JENNIFER HELEN LAITY
Physical Reserve: Oxygen Cost of Physical Function in Older Adults
(Under the Direction of M. ELAINE CRESS)

The purpose of this study was to assess physical reserve (PR) in 15 independent community dwellers (IND) and 15 marginally dependent adults (MDEP) ≥ 70 years. We hypothesized that PR would be higher in the IND group and would be significantly related to physical function. Dependent variables were Continuous Scale Physical Functional Performance (CS-PFP) total score, and oxygen consumption during graded treadmill walking (VO_2peak), physical functional performance (VO_2PFP) and usual gait (VO_2gait). The primary outcome, PR, was determined from physical functional performance (PR-PFP) and usual gait (PR-Gait). After covariating for age, there was a significant difference ($p<0.05$) between groups for PR-PFP, CS-PFP total score, and VO_2peak; VO_2PFP and VO_2gait were not significantly different. PR was significantly related to physical function. Improving PR may improve physical function in marginally dependent older adults and provide independent older adults a larger margin of safety.

INDEX WORDS: Peak oxygen consumption, Usual gait, Activities of daily living, Aged, Energy expenditure, Portable metabolic system, Treadmill

PHYSICAL RESERVE: OXYGEN COST OF PHYSICAL FUNCTION

IN OLDER ADULTS

by

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TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

The ability to maintain independence into old age is contingent upon having the energy stores available to perform everyday tasks. Advancing age, sedentary lifestyle and disease are associated with a decrease in physiologic capacity. A decline in physiologic capacity may cause an individual to work at a higher percentage of their maximum capacity during daily activities (1). The concept of physical reserve has been used to describe this relationship between physiologic capacity and the energy requirements of daily living. Physical reserve, defined as physiologic capacity in excess of that required to perform everyday tasks, has yet to be quantified (2).

Physical function is defined as the ability to perform tasks required for independent living (2) through the integration of physiological capacity, physical performance capability, and psychosocial factors (3). Late-life living status may be characterized by an individual's level of functional ability. Lower physical function may be related to a loss in physical reserve caused by physical inactivity, chronic disease, acute illness or injury. As the energy costs of daily tasks represent a larger percentage of physiologic capacity, it is understandable why older adults may choose to, or are unable to, perform them.

In the absence of orthopedic impairments, the energetic costs of daily activities appear to be the same for older and younger adults; however older adults take longer to complete the tasks (4). Although the oxygen cost of individual activities has been widely reported (4-8), the oxygen cost for some activities is estimated rather than measured through indirect calorimetry. Recent studies have used portable metabolic systems in conjunction with accelerometers to directly measure the oxygen cost of daily activities (9-12). The oxygen costs usually reported are for individual tasks performed by younger and middle aged adults rather than those performed by older adults or tasks performed serially. Since everyday tasks are often performed one right after the other with minimal rest breaks in between, the measurement of the oxygen cost of serial tasks of independent living may more closely mimic everyday life.

Usual gait speed is a common, simple performance measure of mobility in older adults and is highly correlated with health status and functional ability (13-15). Guralnik et al. (16) suggested that a test of gait speed alone is as accurate a predictor of functional ability as a short physical performance battery. Usual gait speed tends to decline with age (13,17-19), however there is evidence that physiologic capacity (i.e. aerobic, strength), more than age, determines gait speed (13,20-22). Therefore, physical reserve may be a better determinant of usual gait speed and overall physical function.

The oxygen cost of usual gait speed is between 10.5 – 12.95 $ml \bullet kg^{-1} \bullet min^{-1}$ (17,19,23,24), regardless of age, gender and speed. Though older adults may walk slower at their usual walking pace, their energy expenditure relative to body weight is not significantly different from younger adults. However, their absolute energy expenditure and work intensity is higher. Waters et al. (23) found that older adults, age 60-80 years, use a greater percentage of their maximum aerobic capacity during usual gait (approximately 50% VO_{2max}) compared to younger adults (approximately 30% VO_{2max}), age 19-59 years.

An age related decline in maximal aerobic capacity, even in endurance trained individuals, has been shown in cross-sectional (25-31) and longitudinal studies (26,32,33). Older adults attempt to compensate for this physiologic decline that encroaches on their “margin of safety” (1), or physical reserve, by using accommodation strategies to lower the demand of daily activities (34). Once accommodation techniques are exhausted an individual is forced to eliminate tasks from their daily routine and rely on assistance from others.

Endurance training for 6-12 months can increase aerobic capacity 8-10%, even up to 30%, in older adults (13,35-38). An endurance training program could reverse the effects of nearly a decade of age-related loss in aerobic capacity, significantly improving physical reserve and, subsequently, physical function. Sustaining an adequate physiologic reserve may be a key factor in preserving an independent lifestyle in older adults.

Purpose of the Study

The purpose of this study is to determine physical reserve in independent, community dwelling older adults and marginally dependent older adults. For this study, physical reserve is defined as the difference between peak oxygen consumption and the oxygen cost of physical function. Once quantified, a secondary purpose is to determine the relationship between physical reserve and physical function.

Hypotheses

The research hypotheses for the study are:

1) Independent, community dwelling older adults will have significantly higher physical reserve than marginally dependent older adults.

2) Physical reserve will be significantly related to performance-based physical function.

Significance of the Study

Physical reserve is a concept that has been defined but not yet quantified. Previous research using older adults has measured components of physical reserve such as aerobic capacity and the oxygen cost of select daily activities, including usual gait. Measurement of the oxygen cost of serial tasks of independent living may more closely approximate the energy needs of everyday life than measurements of individual tasks that have been done previously. If physical reserve is related to physical function, then interventions to improve physical reserve may allow older adults to maintain their independence longer.

Limitations

The study is limited in the following ways:

1. Wearing the Cosmed K4b^2 mask may impose a visual impediment or feelings of claustrophobia for some subjects.
2. Results cannot be generalized beyond the primarily Caucasian sample that is tested.
3. Causal relationships cannot be established due to the cross-sectional design of the study.

Definition of Terms

For consistency of interpretation the following terms and abbreviations are defined.

<u>Terms</u>

Community Dwellers – older adults living in detached, single-family dwellings

Marginally Dependent – older adults living in assisted living or retirement communities, or community dwellers with SF36PF score < 85.

Peak Oxygen Consumption – The highest achieved oxygen uptake during a graded exercise test. (17,39)

Physical function – The ability to perform tasks required for independent living (2). The integration of physiological capacity and physical performance capability mediated by psychosocial factors (3)

Physical Reserve – Physiologic capacity in excess of that required to perform daily activities (2); a “margin of safety” (1)

Usual gait – Preferred walking pace (19); also called normal, comfortable walking pace (13)

<u>Abbreviations</u>

VO_{2peak} – Peak oxygen consumption

PR – Physical reserve

VO_{2PFP} – Average oxygen cost of fixed load physical functional performance

$VO_{2PFPhigh}$ – Highest oxygen cost of fixed load physical functional performance

VO_{2gait} – Oxygen cost of usual gait

RPE – Rating of Perceived Exertion

RER – Respiratory Exchange Ratio

SF36PF – Medical Outcomes Survey SF36 Physical Function Scale

CS-PFP – Continuous Scale Physical Functional Performance Test

CS-PFP total – average of 5 domains of the CS-PFP

UBS – Upper Body Strength Domain of the CS-PFP

LBS – Lower Body Strength Domain of the CS-PFP

UBF – Upper Body Flexibility Domain of the CS-PFP

BALC – Balance and Coordination Domain of the CS-PFP

END – Endurance Domain of the CS-PFP

CHAPTER II

REVIEW OF THE RELATED LITERATURE

The literature related to this investigation is reviewed in this chapter. The chapter begins with a description of physical reserve, its significance, and factors that affect it. Subsequently, the following topics are discussed: Physical function; usual gait; aerobic capacity and physical function; age related changes in aerobic capacity; training related changes in aerobic capacity and oxygen cost of physical function. Finally, a brief review of the measurement techniques used for physical function, aerobic capacity, the oxygen cost of physical function, and the oxygen cost of usual gait is presented.

Physical Reserve

Physical reserve (PR) is a concept used to describe the relationship between physiologic capacity and the energetic costs of everyday life. PR is defined as physiologic capacity in excess of that required to perform daily activities but it has yet to be quantified (2). Physical reserve can be thought of as a "margin of safety" that narrows as physiologic capacity approaches threshold values for functionally important activities (1).

Older adults use accommodation strategies to attenuate the physiological decline that encroaches on their margin of safety, or physical reserve (34). Individuals use task modification, such as living in less of their house or moving to a single level residence, altering their personal standards for completion of more difficult tasks (i.e. cleaning, yard work), or using assistive devices to reach into high places (40). Each of these effectively lowers the demand thereby preserving the margin of safety. Once options for accommodation are exhausted, an individual is forced to discontinue performance of tasks needed for independent living. Task modification may represent early functional changes since individuals who report these modification strategies have performance levels on mobility tasks intermediate to those who report no difficulty and those with frank disability in performing everyday tasks (34).

Inactivity accelerates the age-related loss of physical reserve by reducing maximum physiologic capacity. Acute injury or illness causes an even more rapid physiologic decline leading to frailty. Frailty is defined as loss of physical reserve that increases the risk of disability (41). When an individual's environmental demands exceed personal capabilities they become disabled (42). Many independent older adults are functioning dangerously close to their maximal capacity when performing normal everyday activities (43). These individuals may not be aware of how close they are to disability, because they have successfully employed accommodation techniques, which enable them to function independently, despite physiological impairments.

Physical Function

Physical function is defined as the ability to perform tasks required for independent living (2) through the integration of physiological capacity, physical performance capability, and psychosocial factors (3). Lower physical function may be related to a loss in physical reserve caused by physical inactivity, chronic disease, acute illness or injury. Late-life living status may be characterized by an individual's functional ability. Self-perceived physical function and performance based physical function can be measured in older adults.

Self-perceived physical function

The Medical Outcomes Study 36-Item Short Form Physical Function (SF36PF) scale is a valid and reliable tool for measuring self-perceived physical function in older adults (44,45). A SF36PF score of 80 out of 100 represents the 75th percentile for adults age 75 years and over (46). Cress et al. (3) found that dependent older adults scored less than 65 on the SF36PF while older adults living in a congregate care facility, without self-rated limitations, had an average score on the SF36PF = 85.5. This population may represent older adults who are on the "precipice" of dependency where an acute illness or injury could reduce physical reserve beyond what is required for independent living.

Performance-based physical function

Several performance based tests of physical function have been developed (3,43,47,48). For those with higher levels of fitness, these tests often have a ceiling effect, meaning a large percentage of these individuals attain the maximum score. Another problem is a lack of tests that measure whole body physical function in a way that closely mimics everyday life.

Continuous Scale Physical Functional Performance test

The Continuous Scale Physical Functional Performance (CS-PFP) test is a valid and reliable measure of physical function in older adults (3). The continuous scale minimizes the possibility of a ceiling effect by utilizing multiple metrics (e.g. time, distance, and weight) on 16 different tasks of independent living. The test yields a total physical function score and five physical domain scores: upper and lower body strength, upper body flexibility, balance and coordination, and endurance. The original CS-PFP was validated in 148 older men and women with a broad range of abilities from three different living status groups (community dweller, independent long-term care residents, and dependent long-term care residents). The CS-PFP was able to discriminate differences in physical function among these groups, demonstrating construct validity. High test-retest reliability was shown for the total CS-PFP score and all five physical domain scores (r = 0.85 - 0.97). The CS-PFP has the sensitivity to detect changes in physical function following training that would otherwise go undetected by other commonly used measures of physical function (35).

