sessions met 3 times per week and consisted of four upper-body and four lower-body exercises.

Measurements: The primary outcome measures were leg extensor power (LEP), stair-power (StairP), walking speed, and floor-rise time (FloorT). Leg extensor power is also expressed relative to body mass (LEPrel, $W \bullet kg^{-1}$). StairP was calculated as the product of the individual's body mass and vertical velocity to climb 11 steps. A one-way analysis of covariance was used to examine the difference between the groups on the post-test measure, with the pre-test as the covariate. A Pearson correlation coefficient was calculated to examine the relationship between the change in task performance and the change in LEP.

Results: After controlling for baseline, at post-training, StairP was significantly greater in the PT group than the C group ($p = 0.03$). There was no significant difference between the ST, PT, or C group for LEP, FloorT, or walking speed. At baseline, StairP was significantly related to LEP ($r = 0.74$) and LEPrel ($r = 0.43$), however, there was no significant relationship between the change in LEP and the change in performance of any of the three functional tasks measured ($r = -0.28$ to 0.27, $p > 0.05$).

Conclusion: The ability to climb stairs was improved by the power-training intervention. Power training is no more effective than strength training for improving LEP or individual functional task performance in community-dwelling older adults.

Key words: leg extensor power, older adults, power training, physical function.

Introduction

The ability of muscles to generate and sustain strength and power is of principal importance for the quality of life in older adults (1), since performance of functional tasks is dependent on muscle strength and power. Climbing stairs and walking are daily activities of older adults that require muscle strength and power.

Muscle strength and power are specific to the muscles utilized during the functional task performed. Stair climbing is predominantly dependent on the knee extensors and gluteals, and somewhat on the hamstrings (2). Walking is less dependent than stair climbing on knee-extensor strength, but weak soleus and gastrocnemius muscles reduce the force an individual is able to generate in order to push off the ground (3), thus affecting walking speed. Exercises such as the leg curl, leg extension, calf raise, lunge, and squat activate the quadriceps, hamstrings, gluteus maximus, soleus, and gastrocnemius muscles (4). An individual who performs these exercises can increase strength and power of the muscles required for performance of these tasks, and potentially improve functional task performance.

Leg extensor power (LEP) is important for functional tasks (5, 6). Low levels of LEP make it difficult to climb stairs or recover from a fall. Difficulty climbing stairs, in turn, can negatively affect an individual's use of public transportation. Without adequate LEP, an older adult may not be able to safely cross a busy street in the time allowed.

A significant relationship between LEP, walking speed, stair-climbing speed, and stair-climbing power has previously been established (5). Nonetheless, few longitudinal studies have been conducted to examine the change in LEP and functional task performance after a strength- or power-training program.

The purpose of this project was to determine the effect of strength and power training on task performance and to examine the contribution of change in power to the change in task performance. We hypothesized that the power-training group would improve LEP more than the strength-training and control group because the motor patterns used during power training are similar to those used during the measurement of LEP. We further hypothesized that the change in LEP would be positively related to the change in functional task performance because LEP has been shown to be strongly related to functional task performance.

Methods

Subjects and Procedures

Sixty-five older adults were recruited through an advertisement in the local Athens, GA newspaper. Fifty subjects were interested and eligible to participate in the study. Thirty-nine older adults volunteered to be randomly assigned to strength-training (ST, n = 13), power-training (PT, n = 11) or attention-control (C, n = 15) groups. Subjects were eligible for the study if their LEP was less than 140 W for women and 210 W for men. Unpublished data from our lab indicate that these values of LEP correspond to a low level of physical function (Continuous Scale Physical Functional Performance total score < 55). Criteria for exclusion included the following: poorly controlled or unstable cardiovascular disease or diabetes, recent unhealed bone fracture (within the past 12 months), severe hypertension (> 160/90 mmHg) while resting quietly in the supine position, leg or arm amputation, cognitive impairment, excessive alcohol intake (more than three drinks per day), an anterior compression fracture, terminal illness (life expectancy less than one year), neuromuscular disorders, non-ambulatory, and current or recent (< six months) involvement in a strength-training or running/jogging program. All volunteers signed a written informed consent approved by the Institutional Review Board at the University of Georgia.

The attention-control group continued their usual activity throughout the 16-week study without starting any new exercise program and met on three occasions for lectures about health. At the conclusion of the 16 weeks, subjects in the C group had the opportunity to participate in a strength-training program. All subjects were evaluated on outcome measures at baseline and after 16 weeks.

