MUSCLE ACTIVITY DURING FUNCTIONAL TASKS IN PRE-FRAIL AND FRAIL INDIVIDUALS

by

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Abstract

The ability to identify the progression of frailty is essential to mitigate physical impairments associated with aging. Previous studies have indicated that stages of frailty can be identified through bursts and gaps in electromyography (EMG) for an 8-hour day. The purpose of this study was to determine whether EMG and a specific functional task, or group of functional tasks is sensitive to classify middle-aged, non-frail, pre-frail, and frail older adults.

Fifteen middle-aged (49 ± 5 years), and seventy-six older adults (77 ± 8 years) participated in this study. Older adults were categorized as non-frail (n= 49), pre-frail (n= 20) and frail (n= 7) based-upon gait speed and modified frailty index score. Bursts and gaps were measured in the biceps brachii, triceps brachii, vastus lateralis, and biceps femoris bilaterally during nine functional tasks: (1) Standing-up from a chair; (2) a toilet; and (3) the floor; (4) Dressing and undressing a buttoned shirt; (5) Transferring laundry between washer and dryer; (6) Carrying laundry up stairs; (7) Eating soup; (8) Preparing a light meal; and (9) Loading, carrying and unloading groceries.

Bursts were greater and gaps fewer in frail compared with middle-aged and non-frail. The variable that provided the best prediction of phenotype allocation was the fewer number of gaps in the upper limbs ($\Lambda = 0.677$, $\chi2$ (9) = 33.746, $p< 0.001$), and greater mean burst amplitude in lower limbs during the chair, toilet, and floor tasks ($\Lambda = 0.764$, $\chi2$ (9) = 23.310, $p< 0.001$); where 80.2% and 72.5% of the original grouped cases were correctly classified in this sample. When separated by sex, the number of gaps respectively, correctly classified 100% and 81.8% of males and females. Mean burst amplitude correctly classified 77.8% and 78.2% of males and females. Burst and gap

characteristics indicate that EMG differs across stages of frailty and progression is best identified with mobility tasks of rising from a chair, toilet and floor.

Preface

The University of British Columbia's Behavioral Research Ethics Board granted ethics approval on June 26, 2012, certificate number H12-01560.

This research was conducted through the Healthy Exercise and Aging Laboratory (HEAL) group at the University of British Columbia Okanagan by Dr. Gareth R Jones, Dr. Jennifer M. Jakobi and Noelannah A. Neubauer. Student assistants with data collection were Kaitlyn Hartmann, Adrien DeGroot, Jillian Thomas, Hannah Brown and John Bocti. Dr. Jakobi and Dr. Jones oversaw the conceptual design of the study, writing process, technical aspects of equipment, equipment acquisition, and funding for the study. Noelannah A. Neubauer designed the study concept and experimental methodology, undertook subject recruitment, data collection and analysis, and writing.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AADL: Advanced Activities of Daily Living

ADL: Activities of Daily Living

ANOVA: Analysis of Variance

BADL: Basic Activities of Daily Living

BB: Biceps Brachii

BF: Biceps Femoris

BMI: Body Mass Index

cm: Centimeters

CHS-*fi*: Cardiovascular Health Study Frailty Index

CS-PFP: Continuous- Scale Physical Functional Performance Test

EMG: Electromyography

g: Grams

Hz: Hertz

IADL: Instrumental Activities of Daily Living

Kg: Kilograms

lbs: Pounds

m: Meters

MANOVA: Multivariate Analysis of Variance

min: Minute

Mod-*fi*: Modified frailty index

MB: Megabyte

MMC: Multi Media Card

MU: Motor Unit

MVC: Maximal Voluntary Contraction

MVE: Maximal Voluntary Exertion

Nm: Newton-meters

ROM: Range of Motion

RPE: Rate of Perceived Exertion

s: Seconds

SD: Standard Deviation

VL: Vastus Lateralis

TB: Triceps Brachii

Glossary

Advanced Activities of Daily Living: Represent more sophisticated activities that go beyond those that are necessary to live independently. Include operation of household appliances and technology such as using a dishwasher or oven, the ability to carry-out complex financial transactions such as using a bank card, involvement in sport and leisure activities, and cognitive stimulating activities such as reading books or using the internet. For this study, advanced activities of daily living included standing up from the floor, carrying a load of laundry up a set of stairs, and loading, carrying and unloading groceries onto a shelf

Activities of Daily Living: Used as a measure of functional capacity and is further divided into basic activities of daily living (BADL), instrumental activities of daily living (IADL) and advanced activities of daily living (AADL). For this study, activities of daily living included mobility, laundry, and food tasks

Anisometric: A contraction in which the joint angle and muscle length changes

Basic Activities of Daily Living: Activities necessary for meeting basic physiological and self-maintenance needs; include personal hygiene tasks such as toileting, bathing, dressing, grooming and feeding. For this study, basic activities of daily living included standing-up from a chair, dressing and undressing a buttoned shirt, and eating a bowl of soup