Usual Gait

Usual Gait Speed

Usual gait speed is a common performance measure that is easy to administer in a variety of settings. Guralnik et al. (16) suggested that a test of gait speed alone is as accurate a predictor of functional ability as a short, lower body, physical performance battery. Usual gait speed is highly correlated with health status as well as physiologic capacity measures (e.g. maximum aerobic capacity and strength) (13-15) but does appear to be influenced by level of dependence and depressive symptomatology (15). There is evidence to suggest that gait speed is more a reflection of health status than fitness (13,49).

Buchner et al. (13) found that changes in health status and depressive symptoms were significant independent predictors of changes in gait speed in community dwelling older adults, while changes in aerobic capacity and strength were not. They suggested that, at the higher performance levels of this population, the relationship between gait speed and fitness is curvilinear so that greater strength may partly compensate for losses in aerobic capacity, and vice versa. Therefore, a substantial change in fitness would be necessary to cause a clinically significant change in gait speed. In frail adults, the relationship between gait speed and physiologic capacity may be stronger, however it is also more likely that these individuals are older and have more co-morbidity. Physical reserve, which defines the maximum possible level of performance, may be a better determinant of usual gait speed and overall physical function.

Disability and Usual Gait Speed

Individuals living independently have a significantly faster usual gait speed compared to those living dependently (13-15). Cunningham et al. (14) investigated the determinants of independence in older adults and found that usual gait speed was the most significant independent variable, explaining 30.4% of the observed variance between adults living in the community or in supervised rest homes. Usual gait speed was measured over a 20-m indoor course following the command to “walk at a normal pace, neither fast nor slow” and with the subjects unaware they were being timed. The community dwellers walked significantly faster (females: 1.09 vs. 0.78 $m \bullet s^{-1}$; males: 1.25 vs. 0.85 $m \bullet s^{-1}$) and had greater step length and frequency despite no difference in heart rate between groups. The difference in gait speed, however, may have been related to the significant difference in age between groups, especially since older adults have more co-morbidity (50).

Judge et al. (15) analyzed results from six of the Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) trials and found that there was a consistent negative relationship between gait speed and instrumental activities of daily living (IADL) disability. Gait speed was also found to be the strongest independent predictor of self-perceived function across this diverse population of older adults (49).

<u>Age and Usual Gait Speed</u>

Usual gait speed tends to decline with age (13,17-19), however there is evidence that physiologic capacity (i.e. aerobic, strength), more than age, determines gait speed (13,20-22). In a study of healthy, Caucasian men (age 19-66 years), Cunningham et al. (22) found that usual walking pace was associated with maximal aerobic power, independent of age. Blessey et al. (24) also concluded that usual gait speed was independent of age for adults aged 20-60 years while Waters et al. (23) found a significantly slower usual gait speed in adults over 60 years old ($73\ m{\bullet}min^{-1} = 1.22\ m{\bullet}sec^{-1}$) compared to younger adults ($80\ m{\bullet}min^{-1} = 1.33\ m{\bullet}sec^{-1}$). Binder et al. (20) found that VO_2peak was a significant predictor of gait speed ($r = 0.44$, $p<0.001$) in a population of women over the age of 75. The relationship between age and usual gait speed after the sixth decade remains unclear partly because of the difficulty in determining the interaction between physiologic capacity, physical activity, and level of disability. It may be true that physiologic capacity mediated by physical activity level, more than age, is a significant factor in usual gait speed for older adults.

Aerobic Capacity and Physical Function

The ability to perform sustained work, as measured by maximum aerobic capacity, is one well-documented functional decline in older adults. Peak oxygen consumption (VO_2peak) has been shown to be an important factor in self-reported physical function and performance based physical function in older adults (20,51). VO_2peak was a significant independent predictor of performance on a standardized test of physical function (a modified Physical Performance Test) and gait speed (20).

The concept of a curvilinear relationship between aerobic capacity and measures of physical function has been modeled (2). A threshold is the point where even a small decline in aerobic capacity may compromise the performance of some everyday activities (1). The slope of this relationship above the threshold is less than the slope below the threshold (2).

An aerobic capacity threshold has not been clearly identified, perhaps due to differences in measures of physical function. Shephard (52) reported a maximum aerobic capacity of 13 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ as necessary for independent living. Morey et al. (51) found that individuals below a threshold value of 18 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ for VO_2peak reported significantly more difficulty in performing daily tasks. More women were below this threshold criterion. One possible explanation is that women do not attain as high a VO_2peak as men and therefore reach this threshold sooner.

Posner et al. (39) found VO_2peak to be an important predictor of self-reported ability to perform activities of independent living in mature women (mean age 69 years). For subjects whose VO_2peak was less than 1000 $ml{\bullet}min^{-1}$, there was a positive correlation between their ability to perform activities of daily living (ADL) and level of endurance. VO_2peak up to approximately 1000 $ml{\bullet}min^{-1}$ was linearly related to balance and gait scores.

Exercise interventions that can elevate aerobic capacity in older adults, or in those who are near the threshold, may increase capacity enough to provide a physical reserve. At this time it is unclear whether physical reserve has the same relationship to physical function as VO_2peak.

Age Related Changes in Aerobic Capacity

Numerous cross-sectional and longitudinal studies have shown that there is an age-related decline in maximum aerobic capacity (VO_2max). The rate of decline is estimated to be approximately 10% per decade in sedentary subjects (26,32). Although this decline has generally been described as linear, there is some evidence that VO_2max over the entire age range may be curvilinear (53). Active individuals may decline slowly as long as they maintain a regular exercise program, while sedentary individuals may decline at a more rapid rate (26).

Longitudinal Studies

Longitudinal studies examining the effects of age on maximum aerobic capacity have confirmed the age-related decline, although the rate of decline seems to vary from 0.04 to 1.43 $ml \bullet kg^{-1} \bullet min^{-1} \bullet year^{-1}$ (26). Dehn and Bruce (32) conducted a longitudinal study in which they re-tested 40 healthy men, ranging in age from 40-72 years, after 2.3 years. While their cross-sectional observations of 86 healthy men showed a mean rate of decline of 0.28 $ml \bullet kg^{-1} \bullet min^{-1} \bullet year^{-1}$, the mean annual decline of this subset was 0.94 $ml \bullet kg^{-1} \bullet min^{-1} \bullet year^{-1}$ and was 3.3 times greater in habitually inactive men vs. active men. Over a 6 year period, McClaran et al. (54) found a 1.9% per year reduction in VO_2max in healthy, active older adults (initial mean age = 67 years). A longitudinal study of physical education teachers from 1949 – 1970 found that VO_2max declined approximately 1% per year (25). Data from longitudinal studies confirm the age-related decline in aerobic capacity found in cross-sectional studies, however the variability in the results is likely due to differences in physical activity levels.

Influence of physical activity

Habitual physical activity has a significant impact on maximum aerobic capacity and its rate of decline. Longitudinal and cross-sectional studies in male endurance athletes have suggested that the decline in maximum aerobic capacity is attenuated so that, if physical activity level and body composition remain relatively constant, the decline in VO_2max is approximately 5% per decade (55,56). Ogawa et al. (31) compared sedentary and trained younger and older men and women. The older sedentary subjects had a 40-41% lower VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$) compared to a 25-32% lower VO_2max in trained individuals. In the older groups, the difference in VO_2max of sedentary controls was 75% and 59% for men and women, respectively. Rogers et al. (55) re-measured VO_2max in master endurance athletes and sedentary older men after an 8-year follow-up period. Master athletes had a 59% higher VO_2max ($ml \bullet kg^{-1} \bullet min^{-1}$) than sedentary controls initially and over the 8-year follow-up had a decline in VO_2max 50% less than that of the sedentary men (0.5% vs. 1.2% per year, respectively).

Kasch et al. conducted a 28-year and 33-year follow-up of habitual exercisers (initial mean age = 43 years) compared to men who had dropped out and remained sedentary for 21 years by age 69 years (33,57). Over the 33 years, the exercisers slightly increased their activity levels, from 2290 - 2550 kcal/week, and had no significant change in body weight. In the 28-year follow-up, exercisers had a 0.5% per year, or 0.23 $ml \bullet kg^{-1} \bullet min^{-1} \bullet year^{-1}$, loss in VO_2max with no change in body composition, while the sedentary controls lost 1.9% per year, or 0.70 $ml \bullet kg^{-1} \bullet min^{-1} \bullet year^{-1}$. The 33-year follow-up showed that the decline in maximal aerobic capacity in the exercisers was 0.58 – 0.68% per year (33), which indicates that the slope of decline may have slightly increased during this period when the mean age of the subjects was now at 76.1 years. They concluded that habitual exercise appears to attenuate the loss of VO_2max and that lack of exercise causes a greater loss with increasing age. These data suggest that roughly 50% of the decline in VO_2max with age is the result of physical inactivity and, therefore, is preventable.

Training Related Changes in Aerobic Capacity

Aerobic Capacity

Several recent studies have shown an increase in aerobic capacity following endurance training in older adults, with peripheral adaptations likely playing the largest role (36,38). Most studies prior to 1984 failed to observe substantial increases in VO_2max in older individuals, which was most likely due to inadequate training stimulus. Seals et al. (36) investigated the effects of 6 months of low intensity followed by high intensity endurance training for 6 months in older adults. The low intensity training elicited a 12% increase in VO_2max with an additional 18% increase after high intensity training, mediated primarily by an increase in maximal arteriovenous O_2 difference (36).

Meredith et al. (38) studied the effects of a 12 week endurance training program (cycling 3 times/week, 45 min/session, 70% of heart rate reserve) in elderly and young healthy men and women. The initial VO_2peak was lower in the elderly, however the absolute increase of 5.5 – 6.0 $ml \bullet kg^{-1} \bullet min^{-1}$ was similar in both groups following training. Peripheral adaptations, primarily the 128% increase in muscle oxidative capacity, were the most important factors in the elderly subjects (38). Spina et al. (58) conducted an endurance training study for 9-12 months in healthy men and women, age 60-69. Subjects exercised 45 min/day, 5 days/week at an initial exercise intensity of 60-70% of heart rate reserve. VO_2max increased 19% in males, mostly due to an increase in stroke volume and a small increase in O_2 extraction, while females had a 22% increase in VO_2max due solely to an increase in O_2 extraction. The same group was able to elicit a 24% improvement in VO_2max in healthy, sedentary men and women, age 60-71 years, following 9-12 months of endurance training at 80% of maximal heart rate (average 45 minutes/day, 3.9 days/week). There was no significant difference in relative improvement between genders (37).

Oxygen Cost of Physical Function

Oxygen Cost of Everyday Tasks

Measurements of the oxygen costs of everyday tasks including household chores, work-related tasks, personal care tasks, and recreational activities have been widely reported (4-8). While the oxygen cost of many tasks has been measured through indirect calorimetry, often the number of subjects is extremely small (4,6). These data have often been used to estimate the oxygen cost of similar activities (8,59). Recent studies have used portable metabolic systems in conjunction with accelerometers to directly measure the oxygen cost of daily activities (9-12).

The oxygen costs usually reported are for single tasks performed by younger and middle aged adults rather than those performed by older adults or tasks performed serially. A real life situation requires everyday tasks to be performed one right after the other with minimal rest breaks in between, therefore the measurement of the oxygen cost of serial tasks of independent living may more closely mimic everyday life. In the absence of orthopedic impairments, the energetic costs of daily activities appear to be the same for older and younger adults; however older adults take longer to complete the tasks (4).

Oxygen Cost of Usual Gait

Several determinations of the metabolic cost of usual gait have been reported (17,19,23,24) and normative data is widely available. However, the use of different test procedures and instruments has complicated the comparison of results. The average oxygen cost of usual gait is between 10.5 – 12.95 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ (17,19,23,24).

