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THE EFFECTS OF 6-WEEKS OF RESISTANCE TRAINING
ON THE NEUROMUSCULAR FATIGUE THRESHOLD
IN OLDER ADULTS

by

NADIA S. EMERSON
B.S. University of Central Florida, 2007

A thesis submitted in partial fulfillment of the requirements
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ABSTRACT

Age-related deficits in muscle mass, strength, and function place an increased burden of work on existing skeletal muscle and may lead to early onset of neuromuscular fatigue (NMF) during activities of daily living. Resistance exercise (RE) is the proven method for improving neuromuscular function in healthy older adults. **PURPOSE:** To investigate the effects of 6 weeks of RE on the NMF threshold as well as strength and functional performance in older adults. **METHODS:** Twenty-four older adults were randomly assigned to 6 weeks of RE (EXE; n = 12; age 72 ± 6.3 y; BMI 28.4 kg/m^2) or control (CONT; n = 12; age 70.3 ± 5.6 y; BMI 27.6 kg/m^2). Body fat percent (BF%), lean mass (LM), and fat mass (FM) were measured using DEXA and participants performed a discontinuous cycle ergometer test, physical working capacity at fatigue threshold (PWC$_{FT}$), to determine the onset of NMF. Functional performance was assessed by time to complete 5 chair rises (CHAIR) and walk an 8-foot course (WALK). Lower body strength was assessed by predicted 1-RM leg extension (1RM). Two-way Analysis of Variance (ANOVA; time [PRE, POST] x group [EXE and CONT]) and magnitude based inferences were used to compare dependent variables. **RESULTS:** RE significantly increased 1RM (35%; $p = 0.001$) and CHAIR (20%; $p = 0.047$). RE had a likely beneficial effect on WALK (15%) and a possibly beneficial effect on PWC$_{FT}$ (14%). There were no significant changes to LM or FM, however, women in EXE significantly decreased BF% ($p = 0.020$). **CONCLUSION:** Results suggest that RE improves measures of strength and functional performance and possibly the onset of NMF in older adults.

This thesis is dedicated to the Learning Institute for the Elderly at the University of Central

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LIST OF ACRONYMS/ABBREVIATIONS

1RM	Predicted 1 repetition maximum
ANOVA	Analysis of variance
Ba	Beta-Alanine
BF%	Body fat percent
CHAIR	Chair rise time
CONT	Control
Cr	Creatine
DEXA	Dual x-ray absorptiometry
EMG	Electromyography
EXE	Experimental
FM	Fat mass
ICC	Interclass correlations
LM	Lean mass
MN	Motor neuron
MU	Motor unit
NM	Neuromuscular
NMF	Neuromuscular fatigue
OBLA	Onset of blood lactate accumulation
PWC_{FT}	Physical working capacity at fatigue threshold
RE	Resistance Exercise
RMS	Root mean square
rpm	Revolutions per minute
SD	Standard deviation
SEM	Standard error of measurement
WALK	8 foot walk

CHAPTER 1: INTRODUCTION

Aging is often associated with progressive loss of neuromuscular function that often leads to disability and loss of independence. (Aagard, Suetta, Caserotti, Magnusson, & Kjaer, 2010). After age 50, skeletal muscle declines at an annual rate of 1-2% with a concomitant loss of strength at 1.5% each year and accelerating to 3% per year after age 60 (Hughes, Frontera, Roubenoff, Evans, & Singh, 2002; Hughes et al., 2001). This age-acquired deficit, known as sarcopenia, places an increased burden of work on existing skeletal muscle and may lead to early onset of neuromuscular fatigue (NMF) during activities of daily living. Leisure activity is not enough to prevent sarcopenia, but resistance exercise (RE) has been identified as countermeasure for regaining neuromuscular capacity and function in the aging adult (Aagaard et al., 2010; Raguso, Kyle, Kossovsky et al., 2006).

Progressive RE is considered to be the preferred approach to elicit neuromuscular adaptations for healthy older adults (Aagaard et al., 2010; Peterson, Rhea, Sen, & Gordon, 2010). Early improvements to RE are thought to be the result of neural adaptations through improved motor coordination and efficiency (Moritani & deVries 1979); however, the extent to which RE effects NMF has not been widely investigated. deVries et al. (1987) and Wojcik, Thelen, Schultz, Ashton-Miller, & Alexander (2001) have suggested that falls may be related to fatigue-induced deterioration of motor coordination. Thus, an improved resistance to fatigue with RE, may be important to consider when working with an older population.

The use of electromyographic (EMG) techniques has allowed observation of age-related changes in NM function. It has previously been shown that electrical activity in muscle tissue increases as a function of time when the muscle works against a constant force during isometric

or dynamic activity (deVries, 1968; Lippold, Redfearn, & Vueo, 1960; Petrofsky, 1979). This increase in electrical activity is thought to occur as fatigue progresses as a result of greater recruitment and higher innervation rate to make up for force losses as fatigued motor units drop out (deVries, 1987; deVries & Housh, 1994). deVries and colleagues (1987) developed a submaximal, discontinuous cycle ergometer test which utilizes EMG to objectively measure the first sign of NMF, known as the physical working capacity at fatigue threshold (PWC_{FT}).

The PWC_{FT} represents the highest power output that does not result in a significant increase in electrical activity of the thigh muscle over time ($p > 0.05$). This test is unique in that it measures the work capacity that can be maintained before the onset of NMF rather than the duration a given bout of exercise can be maintained, which may be largely influenced by subjective decisions on the part of the participant and the investigator (deVries & Housh, 1994). The PWC_{FT} has been associated with measures of aerobic power, muscular endurance and efficiency, which are more commonly measured by oxygen consumption rate (VO_2) during tests of maximal exertion (deVries et al., 1987; deVries & Housh, 1994; Stout et al., 2007a). deVries et al. (1989) suggested that the PWC_{FT} may be more appropriate and sensitive to the effects of training in older adults than other GXT that require maximal effort (i.e., VO_2max) and may be ill advised or hazardous for this population.

Previous research has investigated the effects of aerobic training and/or nutritional supplementation on the PWC_{FT} in older adults (deVries et al., 1989; McCormack et al., 2013; Stout et al., 2007b; Stout et al., 2008). deVries et al. (1989) reported a 29.8% and 38.4% improvement in PWC_{FT} following 10 weeks of low (70%) or high (85%) intensity aerobic training in older adults. Without aerobic training, Stout et al. (2007b) observed a 15.6%

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improvement in PWC_{FT} in older adults after 14 days (2 weeks) of creatine supplementation. Similarly, significant increase in PWC_{FT} (28.6% and 13.6%) following twelve weeks of beta-alanine supplementation in older men and women were reported by Stout et al., (2008) and McCormack et al. (2013).

Despite the supporting evidence of the use of RE as a countermeasure for the age-related neuromuscular decline, the effects of RE on PWC_{FT} have yet to be investigated. Therefore the primary purpose of this study was to evaluate the effects of 6 weeks of progressive RE on the NMF threshold (NMFT; as measured by PWC_{FT}) in older adults. In addition, this investigation examined the effect of RE on body composition, strength and functional performance measures.

CHAPTER 2: LITERATURE REVIEW

Aging is often associated with progressive loss of neuromuscular function that often leads to disability and loss of independence. Declines in neuromuscular function are characterized by a reduction in excitable motor units (MUs) and muscle fiber number and size (Aagaard et al., 2010). This age-acquired deficit, known as sarcopenia, places an increased burden of work on existing skeletal muscle and may lead to early onset of neuromuscular fatigue during activities of daily living. Leisure activity is not enough to prevent NM decline, but RE has been identified as a countermeasure for regaining NM capacity and function in the aging individual (Raguso et al., 2006; Aagaard et al., 2010). Therefore, this review will focus on neuromuscular changes with aging, resistance exercise as a countermeasure, and delayed onset of neuromuscular fatigue as a possible outcome of resistance exercise in older adults. Furthermore, due to the practical and clinical significance of lower body function with age, studies reviewed will primarily focus on the knee extensor muscles.

Neuromuscular Changes with Aging

Loss of Neural Function

Several review articles have been published which go into great detail on the remodeling of neural organization and its relationship to muscle tissue maintenance (Lexell, 1995; Vandervoort, 2002; Aagard et al., 2010; Clark & Fielding 2012). While the sarcomere is considered the functional unit of skeletal muscle force generation, the MU is the functional unit of movement. The MU is composed of an α-motor neuron (MN) and the muscle fibers it innervates (Lieber, 2010). What is known is the gradual loss of α-MNs causes denervation of

muscle fibers which may or may not be reinnervated to form very large MUs (Stålberg & Fawcett, 1982).