Exercise Interventions

The strength- and power-training groups met three days per week for 16 weeks. For the first eight weeks, both groups participated in a strength-training program. This was conducted because the literature has suggested that a strength base is needed prior to power training (7). The intensity was gradually increased from 50% to 70% of the one-repetition maximum (1RM) by week eight. The 1RM is the maximal amount of weight that can be lifted one time through the full range of motion while holding to good form (8). After eight weeks, the resistance for the strength-training group increased to 80% of the 1RM performed at a slow, concentric velocity (4 sec), and the resistance for the power-training group decreased to 40% of the 1RM performed at a fast, concentric velocity (1 sec).

Each subject performed three sets of six to eight repetitions for each exercise. Each group performed the same four upper-body (seated row, chest press, biceps curl, triceps extension) and three lower-body (leg press, seated leg curl, knee extension) exercises on Keiser pneumatic machines (Keiser, Corp, 2470 S. Cherry Ave., Fresno, CA 93706). Trunk extension, abdominal crunches, calf raises and squats were also performed. The power-training group performed jump squats instead of squats. A dynamic warm-up utilizing the major joints and muscles to be exercised that day preceded each session. An attempt was made to control absolute power between the two exercise groups by adjusting the time of the concentric muscle action to compensate for the difference in the weight lifted. Absolute total work, however, was different between the groups because the strength-training group lifted more weight than the power-training group. The 1RM was re-tested every four weeks. Muscle-specific stretches were performed after each set.

Outcome Measures

Anthropometric

Body mass and height were measured to the nearest 0.1 kg and 0.1 cm. Body composition was estimated by sex-specific generalized equations using the skinfold technique (9, 10). Lange® calipers were used to measure skinfolds to the nearest 1mm.

Leg extensor power

Leg extensor power was measured using the Nottingham leg power rig (University of Nottingham, Nottingham, U.K.) according to the methods and calculation procedures reported elsewhere (11). The subject was seated in a backless chair on the leg power rig with one foot on a pedal in front of him or her and the other on the floor. When instructed to do so, the subject pushed down as hard and as fast as possible on the pedal. Each subject was allowed three to five familiarization pushes per foot prior to the start of the test. Peak power was recorded as the highest power output prior to the plateau of two consecutive pushes. This procedure was performed on each leg. Leg extensor power is expressed as the average peak power of the right and left leg (LEP, W) and relative to body mass (LEPrel, $W \bullet kg^{-1}$).

Physical Function

Physical function was assessed by three tasks that required lower-body power: the floor sit, stair climb task, and 6-minute walk. The floor-sit (FloorT) task required subjects to sit on the floor, extend their legs, and then rise to an upright posture. For the stair task, subjects were asked to climb 11 steps at their normal pace. The time to complete each task was recorded with a stopwatch to the nearest 0.01 sec. Stair-power (StairP), expressed in $kgm{\bullet}min^{-1}$, was calculated as the product of the individual's body mass and vertical velocity (5). StairP was converted to watts (W) by dividing the value in $kgm{\bullet}min^{-1}$ by 6.12 (12). For the 6-minute walk, subjects were asked to walk at a pace that allowed them to cover the greatest distance possible in 6 minutes. Subjects were given 1-minute split times and not encouraged throughout the test. Walking speed ($m{\bullet}s^{-1}$) was calculated as the average speed an individual walked over the 6-minute time interval.

Statistical Analysis

All analyses were performed using SPSS® (Chicago, IL, version 10). Pearson correlation coefficients were computed to examine the relationship between the change in LEP and the change in functional task performance. A one-way analysis of covariance (ANCOVA) was performed to examine differences between the population means on the outcome measures, with the baseline score as the covariate. Three pairwise comparisons were of primary interest (PT > ST, PT > C, ST > C). An effect size (ES) was calculated according to the procedures of Glass, et al. (13), $((Y_{1adj} - Y_{2adj})/\sqrt{MS_w}) / (1/\sqrt{1-r^2_{xy}})$, where Y_{1adj} = the adjusted mean of group 1, MS_w = the mean square within groups, and r^2_{xy} = the squared correlation between the pre and post measure. An alpha level of 0.05 was required to establish statistical significance.