The oxygen cost of usual gait appears to be independent of age, gender, and speed. A U-shaped relationship between oxygen cost and speed of walking has been identified (19,60) which shows that as speed of walking deviates further from the most economical speed, that the aerobic demand per unit distance increases. Furthermore, there is evidence that an individual's usual gait speed is at or near his or her most economical speed (17).

Blessey et al. (24) measured oxygen uptake during usual gait in men and women ranging in age from 20-60 years. The rate of oxygen uptake was virtually the same for men and women (13.4 and 12.5 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$, respectively) as well as the relative oxygen cost (39.5% and 38.1% VO_2max, respectively). There were no significant differences when subjects were divided into age groups for mean values of oxygen uptake or heart rate although the percent of VO_2max required for usual gait was significantly greater in the older age groups (35.8% for age 20-29 vs. 43.1% for age 50-59).

Similarly, Pearce et al. (17) found that the oxygen cost of usual walking speed (1.33 $m{\bullet}s^{-1}$) was 10.58 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ for treadmill walking and 11.04 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ for floor walking in adults aged 55-66 years. Waters et al., (23) showed that younger and older adults had nearly identical oxygen consumption during usual gait (12.0 and 11.9

$ml \bullet kg^{-1} \bullet min^{-1}$, respectively) despite significant differences in usual gait speed (80 $m \bullet min^{-1}$ vs. 73 $m \bullet min^{-1}$, respectively). Consequently, though older and younger adults have the same oxygen cost during usual gait, older adults have a greater relative oxygen cost at approximately 50% VO_2max compared to approximately 30% for younger adults.

Measurement of Physical Function

Self-Perceived Physical Function

Self-perceived physical function can be measured using the Physical Function Scale of the Medical Outcomes Study 36-Item Short-Form Health Survey (SF36PF). In the 10-item questionnaire, scored on a scale from 0 to 100, an individual rates their ability to perform physical activities, from vigorous activities to bathing and/or dressing, as “Limited a little”, “Limited a lot” or “Not limited at all”. These functional limits must be attributable to their health over the previous 4 weeks.

Performance Based Physical Function

The Continuous Scale Physical Functional Performance Test (CS-PFP) is a battery of 16 everyday tasks that are quantified using distance, weight and/or time (3). Tasks quantified using both weight and time include: carrying a loaded pot, pouring water from a jug into a cup, carrying weight up and down a bus platform, and carrying groceries. Tasks quantified using time include: donning and removing a jacket, picking up four scarves from the floor, putting a Velcro® closed strap over the shoe, floor sweeping, transferring laundry from a washer and dryer, making a bed, vacuuming, getting down and up from the floor, opening a fire door, and climbing stairs. Tasks quantified by distance include highest vertical reach and a 6-minute walk. Participants are asked to perform each task as quickly as possible and to carry as much weight as they can within their own personal limits of safety and comfort. The test yields a score between 0 and 100 for total physical functional performance (CS-PFP total) and five physical domain scores that include upper body strength (UBS), lower body strength (LBS), upper body flexibility (UBF), balance and coordination (BALC) and endurance (END) (61).

Measurement of Aerobic Capacity

The criteria and protocol for attaining maximal aerobic capacity, as well as the use of a portable metabolic system for measuring oxygen consumption are discussed in this section.

Criteria for Attaining Maximum Aerobic Capacity

Maximum aerobic capacity is defined as the highest oxygen uptake an individual can attain during dynamic exercise involving a large part of the total body muscle mass (4,62). Criteria for maximal oxygen consumption (VO_2max) include: a plateau in VO_2 with increasing work rate (36,39,54,56,62-64); achievement of age-predicted maximal heart rate (220-age, ± 10 bpm) (28,58,63); a rating of perceived exertion of at least 18 (28,63), a respiratory exchange ratio of greater than 1.0 (27,35,38); and a blood lactate level 4 minutes after exercise of at least 8mM (36,63). In order to determine if an individual has achieved a maximum effort, researchers often use a combination of these criteria and base maximum aerobic capacity on achieving at least 2 of 3 chosen criteria. Few older subjects, except master athletes, show a plateau of oxygen consumption at maximal effort (38,39) therefore, empirically, few research projects actually utilize this criterion for older adults. In the absence of a leveling off in VO_2, the highest attainable oxygen consumption is often referred to as peak oxygen consumption (VO_2peak). Posner et al. (39) defined VO_2peak as the average of all breaths within a 20 second period surrounding the highest recorded VO_2 consumed during graded exercise.

Protocol for Assessing Maximum Aerobic Capacity

Graded treadmill exercise is commonly used to assess maximum aerobic capacity and yields results approximately 10% higher than cycle ergometry (62). Although protocols vary, generally a graded treadmill test (GXT) involves walking at a constant speed combined with a progressive increase in grade until volitional fatigue is reached. A continuous treadmill protocol that maintains a constant walking speed combined with a 2 – 2.5% increase in grade every 2 minutes is commonly used (20,65) with the test duration lasting, optimally, 8 to 12 minutes (28,62). Twelve-lead electrocardiograph (ECG), blood pressure and rating of perceived exertion (RPE) should be monitored throughout the test (62).

Portable Oxygen Analyzer

Traditionally, oxygen uptake has been measured through indirect calorimetry by collecting and analyzing expired air using the Douglas bag method or an integrated metabolic cart. In recent years, portable metabolic systems have been developed and validated which allow metabolic measurements to be made outside of the laboratory setting. One such portable system is the Cosmed $K4b^2$ (Cosmed S.r.l., Rome, Italy). This lightweight (550 grams), battery operated unit is self-contained and measures oxygen consumption (VO_2) and carbon dioxide production (VCO_2) on a breath-by-breath basis. The unit is also able to measure ventilation (V_E), fraction of expired oxygen (F_EO_2), fraction of expired carbon dioxide (F_ECO_2), temperature, and heart rate.

The manufacturer's guidelines (66) call for the Cosmed $K4b^2$ to be calibrated immediately before each test using a four step process. The protocol includes: 1) calibration with room air, 2) calibration with a reference gas of known composition (4.0% CO_2, 16.0% O_2), 3) delay calibration to compensate for the time lag in expiratory flow measurement and gas analysis, and 4) a turbine flowmeter calibration using a 3.0 L syringe (Cosmed S.r.l., Rome, Italy) to assure accurate volume measurements. Data can either be transmitted via telemetry to a Windows-based PC or stored in the portable unit's memory and downloaded directly to a PC following the test.

A validation study on the latest version of the $K4b^2$ showed that, compared to the Douglas bag method, the $K4b^2$ is accurate for the determination of VO_2, VCO_2, V_E and respiratory exchange ratio (RER) at rest and during work rates up to 200W on a cycle ergometer. Significant differences in F_EO_2 and F_ECO_2 were found due to the fact that the $K4B^2$ "delays" the analysis of expired air to account for the small deadspace of the facemask and flowmeter. This results in a similar V_E, but lower F_EO_2, and higher F_ECO_2 compared to the Douglas bag method. However, the volume of the deadspace is subtracted in the calculation of VO_2, so that VO_2 from the $K4b^2$ and Douglas bag method are virtually the same. Their findings suggest that the $K4b^2$ is a valid and reliable instrument for assessing the energy cost of activities outside the laboratory (67,68). Pilot data from our lab showed no significant difference in VO_2 between the $K4b^2$ and a standard metabolic cart (SensorMedics) during submaximal exercise up to 175W on a cycle ergometer.

Measurement of the Oxygen Cost of Physical Function

In the absence of orthopedic impairments, the energetic cost of daily activities is the same for older and younger adults, however older adults take longer to complete the tasks (4). Astrand et al. (4) found that workers (age 30-70 years) utilized the same percentage of maximum (approximately 40% VO_2max) during work related tasks, irrespective of maximal oxygen uptake. However, older workers kept a slower tempo than younger workers. The volume of work completed was not measured but it appears likely that if the older workers took longer to complete tasks that they accomplished less work than the younger workers. Didier et al. (7) found that the average oxygen cost of moving from a seated or supine position to standing was lower in older adults but generally, took longer to complete compared to younger adults. The authors suggested that, similar to usual gait speed, individuals might, through a learning process, find and utilize their most efficient speed and pattern of motion to optimize energy expenditure.

Some common household chores, such as making beds, mopping and doing laundry, require a VO_2 of up to 14 $ml \bullet kg^{-1} \bullet min^{-1}$ (4,6,8). Bassett et al. (9) used a portable metabolic system (Cosmed K4b^2) to measure the energy requirements of some common everyday activities. Participants completed an average of 4 tasks in one day. The oxygen consumption during each task was measured for 15 minutes and averaged during minutes 5-15 to determine the oxygen cost of the task. The oxygen cost of sweeping and mopping was 12.3 $ml \bullet kg^{-1} \bullet min^{-1}$, for doing laundry was 8.4 $ml \bullet kg^{-1} \bullet min^{-1}$, for slow walking (78$m \bullet min^{-1}$) was 12.1 $ml \bullet kg^{-1} \bullet min^{-1}$ and for walking while carrying a 15 pound box was 10.1 $ml \bullet kg^{-1} \bullet min^{-1}$.

Many tasks of independent living are fairly short (<3 minutes) in duration and therefore achieving a steady state of oxygen consumption is unlikely. The oxygen cost of everyday tasks completed serially is not known but could be expected to fall somewhat lower than the oxygen costs reported for similar individual tasks.

Measurement of the Oxygen Cost of Usual Gait

Measurement of usual gait speed

Usual gait speed is a global measure of health status and function (35). Usual gait speed has been measured over a variety of course lengths. In the FICSIT trials, gait speed was measured over a distance of 6-m up to 40-m with no turns (49). Himann et al. (18) used a 20-m indoor course while Cunningham et al. (22) used a 30-m indoor course and instructed subjects to "walk at a normal pace, neither fast nor slow", a modification of Bassey et al. (69). Waters et al. (23) and Blessey et al., (24) used a level outdoor track 60.5-m in circumference and asked subjects to walk at their customary walking speed.

Oxygen cost of usual gait

Oxygen consumption during usual gait has typically been measured during treadmill walking (19) or using the Douglas bag method (23,24). Pearce et al. (17) used the Douglas bag method during floor and treadmill walking to analyze oxygen consumption during usual gait. The weight of the Douglas bag equipment is 2.4kg which is believed to have a negligible effect on oxygen consumption (17,23,24). The use of a portable metabolic system to measure the oxygen cost of usual gait could offer greater flexibility, less subject burden, and similar accuracy.