Decline in the number of excitable MUs and increase in the average MU innervation ratio begins in the sixth decade of life in healthy adults (Tomlinson & Irving, 1977; Stålberg & Fawcett, 1982; De Koning et al., 1988). However, the degree to which this MU remodeling influences muscular strength may not be present until a critical threshold of MN loss is reached (McNeil, Doherty, Stashuk, & Rice 2005). After comparing groups of young (~25 years), old (~65 years) and very old men (≥85 years), McNeil and colleagues (2005) found estimated MU number to be significantly reduced in old and very old men; however, strength was not affected until beyond 80 years of age. There also appears to be a decreased MU recruitment threshold with age. At 20% of maximal voluntary contraction of the tibialis anterior muscle, older adults recruited 70% of MUs, compared to 40% in young adults (Klass, Baudry, & Duchateau, 2005). Furthermore, other NM properties, such as MN firing behavior reduction in MN firing rate and conduction velocity (Klass, Baudry, & Duchateau 2008), occurrence of MNs firing two action potentials in quick succession (Christie & Kamen, 2006) and changes to the integrity of the NM junction (Jang & Van Remmen, 2011) may further contribute to the declines in NM performance. While the exact mechanism for which aging affects NM function cannot be isolated, and it is likely a combination of these processes leads to a decline in muscle fiber size and number, resulting in impaired mechanical performance and efficiency during tasks of daily living.

Loss of Muscle Mass

With increasing age, skeletal muscle mass gradually decreases in volume, mainly due to a reduced number of MUs and muscle fibers, and a reduced size of type II fibers (Porter, Vandervoort, & Lexell, 1995). Proper functioning on the MU is essential to the survival of the muscle fibers. Age-related loss of muscle mass results from the loss of slow and fast MUs, with a more accelerated loss in fast MUs. The reduction in fast MUs causes an increased burden of work on surviving MUs as dennervated fibers are reinnervated by surviving slow MUs. In addition to the loss of fast MUs, there appears to be fiber atrophy, or loss of cross sectional area, of type II muscle fibers (Lexell, Henriksson-Larsén, Winblad, & Sjöström, 2004; Lang et al., 2010; Lieber, 2010). Biopsy of the vastus lateralis muscle in young and old humans has confirmed the increase in relative area of type I fiber type from 50% in twenty year olds to 60% in seventy year olds, as well as a significant reduction in the size and number of type II fiber type from 55% in young to 30% in old humans (Lexell et al., 2004).

Loss of Muscle Strength

The loss of fast MUs and type II fibers results in loss of muscle strength and power necessary for functional tasks, such as rising from a chair or climbing a flight of stairs (Lang et al., 2010). Cross-sectional studies that have examined age-related changes in strength suggest these alterations are the result of declines in muscle mass, as well as reduction in power per unit area and force per unit area (Vandervoot, 2001). A 12-year longitudinal study by Frontera et al., (2000) found an annual 1.4% reduction in CSA and 1.4 to 2.5% loss of strength in lower body musculature in older men. In this study baseline strength and muscle size were found to be

independent predictors of loss of strength with aging. Similarly, Hughes et al. (2001) found change in leg extensor strength over a 10 year period to be directly related to the change in muscle mass in both older men and women. The results of these studies suggest that preserving lean mass would possibly attenuate the strength decline with age, although, there is some disagreement.

Many investigators have reported a concomitant change in muscle mass and strength with age; however, the more rapid decline in muscle strength suggests these measures may be to some extent distinct. Older men and women exhibited a 3-fold greater loss in strength (3.42-4.12% per year) than decline in muscle mass (1% per year) over the course of 3 years of follow up in the Health, Aging and Body Composition Study. Furthermore, the maintenance or even gain of lean mass did not necessarily prevent the loss of strength (Goodpaster et al., 2006). Since reductions in strength are reported to occur at a faster rate, strength deficit may be a superior indicator of muscular dysfunction (Hughes et al., 2001; Goodpaster et al., 2006; Rolland et al., 2008).

<center>Loss of Muscle Function</center>

The most important anatomic sites for neuromuscular function assessment have primarily been in the lower body, as the muscles in these sites are critical for daily function (Lang et al., 2010). Salem, Wang, Young, Marion, & Geendale (2000) examined the relationship between knee strength and lower and higher intensity functional tests in older men and women. Lower intensity tests included the timed 8-foot and 50-foot walking tests at normal pace, and standing reach task, and higher intensity tests included the timed 50-foot walk at maximal speed, timed chair rise, and timed stair climb. They found that during timed tests, greater knee extensor

strength was consistently and statistically significantly ($P < 0.05$) related to faster performance times, with chair rise performance having the strongest relationship to strength ($P = 0.0001$).

Weakness of the extensor muscles of the knee is a clinically important and statistically significant risk factor for falls in the elderly (Pijnapples, van der Burg, Reeves, & van Dieen, 2009). In a meta-analysis conducted by Moreland, Richardson, Goldsmith, and Clase (2004), a 1.76 greater risk for falls and 3.06 greater risk for recurrent falls in older adults with lower extremity weakness was reported. Furthermore, Pijnapples et al. (2009) found whole leg extension strength to be associated with the ability to prevent falls after a gait perturbation. With the support of a safety harness, participants walked a 12 meter walkway in which obstacles were placed to cause the participant to trip. Participants were categorized as fallers or non-fallers based upon the results of the test. Performance measures of leg extension strength were significantly ($p = 0.001$) different between fallers and non-fallers. The authors suggested leg extension weakness may help identify elderly at risk of falling.

In the absence of muscle weakness, any additional strength does not appear to benefit functional capacity. There is a suggested non-linear relationship between leg strength and gait speed where to a certain point even large physiological changes do not affect performance, such as in the physically fit; however, in the very old or frail, small changes to physiological capacity may have a relatively large effect. This is primarily seen in intervention studies where functional performance is only significantly improved if muscle weakness is present (Latham, Bennett, Stretton, & Anderson, 2004; Liu & Latham, 2009). Therefore, it seems likely that there is a threshold of muscle strength, below which functional capacity is impaired (Judge, Underwood, & Gennosa 1993). Furthermore, intervention studies showing functional improvement have

reported significant initial change in the first few weeks of training, with modest improvements thereafter (Lockes et al., 2012). This highlights the importance of NM function where, in the absence of strength deficits, neural factors may account for functional capacity (Moritani & deVries, 1979).

<div align="center">Neuromuscular Adaptations to Resistance Exercise</div>

Many studies have documented that exercise provides a wide range of physiological benefits; however, resistance exercise (RE) is considered to be the preferred approach to elicit NM adaptations for healthy older adults (Aagaard et al., 2010; Peterson, Rhea, Sen, & Gordon, 2010). Progressive RE from 10 weeks to 2 years has been shown to increase muscle mass, strength, and NM function (Latham et al. 2004; Forbes, Little, & Candow, 2012). Furthermore, progressive RE appears to be an effective intervention to reduce physical disability in older adults (Liu & Latham, 2011).

<div align="center">Muscle Mass</div>

Resistance exercise has been shown to increase both type I and type II fiber area and whole body lean mass (LM) in older adults. Muscle biopsy of the vastus lateralis muscle of the dominant leg resulted in significant increase in the mean fiber area for type I ($p < 0.05$) and type IIx ($p < 0.001$) fibers in older men and women after 14 weeks of three times weekly RE (Brose, Parise, & Tarnopolsky, 2003). Candow, Chilibeck, Facci, Abeysekara, & Zello (2006) reported 12 weeks of three times weekly progressive RE significantly increased LM and knee extensor muscle thickness by 1.0% and 4.9%, respectively, in older men. Older men also had significantly greater improvements in knee extensor thickness compared to young men ($P <$

0.05). However, there is a great deal of variability in the dose-response relationship between RE and body composition changes in the literature. A recent meta-analysis suggested that an average of 20.5 weeks of progressive RE is necessary to produces a significant increase in LBM in aging men and women (Peterson et al., 2011). Furthermore, results from the meta-analysis identified volume as a significant predictor of LM changes.

Muscle Strength and Function

Several studies have shown significant strength and functional improvements among older persons following 8-24 weeks of progressive RE. Early research by Frontera et al. (1988) reported 107.4-116.7% improvement in knee extensor strength and 9.8-11.4% increase mean CSA area of the vastus lateralis following 12 weeks of high intensity (80% 1RM) RE in older men. Weekly measurements of 1RM strength showed improvements on average of 5% per day. The dramatic increase in 1RM strength was 10 times greater than strength measured by the isokinetic testing. The authors concluded this to be due to specificity of training and neural adaptations to the slow speeds (6-9 seconds per repetition) of contraction used in training. However, many other studies have reported more modest (27-50%) improvement in knee extension strength following 8 to 12 weeks of RE in older adults (Taaffe, Duret, Wheeler, & Marcus et al., 1999; Henwood & Taaffe, 2006; Kalapotharakos, Diamantopoulos, & Tokmakidis, 2010).