Burst: Represents muscle activity and is defined as having a duration of >0.1s and a threshold amplitude >2% of the subjects MVE

Electromyography: Electrical recording of global muscle activity

Gap: Represent muscle quiescence and is quantified as a period of EMG less than 1% of MVE for duration longer than 0.1s

Gait Velocity: The speed of a person's walk generally measured in meters per second (m/s)

Isokinetic Contraction: A contraction in which the muscle contracts and shortens at a constant rate of speed, with the assistance of specialized equipment

Instrumental Activities of Daily Living: Involve activities necessary to reside in one's personal environment. Tasks include meal preparation, laundry, ability to handle finances, and responsibility for own medications. For this study, instrumental activities of daily living included rising from a toilet, transferring a load of laundry between front loading washing machine and dryer, and preparing a light meal

Maximal Voluntary Exertion: When an individual attempts to voluntarily contract a muscle while producing as much force as possible. This is used as a baseline measure of

maximal EMG output of the muscle to facilitate the normalization of the surface EMG recordings that are obtained.

Motor Neuron: Neurons that send motor command signals from the spinal cord to muscles or other effector organs

Motor Unit: A motor neuron and all of the muscle fibers it innervates

Spike Amplitude: Voltage indicating height of an action potential

Recruitment Order: Progressive activation of a muscle by successive recruitment of contractile units to accomplish increasing gradation of contractile strength

Surface EMG: A non- invasive means to record the electrical activity of skeletal muscle, whereby a pair of electrodes is typically placed on the skin above the muscle of interest. The measure obtained is a global representation of the electrical activity between the two electrodes

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everything I have because of you. I cannot thank you enough for what you have done for me.

Dedication

To my Nana and Papa. Two very important people in my life.

Chapter 1: Literature Review

Over 50% of community-dwelling older adults exhibit signs of physical frailty (Fried et al. 2001). Frailty is a geriatric syndrome, that results in increased vulnerability to acute and chronic illness, loss of functional independence, and develops across a spectrum of phenotypes ranging from non-frail to pre-frail to frail (Roland et al. 2011). Exercise interventions have a positive effect on physical performance in pre-frail, but not in frail older adults (Faber et al. 2006). Pre-frail older adults have a greater ability to perform functional tasks, allowing them to perform more challenging exercise interventions required to engender physical changes (Faber et al. 2006). Paradoxically, these same exercise interventions may increase a frail older adult's risk for adverse events such as falls and/or fractures, resulting in loss of functional independence (Stathokostas et al. 2013). Therefore, early identification of frailty is essential to prevent physical impairments associated with frailty. The criteria used for determining frailty continue to be a matter of debate. However, there is a need to develop assessment tools that can be used in the field that provide an accurate identification of frailty status. Discrete functional tasks, which are direct components of activities of daily living (ADL), are used to identify functional performance in older adults (Cress et al. 1996). Although an extensive body of literature exists on the measurement of frailty there remains a paucity of information related to how neural activity in muscle (muscle activity) changes during performance of functional tasks by non-frail and frail individuals. Alterations in muscle activity, measured by surface electromyography (EMG), are indicators of changing frailty status (Theou et al. 2010). Theou's investigation suggested that there was

less muscle quiescence observed in the EMG muscle activity patterns of frail individuals, and these changes were related to poor functional task performance and frailty status. However, it was unknown which functional tasks were influenced most by these changes in muscle activity. Therefore, quantifying muscle activity during specific functional tasks, may determine if there is a specific functional task or group of tasks that may better predict frailty than other measures. Understanding how changes to everyday functional tasks influence frailty status will facilitate community-based, early diagnosis of frailty status.

1.1 Physiological Changes Associated with Decline in Functional Performance

An increase of 22% in the probability of dependence occurs with each additional year of life after 70 years of age (Paterson et al. 2004). Chronic disease, disability and frailty are associated with physiological decline that culminates in functional dependence (Boult et al. 1994, Wang et al. 2002, Wolff et al. 2004). Reduced functional performance is a key predictor of disability (Guralnik et al. 1994). Physiological factors that lead to decreased functional performance includes reductions in muscle mass, quality, strength and power (Bassey et al. 1992, Goodpaster et al. 2006). Kyle et al. (2001) reported that older adults had significantly less fat free mass and more body fat than younger adults, and the changes found in fat free mass were suggested to be a result of a loss of skeletal muscle mass. This age-associated loss of skeletal muscle mass is often identified as sarcopenia (Cruz-Jentoft et al. 2010, Doherty 2003, Metter et al. 1999) and is commonly associated with concomitant reductions in muscle strength and power (Frontera et al. 2000, Morley et al. 2001). Research suggests that the cause of sarcopenia that precedes reductions in strength and power is primarily due to a loss in size and number of type II

muscle fibers (Aniansson et al. 1986, Kanda et al. 1986, Lexell et al. 1988). However, the loss of strength in older individuals is not only due to shrinking muscle mass, but also the result of reduced muscle activation (Narici et al. 1999).