Results

Group Characteristics

The physical characteristics of the groups were similar at baseline (Table 4.1). Age, height, and body mass were almost identical across groups. Fifteen of the sixty-five recruited volunteers did not participate in the study because they were unable to gain medical clearance from their physicians, were disinterested in the study due to the length of the program, or did not meet the eligibility criteria. Eleven of the fifty volunteers (22%) did not complete the study because of family and/or personal medical reasons, injuries, or relocations (ST, $n = 4$; PT, $n = 6$; C, $n = 1$). Fourteen participants (93.3%) in the C group participated in the strength-training program at the conclusion of the 16 weeks.

Descriptive information for each outcome variable is presented in Table 4.2.

Leg Extensor Power

After the intervention, there was no significant difference between groups for LEP ($p = 0.52$) or LEPrel ($p = 0.95$) (Table 4.3) when baseline was controlled for. At baseline, StairP was significantly related to LEP (Figure 4.1) and LEPrel, however, the change in LEP and LEPrel was not significantly related to the change in any functional task (Table 4.4).

Physical Function

StairP was significantly different between the PT and C groups after the intervention ($p = 0.03$). There was no significant difference between the ST, PT, and C groups for walking speed or FloorT.

Discussion

The major finding of this study was that power training significantly improved the ability of older adults to climb stairs. Leg extensor power was strongly related to this lower-body functional task. The linear relationship between LEP and StairP suggests that improvements in LEP may allow an older adult to complete daily tasks more quickly and may possibly protect against falls.

The power-training program employed in this study utilized exercises that trained the muscles required for stair climbing. Extension of the hips and knees during stair climbing is similar to the actions of the squat exercise. The leg press, leg curl, leg extension, and squat exercise trained the knee extensors, gluteals, and hamstrings. Since stair-climbing performance requires strength and power in these muscle groups (2), and strength was improved after the intervention (Results reported in Chapter 3), stair-climbing performance was expected to improve after the power-training intervention. We had expected the same outcome for LEP after the power-training program.

Because of the slow velocity used during strength training, we hypothesized that the power-training group would improve LEP more than the strength-training group. According to Rutherford and colleagues (18), gains in strength may not be transferred to tasks that require different motor patterns than those used during training. Power training, however, demands motor activity that should improve LEP. Power training on the leg press machine resembles movement during performance on the Nottingham leg power rig. While similar motor patterns and velocities appear to be utilized, we don't have muscle electromyogram data to provide evidence that we were stimulating the same muscles in training as were used for the measurement of LEP.

Differences in the methods of measuring LEP may make comparison of our results to previous ones difficult. Improvements in LEP after 10 to 12 weeks of resistance training have ranged from 18% to 140% (14, 15, 16) when LEP has been measured with the Nottingham leg power rig, isokinetic dynamometers, and isotonic leg press machines. Typically, the same device that was used for power training the older adults was also used for testing LEP (1, 17). Results from these studies have demonstrated large improvements in LEP (40% to 140%). These results may be exaggerated due to the practice effect of training to task. The improvements in LEP are less dramatic (18%) when older adults strength train isotonically and are tested on a different device.

Our results fail to confirm the significant improvements in walking speed that other researchers have found following an exercise intervention (14, 19). Our values for walking speed were much higher (185%) than those reported by Bassey, et al. (5). Our sample of older adults also had higher initial values of LEP than Bassey and colleagues (5) found for their subjects (173.2 ± 32.2 W for men and 98.6 ± 31.9 W for women vs. 67.0 ± 8.3 W for men and 34.8 ± 5.1 W for women). Furthermore, our subjects were younger (mean age ± SD = 72 ± 6.2 years vs. 87 ± 1.6 years) and lived as community dwellers rather than in a long-term care institution. The difference between our findings and others may be due, in part, to the fact that individuals with low initial levels of strength or power will exhibit larger gains in strength or power than individuals with high initial levels of strength or power. Thus, persons with lower physical function will exhibit greater gains in function per unit change in the underlying physiology, such as strength, than those who have higher levels of function. The fact that our sample of subjects had high initial values for walking speed (1.4 ± 0.3 m•s^{-1}) and LEP (131.1 ± 48.9 W) may explain our lack of significant change in the functional tasks.

Consideration of the characteristics of the measurement used to assess physical function may provide additional insight into our lack of significant improvement for the functional tasks. In order to maximize the potential benefits of a physical intervention, subjects with low physical function must be targeted when evaluating changes in functional status. While we targeted older adults with low levels of LEP, which corresponded to low functional levels, the values for LEP were still larger than what has been reported in the literature.