A recent meta-analysis by Peterson et al. (2010) reported an average 33% increase in knee extensor strength following 8-24 weeks of RE in older adults, indicating higher intensity RE training was associated with greater improvements in strength. In a study by Kalapotharakos et al. (2010) very old men (aged 80-88 years) underwent a twice weekly, full body RE program

of moderate intensity (70% of 3-RM). After 8 weeks of RE, knee extensor strength (41 to 50%; $p < 0.001$) significantly improved, with a further increase in strength from week 8 to 14 (6 to 12%). The rapid initial increase in strength was thought to be the result of neural adaptations and was significantly correlated to functional measures of chair rise time $(r = 0.81; p < 0.001)$ and 6-minute walk distance $(r = 0.82; p < 0.001)$. Henwood & Taaffe (2006) investigated three varied short-term (8 weeks) training protocols on muscle strength in older men and women and found that participants who underwent traditional slow to moderate-velocity velocity RE increased maximal leg extension strength by 27% $(P < 0.001)$. However, functional performance was only improved in the high-velocity RE group.

Progressive RE, performed 2-3 times per week, has been shown to increase strength and functional performance in older adults; however, even one training session per week may be sufficient for similar improvements. In a study by Taaffe et al. (1999) significant improvements in strength (37 – 41.9%) and NM performance (19.5 – 30.2%) were seen with one, two, and three days RE per week of a 24 week program for older adults, with two days RE per week having the greatest improvements. Significant $(P = 0.001)$ gains in strength were seen primarily following the first 8 weeks of training, with no difference between groups. NM performance was assessed using a timed backward walk over a 6-m course and chair rise test. A significant decrease in chair rise time was seen following 24 weeks of RE. Knee extension strength (1RM) was also assessed and significantly associated with chair rise time $(r = -0.40, P < 0.01)$ and 6 meter backward tandem walk $(r = -0.30, P < 0.05)$. Similarly, percent change in LM was significantly associated with chair rise time $(r = -0.40, P < 0.01)$. Locks et al. (2012) found an initial

improvement of 13.3% in chair rise time following six weeks of twice weekly low to moderate-intensity (65-75% 1RM) RE, and a more modest 6% improvement in weeks six to twelve.

Aerobic Capacity

Recently, a few studies have reported equivocal results of the effects of RE on measures of aerobic capacity in older adults (Vincent et al., 2002; Hagerman et al., 2000; Cadore et al., 2011a). Vincent et al. (2002) reported 23.5% and 20.1% increases in VO_2peak and 26.4% and 23.3% increases in time to exhaustion following 24 weeks of low and high intensity RE in older adults, respectively. Hagerman et al. (2000) reported an 8.9% and 9.4% increase in treadmill time to exhaustion and VO_2peak, respectively, after 12 weeks of high intensity (75-80% 1RM) RE in older men.

Neuromuscular Economy

Investigation by Cadore et al. (2011b) examined the effects of 12 weeks of either strength, aerobic, or concurrent training on aerobic power in older adults and found no significant increase in VO_2peak following RE. However, they did find a significant decrease in myoelectrical activity of the vastus lateralis muscles at the same workloads previously measured during a cycle ergometry test. The authors concluded that this decrease in myoelectric activity was the result of improved NM economy. Hartman et al. (2003) suggested that an increase in the economy of movement from RE can be attributed in part to increases in strength which would require fewer motor units to maintain the same submaximal load. In support, Cadore et al. (2011a) found significant negative correlations (r=-0.44 to -0.61, p=0.038 to 0.002) between

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strength and percent muscular activation during submaximal cycle ergometry, suggesting that NM economy was associated with muscular strength during aging.

<center>Electromyography and Neuromuscular Function</center>

The use of electromyographic (EMG) techniques has allowed observation of age-related changes in NM function. During voluntary contraction, action potentials conducted by the nerve, along the muscle, and into the muscle fiber produce an electrical signal during each activation (Lieber, 2010). Thus, with surface EMG it is possible to measure the combined number of units involved and the nerve impulse frequency of the active muscles within the electrode detection area (Petrofsky, 1979). Furthermore, electrical activity in muscle tissue increases as a function of time when the muscle works against a constant force during isometric or dynamic activity and provides objective measurement of fatigue when plotted over time (deVries et al., 1987).

<center>Neuromuscular Activation</center>

Impaired NM activation has been reported in old compared to young adults (Pousson, Lepers, & Van Hoecke, 2001) and older adults with mobility limitations compared to those with high mobility function (Clark et al., 2010). Pousson et al., (2001) observed significantly lower EMG amplitude and torque production ($p = 0.03$ and $p = 0.04$) during isometric and concentric contractions of the elbow flexor muscles in older adults compared to young. They also noted that for the same absolute values of torque, older adults presented greater muscular activation indicating lower neuromuscular efficiency. Clark et al. (2010) reported similar NM activation between middle-aged and older adults during maximal voluntary leg extension, with significant differences in torque ($p < 0.0001$) and power ($p < 0.0001$) related to muscle size. Furthermore,

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older adults who had mobility limitations had significantly lower torque, power, and agonist muscle activation ($p < 0.0001$) than those with high mobility function. These findings suggest that impaired voluntary NM activation may not be an obligatory consequence of aging, but has important implications for NM efficiency and the onset of mobility disability in some older adults.

Neuromuscular Fatigue

Early studies have used EMG to show that the electrical activity in muscle tissue increase as a function of time when muscle works against a constant force during isometric or dynamic activity (Lippold, Redfearn, & Vueo, 1960; deVries, 1968; Petrofsky, 1979). Many investigators have provided evidence that changing the rate of work results in markedly different fatigue curves, which have been shown to increase linearly over time (deVries, 1968; Petrofsky, 1979). Petrofsky (1979) found a linear relationship in root mean square (RMS) amplitude of EMG and work load during 3 minute bouts of cycle ergometry. At 20 and 40% of VO_2max the RMS amplitude of EMG stayed constant, while at 60, 80, and 100% of VO_2max (to the point of fatigue) the RMS amplitude continually increased. deVries et al. (1987) observed a significant rate of rise in electrical output from the vastus lateralis of young men when they performed workbouts of 70 W and 135 W to 170 W and even greater muscle activation (as measured by EMG) at 205 W on the cycle ergometer. The authors concluded that the increased electrical activity in the muscle as fatigue progresses is a result of greater recruitment and higher innervation rate to make up for force losses as fatigued motor units drop out. Therefore, reduced electrical activity during the same previously measured workload would suggest a delay in NM fatigue.

The Physical Working Capacity at Fatigue Threshold (PWC$_{FT}$)

deVries et al. (1987) developed a submaximal, discontinuous cycle ergometer test which utilizes EMG to objectively measure the first sign of neuromuscular fatigue during a test of physical working capacity (PWC). The PWC$_{FT}$ represents the highest power output that does not result in a significant increase in electrical activity of the thigh muscle over time ($p > 0.05$). It has been associated with measures of aerobic power, muscular endurance and efficiency, which are more commonly measured by oxygen consumption rate (VO$_2$) during tests of maximal exertion. The PWC$_{FT}$ is unique in that it measures the work capacity that can be maintained before the onset of NMF rather than the duration a given bout of exercise can be maintained, which may be largely influenced by subjective decisions on the part of the participant and the investigator (deVries & Housh, 1994). It has been demonstrated to be reliable (deVries et al., 1989; Stout et al., 2000; Stout et al., 2007), valid (deVries et al., 1989), and comparable to tests of maximal exertion (critical power) (deVries, Moritani, Nagata, & Magnussen, 1982).

The physiological mechanism responsible for the increase in EMG amplitude over time is unknown and investigations have been limited to aerobic training (deVries et al., 1989) or supplementation in young and old adults (Housh, deVries, Johnson, Evans, & McDowell, 1991; Stout et al., 2000; Stout et al., 2006; Stout et al., 2007a; Stout et al., 2007b; Stout et al., 2008; McCormack et al., In 2013). Several possible mechanisms have been suggested, such as, the accumulation of metabolic by-products (lactate, H$^+$, P$_i$, and ammonia), depletion of stored energy substrates (ATP, phosphocreatine, and glycogen), and/or impaired excitation-contraction coupling due to fiber type distribution characteristics. deVries et al. (1987) investigated the relationship between the onset of blood lactate accumulation (OBLA), critical power, and the

PWC$_{FT}$ in fit and unfit young men (aged 23.4±3.1 years). They found a significant correlation between PWC$_{FT}$ and critical power ($r = 0.670$, $p < 0.01$), with no significant difference between mean power outputs at PWC$_{FT}$ (236 W) and critical power (229 W). There was also a significant correlation between PWC$_{FT}$ and OBLA ($r = 0.569$, $p < 0.01$); however, the difference between mean power outputs at PWC$_{FT}$ and OBLA was significantly different (75 W, $p > 0.05$). Further analysis showed this significant difference existed only in the fit quartile (124 W, $p < 0.001$), and not the unfit quartile (8 W, $p > 0.05$). The authors suggested the physiological mechanism responsible for PWC$_{FT}$ and OBLA must be different in trained individuals.