Although the evidence of functional decline as a consequence of aging appears well established, its primary contributors, muscle strength, power, and muscle mass are known to vary depending on the condition assessed. There are a number of factors that play key roles in the age-related rates of muscle weakness, loss of power, and decreased muscle mass; namely, sex and type of limb measured.

Sex-differences influence age-related decline of muscle power and strength as the rate of strength decline in males differs from females (Daneskiold-Samsoe et al. 2009, Goodpaster et al. 2006, Phillips et al. 1993). These differences are associated with differential rates of decline in muscle mass (Frontera et al. 1991), and sex dependent hormones (Greeves et al. 1999, Ottenbacher et al. 2006, Phillips et al. 1993) such as estrogen during menopause (Phillips et al. 1993, Skeleton et al. 1999), and testosterone (Morley et al. 1997), and growth hormone (Blackman et al. 2002, Liu et al. 2007) after age 70.

Differences in loss of strength and power in lower and upper limb muscles also differs with age. Loss of strength and power in lower limbs is greater with age than upper limbs (Aoyagi et al. 1992, Candow et al. 2005, Frontera et al. 1991), and is suggested to be due to a decreased use of lower, compared with upper, limb muscles in older adults (Sperling et al. 1980). Older individuals are known to complement weaker lower body movements with upper body movements, such as arm contractions when rising from a chair (Macaluso et al. 2004). These movements may thereby enhance upper limb function

and further delay age-related loss in strength while lower limb strength measures decline. When muscles of the same limb are compared differences in the rate of decline also exist. For example, the strength and muscle quality of the biceps significantly declines with age, whereas the strength and muscle quality of the triceps is relatively well maintained with age (Dalton et al. 2010, Lynch et al. 1999).

Age-associated decline in strength and power with age are known to impact the ability to perform daily functional tasks, which further inhibits individuals from remaining independent (Davis et al. 1998). Daily functional tasks, often described as Activities of Daily Living (ADL), are used as a measure of functional capacity (Thomas et al. 1998). They are further divided into basic activities of daily living (BADL), instrumental activities of daily living (IADL) and advanced activities of daily living (AADL) to distinguish varying levels of ability in older adults.

Basic activities of daily living (BADL) are activities necessary for meeting basic physiological and self-maintenance needs. BADL typically include personal hygiene tasks such as toileting, bathing, dressing, grooming and feeding. Levels of dependence are expressed in grades: "A" representing most independent (requiring no assistance to complete all 6 activities) and "G" representing the most dependent grade (requiring assistance to complete in all 6 activities) (Katz et al. 1963). Within the BADL an underlying hierarchy exists, with bathing as the earliest and eating as the latest function for which personal assistance is required (Borchelt et al. 1992).

Instrumental activities of daily living (IADL) involve activities necessary to reside in one's personal environment. Tasks include meal preparation, laundry, ability to handle finances, and responsibility for own medications (Lawton et al. 1969, Spector et

al. 1998). Although a number of researchers have asserted that BADL and IADL scales should be modeled separately, others have advocated for combining BADL and IADL items (Kempen et al. 1990). Both sets of items are suggested to be better than BADL items alone at identifying the extent of dysfunction and service needs in older adult community populations because of reductions in ceiling effects and inclusion of measures of adaptations one's environment (Lawton et al. 1998, Spector et al. 1998). Together, BADL and IADL are essential to maintain independent living (Vriendt et al. 2013).

Advanced activities of daily living (AADL) take activities one step further in complexity, and represent more sophisticated activities that go beyond those that are necessary to live independently (Reuben et al. 1990). AADL include operation of household appliances and technology such as using a dishwasher or oven, the ability to carry-out complex financial transactions such as using a bank card, involvement in sport and leisure activities, and cognitive stimulating activities such as reading books or using the internet (Pincus et al. 1999, Vriendt et al. 2013). While BADL and IADL tend to be stable across populations, AADL are largely sex and culture specific and are often influenced by personal choices (Reuben et al. 1990). AADL impairment is therefore suggested to be due to cognitive deficits rather than co-morbidities and/or physical impairments (Winblad et al. 2004). Loss of AADL equates to loss of functional independence (Trottier et al. 2000) and may indicate functional decline before the loss of BADL and IADL (Borchelt et al. 1992). Identifying tasks in progressing difficulty, BADL, IADL, to AADL, is integral in the evaluation of independence of older adult irrespective of the living environment (Trottier et al. 2000).

Physical activity is a critical component in delaying age associated functional declines. Paterson et al. (2004) demonstrated that cardiorespiratory fitness is a significant determinant of becoming dependent. It was found that those who were classified as having low cardiorespiratory fitness had a 14% greater occurrence of dependence after accounting for other factors such as body mass index, hip flexion and disease (Paterson et al. 2004).