Furthermore, single-item measures of function capture only function that can be changed with an exercise intervention. The tasks that comprise functional performance are short in duration, most under 15 to 30 sec, which leaves little room for improvement. Training programs are not designed to make large impacts on performance of short-duration tasks. Serial task performance, the foundation of the CS-PFP test, has demonstrated sensitivity to change where single-item measurements have not (20).

When we studied the relationship between walking speed and LEP, our results differed from previous research. According to Kozakai, et al. (22), LEP is the most important factor related to walking speed. A relative measure of LEP, however, may be more related to function because daily tasks require an individual to move his or her body mass (5), such that a reduction in LEP may affect an older adult's mobility and ability to rise from the floor (21). In this study, we did not find walking speed to be significantly related to LEP or LEPrel. Our lack of significant correlation was due to the fast walking speed of our subjects; we did not have large variability in walking speed for our group.

Additionally, the Nottingham leg power rig measures lower-body power produced by the leg extensors. The leg extensors are utilized more during stair climbing than walking. Therefore, the different muscle actions required of walking and LEP may also explain the non-significant relationship between the two.

The reduction in maximum walking speed and LEP associated with an increase in age (22) can affect an older adult's mobility. The importance of walking speed becomes evident when an older adult needs to cross a city street in the time allotted (28 sec) before the stoplight turns green. Crossing a typical four-lane street (14.6-m wide) would require an older adult to walk approximately 0.52 $m \bullet s^{-1}$. Low levels of LEP could make an older adult unable to get across safely. Another potentially dangerous situation arises if a person falls (as several did in this study), but lacks the leg power to get back up. Half of our subjects who fell were able to get up from the floor without assistance; the other half required medical assistance or help from a relative. Each subject recovered within six months, however, one subject's daily activities are still limited by the injury. In addition to LEP, which involves hip and knee extension, hip flexion is important. Older adults need to be able to flex the hip quickly in order to "catch" themselves in a lunge position if they trip. These situations demonstrate the importance of LEP for an older adult's safety.

Limitations

The results of our study were limited due to a small sample size. Eighty subjects per group would have been required for us to demonstrate a significant difference between the groups for LEP. A larger sample size may have resulted in a statistically significant difference between the groups.

Another possible limitation is that the absolute total work performed during the exercise sessions was different between the two exercise groups. The PT group had to apply less force to start movement of the resistance lever of the machine and less force throughout the range of motion (ROM) of the movement. The impulse generated to initiate the movement may have created more momentum of the resistance load to carry it through the ROM without applying much more force. Conversely, the strength-training program required the participants to apply higher levels of force throughout the ROM. Thus, the load each group was moving was different throughout the ROM.

In summary, LEP is important for select lower-body functional tasks requiring a transfer of body mass. For individuals with low levels of LEP, performance of daily tasks may be difficult or impossible to perform. The strength- and power-training programs employed in this study were not effective for improving LEP or select functional task performance in community-dwelling older adults. Stair-climbing ability, however, was improved after the power-training program. These results suggest that performance of a lower-body functional task can be improved without an improvement in LEP. Considering that LEP is lost at a faster rate than muscle strength (23), it is important to determine which type of exercise interventions are most effective for attenuating this age-associated loss. Future research should examine the effect of a power-training program on leg flexion power and the subsequent effect on fall frequency.

Acknowledgements

This study was funded by the Georgia Gerontology Consortium Seed Grant. The authors would like to acknowledge St. Mary’s Wellness Center in Athens, GA for allowing us to use their facility for the training interventions.

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Table 4.1: Participant characteristics (Mean ± SD) at baseline

Variable	Control N=15	Strength N=13	Power N=11
% Female (%)	60	58	50
Age (yrs)	72.40 ± 7.2	72.77 ± 5.4	72.27 ± 6.7
Height (cm)	169.99 ± 10.0	170.95 ± 9.8	170.42 ± 11.3
Body mass (kg)	68.22 ± 13.5	80.20 ± 24.0	79.73 ± 15.6
Lean body mass (kg)	19.25 ± 2.9	19.71 ± 4.1	20.13 ± 3.1