CHAPTER III

PHYSICAL RESERVE: OXYGEN COST OF PHYSICAL FUNCTION IN OLDER ADULTS[1]

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Abstract

The purpose of this study was to assess physical reserve (PR); a concept defined as physiologic capacity in excess of that required to perform everyday tasks, that has yet to be quantified. In a cross-sectional design, adults ≥ 70 years were recruited from 2 living status groups, 15 independent community dwellers (IND, mean age = 73.4 ± 4 years) and 15 marginally dependent adults (MDEP, mean age = 78.7 ± 7 years; SF36PF<85 and/or assisted living residents). We hypothesized that the IND group would have higher PR compared to the MDEP group and that PR would be significantly related to physical function. Oxygen consumption was assessed using a portable metabolic system during graded treadmill walking (VO_2peak), a fixed load physical functional performance (VO_2PFP) test, and usual gait (VO_2gait). Physical function was assessed using the Continuous Scale Physical Functional Performance (CS-PFP) test. PR was determined for physical functional performance (PR-PFP) and usual gait (PR-Gait). A one way ANOVA indicated a significant difference ($p<0.05$) between the IND and MDEP groups for PR-PFP (14.8 ± 6 vs. 8.8 ± 3 $ml \bullet kg^{-1} \bullet min^{-1}$), PR-Gait (12.8 ± 6 vs. 7.1 ± 4 $ml \bullet kg^{-1} \bullet min^{-1}$), CS-PFP total score (60.3 ± 8 vs. 44.1 ± 11), VO_2peak (23.2± 7 vs. 16.6 ± 3 $ml \bullet kg^{-1} \bullet min^{-1}$), and usual gait speed (1.33 ± 0.13 vs. 1.05 ± 0.15 $m \bullet sec^{-1}$). All variables, except PR-Gait, remained significantly different after covariating for age. VO_2PFP and VO_2gait were not significantly different between groups. PR-PFP and PR-Gait were significantly related to CS-PFP total score ($r = 0.48$ and $r = 0.45$ respectively, $p<0.05$). These data indicate that those with higher PR have more functional ability. Improving PR may improve physical function in marginally dependent older adults and provide independent older adults with a larger margin of safety.

INDEX WORDS: **Peak oxygen consumption, Usual gait, Activities of daily living, Aged, Energy expenditure, Portable metabolic system, Treadmill**

Introduction

The ability to maintain independence into old age is contingent upon having the energy reserves available to perform everyday tasks. Advancing age, sedentary lifestyle and disease are associated with a decrease in physiologic capacity. A decline in physiologic capacity may cause an individual to work at a higher percentage of their maximum capacity during daily activities (1). The concept of physical reserve has been used to describe this relationship between physiologic capacity and the energy requirements of daily living. Physical reserve, defined as physiologic capacity in excess of that required to perform everyday tasks, has yet to be quantified (2).

An age related decline in maximal aerobic capacity, even in endurance trained individuals, has been shown in cross-sectional (3-9) and longitudinal studies (4,10,11). Older adults attempt to compensate for this physiologic decline that encroaches on their "margin of safety" (1), or physical reserve, by using accommodation strategies to lower the demand of daily activities (12). Once accommodation techniques are exhausted an individual is forced to eliminate tasks from their daily routine and rely on assistance from others.

Late-life living status may be characterized by an individual's level of functional ability. Physical function is defined as the ability to perform tasks required for independent living (2) through the integration of physiological capacity, physical performance capability, and psychosocial factors (13). Lower physical function may be related to a loss in physical reserve caused by physical inactivity, chronic disease, acute illness or injury. Many independent older adults are functioning dangerously close to their maximum capacity when performing everyday tasks so that any episodic loss of capacity can deplete physical reserve, leading to frailty.

In the absence of orthopedic impairments, the energetic cost of daily activities appears to be the same for older and younger adults, although older adults take longer to complete the tasks (14). However, the oxygen costs of individual tasks are almost exclusively reported for younger and middle aged adults (14-19) while the oxygen costs of most tasks performed by adults over the age of 70 and those performed serially are under-reported. Since everyday tasks are often performed one right after the other with minimal rest breaks in between, the measurement of the oxygen cost of serial tasks of independent living may more closely mimic everyday life.

While performance based physical function has been measured using a battery of individual tasks (13,20,21), the oxygen cost of these serially performed tasks has not been assessed. Usual gait speed is a global measure of health status and physical function that is easily conducted and requires minimal time and equipment (22-26). Normative data for usual gait speed (23,27-30) as well as the oxygen cost of usual gait (27,30-32) is widely available. While the oxygen cost of serial tasks would be expected to be higher than usual gait, a determination of physical reserve from usual gait and serial tasks would be expected to have the same directionality with independent older adults having a higher physical reserve.

The purpose of this study was to assess physical reserve in older adults and to determine the relationship between physical reserve and physical function. We hypothesized that independent community dwelling older adults (IND) would have significantly higher physical reserve than marginally dependent older adults (MDEP), and that physical reserve would be significantly related to performance based physical function.

Methods

Participants. Thirty men and women (aged 70-92 years) were recruited from the surrounding community and categorized into two groups: independent community dwellers (IND; n=15) living in detached single family residences and marginally dependent (MDEP; n=15) adults. MDEP participants scored less than 85 on the SF36 Physical Function (SF36PF) scale and/or were residents of an assisted living or retirement community. The IND group consisted of 11 females and 4 males and the MDEP group consisted of 13 females and 2 males who, within groups, were not significantly different from each other in age, height, weight, or SF36PF. Exclusion criteria for both groups included vigorous, aerobic exercise greater than 3 days per week, 30 minutes per session, uncontrolled cardiovascular disease or diabetes, cardiovascular intolerance to exercise, diseases with a variable course, recent bone fracture or joint replacement, severe osteopenia, severe hypertension, and severe psychiatric illness. Prior to testing, written physician clearance and participant consent were obtained as approved by the Institutional Review Board of the University of Georgia.

Design. In cross-sectional design, living status (IND and MDEP) was the independent variable and physical reserve (PR) was the primary outcome. Dependent variables included peak oxygen consumption (VO_2peak), Continuous Scale Physical Functional Performance (CS-PFP total) total score, oxygen consumption during fixed load physical functional performance (VO_2PFP) and oxygen consumption during usual gait (VO_2gait). Participants performed a graded treadmill test and tests of physical function and usual gait on three separate days. Physical reserve was calculated as follows:

PR-PFP = VO_2peak – VO_2PFP

PR-Gait = VO_2peak – VO_2gait

Performance Based Physical Function. The Continuous Scale Physical Functional Performance (CS-PFP) test is a valid and reliable measure of physical function in older adults (13). A detailed description of the CS-PFP tasks has been published elsewhere (13) and the procedures for administration and environmental requirements are available on the World Wide Web (http://www.coe.uga.edu/cs-pfp). The battery of sixteen serially performed tasks quantified using distance, weight and/or time include: carrying a loaded pot, pouring water from a jug into a cup, donning and removing a jacket, picking up four scarves from the floor, putting a Velcro® closed strap over the shoe, highest reach, floor sweeping, transferring laundry from a washer and dryer, making a bed, vacuuming, getting down and up from the floor, opening a fire door, climbing stairs, carrying weight up and down a bus platform, carrying groceries and a 6-minute walk. The test yields a score between 0 and 100 for total physical functional performance (CS-PFP total) and five physical domain scores that include upper body strength (22), lower body strength (LBS), upper body flexibility (UBF), balance and coordination (BALC) and endurance (END).

Peak Oxygen Consumption (VO_2peak). VO_2peak was assessed using a continuous, incremental treadmill protocol established by Binder et al. (33). During a 2-minute warm-up, the fastest, comfortable walking speed was determined and was maintained throughout the test while elevation was increased 2-3% every 2 minutes. A cardiologist continually monitored a 12-lead Quinton 4000 (34) electrocardiogram and heart rate, blood pressure and ratings of perceived exertion, using the Borg scale (6-20 scale) (35), were recorded at the end of each stage. Participants were verbally encouraged throughout the test. The test was terminated when the participant reached volitional fatigue or showed signs of cardiovascular incompetence according to American College of Sports Medicine guidelines (36).

Continuous breath-by-breath analysis of ventilation, carbon dioxide production and oxygen consumption was monitored via indirect calorimetry using the Cosmed $K4b^2$ portable metabolic system (Cosmed S.r.l., Rome, Italy). The Cosmed $K4b^2$ is a valid instrument for measuring oxygen consumption, carbon dioxide production, ventilation and heart rate, at rest and at workloads up to 200W, when compared to the Douglas bag method (37,38). The Cosmed $K4b^2$ was calibrated immediately before each test according to the manufacturer's guidelines (39). This four step process consisted of room air calibration, calibration with a reference gas of known composition (4.0% CO_2, 16.0% O_2), delay calibration to compensate for the time lag in expiratory flow measurement and gas analysis, and a turbine calibration to assure accurate volume measurements by the flowmeter using a 3.0 L syringe (Cosmed S.r.l., Rome, Italy). Data collected during the test was stored directly in the Cosmed $K4b^2$ and downloaded to a desktop computer upon completion of the test.

VO_2peak was defined as the maximal attained oxygen uptake during the treadmill test, calculated as the average of all breaths during the last 30-second period of a stage. The following are used as criteria for maximal effort: (a) maximum achieved heart rate (Max HR) within 10 beats/minute of age-predicted maximum heart rate (6,40,41), (b) respiratory exchange ratio (RER) > 1.0 (5,23,42), or (c) rating of perceived exertion (RPE) of at least 18 on the Borg 6-20 scale (6).

Oxygen Cost of Fixed Load Physical Functional Performance (VO_2PFP). Participants performed a modified version of the CS-PFP while wearing the Cosmed $K4b^2$ to measure oxygen consumption. To equate the workload a fixed weight was carried by all participants during the three tasks that required a load to be carried (transferring a loaded pot from one counter to another, carrying luggage on to a bus platform and carrying groceries). The weight designated for each task corresponded to the 25th percentile of the weight chosen by older adults (13). Since the Cosmed is worn on the torso, donning a jacket was eliminated and the 6-minute walk was not performed for logistical reasons. Collection and analyses of gas volumes and composition were carried out using the same procedures previously described for the VO_2peak test. To determine the highest oxygen cost of everyday tasks, the highest average of all breaths in a 30-second period during the fixed load CS-PFP (VO_2PFPhigh) was calculated. The average oxygen cost during the fixed load CS-PFP (VO_2PFP) was determined by the average oxygen cost of all breaths over the entire test.

Oxygen Cost of Usual Gait (VO_2gait). Participants walked a comfortable walking speed for a minimum of 3 minutes during which oxygen consumption was measured using the Cosmed $K4b^2$. VO_2gait was considered the average of all breaths during the last 30 meters; usual gait speed was recorded as $m \bullet sec^{-1}$.

Statistical Analysis. Statistical analyses were performed using SPSS for Windows (Version 10, SPSS Inc., Chicago, IL). A one-way analysis of variance (ANOVA) was used to determine significant differences in PR-PFP, PR-Gait, VO_2peak, usual gait speed,

VO_2gait, VO_2PFP, and VO_2PFPhigh between groups. Pearson's correlation was used to determine the relationship between physical reserve and physical function. Using age as a covariate, a one-way analysis of covariance (ANCOVA) was also performed. A univariate analysis of variance was used to determine significant differences between gender. Statistical significance was set at $p < 0.05$ for all analyses.

Results

Forty-four older men and women were recruited from the Athens, Georgia area. Of the 44 recruited and screened, 7 were not medically cleared and 7 chose not to participate for personal reasons. The final sample of 30 volunteers (24 females, 6 males) represents 68% of the original sample. Testing was completed in a three-day period.

Participant characteristics are listed in Table 1. There was a significant difference in age between the IND and MDEP ($p = 0.02$) groups. Body weight and height were similar for both groups. There were no significant differences in age, height, weight, and SF36PF between males and females by group, therefore data for all participants was analyzed by group and not separated by gender. SF36PF scores, used for categorizing the participants into groups, were significantly higher in the IND group compared to the MDEP group ($p<0.001$). No interactions were detected using the one-way ANCOVA, with age as the covariate, with the exception of PR-Gait. Therefore all data reported are actual means, rather than age-adjusted, unless noted.