The decline in muscle strength is associated with loss of muscle mass and muscle quality (Frontera et al. 2000), which in turn is associated with functional limitations in ADL (Aniansson et al. 1980, Borchelt et al. 1992, Foldvari et al. 2000). Loss of muscle mass is related to diminished gait speed, poor balance, and falls in older females (Porter et al. 1995). Resistance training coupled with cardiorespiratory training has been found to lead to a two-fold greater increase in strength than an endurance program alone (Ferketich et al. 1998) and appears to improve ADL performance (Binder et al. 2002). Task-specific resistance training also has a similar outcome improving BADL tasks such as bed and chair rise time (Alexander et al. 2001). Overall, each additional hour of physical activity performed per week will slow functional decline, preserve physical independence and prevent frailty (Buchman et al. 2007).

1.2 Frailty and Aging in Canada

In Canada, since 1982 the population of older-adults (≥65 years) has more than doubled. In 2012, older adults accounted for 15% of the population in Canada. This group of older adults continues to increase faster than all other Canadian age cohorts. Demographic projections show that older Canadians will account for more than one quarter of the population by 2036. In part, this increase in the cohort of older adults is due

to an increased life expectancy in Canada, from 74.9 years in 1979 to 81.1 years in 2009. Currently life expectancy for Canadian males is 78.8 years and 83.3 years for Canadian females (Statistics Canada, 2012).

It is important to note that reported life expectancy values are not representative of individuals that are disability free. In 2006, over 1 million older adults in Canada aged 75+ lived with physical limitations including poor mobility (44.7%) and functional task related issues (42.9%) as the most common forms of disability. Females consecutively have a greater incidence of mobility and agility disabilities (48.4% and 44.3% respectively) than males (39.4% and 38.6%) (Statistics Canada, 2006). The number of functionally disabled older adults is projected to continue to increase and may contribute to a greater incidence of functional dependence within this aging cohort.

Frailty is one of the leading domains associated with age-related disabilities. Mortality rate in older adults continues to increase irrespective of increased life expectancy (Collard et al. 2012). It is estimated that nearly 1 in 4 older adults ($\geq$ 65yrs) are frail (Song et al. 2010), with an annual incidence of 7% (Fried et al. 2001). The development of frailty progresses across a spectrum of defined stages described as non-frail, pre-frail, and frail (Bandeen-Roche et al. 2006, Fried et al. 2001, Roland et al. 2011). Frailty is more common in females than males and transitioning toward frailty likely occurs earlier in females because of lower percentages of muscle mass (Cesari et al. 2006, Fried et al. 2001). Frailty is of concern because it is associated with adverse health outcomes such as: recurrent falls, functional decline, which precipitates physical dependency, fractures, institutionalization, and increased mortality in older people (Cawthon et al. 2007, Ensrud et al. 2007, Ferrucci et al. 2004, Fried et al. 2001, 2004).

Many, often controversial, definitions of frailty exist as a result of numerous factors that are reported to contribute to frailty (Borges & Menezes, 2011, Sternberg et al. 2011). Frailty is characterized through measures of loss of flexibility, balance, muscle strength and mass, neuromuscular coordination, cardiovascular function, and physical inactivity (Binder et al. 2002, Ferucci et al. 2004, Roland et al. 2012, Studentski et al. 2004; Syddall et al. 2003). Frailty can be defined as impairment in function as it relates to basic and/or instrumental activities of daily living (Hogan et al. 2003), yet can also be described as a wasting syndrome involving negative energy balance and weight loss as important elements that influence frailty (Fried et al. 2001). More recent criteria have emphasized cognitive, psychological, and environmental factors (Kuh 2007, Rockwood et al. 2007). This lack of consensus on identifying frailty leads to several problems, namely, which factors are a consequence of frailty and which are markers that should be used to identify the syndrome (Levers et al. 2006). Although Fried's (2001) definition of frailty is widely used for research purposes, it has so far proven impractical in the clinical setting (Rockwood et al. 2005) due to scheduling and space constraints (Ensrud et al. 2008). Thus, a more direct measure to diagnose frailty would assist physicians, researchers, and policy makers alike with earlier identification strategies in order to enable effective and timely interventions in older adults.

1.3 Current Measures to Determine Frailty

Frailty is an important clinical health problem (Fried et al. 2004); but its measurement remains controversial. Two of the most commonly used measurements to determine frailty are; the Cardiovascular Health Study frailty index (CHS-*fi*) (Fried et al. 2001) and the Frailty Index (Rockwood et al. 2005). For the purpose of this literature

review, CHS-*fi* and Frailty Index will be discussed in detail below. It is important to note, that there are many other, less commonly used measurements to determine frailty. These are highlighted in Table 1 in Appendix B.