Table 4.2: Pre- and post-intervention outcome measures (Mean ± SD) by group

	Control N=15		Strength N=13		Power N=11	
	Pre	Post	Pre	Post	Pre	Post
Leg extensor power						
LEP (W)	121.0 ± 48	129.0 ± 56	135.4 ± 47	155.9 ± 66	139.7 ± 53	149.2 ± 70
LEPrel ($W \bullet kg^{-1}$)	1.8 ± 0.5	1.8 ± 0.7	1.7 ± 0.8	1.9 ± 0.7	1.8 ± 0.6	1.8 ± 0.7
Physical Function						
FloorT (s)	9.7 ± 5.3	10.5 ± 6.1	11.9 ± 6.6	11.4 ± 6.2	9.9 ± 4.1	9.9 ± 4.6
StairP (W)	391.0 ± 103.6	388.6 ± 99.3	436.9 ± 128.4	464.0 ± 186.4	463.6 ± 129.2	535.7 ± 146.2
Walking speed ($m \bullet s^{-1}$)	1.5 ± 0.3	1.5 ± 0.2	1.3 ± 0.2	1.3 ± 0.2	1.5 ± 0.3	1.5 ± 0.2

LEP = leg extensor power, LEPrel = leg extensor power relative to body mass, FloorT = time to sit and rise from floor, StairP = stair-power

Table 4.3: Results from planned comparisons

	Control N=15	Strength N=13	Power N=11	F-value
Variable				
Leg extensor power				
LEP (W)	140.62 ± 7.3	150.98 ± 7.8	139.17 ± 8.5	0.661
LEPrel ($W{\bullet}kg^{-1}$)	1.84 ± 0.1	1.88 ± 0.1	1.81 ± 0.2	0.051
Physical Function				
StairP (W)	426.42 ± 20.6	453.41 ± 21.5	497.37 ± 23.6*	2.553
Walking speed ($m{\bullet}s^{-1}$)	1.47 ± 0.0	1.46 ± 0.1	1.51 ± 0.1	0.264
FloorT (s)	11.22 ± 0.6	10.06 ± 0.6	10.44 ± 0.7	0.891

Post-test means adjusted for baseline. Values are mean ± SE, LEP = leg extensor power, LEPrel = LEP relative to body mass, StairP = stair-power, FloorT= time to sit then rise from the floor, * Significantly different from control, $p<0.05$

Table 4.4: Pearson correlation coefficients for the change from pre- to post-training in the primary outcomes

	ΔLEP	ΔLEPrel
ΔFloorT	-0.28 (.09)	0.02 (.89)
ΔStairP	0.27 (.10)	0.02 (.91)
ΔWalking speed	-0.01 (.96)	-0.174 (.29)

Correlation coefficient (p-value), ΔFloorT = change in the time to sit and rise from floor, ΔStairP = change in stair-power, ΔWalking speed = change in walking speed, ΔLEP = change in leg extensor power , ΔLEPrel = change in LEPrel