The one-way ANOVA indicated that the groups were significantly different for VO_2peak ($p = 0.002$), maximum achieved heart rate ($p = 0.002$), and percent of predicted maximum heart rate achieved ($p = 0.008$) as shown in Table 2. After controlling for performance degrading medications (i.e. beta-blockers, anti-depressants), the significant group differences for VO_2peak ($p = 0.005$) and maximum achieved heart rate ($p = 0.02$) remained, however there was no significant group difference in the percent of predicted maximum heart rate achieved (103.5 ± 10 vs. 95.9 ± 14 %; $p = 0.13$). RER ($p = 0.19$) and RPE ($p = 0.62$) at VO_2peak were not different between groups. Ninety-three percent of all participants met at least one of the three criteria for VO_2peak and 83% of all participants met at least two of the criteria.

During the fixed load physical functional performance test, the groups did not differ significantly in VO_2PFP (8.4 ± 1.4 and 7.8 ± 1.3 $ml \bullet kg^{-1} \bullet min^{-1}$ for IND and MDEP respectively) or VO_2PFPhigh (15.4 ± 3.3 and 13.7 ± 2.6 $ml \bullet kg^{-1} \bullet min^{-1}$ for IND and MDEP respectively). However, VO_2PFP represented a significantly higher percentage of VO_2peak in the MDEP group (48.3 ± 10.4%) than the IND group (38.2 ± 7.8%) as did VO_2PFPhigh (84.7 ± 18.5% vs. 69.3 ± 15.8% VO_2peak, respectively). Three of the MDEP participants elicited a VO_2PFPhigh that was at or above their VO_2peak, while no subject surpassed Max HR during the fixed load physical functional performance test. Usual gait speed was 21% ($p < 0.001$) faster in the IND group (1.33 ± 0.13 $m \bullet sec^{-1}$) compared to the MDEP group (1.05 ± 0.15 $m \bullet sec^{-1}$); however VO_2gait was similar (10.4 ± 1.9 and 9.5 ± 2.2 $ml \bullet kg^{-1} \bullet min^{-1}$; $p = 0.23$). VO_2gait also represented a larger percentage of VO_2peak in the MDEP group compared to the IND group (58.9 ± 14.8 and 47.6 ± 13.5 %VO_2peak, respectively).

Physical function (CS-PFP total) was significantly higher in the IND group ($p<0.001$) as shown in Figure 1. Of the five CS-PFP domains, upper and lower body strength, endurance, and balance and coordination domain scores were significantly higher in the IND group, while the upper body flexibility domain was similar. The significance between groups did not change after correcting for the advanced age of the MDEP group (CS-PFP total; $F = 11.56$, $p = 0.002$). The IND group completed tasks 25% faster than the MDEP group (666.5 ± 37 vs. 766.1 ± 112 sec; $p = 0.003$).

PR-PFP and PR-Gait were significantly higher for the IND group (14.8 ± 6 and 12.8 ± 6 $ml \bullet kg^{-1} \bullet min^{-1}$, respectively; $p<0.01$) compared to the MDEP group (8.8 ± 3 and 7.1 ± 4 $ml \bullet kg^{-1} \bullet min^{-1}$, respectively; $p<0.01$). After correcting for age, PR-PFP remained significantly different between groups but PR-Gait did not. Age-adjusted means are presented in Figure 2.

Pearson's correlation revealed a significant relationship between physical function and physical reserve (Table 3). CS-PFP total score was significantly related to PR-PFP ($r = 0.51$, $p<0.01$) and PR-Gait ($r = 0.47$, $p<0.01$). PR-PFP and PR-Gait were also significantly related to the lower body strength domain, the endurance domain, and balance and coordination domain of the CS-PFP.

Discussion

The results of this study indicate that IND adults have significantly higher physical reserve and higher physical function than MDEP adults and that there is a significant, positive relationship between physical reserve and physical function. The oxygen cost of physical function was similar in both groups; therefore the difference in PR between groups would appear to be due to a higher VO_2peak in the IND group. However, accommodation techniques employed by the MDEP group may have effectively lowered the demand of individual tasks

Individuals who scored less than 85 on the SF36PF were categorized as marginally dependent. The most commonly reported limitations were in vigorous activities, bending, kneeling and stooping, climbing several flights of stairs and walking more than a mile. Older adults living without self-rated limitations but in a congregate care facility had an average score on the SF36PF = 85.5, whereas residents who score themselves as more functionally limited (SF36PF < 65) have lower CS-PFP total scores than our MDEP group (22 vs. 44) and lower VO_2peak (12.4 vs. 16.6 $ml \bullet kg^{-1} \bullet min^{-1}$) (13). A SF36PF score = 80 represents the 75th percentile for adults age 75 years and over (43). We reasoned that the MDEP group in this study, while not severely limited, were reporting some limitation and were therefore marginally dependent.

PR-PFP and VO_2peak were significantly higher for the IND group compared to the MDEP group after adjusting for age. However, PR-Gait did not reach significance after adjusting for the advanced age of the MDEP group. This could be due to a number of factors including: after adjusting for age, the difference in VO_2peak between groups was smaller; usual gait is highly related to health status in older adults, which is also highly related to age; and, unlike during usual gait, participants did not reach a steady state during the fixed load physical functional performance test. Since physical functional performance is more related to fitness than health status in robust older adults, it may be a better measure for calculating physical reserve.

The difference in PR between groups was primarily due to the difference in VO_2peak since VO_2PFP and VO_2gait were not significantly different. However, it is likely that older adults with low VO_2peak use accommodation techniques to lower the demand of daily tasks, thereby reducing VO_2PFP. Shephard (44) has identified a maximum aerobic capacity necessary for independent living of 13 $ml \bullet kg^{-1} \bullet min^{-1}$, however older adults with VO_2peak lower than this threshold are still able to complete daily tasks. Therefore, the possibility of preserving physical reserve by lowering the demand through modification of tasks, increased social support, modifications to the environment or use of assistive devices is likely a common strategy for older adults to prolong independence.

Despite the similarity between groups in VO_2PFP and VO_2gait values, the IND group completed the CS-PFP tasks 25% faster than the MDEP group and had a 21% faster usual gait speed. These findings are similar to those of Cress et al. (13) in which independent older adults completed the tasks 25% faster than dependent older adults during the CS-PFP. If time to complete the tasks had been fixed along with the workload, the MDEP group likely would have had a higher VO_2PFP than the IND group. We hypothesized that VO_2PFP would be higher than VO_2gait, however, perhaps due to the fact that subjects did not reach a steady state in most tasks, lower VO_2PFP values were observed. VO_2PFP and VO_2gait represented a significantly higher percentage of VO_2peak in the MDEP group compared to the IND group. While VO_2PFP and VO_2gait represented approximately 40% and 50% of VO_2peak in the IND group, the MDEP group completed these tasks at a significantly higher relative oxygen cost (approximately 50% and 60% of VO_2peak, respectively). Waters et al. (27) found VO_2gait, while not significantly different between age groups, represented nearly 50% of maximum aerobic capacity in older adults compared to approximately 30% in younger adults.

The average oxygen cost of usual gait is between 10.5 – 12.95 $ml \bullet kg^{-1} \bullet min^{-1}$, independent of age, gender, and speed (31). The use of different test procedures and instruments has complicated the comparison of results. VO_2gait in our participants was slightly lower than these values despite similar usual gait speeds as those reported in these studies. We assumed that a 3 minute walk would elicit a steady state of oxygen consumption, however it is possible that the oxygen consumption had not yet reached a plateau, giving us lower measures of VO_2gait than previously reported. Usual gait in independent adults over the age of 70 years ranges from 1.2 -1.4 $m \bullet sec^{-1}$. The MDEP group had a slower usual gait speed than that reported for independent adults but higher than that of dependent older adults.

Two previous studies measured both VO_2gait and maximum aerobic capacity (VO_2max), which makes a calculation for PR-Gait possible using their mean data. Blessey et al. (30) measured VO_2gait in adults less than 60 years of age over a 60.5-meter indoor course. VO_2max in the oldest quartile (50-59 years) was 31.8 $ml \bullet kg^{-1} \bullet min^{-1}$ in females and 29.6 $ml \bullet kg^{-1} \bullet min^{-1}$ in males, while VO_2gait was similar at 12.7 $ml \bullet kg^{-1} \bullet min^{-1}$. This yields a PR-Gait of 19.1 $ml \bullet kg^{-1} \bullet min^{-1}$ in females and 16.9 $ml \bullet kg^{-1} \bullet min^{-1}$ in males. Pearce et al. (32) measured VO_2gait on the floor and on a treadmill in men aged 55-66 years. VO_2max was 33 $ml \bullet kg^{-1} \bullet min^{-1}$ and VO_2gait on the floor was 11.0 $ml \bullet kg^{-1} \bullet min^{-1}$, which yields a PR-Gait of 21.94 $ml \bullet kg^{-1} \bullet min^{-1}$. Since VO_2gait was similar, the differences in PR-Gait between these participants, and compared to our participants, can be accounted for by the higher VO_2max. The participants in these studies were significantly younger and may have been more fit, which likely accounts for the higher maximum aerobic capacity and higher PR-Gait than in our sample.

VO_2PFP was somewhat lower than oxygen cost values reported for individual tasks of daily living. Individual household chores are reported to have an oxygen cost between 8 – 18 $ml \bullet kg^{-1} \bullet min^{-1}$ (15). The average VO_2PFPhigh was less than 16 $ml \bullet kg^{-1} \bullet min^{-1}$, however the range of VO_2 during the fixed load physical functional performance test was between 4 – 23 ml•kg^{-1}•min^{-1} in our participants. The fact that some daily activities require significant contribution from upper and lower body musculature over brief periods of time may explain why three MDEP participants elicited supramaximal values for VO_2PFPhigh during the fixed load CS-PFP.

The concept of threshold values of physiologic capabilities is an important consideration when discussing independence vs. disability in older adults. The age-related decline in aerobic capacity, shown in cross-sectional (3) and longitudinal studies (10), moves an older adult perilously close to the point where any further decline may render some everyday activities impossible (1). Buchner et al. (45) proposed a curvilinear relationship between physical function (i.e. gait speed) and measures of physiological capabilities (i.e. aerobic capacity) similar to Figure 3. The ability of interventions to improve physical reserve depends on where an individual is on this curve. An IND adult who improves their physical reserve will move further away from the “precipice” (Figure 3) without significantly altering their performance in everyday tasks. While a MDEP adult who improves physical reserve may have a substantial increase in physical function.

While exercise interventions can potentially improve physical reserve, reducing daily task demand would also increase physical reserve and potentially improve quality of life. Increasing capacity when a person is already challenged by the demand of daily life may be harder than increasing reserve in a person who has some energy left over after daily tasks are completed. Future studies are needed to measure the effect of training on physical reserve in independent and marginally dependent older adults. Longitudinal follow-up would provide a better understanding as to how maintaining physical reserve can protect against an episodic loss of capacity due to illness or injury.

This study has some limitations. The Cosmed $K4b^2$ mask (Hans Rudolf, Inc., Kansas City, MO) may have been a visual impediment for certain tasks (i.e. sweeping, descending stairs) and some participants may have had feelings of claustrophobia or excessive heat build-up. Since all participants wore the same apparatus, these effects would presumable affect only overall sample results and not affect results between groups. The results of the study cannot be generalized beyond the mostly female, Caucasian sample tested and causal relationships cannot be established due to the cross-sectional nature of the study.

The results of this study indicate that there is a significant positive relationship between physical reserve and physical function. Physical reserve and physical function are significantly higher in independent older adults compared to marginally dependent older adults. While the oxygen cost of physical function appears to be the same, independent older adults complete tasks faster than marginally dependent older adults and at a lower relative oxygen cost. Marginally dependent adults may employ accommodation strategies to preserve physical reserve in an attempt to maintain independence. Maintaining an adequate physical reserve may be a key factor in preserving quality of life and disability free years in older adults.