CHS-*fi* (Fried et al. 2001), is determined using five physical measures: (1) Walk time, measured and calculated according to height; (2) Grip strength, measured according to BMI; (3) Physical activity, calculated using the Minnesota Leisure Time Physical Activity Questionnaire (Taylor et al. 1978); (4) Exhaustion, recorded by asking participants if in the last week they felt that everything they did was an effort, and how often they felt that they could not get going; and (5) Unintentional weight loss, of more than 10 lbs in the last year. Frailty phenotype is defined according to the number of criteria that the individual met: no component indices (0) considered non-frail; one to two component indices indicates pre-frail; and three or more of the five component indices were determined as frail (Fried et al. 2001). A specific description of each is provided in Chapter 3.

CHS-*fi* is extensively validated in the research literature (Bandeen-Roche et al. 2006, Santos-Eggimann et al. 2009, Szanton et al. 2009, Xue et al. 2008) and has achieved an international reputation (Romero-Ortuno et al. 2010). However, the primary limitation with this method is the dichotomization of individual criteria that are measured on a continuous scale (grip strength, physical activity). As noted by Streiner (2009), dichotomizing continuous variables results in a tremendous loss of information. For people near the 20% cut-off point (Fried et al. 2001), this can easily result in misclassification error (Streiner, 2009) and further discriminates broad levels of risk (Rockwood et al. 2007). Another disadvantage is that Fried et al. (2001) utilized handgrip

strength as an indicator of frailty. While handgrip strength is proposed as a good indicator of health related events (Rantanen et al., 2000), it only measures upper limb strength, which may not capture changes to lower limb strength associated with mobility (Cesari et al., 2006). Age-related decline in strength is not similar across all muscles (Aoyagi et al. 1992, Frontera et al. 1991), thus when examining frailty various muscles need to be considered.

The Frailty Index accounts for 70 accumulating clinical deficits that influence frailty which were derived from the Canadian Study of Health and Aging (CSHA) clinical assessment (Rockwood et al. 2005). Items include the presence and severity of current diseases, ability to execute ADL, and neurological and physical signs from clinical examinations. The choice of deficits is restricted to those that have the possibility of accumulating with age (muscle weakness). The deficits cannot occur at a young age (e.g. corrected eye vision). Someone who has accumulated more deficits (thirty-five deficits for example) would rank higher in the frailty index than someone who only has seven deficits. The relative frailty of an individual is calculated as a percentage difference from the average score for people of that age. For both males and females death rate increases significantly with increases in the frailty index (Mitnitski et al. 2005). More deficits resulted in a higher score for the frailty index.

What the Frailty Index shares with other measures, is that scoring greater levels of frailty is the result of accumulating deficits. More recently, cut-points to identify frailty groups using the Frailty Index were created. Hoover et al. (2013) established these as 0 to ≤ 0.10 to classify frail, > 0.10 to ≤ 0.21 to classify pre-frail, and > 0.21 to classify frail. This index reveals a gradient in degrees of fitness and frailty, which is recognized

clinically (Studentski et al. 2004). An advantage of using the Frailty Index over CHS-*fi* is that it does not assume that the groups of elements that make up frailty are statistically independent (Rockwood et al. 2007). Another strength of the Frailty Index is that little attention is given to which items are present in a 'frail' person, rather the measurement counts the number of positive identifiers and proposes a frailty index based on a count of accumulated deficits (Mitnitski et al. 2001). The frailty index was cross-validated across populations, and other frailty measures (Jones et al. 2005, Mitnitski et al. 2005); however, clinical use of this measure remains to be fully demonstrated (Goggins et al. 2005).

CHS-*fi* and Frailty Index place a heavy reliance on indirect self-report measurements to classify frailty. Self-report assessment tools are known to under and overestimate factors such as body weight (Shields et al. 2008), physical activity levels (Prince et al. 2008) and diet (Maurer et al. 2006). Therefore, estimates of the prevalence of frailty may be lower or higher than those based on direct measurements, posing a problem for both reliance on self-report measures and for attempts to correct for differences between self-reported and direct measures. Another important disadvantage of the above measurements is their inability to determine discrete changes in an individual's frailty status. CHS-*fi* for example, is based upon three categories. In order to observe any changes in frailty status, individuals must either acquire one to two additional components, or no longer meet one to two existing components to be classified into a different category (e.g. non-frail to pre-frail or pre-frail to frail). Therefore, it becomes almost impossible to monitor changes that occur before items such as strength differences are present. Declines in muscle activity are known to occur before strength changes are observed (Theou et al. 2010). Thus, clinicians are unable to determine

whether an individual is frail until observable components, such as functional dependence, are already present. This can lead to delayed identification of frailty, further hindering the effectiveness of interventions to prevent or delay the onset of frailty.