deVries et al. (1989) evaluated the feasibility of the PWC$_{FT}$ in elderly populations, as well as its sensitivity to aerobic training adaptations. Participants were divided up into one of three groups, high intensity training (85% PWC$_{FT}$; n = 7), low intensity training (70% PWC$_{FT}$; n = 10), or control (no exercise; n = 10). The training groups underwent 10 weeks of three times weekly aerobic training on a cycle ergometer, broken up into three 10 minute bouts of cycling for the first five weeks and two 15 minute bouts of cycling for the last five weeks, all bouts separated by 2 minute rest intervals. The authors determined the PWC$_{FT}$ was feasible with six of eight (75%) participants having evidence of NMF. Furthermore, the average rate of exertion during the PWC$_{FT}$ did not exceed 14.2 or "somewhat hard" on the Borg rate of perceived exertion scale. Aerobic training results in 29.8% (ΔPWC$_{FT}$ of 24 W) and 38.4% (ΔPWC$_{FT}$ of 32 W) improvement in PWC$_{FT}$ in low and high intensity groups, respectively. While the improvements in the low and high training groups were statistically different ($p < 0.001$) from the control group, they were not statistically different ($p > 0.05$) from each other. The authors also reported improvements in heart rate/power output of 18% in the low intensity group and

33% in the high intensity group. The physiological mechanism responsible for these changes following aerobic training was thought to be a decrease in the ventilatory cost of exercise and/or an improvement to muscle contractility. Therefore, deVries et al. (1989) suggested that the PWC_{FT} may be more appropriate and sensitive to the effects of training in older adults than other GXT that require maximal effort (i.e. VO_2max) and may be ill advised or hazardous for this population.

Housh et al.(1991) investigated the effects of ammonium chloride (NH_4Cl) and sodium bicarbonate ($NaHCO_3$) ingestion to determine the effect of acidosis and alkalosis, respectively, on the PWC_{FT} in young men and women (23 ± 2 years). NH_4Cl and $NaHCO_3$ have been previously shown to effect blood pH which affects the acidity of the cellular environment, and therefore, energy production (Costill, Verstappen, Kuipers, Janssen, & Fink, 1984; Sutton, Jones, & Toews, 1981). Furthermore, energy production has been shown to have an effect on the electrical events leading to muscular contraction (Maclaren, Gibson, Parry-Billings, & Edwards, 1989). Therefore, the investigators conducted 2 experiments to determine the effects of NH_4Cl and $NaHCO_3$ on myoelectric evidence of fatigue, as measured by the PWC_{FT}. During the experiment 1, following ingestion of the supplement, participants performed the discontinuous PWC_{FT} which resulted in no significant effect ($P > 0.05$). The investigators thought this to be due to the discontinuous nature of the test which may not have been sensitive to the effects of the supplements. For this reason, a continuous protocol of the PWC_{FT} was performed during the second experiment and also resulted in no significant effect ($P > 0.05$). These findings were consistent with previous investigations (Kowalchuk, Haigenhauser, & Jones, 1984) which found that acidosis and alkalosis had no effect on ventilatory or lactate thresholds. Therefore, the

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authors concluded that glycogen stores and blood pH are not responsible for the significant rate of rise in myoelectric activity which characterizes the onset of fatigue as measured by the PWC_{FT} test. They suggested impaired excitation-contraction coupling due to fiber type distribution characteristics, and not solely lactate accumulation, may explain the lack of pH effect on PWC_{FT}. However, McCartney, Heignehauser, & Jones (1983) suggested that alterations in the blood acid-base state have little influence on muscle pH.

Stout et al. (2000) investigated the effects of creatine loading on NMF in female collegiate athletes to determine if skeletal muscle phosphocreatine would serve as a temporal energy buffer and modulator of glycolysis, therefore delaying NMF during the PWC_{FT}. Participants performed the PWC_{FT} test prior to and following five days of supplementation of 20g creatine monohydrate (Cr) or placebo. After covarying for pre-supplementation PWC_{FT} values, PWC_{FT} for the Cr group (mean = 186 W) was significantly higher ($P < 0.05$) compared to the placebo group (mean = 155 W). Although not directly measured in the present study, Cr loading has been previously been shown to increase intramuscular phosphocreatine stores and increase exercise performance (Vanderberghe et al., 1997). Therefore, Stout et al. (2000) suggested "Cr loading may delay the onset of NMF and the fatigue-induced increase in EMG at submaximal power outputs by reducing the reliance on anaerobic glycolysis and attenuating the accumulation of lactate and ammonia in the working muscles and blood." Similar findings were reported in older men and women by Stout et al. (2007). After supplementing with 20 g/day Cr for one week and 10 g/day for an additional week, participants significantly increased PWC_{FT} (15.6%; $p < 0.05$), compared to the placebo group. They also observed significant increases in isometric grip strength (6.7%; $p < 0.05$) in the Cr group only. Similar physiological mechanisms

as those reported by Stout et al. (2000) were thought to be the result of these improvements in an older population. Additionally, a possible increase in muscle efficiency was suggested to be a potential mechanism of delayed NMF during the PWC_{FT}.

In addition to Cr supplementation, beta-alanine (Ba) supplementation has been shown to enhance performance by delaying fatigue (Hoffman, Emerson, & Stout, 2012). Stout et al. (2006) examined the effects of Cr (5.25 g), Ba (1.6 g), and a combination of Cr and Ba (5.25 g Cr and 1.6 g b-Ala) on PWC_{FT} in untrained young men (aged 24.5±5.3 y). Twenty-eight days of supplementation resulted in significant increase in PWC_{FT} for Ba (14.5%; $p = 0.004$) and CrBa (11.3%; $p = 0.011$) groups, but not Cr only (6.5%; $p > 0.05$), compared to placebo. Interestingly, Cr did not provide any additional benefit in the CrBa compared to Ba only ($p > 0.05$). The results indicated Ba may delay NMF with or without Cr. The authors suggested the delay in NMF following Ba supplementation to be the result of augmented muscle carnosine levels, which may have allowed a greater capacity to buffer H^+ during exercise. In support, Stout et al. (2007a) reported a significant increase in PWC_{FT} (12.6%; $p < 0.001$), ventilatory threshold (13.9%; $p < 0.001$) and time to exhaustion (2.5%; $p < 0.05$) of young women following 4 weeks of Ba supplementation (3.2 g and 6.4 g for week1 and week 2-4, respectively). These finding support the hypothesis that increased blood lactate during exercise, and subsequent H^+ accumulation, may increase muscle activation (EMG amplitude) due to a decrease in pH. Furthermore, Ba supplementation may delay fatigue-induced increases in EMG amplitude and ventilation rate during incremental cycle ergometry at submaximal loads.

Stout et al. (2008) investigated the effects of Ba on PWC_{FT} and functional performance in older men and women to determine if the findings in young men (Stout et al., 2006) and women

(2007a) could be extended to the elderly. Twelve weeks of Ba supplementation (2.4 g/day) resulted in a significant increase in PWC_{FT} (28.6%; $p < 0.05$) compared to the placebo group. The two-fold increase in PWC_{FT} in older adults compared to young adults (12.6-14.5%) was explained to be due to the difference in intramuscular carnosine levels in young versus old (Tallon, Harris, Maffulli, & Tarnopolsky, 2007) or longer supplementation period. However, McCormack et al. (2013) recently reported a 13.6-17.8% increase in PWC_{FT} following twelve weeks of beta-alanine supplementation in older men and women which is more consistent with findings in young men and women.

Despite the substantial evidence supporting RE as a countermeasure for age-related NM decline, there has yet to be an investigation of the effects of RE on PWC_{FT} of older adults. Furthermore, determination of any possible benefit of RE on NMF may help isolate the potential mechanism for NM fatigue as indicated by a rise in EMG amplitude over time. Perhaps neural adaptations with acute RE (6 weeks) may increase efficiency of MU recruitment as suggested by Cadore et al. (2011a); however, further investigation is necessary to determine the possibility.

CHAPTER 3: METHODOLOGY

<u>Participants</u>

Twenty-six healthy men (n= 13) and women (n= 13) (70.6 ± 6.1 y), living independently in Central Florida, volunteered to participate in this study. Prior to testing all volunteers were cleared for participation by medical history questionnaire and physical activity readiness questionnaire, or physician clearance. No participants had major surgery within the previous 6 months, or a history of asthma, heart or pulmonary disease, uncontrolled hypertension, or were taking any medications that would interfere with exercise. At the beginning of the study, all participants were advised of any possible risks before providing written informed consent. All procedures were approved by the University Institutional Review Board.

<u>Research Design</u>

This study followed a randomized, between groups, repeated measures design consisting of two groups: exercise (EXE) and control (CONT). The volunteers participated in initial testing, underwent 6 weeks of an exercise intervention or control period, and competed post-treatment testing.