Table 1. Participant characteristics

	IND (n = 15)	MDEP (n = 15)
Age (years)	73.4 ± 4	78.7 ± 7 *
Height (27)	162.9 ± 9	164.4 ± 11
Weight (kg)	70.9 ± 9	70.0 ± 13
SF36PF score	91.3 ± 5	72.3 ± 15 *

Table 1. Participant characteristics. Values are mean ± SD. * = Significantly different from IND ($p<0.02$), IND = Independent, MDEP = marginally dependent.

Table 2. Results of graded treadmill test

	IND (n = 15)	MDEP (n = 15)
VO_2peak (ml•min^{-1})	1630.3 ± 490	1158.5 ± 313*
VO_2peak (ml•kg^{-1}•min^{-1})	23.19 ± 6.8	16.57 ± 3.3*
Max HR (beats•min^{-1})	152.6 ± 18	128.6 ± 22*
% Pred. Max HR	103.9 ± 10	90.9 ± 15
RER	1.03 ± 0.1	1.00 ± 0.1
RPE	18.9 ± 1	18.3 ± 1

Table 2. Results of graded treadmill test. Values are mean ± SD. * = Significantly different from IND ($p<0.05$), VO_2peak, Peak oxygen consumption; Max HR; Maximum achieved heart rate; % Pred. Max HR = percent of predicted maximum heart rate achieved (includes participants on medication); RER, respiratory exchange ratio; RPE, rating of perceived exertion

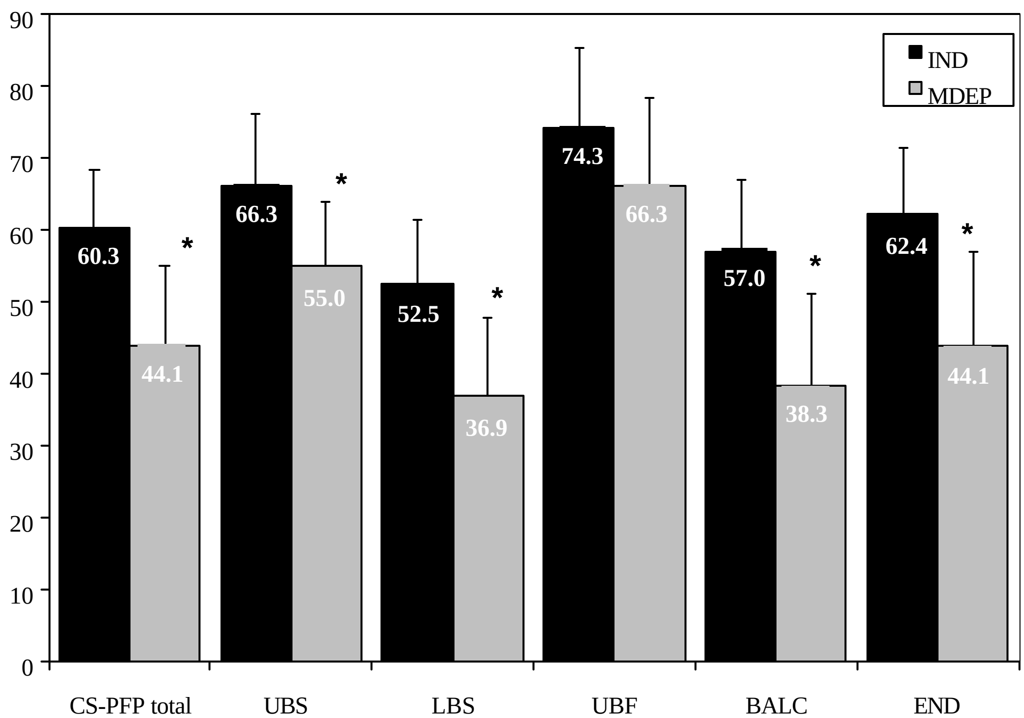

Figure 1. Continuous Scale Physical Functional Performance (CS-PFP) scores expressed as mean ± SD. * Significantly different from IND ($p<0.005$). UBS = Upper body strength domain; LBS = Lower body strength domain; UBF = Upper body flexibility domain; BALC = Balance and Coordination domain; END = Endurance domain

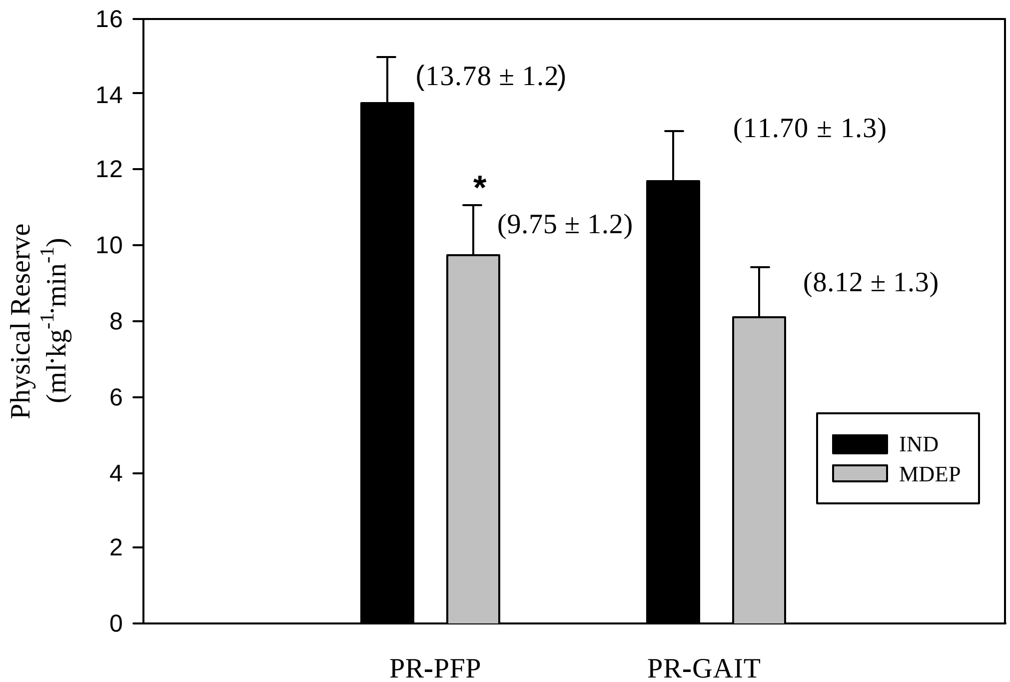

Figure 2. Primary outcome: Physical reserve (ml•kg^{-1}•min^{-1}) for Independent (IND) and Marginally Dependent (MDEP) expressed as age-adjusted mean ± SD. PR-PFP = Physical reserve from physical functional performance (p = 0.03), PR-gait = physical reserve from usual gait (p = 0.07).

Table 3. Correlation coefficients

	CS-PFP tot	PR-PFP	PR-Gait	VO_2peak	Usual gait	SF36PF
CS-PFP tot	1.00	0.51*	0.47*	0.52*	0.60*	0.53*
PR-PFP		1.00	0.97*	0.98*	0.61*	0.63*
PR-Gait			1.00	0.94*	0.55*	0.56*
VO_2peak				1.00	0.61*	0.62*
Usual gait					1.00	0.51*
SF36PF						1.00

Table 3. Correlation coefficients. * Significant correlation p<0.01. CS-PFP tot = Continuous Scale Physical Functional Performance total score, PR-PFP = Physical reserve for physical functional performance, PR-Gait = Physical reserve for usual gait, SF36PF = SF36 Physical Function Scale.

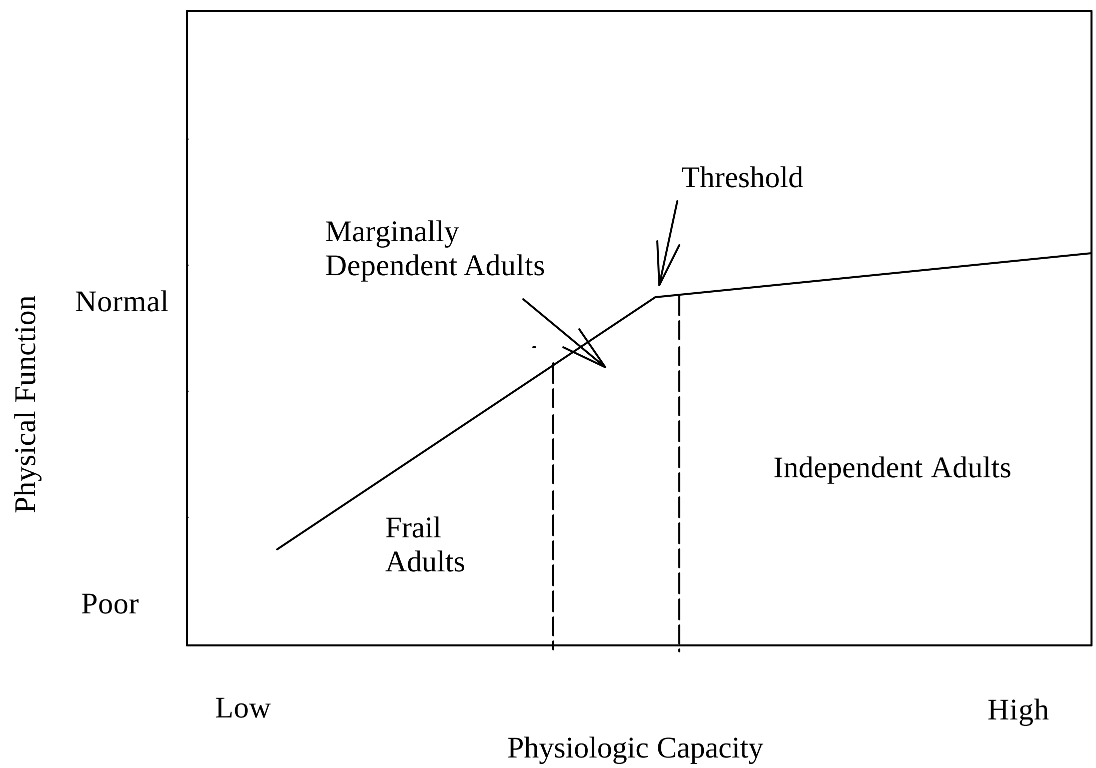

Figure 3. Relationship between physiologic capacity and physical function. The curvilinear relationship shows a threshold effect: above the threshold, function is normal; below the threshold, function is impaired.
Adapted from Buchner et al. (1992).

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CHAPTER IV

SUMMARY AND CONCLUSIONS

Determining the factors that contribute to independence in older adults is an important consideration in light of our aging population. The ability to maintain physical function and an independent lifestyle into old age is contingent upon having the energy stores available to perform everyday tasks. Physical reserve is defined as physiologic capacity in excess of that required to perform every day tasks. Advancing age, sedentary lifestyle and disease are associated with decreases in physiological capabilities. Older adults attempt to compensate for this physiologic decline that encroaches on their "margin of safety", or physical reserve, by using accommodation strategies to lower the demand of daily activities. Once accommodation techniques are exhausted an individual is forced to discontinue performance of tasks of independent living and rely on assistance from others.

Some researchers have proposed a curvilinear relationship between physical function and physiologic capabilities, showing a threshold effect, which implies that the impact of interventions depend on an individual's position on the curve. As physiologic capacity declines older adults may find themselves perilously close to the threshold, or precipice, where any episodic loss could deplete physical reserve leading to frailty. An individual functioning above the threshold can benefit from interventions to improve physiologic capacity by increasing physical reserve thereby providing a buffer against future illness or injury. If an individual's physiological capacity is near or below the minimal level needed to function independently then modest gains in physiological capacity combined with accommodation strategies may yield clinically significant changes in physical function.