There is a growing interest in applying gait speed assessments as a simple test to detect mobility problems and to predict adverse outcomes in the older adult population (Guralnik et al. 2000, Studenski et al. 2003), on which preventative strategies could be implemented. Gait speed improvements as small as 0.1 meters per second (m/s) have shown substantial reductions in mortality, and delayed the risk for onset of frailty (Hardy et al. 2007, Peterson et al. 2009). More recently, cut-points to identify frailty groups using gait speed were suggested (van Kan et al. 2009, Montero-Odasso et al. 2005); however, these thresholds have yet to be validated across a variety of populations and clinical settings (van Kan et al. 2010).

Clinicians are faced with how to measure frailty in the community before the patient arrives at a clinical setting and there is a need to provide sensitive measures of change in ADL performance. Tools such as the Short Physical Performance Battery (SPPB) (Guralnik et al. 1994), and the Physical Performance Test (PPT) (Reuben et al. 1990) provide performance-based information; however, neither tool captures the functional decline associated with ADL loss. The Continuous- Scale Physical Functional Performance Test (CS-PFP) does provide a useful measure of physical function in older adults that reflects abilities in multiple physical domains. The CS-PFP consists of 15 everyday tasks ranging from those requiring little strength or endurance, such as donning and removing a jacket, to those demanding greater stamina, such as getting into and out of a bathtub. The CS-PFP utilizes activities that reflect physical domains of lower and

upper body strength, balance and coordination, endurance, and upper body flexibility (Cress et al. 1996). Tasks are quantified by one or a combination of the following categories: weight carried, time to complete the tasks, and distance. The instruction for each task is to perform it safely but to work at a maximal perceived level (Cress et al. 1996). This test is unique from other functional measures because it closely mimics the real demands of everyday physical functions such as going shopping, taking the bus, cooking, washing dishes and a number of other activities of daily living. It also highlights the importance of assessing progressive functional tasks. While measuring discrete functional tasks is useful at determining age and sex differences (Harwood et al. 2008), progressive tasks may be more sensitive to change in frail populations, allowing for an earlier prediction of frailty. This scale is reported as a valid and reliable measure of physical function having minimal floor and ceiling effects, and its scores strongly correlate with the level of independence of each individual (Cress et al. 1996).

Although an extensive body of literature exists on the measurement of frailty, most assessment tools lack the capability to measure discrete changes in an individual's frailty status, which can inhibit their sensitivity for early frailty identification. In addition these tools do not yet describe the significant interaction between the muscular and nervous systems, which are a critical component in understanding the different stages of frailty.

1.4 Surface Electromyography

Surface electromyography (EMG) is a non- invasive means to record the electrical activity of skeletal muscle, whereby a pair of electrodes is typically placed on the skin above the muscle of interest. The measure obtained is a global representation of

the electrical activity between the two electrodes (Merletti et al. 2001). As such, EMG is used as a comprehensive measure of whole muscle activity, but the action potentials are gained only from the recording area under the electrode. Surface EMG is most commonly used because it is a non-invasive recording of muscle activity.

Traditionally surface EMG is used in a laboratory setting for the measurement of specific tasks, most notably isometric contractions (Duchateau et al. 2006, Rainoldi et al. 1999). With further advancements in technology, surface EMG is employed for the measure of anisometric contractions in laboratories (Farina 2006). EMG has been found to be a useful measure to determine the mechanisms responsible for age related muscle and power decline. By using EMG, Merletti et al. (2001), were able to determine that changes in fiber type distribution and decrease in motor unit firing rate with aging were associated with a decrease in maximal voluntary contraction torque and increased muscle fatigue. This further demonstrates that surface EMG can provide insight into both peripheral properties and central changes of the neuromuscular system that occur with advancing age.

More recently outside of a laboratory setting, muscle activity and quiescence, also termed low-threshold EMG, was successfully quantified through the use of portable devices to evaluate long-term muscle activity of individuals in the workplace and during their typical daily activities (Blangsted et al. 2003, Jakobi et al. 2008, Laursen et al. 2001, Madeleine et al. 2006, Theou et al. 2010). For example, this device was used to measure muscle activity in healthy younger and older adults (Harwood et al. 2008), and older adults post-stroke while they pursued typical daily activities (Jakobi et al. 2008). The work suggested that portable EMG does not impede typical daily routines in healthy

younger and older adults, or in people with co-morbidities. Measuring long term EMG activity with portable devices to provide an indication of overall muscle activity can also be an effective way to identify age-related changes in muscle quality that may lead to functional decline, disability and frailty in older adults.

The reliability of this device over testing periods of several hours and between different test sessions is well established. Ochia and Cavanagh (2007) evaluated the reliability of 12-hour recordings for the biceps brachii, vastus medialis, and gastrocnemius. Results indicated that the normalized integrated EMG for two of the three muscles showed no significant changes during the 12-h period. Thus, the stability of surface EMG measurements over the 12-h period suggests that this methodology is feasible for use in long-term EMG studies.