Group randomization was based upon the participant's availability and willingness to attend the training sessions during the 6 week period. Participants assigned to the EXE group underwent 6 weeks of resistance training. Participants in the CONT group were instructed to maintain their current activity status for the following 6-weeks.

Procedures

Testing occurred on two separate days, approximately 24 hours apart (Figure 1). On the

first testing day, participants reported to the laboratory after an overnight fast for body

composition assessment. On the second test day, participants completed the performance tests in

the following order: PWC_{FT}, CHAIR, WALK, and 1RM. Participants were advised to maintain a

similar daily routine on testing dates.

Pre-Testing
- **Day 1**
  - DEXA
  - Familiarization (EXE)
- **Day 2**
  - PWC_{FT}
  - Chair rise
  - Gait speed
  - 1-RM
  - Familiarization (EXE)

EXE or
CONT
(6 weeks)

Post-Testing
- **Day 1**
  - DEXA
- **Day 2**
  - PWC_{FT}
  - Chair rise
  - Gait speed
  - 1-RM

Figure 1
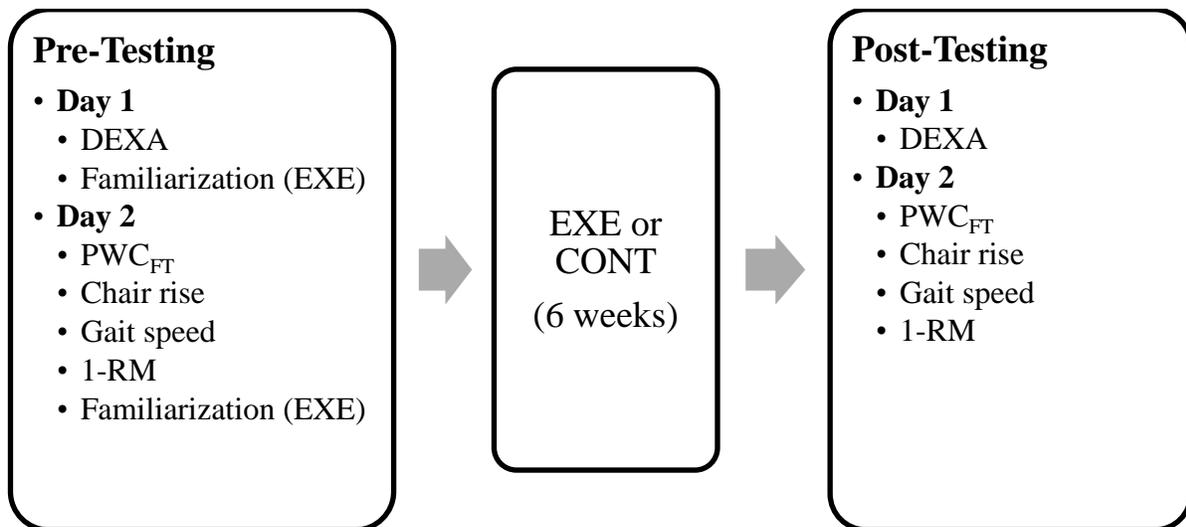Flow chart of testing

Body Composition

Body composition was determined using whole body-dual energy x-ray absorptiometry

(DEXA) scans (Prodigy[TM]; Lunar Corporation, Madison, WI). Total body estimates of percent

fat (BF%), fat (FM), and non-bone lean tissue (LBM) were determined using the company's

recommended procedures and supplied algorithms. Quality assurance was assessed by daily

calibrations and was performed prior to all scans using a calibration block provided by the manufacturer.

<center>Neuromuscular Fatigue</center>

Electromyographic (EMG) measurements

A bipolar (4.6 cm center-to-center) surface electrode (Quinton Quick-Prep silver-silver chloride) arrangement was placed over the right vastus lateralis muscle, at approximately 60 percent of the distance from the lateral portion of the patella on a line with the greater trochanter. The reference electrode was placed over the lateral epicondyle of the distal femur. Inter-electrode impedance was kept below 5,000 ohms with abrasion of the skin beneath the electrodes. The raw EMG signals were pre-amplified using a differential amplifier (MP150 BIOPAC Systems, Inc., Santa Barbara, CA), sampled at 1,000 Hz, and stored on a personal computer (Dell Latitude E6530, Dell Inc., Round Rock, TX) for off-line analysis. The EMG signals were expressed as root mean square (RMS) amplitude values (μVrms) by software (AcqKnowledge v4.2, BIOPAC Systems, Inc., Santa Barbara, CA).

Determination of PWC_{FT}

Determination of PWC_{FT} values was previously described by deVries et al. (1987) for the vastus lateralis. The initial work rate was set at 30 watts for each test. The participants pedaled at 50 revolutions per minute (rpm) for each two-minute stage of the test on an electronically-braked cycle ergometer (Lode, Excalibur Sport, Groningen, the Netherlands). Toe clips were utilized for each participant. Following each stage, the raw EMG RMS amplitude values were saved on a personal computer (previously described) and further analyzed with custom-written

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software (LabView, National Instruments Corporation, Austin, TX). If the stage did not produce a statistically significant, positive slope ($p < 0.05$), the resistance was increased 10-20 watts until a statistically significant, positive slope was achieved or the participant reached 75% of their age-predicted maximal heart rate, or surpassed a rating of perceived exertion (RPE) of 13 ("Somewhat Hard") on the Borg scale. Once a statistically significant, positive slope was reached, one final stage was performed at 5-10 watts less than the resistance of the stage that produced the statistically significant, positive slope. The PWC$_{FT}$ was estimated to be the mean resistance of the highest non-statistically significant positive slope and the lowest statistically significant positive slope. In the event the participant did not have a statistically significant, positive slope during any stage of their PWC$_{FT}$, a regression analysis was performed utilizing slope and the corresponding workload (watts) as described by deVries et al. (1982). The y-intercept (watts) produced in this analysis was then used as the PWC$_{FT}$.

Test-retest reliability for the PWC$_{FT}$ test was determined from 10 participants measured 40 days apart. The intraclass correlation coefficient (ICC) was 0.95 (SEM = 13.7 W). No significant difference ($p > 0.05$) was noted between the mean PWC$_{FT}$ values from trial 1 (69.5 ± 44.1 W) to trial 2 (68.5 ± 43.3 W). In addition, the ICC (0.95) and SEM (12.3 W) for estimating PWC$_{FT}$ from plotting the slopes of EMG-RMS versus time against each workload revealed no significant differences between the estimated mean PWC$_{FT}$ values from trial 1 (46.7 ± 12.3W) to trial 2 (51.1 ± 11.1W). These ICC results were similar to de Vries et al. (1989) and Stout et al. (2008) who reported ICC values of 0.97 and 0.83, respectively in older adults.

Functional Performance

Functional lower body strength was evaluated with the chair rise test (Bohannon, 1995). This test required participants to stand from a seated position in an 18-inch armless chair 5 times, consecutively. Participants were instructed to do so as rapidly as possible with the arms folded across the chest. If participants could not perform a single chair rise without the use of their arms, the test was concluded. Otherwise, time to perform 5 consecutive chair rises was measured with a stopwatch in seconds. Test-retest reliability for the CHAIR test was determined using 10 participants measured 40 days apart. The ICC was 0.75 (SEM = 1.25 s). There was no significant difference ($p > 0.05$) between mean CHAIR values from trial 1 (12.27 ± 1.73) and trial 2 (11.74 ± 1.74).

Normal walking gait speed was evaluated with the 8-foot walk test (WALK). An 8-foot level course was marked by tape in an indoor corridor. Participants were instructed to walk at their normal pace and were allowed to use any usual walking aids. Spotters walked along the side of the volunteers during the test to ensure safety. Time began when the volunteer initiated foot movement and stopped when 1 foot (completely) crossed the end line (8-foot mark). Time was measured with a stopwatch to the nearest one hundredth of a second. The best time of two attempts was recorded. Test-retest reliability for WALK was determined by using 10 participants measured 40 days apart. The ICC was 0.75 (SEM = 0.16 s). There was no significant difference ($p > 0.05$) between mean WALK values from trial 1 (1.89 ± 0.23) and trial 2 (1.79 ± 0.23).