In the present study we quantified physical reserve in independent and marginally dependent older adults, by measuring the difference between peak oxygen consumption and the oxygen cost of physical function, and identified the relationship between physical reserve and physical function. These data indicate that physical function is significantly related to physical reserve with independent participants having higher physical reserve and higher physical function. Although the independent and marginally dependent groups had similar oxygen costs during fixed load physical functional performance and usual gait, the marginally dependent group worked slower and at a higher percentage of their peak oxygen consumption during these tasks.

An endurance training program could reverse the effects of nearly a decade of age-related loss in aerobic capacity, significantly improving physical reserve and, subsequently, physical function. For marginally dependent older adults, interventions that lower the demand of daily activities may provide them with enough physical reserve to allow them to live more independently. Sustaining an adequate physical reserve may be a key factor in enhancing quality of life and increasing disability free years in older adults.

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APPENDIX A

RAW DATA

Participant Characteristics								Graded Treadmill Test									
Subject #	Gender	Group	Age	SF 36 PF	# of Meds	Weight (kg)	Height (27)	VO_2 peak (ml/min)	VO_2 peak (ml/kg/min)	Max HR (bpm)	% of Pred. Max HR	Max RPE	Max RER	Max Speed (74)	Max Speed (74)	Max Grade (%)
119	Female	IND	70	90	0	84.0	147.0	1949	23.21	175	116.0	19	0.99	2.8	2.8	10.0
120	Female	IND	77	95	0	60.9	167.0	1613	26.48	146	102.0	18	0.81	3.0	3.0	13.0
302	Female	IND	70	100	0	60.0	161.5	2056	34.27	156	104.0	15	0.82	4.0	4.0	19.0
303	Female	IND	70	90	0	83.9	169.5	2042	24.37	169	112.5	19	1.00	3.4	3.4	15.0
306	Female	IND	77	90	0	63.2	154.5	1014	16.10	138	96.5	20	1.12	2.4	2.4	12.0
309	Female	IND	80	85	0	76.4	153.4	1184	15.58	134	96.0	20	1.11	2.4	2.4	11.0
316	Female	IND	78	85	0	70.0	154.5	1590	23.04	137	96.5	19	0.89	2.4	2.4	14.0
322	Female	IND	70	95	0	58.0	165.5	1883	32.47	165	110.0	19	1.13	3.8	3.8	15.0
323	Female	IND	72	85	0	77.3	173.0	1321	17.16	133	90.0	20	1.07	2.0	2.0	14.0
324	Female	IND	70	90	0	67.5	176.5	1392	20.78	162	108.0	19	0.96	2.5	2.5	10.0
325	Female	IND	70	90	0	76.8	163.0	1310	17.02	186	124.0	20	1.19	2.0	2.0	16.0
327	Male	IND	70	95	0	76.5	174.5	2479	32.62	161	107.0	18	0.99	3.5	3.5	16.0
328	Male	IND	74	100	1	80.5	165.4	2436	30.45	159	109.0	19	1.10	3.0	3.0	13.5
329	Female	IND	79	90	0	64.6	161.5	1273	19.89	125	89.0	19	1.10	3.2	3.2	11.0
330	Female	IND	74	90	0	63.4	157.0	912	14.48	143	97.3	19	1.11	3.0	3.0	6.0
217	Female	MDEP	73	75	0	86.5	162.0	1156	13.44	109	74.1	19	1.03	1.4	1.4	4.5
222	Female	MDEP	75	95	1	75.5	162.5	1412	18.83	143	98.5	19	1.07	2.8	2.8	7.0
226	Female	MDEP	89	90	0	59.5	147.5	916	15.52	121	92.0	20	1.04	2.2	2.2	10.0
307	Female	MDEP	71	75	1	60.5	167.0	1398	23.30	160	107.0	19	0.97	2.5	2.5	12.0
313	Female	MDEP	90	65	1	58.0	155.0	1030	17.75	101	78.0	17	1.02	2.3	2.3	8.0
317	Female	MDEP	76	75	0	58.4	160.0	1138	19.30	143	99.0	19	0.87	2.5	2.5	10.0
319	Female	MDEP	86	40	0	72.0	168.0	1068	14.83	141	105.0	18	0.89	2.0	2.0	6.0
326	Male	MDEP	73	75	1	63.6	177.0	1187	18.55	121	82.3	20	1.02	2.2	2.2	7.0
331	Female	MDEP	76	45	1	49.3	152.5	736	15.03	95	66.0	17	0.99	1.8	1.8	12.0
333	Female	MDEP	76	70	0	64.3	159.5	787	12.29	129	89.0	17	0.84	2.0	2.0	4.0
334	Male	MDEP	75	80	0	88.0	179.0	1550	17.61	112	77.2	19	0.99	1.8	1.8	15.0
336	Female	MDEP	76	80	1	81.8	164.0	1474	17.97	115	80.0	18	1.16	1.7	1.7	16.0
337	Male	MDEP	80	80	0	89.8	189.5	1725	19.16	166	118.6	16	1.12	1.7	1.7	19.0
338	Female	MDEP	73	80	0	77.3	157.0	1166	15.14	154	104.0	19	0.98	2.4	2.4	9.5
340	Male	MDEP	92	60	0	65.0	165.0	634	9.76	119	93.0	17	1.11	1.2	1.2	5.0

Usual Gait						Oxygen Cost of Physical Functional Performance				
Subject #	VO_2 gait (ml/min)	% VO_2 peak (ml/min)	VO_2 gait (ml/kg/min)	% VO_2 peak (ml/kg/min)	Usual Gait spd (m/sec)	VO_2 PFP (ml/min)	VO_2 PFP (ml/kg/min)	%VO_2 peak (ml/min)	VO_2 PFP high (ml/min)	%VO_2 peak (ml/kg/min)
119	826.5	42.0	9.84	42.4	1.55	761.5	9.06	73.5	1446.2	39.0
120	725.6	41.9	12.19	46.0	1.41	654.9	11.04	80.3	1391.3	41.7
302	589.1	28.2	9.82	28.7	1.50	578.7	9.45	48.4	1012.5	27.6
303	808.7	37.2	9.64	39.6	1.29	755.6	8.76	57.1	1243.1	36.0
306	812.4	79.2	12.90	80.1	1.30	495.5	7.87	78.5	805.0	48.9
309	768.3	64.0	10.11	64.9	1.16	589.3	7.75	97.7	1171.9	49.7
316	695.5	42.4	9.91	43.0	1.30	490.8	7.35	56.5	925.9	31.9
322	584.6	30.4	10.07	31.0	1.46	393.3	7.49	37.6	724.1	23.1
323	746.3	56.4	9.69	56.5	1.24	631.7	8.19	85.9	1136.0	47.7
324	856.6	60.0	12.60	60.6	1.52	566.5	8.33	81.0	1156.3	40.1
325	707.3	52.3	9.19	54.0	1.18	516.9	6.71	65.7	888.5	39.4
327	943.8	37.5	12.40	38.0	1.23	747.8	9.83	61.0	1537.4	30.1
328	1044.2	42.6	13.05	42.9	1.29	838.7	10.48	58.1	1424.0	34.4
329	618.8	46.8	8.76	44.0	1.29	533.6	8.34	64.1	848.0	41.9
330	391.7	39.1	6.22	43.0	1.21	378.6	6.00	68.1	681.4	41.4
217	510.0	42.0	5.93	44.1	1.10	434.1	5.05	60.4	733.5	37.6
222	748.4	52.1	9.98	53.0	0.96	551.5	7.35	67.8	974.2	39.0
226	697.4	72.9	11.80	76.0	1.01	523.8	8.88	96.3	921.8	57.2
307	518.2	36.4	8.57	36.8	1.26	489.5	8.01	71.4	1017.0	34.4
313	770.0	74.0	13.30	74.9	1.16	530.5	9.14	96.4	1002.4	51.5
317	636.3	54.8	11.17	57.9	1.08	553.6	9.73	85.8	996.0	50.4
319	866.9	80.9	12.04	81.2	0.91	648.3	9.45	115.2	1233.3	63.7
326	616.7	49.8	9.63	51.9	1.13	504.7	7.89	67.2	831.7	42.5
331	361.8	46.8	7.38	49.1	1.21	398.9	8.14	83.6	647.2	54.2
333	594.4	75.1	9.30	75.7	1.11	512.3	8.00	104.3	825.9	65.1
334	850.5	54.6	9.66	54.9	1.08	688.1	7.82	72.0	1123.0	44.4
336	860.4	50.1	10.50	58.4	0.94	685.2	8.35	65.9	1133.1	46.5
337	564.6	26.4	6.34	33.1	0.79	641.5	7.21	52.8	1129.6	37.6
338	811.3	65.0	10.54	69.6	1.22	442.3	5.71	64.8	806.6	37.7
340	417.6	56.7	6.57	67.3	0.77	396.4	6.10	101.9	750.0	62.5

Continuous Scale Physical Functional Performance									Physical Reserve				
Subject #	CS-PFP Total	UBS Domain	UBF Domain	LBS Domain	BALC Domain	END Domain	6 Min. Walk Dist. (m)	6 Min. Walk Spd (m/sec)	PR-PFP (ml/min)	PR-PFP (ml/kg/min)	PR-Gait (ml/min)	PR-Gait (ml/min)	PR-Gait (ml/kg/min)
119	60	63	61	53	60	62	497.8	1.38	1207.5	14.15	1142.5	1142.5	13.37
120	80	75	87	71	82	84	664.6	1.85	1078.2	15.44	1007.4	1007.4	14.29
302	55	64	67	52	52	54	582.0	1.62	1513.3	24.82	1502.9	1502.9	24.45
303	63	64	84	56	62	66	545.7	1.52	1420.5	15.61	1367.4	1367.4	14.73
306	55	62	65	43	54	60	545.4	1.52	530.5	8.23	213.6	213.6	3.20
309	60	59	57	49	64	64	470.4	1.31	610.7	7.83	431.8	431.8	5.47
316	52	62	73	45	45	54	592.2	1.65	1149.2	15.69	944.5	944.5	13.13
322	60	58	86	52	57	65	606.6	1.69	1530.7	24.98	1339.4	1339.4	22.40
323	63	74	73	51	59	65	530.3	1.47	691.3	8.97	576.7	576.7	7.47
324	48	52	93	39	43	50	625.6	1.74	861.5	12.45	571.4	571.4	8.18
325	66	71	78	58	60	69	553.7	1.54	836.1	10.31	645.7	645.7	7.83
327	71	91	79	67	58	69	666.7	1.85	1772.2	22.79	1576.2	1576.2	20.22
328	62	76	64	60	57	60	553.3	1.54	1611.3	19.97	1405.8	1405.8	17.40
329	48	57	67	38	44	49	503.7	1.40	789.4	11.55	704.2	704.2	11.13
330	62	67	80	54	58	65	478.8	1.33	622.4	8.48	609.3	609.3	8.26
217	54	59	57	50	51	54	313.6	0.87	780.9	8.39	705.0	705.0	7.51
222	38	44	63	25	37	41	463.2	1.29	884.5	11.48	687.6	687.6	8.85
226	36	45	58	30	31	36	378.5	1.05	433.2	6.64	259.6	259.6	3.72
307	56	58	75	49	53	59	496.1	1.38	934.5	15.29	905.8	905.8	14.73
313	37	45	56	26	34	40	470.4	1.31	509.5	8.61	270.0	270.0	4.45
317	64	60	89	53	66	67	510.2	1.42	607.4	9.57	524.7	524.7	8.13
319	41	48	77	30	38	41	309.5	0.86	422.7	5.38	204.1	204.1	2.79
326	35	61	76	29	21	31	425.8	1.18	733.3	10.66	621.3	621.3	8.92
331	40	47	59	32	37	42	481.2	1.34	375.2	6.89	412.2	412.2	7.65
333	45	55	74	41	36	45	353.3	0.98	279.7	4.29	197.6	197.6	2.99
334	52	71	61	49	42	49	421.1	1.17	870.9	9.79	708.6	708.6	7.95
336	42	53	70	31	38	42	392.0	1.09	1033.8	9.62	858.6	858.6	7.47
337	40	67	45	35	31	34	274.3	0.76	1497.5	11.95	1574.4	1574.4	12.82
338	58	67	79	50	48	62	470.4	1.31	802.7	9.43	434.0	434.0	4.60
340	24	45	56	24	11	19	306.5	0.85	339.6	3.66	318.4	318.4	3.19