Low-threshold EMG is generally characterized by bursts and gaps. A burst, which represents muscle activity, is defined as having a duration of >0.1 s and a threshold amplitude >2% of the subjects maximal voluntary exertion (MVE). They are typically quantified as number of bursts, mean burst duration (burst/s), peak burst amplitude (average peak amplitude of all bursts, %MVC), burst activity (average mean amplitude of all bursts, %MVE), and percentage of burst (% of total recording time occupied by bursts). Gaps, which represent muscle quiescence, is quantified as a period of EMG less than 1% of MVE for a duration longer than 0.1s. It is typically quantified by the number of gaps, mean duration (s), and gap percentage (% of total recording time occupied by gaps). Burst and gap characteristics differ between muscles, males and females as well as young and old. For example, burst number and duration indicate that muscle activity is greater in the upper compared with lower limbs (Theou et al. 2010) of older adults and is

suggested to be due to their greater use of upper limbs while performing ADL (Hortobagyi et al. 2003). Older adults may spend much of the day seated or standing while performing a variety of household activities that utilize the upper limbs, such as using the armrest of a chair to stand-up (Malcaluso et al. 2004). This finding may further support why age-related strength loss in lower limbs is greater with age than upper limbs.

Burst and gap characteristics have previously been used to explore sex, and age-related differences in the performance of functional tasks. Harwood et al. (2008) had 14 young and 15 old adults perform a discrete functional task, which involved subjects bending down to lift a 4.5 kg bag with their non-dominant arm, carry it eight meters at a self-paced rate, and return to the point of origin and lower the load to the floor. Gaps in the EMG signal for the females and old adults were fewer compared with males and young adults during this discrete task. Similarly, Blangsted et al. (2003) found shorter gap durations reported for females than males in the trapezius over a one hour duration typing task. Females and older adults also demonstrated heightened burst areas (the product of burst duration and amplitude) and longer burst durations (Harwood et al. 2008). Such differences coincide with strength differences between the sexes. Females and older adults having lower absolute strength than males and young adults, therefore, it is expected that this difference would manifest as greater muscle activity in females. These findings suggest that longer duration of bursts of muscle activation allow for a greater level of force production during specified tasks. Quantifying muscle activity during discrete tasks provides further insight into muscle activity differences between sexes and age employed during ADL.

The measure of EMG to examine frailty was recently investigated (Theou et al. 2010). Theou et al. (2010) categorized thirty-three community- dwelling females as non-frail, pre-frail, and frail based upon the CHS-*fi* (Fried et al. 2001). The EMG of their upper and lower limbs was then measured by wearing a portable device for nine hours where subjects proceeded with their normal daily activities while wearing the device. Results demonstrated that burst and gaps in EMG characteristics differed as older females transition through stages of frailty. In fact the number of bursts was 28% fewer and the mean duration was 26% longer in frail females compared with non-frail females (Theou et a. 2010). It is suggested that increased subjective fatigue and impaired motor control, which are both outcomes of frailty, likely contribute to these differences in EMG between groups (Ferucci et al. 2004). It was also found that mobility and strength measurements, which are known frailty measures, were statistically similar between non-frail and pre-frail groups; however, EMG was different. Measuring muscle activity and quiescence allows for the understanding of the interaction between the muscular and nervous system in frail and non-frail older adults, which is suggested being a more complete indicator of frailty than handgrip strength (Theou et al. 2010). Because frailty alters the individual characteristics of EMG, this measure may therefore assist in disassociating stages of frailty, and allow for earlier identification of frailty.

1.5 Summary of Literature

To date no investigation has quantified muscle activity during a set of functional tasks to predict frailty. It is well established that there is a lack of consensus on the best definition of frailty (Borges & Menezes, 2011, Ferrucci et al. 2004, Sternberg et al. 2011), and how it should be measured (Bergman et al. 2007, Mitnitski et al. 2004,

Rockwood et al. 2005). Multiple assessment tools have been created as a means to define and identify frail individuals. These tools assess functional decline, weight loss (Fried et al. 2001), accumulation of clinical deficits (Rockwood et al. 2004), and the influence of social support (Rolfson et al. 2006). However, most of these assessment tools depend on some level of participant self-report, which is often associated with greater measurement error. More importantly, most frailty assessment tools lack the capability to measure discrete changes in an individual's frailty status, which can inhibit their sensitivity for early frailty identification. In addition these tools do not yet describe the significant interaction between the muscular and nervous systems, which are a critical component in understanding the different stages of frailty.

Full day assessment of muscle activity during daily living is a useful predictor of frailty (Theou et al. 2010) although its' eight – nine hour sampling period is thought to be impractical for the clinical (immediate) setting. However, measurement of muscle activity during specific functional tasks would significantly decrease the testing period and allow for a greater understanding of muscle activity during specific functional tasks in frail older adults. This would also help determine whether a particular set of functional tasks better dissociates between stages of frailty than others. No study to date has examined muscle activity during a set of discrete and progressive functional tasks relative to frailty identification.