Predicted 1-RM

Lower body voluntary isotonic strength was evaluated on the PLLE Power Lift® knee extension machine (Conner Athletic Products, Inc., Jefferson, IA) by a Certified Strength & Conditioning Specialist. Participants were fitted into the machine with the shin pad positioned just proximal to the lateral malleolus. The starting and ending position for the knee extension exercise was approximately 90° of knee flexion. From the starting position, each participant extended the knee until full available knee extension was reached and then returned to the starting position.   In the current study, predicted 1RM was based on protocol described by McNair, Colvin, & Reid (2011). Initially, participants performed a set of 10 repetitions without a load to assess comfort and form while performing the exercise. Following a 3 minute rest period, a load was selected that the participant believed they could lift for 10 repetitions or less. If the participant was able to perform more than 10 repetitions with this load they stopped and rested for 3 minutes. Depending on the participants perceived level of exertion using the OMNI scale (Gearhart, Lagally, Riechman, Andrews, & Robertson, 2011) the load was increased by ~10-20% and the test was repeated. When required this process was continued until a load was reached that restricted the participant to 10 repetitions or less. Participants performed up to 3 attempts to reach the goal. The Brzycki prediction equation [load in kg/(1.0278 – 0.0278 x repetitions)] was selected to calculate predicted 1RM and has been previously validated in clinical populations (McNair et al. 2011). Test-retest reliability for 1-RM was determined by using 10 participants measured 40 days apart. The ICC was 0.92 (SEM = 5.29 kg). There was no significant difference ($p > 0.05$) between mean 1-RM values from trial 1 (29.27 ± 12.22) and trial 2 (31.67 ± 14.52).

Familiarization of Resistance Exercises

At initial baseline testing, participants in EXE underwent two sessions of RE familiarization following data collection. All exercises that were included in the strength training program were introduced during the familiarization sessions. During the first familiarization session participants performed exercises without additional weight. Weight loads were assigned for each exercise during the second training session based upon the participants perceived rate of exertion of a 5-6 on the 10 point OMNI scale (Gearhart et al., 2009).

Resistance Exercise Training

The exercise training equipment used in this investigation included PowerLift® resistance machines, UltraFit™ dumbbells, and Power Systems® medicine balls. Resistance machines included were the prone leg curl, leg extension, lat pull down, and low row. Dumbbells and medicine balls were selected for the squat, lunge, step-up, calf raise, chest press, shoulder press, biceps curl, and triceps extension exercises.

Participants in the experimental (EXE) group trained twice a week for six weeks, completing a total of twelve training sessions. At least 48 hours passed between all training sessions to allow for proper recovery. Each training session began with a dynamic warm-up consisting of body weight squats, high knee walking, butt kick walking, torso rotation, and arm rotations. Full-body workouts were performed during each session with seven to eight exercises performed each day. Three sets of each exercise were performed with the number of repetitions systematically varying on a weekly basis ranging from eight to fifteen repetitions (APPENDIX A). There was a 90-second rest period allowed between each set and exercise. Load was

adjusted with the number of repetitions assigned but generally consisted on 70-85% of 1-RM.

The OMNI scale (Gearhart et al. 2009) of perceived exertion for resistance type exercise ranging

from zero to ten was used to assess difficulty during the training. Load was increased if

participants indicated that the resistance felt "light" on the OMNI scale (APPENDIX B) to

ensure loading was within the prescribed range. All training sessions were supervised one-on-

one training sessions overseen by a Certified Strength and Conditioning Specialist. The exercise

program followed the recommended guidelines for older adults by the American College of

Sports Medicine (Chodzko-Zajko et al., 2009; Pollock et al., 1998).

<center>Data Analysis</center>

Five separate 2-way mixed factorial analyses of variance (ANOVAs; time [PRE, POST]

x group [EXE and CONT]) were used to analyze the BF%, FM, LST, PWC_{FT}, 1RM, 8-foot walk,

and chair rise time. When appropriate, follow-up analysis included paired sample t-test. An

alpha level was set at $p \leq 0.05$, and all analyses were performed using PASW version 18.0

(SPSS, Inc., Chicago, IL).

The effects of strength training were calculated as the changes from pre-training to post-

training body composition and performance measurements among EXE and CONT. Magnitude-

based inferences were used to identify clinical differences in the physical changes between the

EXE and CONT. Several studies have supported the use of magnitude-based inference statistics

as a complementary tool for null hypothesis testing to reduce errors in interpretation (Batterham

& Hopkins, 2005; Hopkins, Batterham, Marshall, & Hanin, 2009) and to provide more clinically

meaningful results. The precision of the magnitude inference was set at 90% confidence limits,

using a p value derived from an independent t-test. Threshold values for positive and negative

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effect were calculated by multiplying standard deviations of baseline values by 20% (Hopkins 2009). Inferences on true differences between the exercise and control group were determined as positive, trivial, or negative according to methods previously described by Batterham and Hopkins (2005). Inferences were based on the confidence interval range relative to the smallest clinically meaningful effect to be positive, trivial, or negative. Unclear results are reported if the observed confidence interval overlaps both positive and negative values. The probability of the effect was evaluated according to the following scale: : <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely (Hopkins 2010).

CHAPTER 4: RESULTS

Participants

Twenty-four of the original 26 participants completed the study (CONT: n = 12, EXE: n = 12) Of the 2 that did not finish, one dropped out after pre-testing due to health concerns, and data from one participant was excluded due to an anomaly. Only participants who attended pre- and post-testing and completed all of the 12 training sessions were included in the statistical analysis. Characteristics of those participants who completed the study are listed by group in Table 1. There were no statistically significant differences ($p > 0.05$) between groups for age, height, or body mass either before or after the study.

Body Composition

Total body estimates of BF%, FM, and LBM are presented in Table 1. BF%, FM, and LBM did not differ between groups at study entry. There were no significant time x group interactions and no main effects for group or time for BF%, FM, or LBM ($p > 0.05$). It was unclear if 6 weeks of RE provided any benefit for improving body composition (Table 2). There was, however, a significant gender effect in EXE for BF% (Figure 2). Women in EXE decreased BF% significantly greater than men ($p = 0.020$). There was no gender effect in FM or LBM.

Neuromuscular Fatigue

Baseline and post-testing values for PWC_{FT} can be found in Table 1. PWC_{FT} was not significantly different between groups at study entry ($p > 0.05$). There was a 14% increase in PWC_{FT} in the EXE group compared to a 2% decrease in the CONT group. While these results

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were not significant ($p > 0.05$), RE had a possible benefit on Δ change in PWC_{FT} in the EXE

group (Table 2). There was no gender effect in PWC_{FT} for either group.

Functional Performance

CHAIR and WALK did not differ between groups at study entry (Table 1). Participants

in the EXE and CONT group improved CHAIR by 20% and 6%, respectively. However, only

the EXE group significantly improved CHAIR from pre- to post-testing (p = 0.047). Participants

in the EXE and CONT group improved WALK by 15% and 5%, respectively. Improvements in

WALK for EXE approached significance (p = 0.108). The Δ change in CHAIR and WALK

show a likely benefit from RE (Table 2). There was no gender effect in CHAIR or WALK for

either group.

Predicted 1-RM

Muscular strength did not differ between groups at study entry (Table 1). Participants in

the EXE and CONT group increased in 1-RM by 35% and 7%, respectively. However, only the

EXE group significantly increased 1-RM from pre- to post-testing ($p = 0.001$). The Δ change in

1-RM shows a most likely benefit from RE (Table 2). There was no gender effect in 1-RM for

either group.

Table 1
Participant Characteristics Pre- and Post-Testing

Variable	CONT (n=12)		EXE (n=12)	
	Pretest	Posttest	Pretest	Posttest
Age (yr)	70.3 ± 5.6		72 ± 6.3	
Height (cm)	166.5 ± 7.9		169.4 ± 8.4	
Mass (kg)	76.6 ± 18.3	76.8 ± 18.5	81.4 ± 17.6	81.6 ± 18.6
BF (%)	35.6 ± 8.5	35.4 ± 8.3	37.3 ± 9.6	37.3 ± 9.4
FM (kg)	26.3 ± 8.9	26.3 ± 9	29.5 ± 10.8	29.9 ± 11.6
LBM (kg)	47.3 ± 12.7	47.4 ± 12.7	48.1 ± 10.1	48.2 ± 9.8
PWC_{FT} (W)	52.9 ± 16	51.7 ± 18.5	46.7 ± 22.8	53.3 ± 24.3
1-RM (kg)	31.1 ± 11.8	33.3 ± 14.8	36.1 ± 11.9	48.9 ± 15.2**
CHAIR (sec)	12.8 ± 2.1	12 ± 1.7	14.4 ± 2.9	11.5 ± 1.8*
WALK (sec)	1.8 ± 0.4	1.7 ± 0.2	2 ± 0.4	1.7 ± 0.3