APPENDIX B

FIGURES

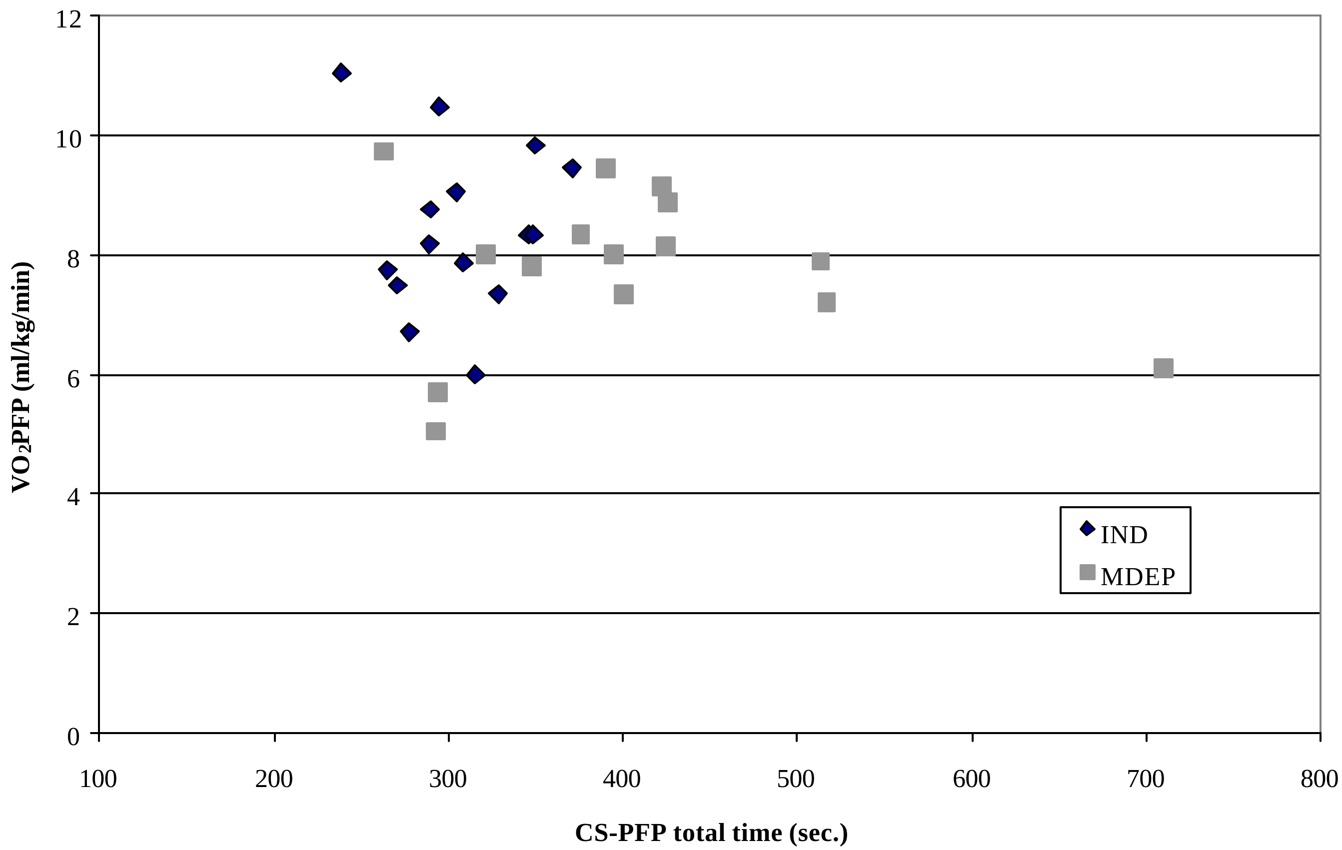

Figure 4. CS-PFP total time vs. VO_2PFP. The IND group completed the CS-PFP significantly faster ($p = 0.003$), however VO_2PFP was not significantly different ($p = 0.20$) between the IND and MDEP groups

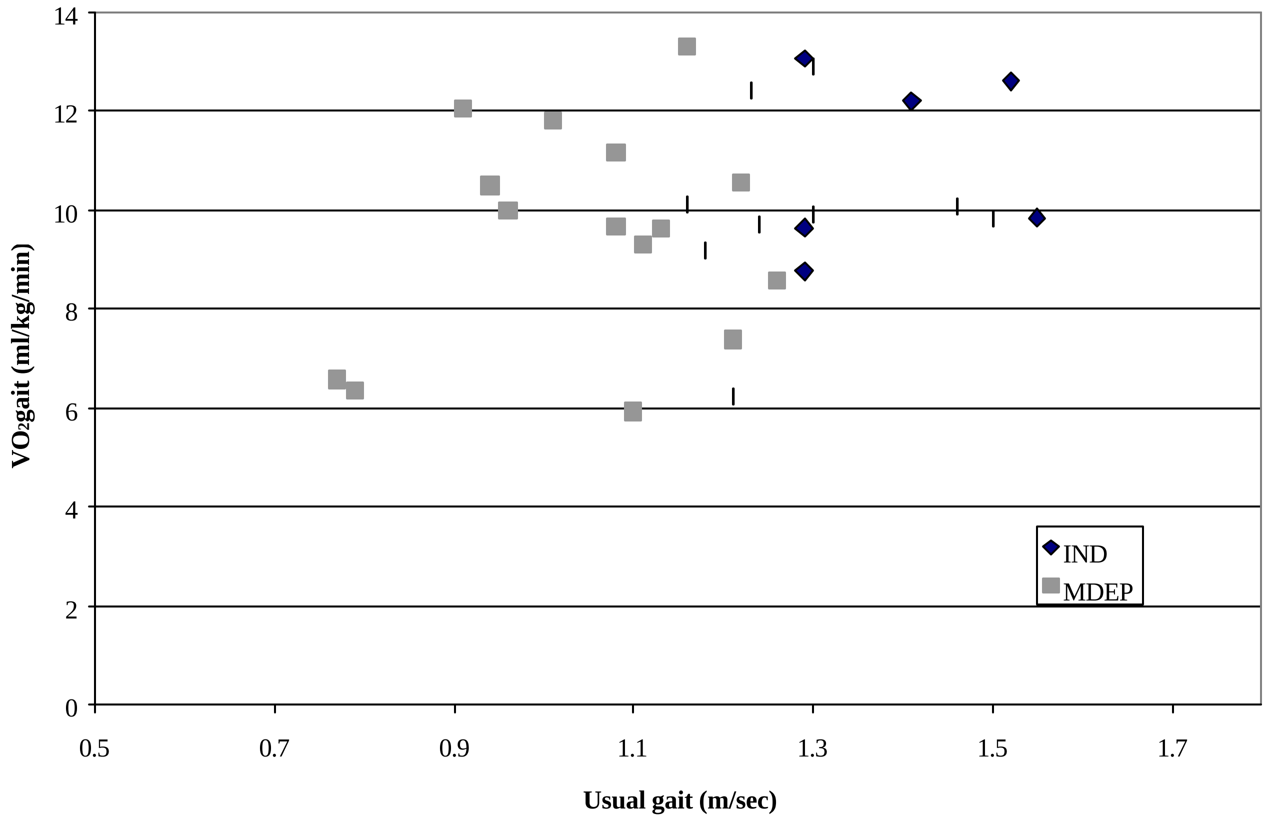

Figure 5. Usual gait vs VO_2gait. Usual gait was significantly faster in the IND group ($p<0.001$), however VO_2gait was not significantly different between groups ($p=0.64$).

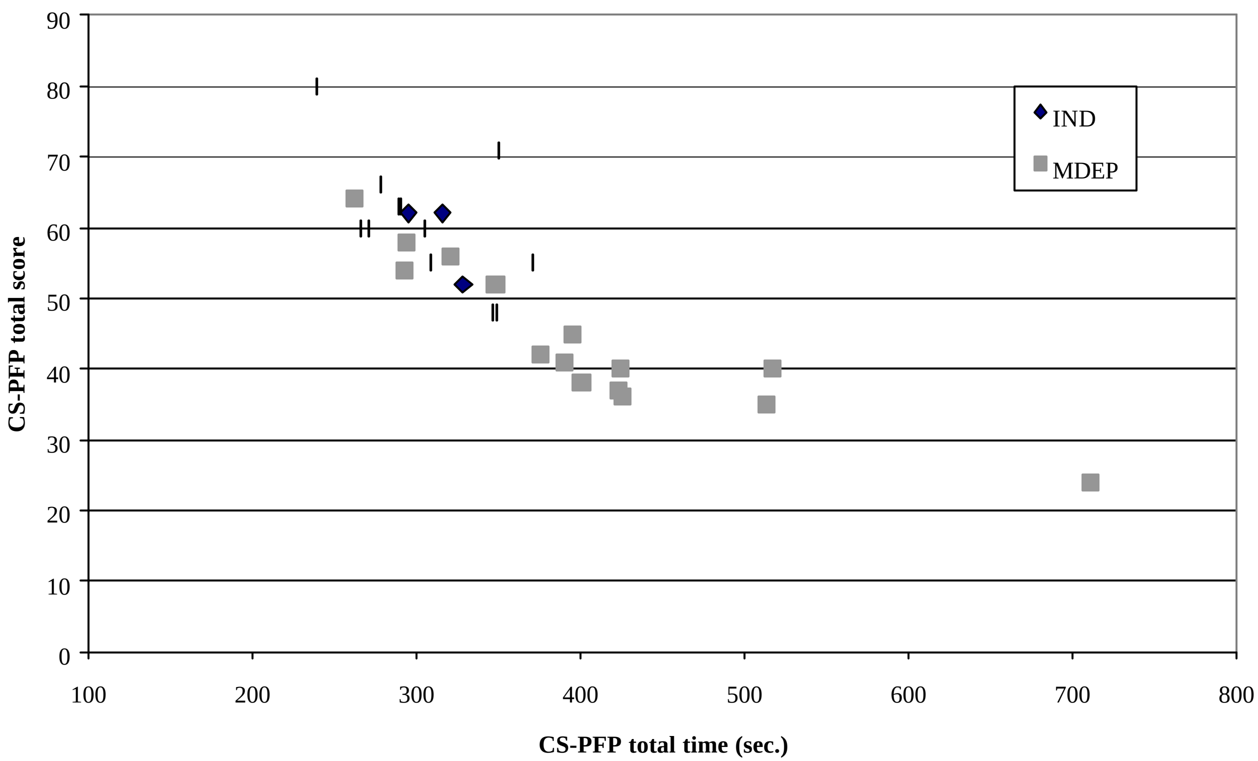

Figure 6. CS-PFP total time vs CS-PFP total score. The IND group completed the CS-PFP significantly faster (p=0.003) and had a higher CS-PFP total score (p<0.001) than the MDEP group.