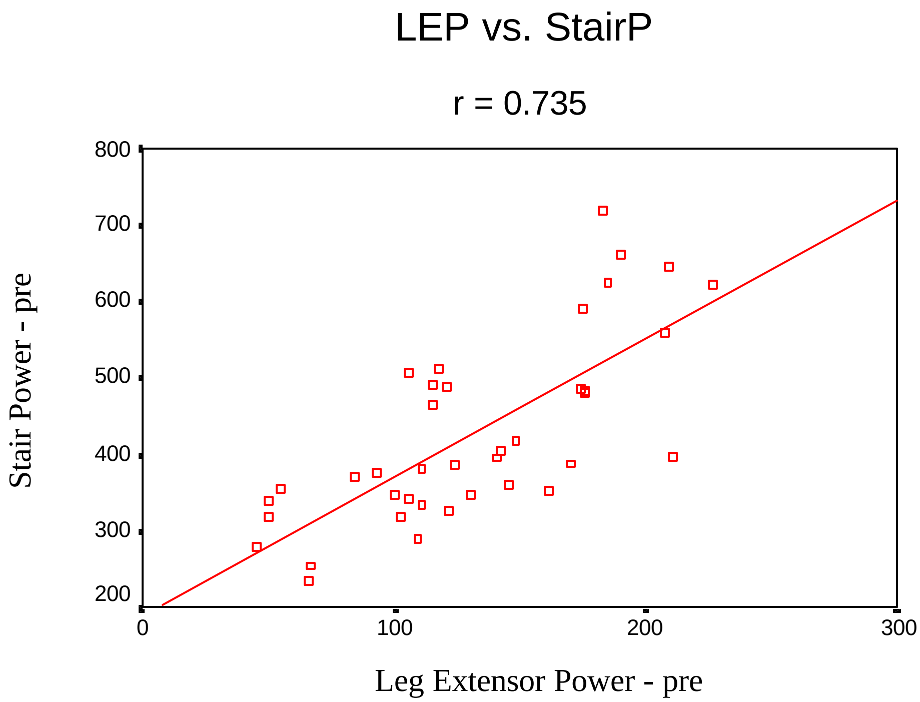

Figure 4.1: The relationship between stair-power (StairP) and leg extensor power (LEP) at baseline.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The purposes of this study were to determine the effect of a strength- and power-training intervention on physical function, leg extensor power (LEP), and anaerobic power in community-dwelling older adults and to examine the relationship between changes in physical function and changes in anaerobic power, muscle strength, and LEP. Thirty-nine men and women (mean age ± SD =72.6 ± 6.3 years) participated in a strength-training (ST), power-training (PT), or an attention-control (C) group for 16 weeks. The strength- and power-training groups performed three sets of six to eight repetitions on seven exercise machines. The intensity was gradually increased from 50% to 70% of the one-repetition maximum (1RM) for the ST and PT groups during the first eight weeks. After eight weeks, the intensity for the ST group was increased to 80% of the 1RM performed at a slow velocity and the intensity for the PT group was reduced to 40% of the 1RM performed at a fast velocity.

Physiological capacity measures are traditional measures used to demonstrate program efficacy. The interventions we used improved measures of strength and anaerobic power, but not LEP. After the 16-week training interventions, neither exercise group was more effective than the other for improving 1RM strength, anaerobic power, or LEP. The ST group, however, was significantly stronger than the C group for leg press and chest press 1RM strength. Mean anaerobic power relative to body mass ($W \bullet kg^{-1}$) was significantly different between the ST and C groups after the 16 weeks. After the exercise interventions, there were no significant differences between the ST, PT, or C groups for LEP.

The power-training program significantly improved whole-body physical function, while the two exercise interventions differed according to the specific domains that were improved. The PT group had significantly higher CS-PFP scores than the ST group for whole-body physical function and for several CS-PFP physical domains, including upper-body flexibility, balance and coordination, and endurance. The PT group was also significantly different from the C group after 16 weeks for CS-PFP whole-body physical function and for the balance and coordination and the endurance domains. The results were different, however, when single-item-functional tasks were examined.

When analyzing individual functional tasks, fewer tasks showed sensitivity to change after the interventions than was shown by the summary measure of physical function. Stair-power was significantly greater in the PT group than the C group after the intervention, however, there was no significant difference between groups for walking speed or FloorT. A significant relationship between stair-power and LEP was evident at baseline, but not after the strength- or power-training intervention. The change in LEP, AP, and 1RM strength was not significantly related to the change in any single-item functional task or the change in CS-PFP whole-body physical function.

Based upon the results found in this study--that power training more than strength training improved whole-body physical function measured by the CS-PFP test--further research is needed to establish the physiological mechanisms responsible for these changes. Changes in muscle ultrastructure, muscle activation, and motor unit synchronization are possible physiological mechanisms that could account for the changes in physical function after the power-training intervention. Their role in altering physical function should be investigated. This type of research would provide evidence to substantiate the neural and muscular contributions to physical function.

The completion of daily tasks requires movement of an individual's body mass across multiple joints, as well as agility, coordination, and balance. Free-weight, multi-joint exercises are typically weight bearing. Isotonic and isokinetic single-joint machine exercises, on the other hand, are non-weight bearing. Both free-weight and machine exercises can be performed using single- or multi-joint movements, however, only free-weight exercises are weight bearing, similar to functional tasks. Thus, application of the principle of specificity would suggest that an improvement in physical function would best be accomplished utilizing a multi-joint free-weight exercise program. The efficacy of power training with isokinetic machines, isotonic machines, and free weights should be examined to establish the optimal training modality to improve physical function.

This study demonstrated that power training was more effective than strength training for improving CS-PFP whole-body physical function in community-dwelling older adults. The improved velocity of movement resulting from power training explained the different improvements for the CS-PFP domains between the strength- and power-training groups. Improvements in physical function were accomplished by the participants' performing the functional tasks faster while carrying the same amount of weight. Improvements in physical function were not related to improvements in maximal strength, LEP, or AP. The results from this study suggest that daily tasks can be made easier without an improvement in maximal strength, LEP or AP.

These results can guide exercise prescription for older adults. The study demonstrated that power training was effective for improving whole-body and lower-body function, while strength training was effective for improving upper-body function. Therefore, the exercise prescription can be specific to the desired functional domain an individual seeks to improve. Improvements in physical function may be a more appropriate training goal for older adults than gains in absolute strength or power, since physical function is an integration of these physiological systems.

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