Values reported as mean ± standard deviation (SD); *EXE* exercise, *CONT* control, *BF%* body fat percent, *LBM* lean body mass, *FM* fat mass, PWC_{FT} physical working capacity at fatigue threshold, *1-RM* predicted 1 repetition maximum, *CHAIR* chair rise time, *WALK* 8-foot walk; *p< 0.05, **p< 0.01
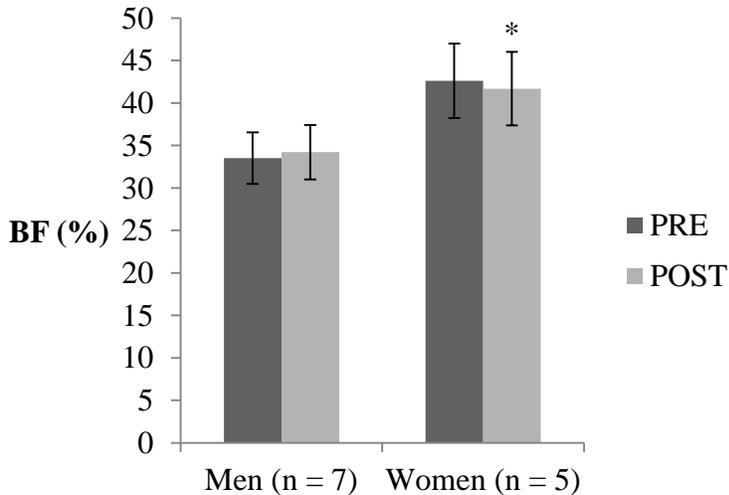

Figure 2
BF% between genders in EXE from pre- to post-testing

Table 2

Magnitude Based Inferences for Body Composition and Performance Measures

Measures	EXE Mean ± SD	CONT Mean ± SD	Difference; ± 90% CI[a]	Qualitative inference
FM (kg)	0.4 ± 1.9	-0.02 ± 0.8	-0.06; ± 0.6	Unclear
LBM (kg)	0.1 ± 1	0.1 ± 0.7	0.59; ± 1.5	Unclear
PWC$_{FT}$ (W)	6.7 ± 19.6	-0.8 ± 7.9	7.5; ± 10	Possibly Beneficial
1RM (kg)	12.8 ± 5.9	2.2 ± 2.2	10.6; ± 4.8	Most Likely Beneficial
WALK (sec)	-0.2 ± 0.4	-0.01 ± 0.3	-0.2; ± 0.2	Likely Beneficial
CHAIR (sec)	-2.9 ± 2.9	-0.9 ± 1.4	2.0; ± 1.6	Likely Beneficial

Values reported as mean ± standard deviation (SD); *EXE* exercise, *CONT* control, *BF* body fat *LBM* lean body mass, *FM* fat mass, *PWCFT* physical working capacity at fatigue threshold, *1RM* predicted 1 repetition maximum, *CHAIR* chair rise time, *WALK* 8-foot walk

[a]±90% CI: add and subtract this number to the mean difference to obtain the 90% confidence intervals for the true difference. Qualitative inference represents the likelihood that the true value will have the observed magnitude.

CHAPTER 5: DISCUSSION

To the best of our knowledge this is the first study to examine the effects of resistance exercise (RE) on the PWC_{FT} in older men and women. The main finding of this study suggests that 6 weeks of resistance exercise was possibly beneficial at increasing the PWC_{FT} by an average of 14% (Table 1). In addition, the results support previous research (Kalapotharakos et al., 2005; Henwood & Taaffe, 2006; Kalapotharakos et al., 2010; Latham et al., 2004; Forbes, Little, & Candow, 2012) on the beneficial effect of RE improving 1RM (35%), CHAIR (20%) and WALK (15%), while no changes were observed for FM and LBM. These data suggest that short term (6-weeks) RE may increase strength and functional performance, and delay the onset of neuromuscular fatigue (NMF; as measured by the PWC_{FT} test) in older adults.

Theoretically, the PWC_{FT} estimates the highest power output that can be sustained for an extended period of time without the onset of NMF during cycle ergometry. It has been associated with measures of aerobic power, muscular endurance and efficiency, which are more commonly measured by oxygen consumption rate (VO_2) during tests of maximal exertion (deVries et al., 1994). Recently, a few studies have reported equivocal results of the effects of RE on measures of aerobic capacity in older adults (Vincent et al., 2002; Hagerman et al., 2000; Cadore et al., 2011a). In support of our findings, Vincent et al. (2002) reported 23.5% and 20.1% increases in VO_2peak and 26.4% and 23.3% increases in time to exhaustion following 24 weeks of low and high intensity RE in older adults, respectively. In agreement Hagerman et al. (2000) reported an 8.9% and 9.4% increase in treadmill time to exhaustion and VO_2peak, respectively, after 12 weeks of high intensity (75-80% 1RM) RE in older men. However, a recent investigation by Cadore et al. (2011b) examined the effects of 12 weeks of either strength,

aerobic, or concurrent training on aerobic power in older adults and found no significant increase in VO_2peak following RE.

deVries et al. (1989) suggested that the PWC_{FT} may be more appropriate and sensitive to the effects of training in older adults than other GXT that require maximal effort (i.e. VO_2max) and may be ill advised or hazardous for this population. Consequently, studies involving aerobic training (deVries et al., 1989) and/or nutritional supplementation (Stout et al., 2007b; Stout et al., 2008; McCormack et al., 2013) in older adults have reported significant improvement in PWC_{FT}. deVries et al. (1989) reported a 29.8% and 38.4% improvement in PWC_{FT} following 10 weeks of low (70%) or high (85%) intensity aerobic training in older adults possibly due to a decreased ventilatory cost of exercise following training or improved muscle contractility. After 14 days (2 weeks) of creatine supplementation Stout et al. (2007) observed a 15.6% improvement in PWC_{FT} in older adults without undergoing an exercise training program, suggesting increased availability of intramuscular phosphocreatine may have delayed the transition from aerobic to anaerobic glycolysis following supplementation. Furthermore, two other studies involving beta-alanine supplementation reported significant improvements in PWC_{FT} by 13.6% to 28.6% in older adults, thought to be the result of increased intramuscular buffering capacity, therefore delaying the accumulation of metabolites (Stout et al., 2008; McCormack et al., 2013). While this is the first study to examine the effects of RE on the PWC_{FT} in older adults our average improvement of 14% is in line with the previously described studies examining different nutritional and exercise interventions.

The mechanism underlying an increase in PWC_{FT} following RE is unclear. It has been stated that the physical working capacity is dependent on the body's capacity to supply oxygen

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to the working muscles (deVries & Housh, 1994). Therefore, it seems reasonable to suggest that an increase in the NMF threshold may be a result of increased oxygen efficiency to the working muscles. Previous research examining intramuscular metabolic adaptations to RE has reported increased oxidative capacity by 38% and 57% after 12 weeks to 6 months of training, respectively (Frontera et al., 1988; Jubrias et al., 2001). Intramuscular adaptations may act as an aerobic stimulus as suggested by Hagerman et al., (2000) who found a significant transformation of IIB to IIA or IIAB fibers and increased capillarization following 16 weeks of high intensity (85%-90% 1RM) RE in older men. Ploutz, et al. (1994) found significant decrease in percentage of type IIB fibers with a concomitant increase in type IIAB fibers following 9 weeks of RE, however, increases in oxidative enzyme activity were not significant. They also reported significant decreases in muscle activation during sets of submaximal leg extensions following training, suggesting improved neuromuscular efficiency.

Improving neuromuscular economy is another possible mechanism for the 14% increase in PWC_{FT} observed in this study. Recently, the term neuromuscular economy has been described as the number of motor units necessary to perform a given activity (Cadore et al., 2011b). Hartman et al. (2003) suggested that an increase in the economy of movement from RE can be attributed in part to increases in strength which would require fewer motor units to maintain the same submaximal load. The reported decreases in muscle activation by Ploutz et al. (1994) were thought to be the result of neurological adaptations to firing rate, recruitment threshold, and/or transmission of force from the contractile proteins to the skeleton. In support, Cadore et al. (2011b) reported significant decreases in myoelectric activity (as measured by EMG) of the vastus lateralis muscles at the same submaximal cycle ergometry workloads, following 12 weeks

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of RE in older adults. Furthermore, Cadore et al. (2011a) described significant negative correlations (r=-0.44 to -0.61, p=0.038 to 0.002) between strength and percent muscular activation during submaximal cycle ergometry, suggesting that improved NM economy was due to the significant increase in strength.

As expected, body composition measures of BF%, FM, and LBM did not show any changes in the EXE or CONT group (Tables 1, 2). In support of these results, a recent meta-analysis suggested that an average of 20.5 weeks of progressive RE is necessary to produces a significant increase in LBM in aging men and women (Peterson, Sen, & Gordon, 2011). Thus, the short duration of RE training (6 weeks) may explain the lack of any detectable changes in body composition in the EXE group. Interestingly, we did observe a significant gender effect for BF% in women in the EXE group. Previous research has suggested the difference in hormonal response to exercise may increase lipid oxidation rates in women more so than men (Braun & Horton, 2001); however, because we did not measure hormones in this study we can only speculate this possibility.

Six weeks of RE significantly increased leg extension predicted 1-RM by 35% in the EXE group (Table 1). In support of our findings, Henwood & Taaffe (2006) reported a 27% increase in maximal leg extension strength following 8 weeks of RE in older men and women. Similarly, Kalapotharakos, Diamantopoulos, & Tokmakidis (2010) reported a 42% improvement in 1-RM leg extension strength following 8 weeks of RE in older men; however, participants were aged 80 years or older, compared to the mean age of 71 in the current study. Strength gains following RE (8 weeks to 2 years) in older adults are well documented in previous literature (Latham et al. 2004; Forbes et al., 2012). To the best of our knowledge, the results of the present

study appear to be unique in that the duration of RE was significantly shorter (6 weeks) than previous research demonstrating significant improvement in 1-RM in older adults. Furthermore, the significant strength gains were seen in the absence of detectible LBM changes, which suggest that improvements are most likely due to neuromuscular adaptations (Moritani & deVries 1979; Kamen, 2005).

Lower-body functionality has been associated with disability, hospitalization and mortality (Onder et al. 2002; Guralnik et al. 2000). Recently, Studenski et al. (2011) suggested a gait speed decrease of 0.1m/s was associated with 12% higher mortality in older adults. Therefore, improving lower body functionality should be a goal of any intervention. In the present study, 6 weeks of RE resulted in improved CHAIR by 20% and WALK by 15% with no significant change to the CONT group (Table 1). These results support previous research that RE improves physical function in older adults (Liu & Latham et al., 2009). Kalapotharakos et al. (2005) reported a 31% and 33% improvement in CHAIR and gait speed, respectively, following 12 weeks of RE in older men and women. Although the magnitude of change is lower in the current study, this difference is likely due to 6 weeks versus 12 weeks of RE. In support, Locks et al. (2012) reported a 13% improvement in CHAIR and significant improvement in 6-minute walking distance following 6 weeks of RE in older adults; however, a non-significant improvement was observed from week 6 to week 12. Several studies have reported significant gains in functional performance only within first few weeks of RE with minimal improvement thereafter, suggesting a large role due to neuromuscular adaptations (Kalapotharakos et al., 2005; Kalapotharakos et al., 2010; Locks et al., 2012). As suggested previously for PWC_{FT} and 1RM, the functional improvements may be the result of improved NM economy.

The current study had limitations, such as the relatively small sample size and short term training period. A larger sample size and longer training period would strengthen the power and consequently may have affected the results of our study. Additionally, although participants were not previously resistance trained, there was a large variation in physical status at study entry (Table 2). This may explain the large deviation in training response we saw between participants and may have been corrected by a larger sample size.

Conclusions

Perhaps of greatest importance to the aging adult is maintaining independence and quality of life. Physical activity has been shown to postpone physical disability and dependence in older adults (Spirduso & Cronin, 2001). In the present study, 6 weeks of RE significantly improved lower body strength (1-RM) by 35% and function (CHAIR) by 20%. There were also beneficial improvements in the delay of neuromuscular fatigue (PWC_{FT}) by 14% and gait speed (WALK) by 15%. The results of this study indicate 6 weeks of RE has a beneficial effect on improving strength and functionality and possibly beneficial at delaying the onset of neuromuscular fatigue in older adults.

APPENDIX A: RESISTANCE TRAINING PROGRAM

Week 1 (3 X 12-15RM)		Week 2 (3 X 12-15RM)	
Day 1	Day 2	Day 1	Day 2
Squat	Step up	Squat	Lunge
Push up	Lat pull down	Push up	Lat pull down
Leg extension	Calf raise	Hamstring curl	Leg extension
Shoulder press	Bicep curl	Shoulder press	Seated row
Leg curl	Seated row	Triceps extension	Biceps curl
Triceps extension	Upright row	Calf raise	Upright row
Plank	Reverse crunch	Plank	Reverse crunch
		Superman	

Week 3(3 X 10-12RM)		Week 4 (3 X 10-12RM)	
Day 1	Day 2	Day 1	Day 2
Squat	Step up	Squat	Lunge
Push up	Lat pull down	Chest press	Lat pull down
Leg curl	Calf raise	Leg curl	Leg extension
Shoulder press	Seated row	Shoulder press	Seated row
Leg extension	Upright row	Calf raise	Calf raise
Triceps extension	Modified RDL	Triceps extension	Upright row
Plank	Bicep curl	Plank	Bicep curl
	Reverse crunch		Reverse crunch

Week 5 (3 X 8-10RM)		Week 6 (3 X 10-12RM)	
Day 1	Day 2	Day 1	Day 2
Squat	Lunge	Squat	Leg extension
Push up	Lat pull down	Chest press	Lat pull down
Leg curl	Calf raise	Leg curl	Step up
Shoulder press	Seated row	Shoulder press	Seated row
Leg extension	Upright row	Calf raise	Shoulder press
Triceps extension	Biceps curl	Triceps extension	Bicep curl
Plank	Reverse crunch	Modified RDL	Reverse crunch
		Plank	

APPENDIX B: OMNI SCALE
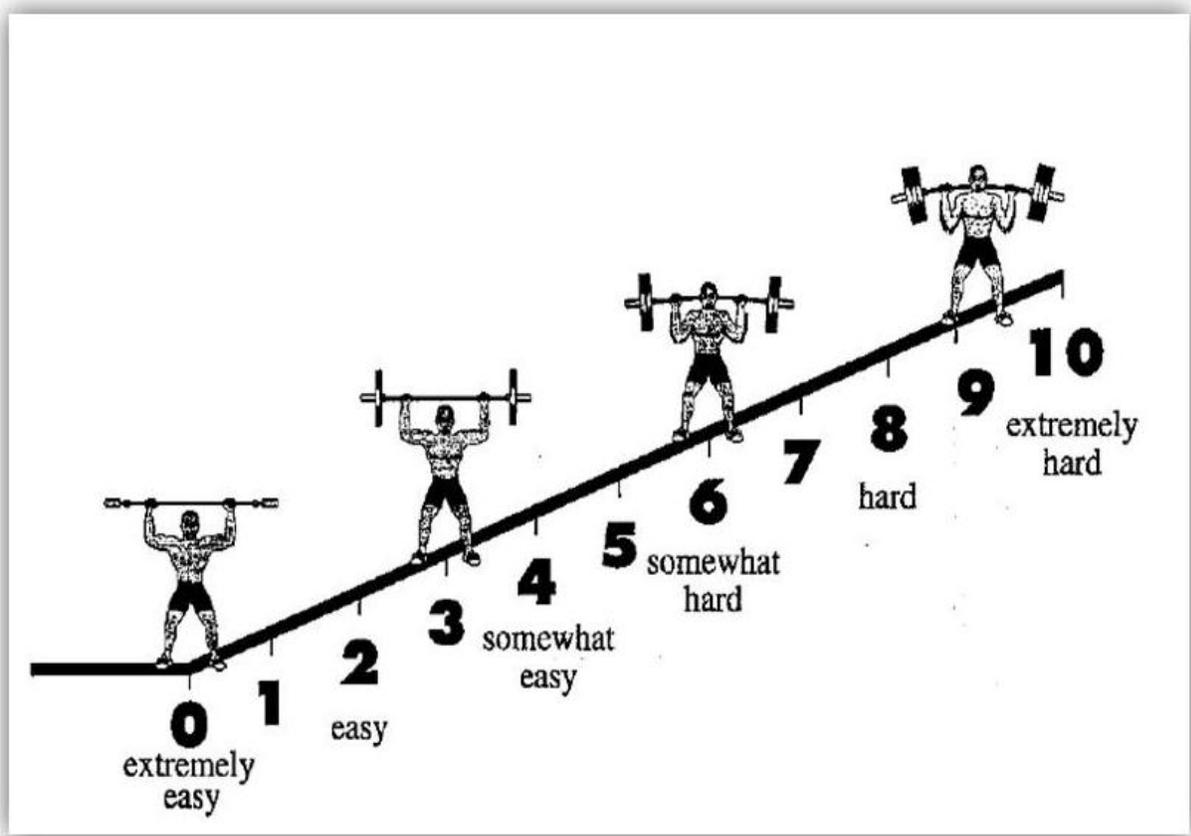
APPENDIX C: UCF IRB LETTER OF APPROVAL

![University of Central Florida logo]

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: UCF Institutional Review Board #1
          FWA00000351, IRB00001138

To: Maren Susan Fragala and Co-PI: Jay R. Hoffman

Date: August 16, 2012

Dear Researcher:

On 8/16/2012 the IRB approved the following modifications to human participant research until 06/19/2013 inclusive:

Type of Review:	IRB Addendum and Modification Request Form
	Expedited Review for the Addendum to this Full Board study
Modification Type:	Protocol Revisions and Consent Form Revision;
Project Title:	Muscular Adaptations to Strength Training Exercise in Seniors (The MASTERS Study)
Investigator:	Maren Susan Fragala
IRB Number:	BIO-12-08447
Funding Agency:	Learning Institute for Elders(LIFE)
Grant Title:	
Research ID:	1053811

The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form cannot be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 06/19/2013, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a signed and dated copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Patria Davis   on 08/16/2012 12:27:51 PM EDT

![Signature of Patria Davis]

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