Chapter 2: Purpose and Hypotheses

2.1 Purpose

This investigation addressed three aims:

Aim 1: Evaluate EMG differences between nine functional tasks, as each task becomes progressively more challenging to complete.

Aim 2: Assess EMG during nine functional tasks across frailty phenotypes.

Aim 3: Determine whether a particular functional task, or progression of functional tasks, coupled with EMG, can identify non-frail, pre-frail, and frail older adults.

2.2 Hypotheses

a. There will be more frequent and longer bursts, and fewer gaps in the more difficult functional tasks compared with the more basic functional tasks

b. Muscle activity will be greater and quiescence less in frail compared with non-frail individuals.

c. Frailty phenotype allocation will be predicted by more than one functional task

Chapter 3: Manuscript

3.1 Introduction

Frailty is a geriatric syndrome that results in increased vulnerability to acute and chronic illness, loss of functional independence, and develops across a spectrum of phenotypes ranging from non-frail to pre-frail to frail (Fried et al. 2001, Rockwood et al. 2007, Roland et al. 2011, 2014). Over 50% of community-dwelling older adults exhibit signs of physical frailty, and it is estimated that nearly 1 in 4 older adults (≥65yrs) are frail (Song et al. 2010). While frailty often culminates in the need for long-term care (Fried et al. 2004), many frail older adults still remain in the community despite impairments in one or more ADL (Chandler et al. 1998). Frailty is less common in males, and likely occurs earlier in females because of the lower percentage and faster rate of decline in muscle mass, bone mineral density (Cesari et al. 2006, Fried et al. 2001, Morley et al. 2005) and lower levels of anabolic hormones (Blackman et al. 2002, Liu et al. 2007, Ottenbacher et al. 2006, Phillips et al. 1993).

Exercise interventions have a positive effect on physical performance in pre-frail, but not in frail older adults (Faber et al. 2006). Pre-frail older adults have a greater ability to perform functional tasks and this enables them to successfully participate in exercise interventions that positively challenge their physiological capacity (Faber et al. 2006). Paradoxically, these same exercise interventions may increase a frail older adult's risk for adverse events such as falls and/or fractures, resulting in loss of functional independence (Stathokostas et al. 2013). Therefore, early identification of frailty is essential to prevent physical impairments associated with this geriatric syndrome.

Frailty is an important clinical health problem (Fried et al. 2004); however, defining and effectively measuring it remains controversial (Bergman et al., 2007, Borges & Menezes 2011, Mitnitski et al. 2004, Sternberg et al. 2011). There are multiple tools to identify frailty (Theou et al. 2011). These range from quantifiable measures of functional decline (Guralnik et al. 1994) such as gait speed (Montero-Odasso et al. 2005), weight loss (Fried et al. 2001), qualitative indices of number of clinical deficits (Hoover et al. 2013, Rockwood et al. 2004), and social support (Rolfson et al. 2006). While cut values such as those described by Hoover et al. 2013 and Montero-Odasso et al. (2005) have been established, most tools do not involve absolute measurement, for example weight, placing dependence on self-report, which has been associated with greater error (Prince et al. 2008, Shields et al. 2008). More importantly, most frailty assessment tools lack the sensitivity to examine discrete changes in an individual's frailty status, which may constrain early identification of frailty and dissociation of persons transitioning between stages of frailty. Functional performance assessment tools, such as the Continuous- Scale Physical Functional Performance Test (CS-PFP) (Cress et al. 1996), are capable of reflecting small changes in physical function in older adults through multiple domains. However, these tools do not yet describe the significant interaction between skeletal muscle and nervous systems change with functional decline, which are critical interactions in frailty progression (Theou et al. 2010).

Surface electromyography (EMG) provides a means of measuring muscle activity that governs movement and is strongly associated with functional performance (Roland et al. 2014). Electromyography provides an indication of overall muscle activity and is an effective method of identifying age-related changes in muscle function that lead to

functional decline, disability and frailty in older adults (Hardwood et al. 2008, Jakobi et al. 2008, Roland et al. 2014, Theou et al. 2010). Recent investigations have used EMG to quantify periods of muscle activity (bursts) and quiescence (gaps), to successfully compare muscle function in non-frail, pre-frail, and frail older adults during a nine-hour field assessment (Theou et al. 2010). Results suggested that there was less muscle quiescence between bursts of muscle activity in frail individuals, which was related to poor functional task performance and frailty status. However, it was unknown whether the differences in EMG detected between frailty groups was most evident in activities classified as BADL, IADL and AADL as recordings were made for eight-hour durations of everyday normal life. While serving as a useful predictor of frailty (Theou et al. 2010), its full-day sampling period is challenging for immediate assessment in the clinical setting. The measurement of EMG during specific functional tasks that represent the three groups of ADL, under controlled laboratory conditions, would enable identification of the threshold of sensitivity of EMG across various activities. Measurement of EMG during controlled tasks would also decrease testing duration and allow for a direct determination of thresholds of muscle activity across stages of frailty. This would assist in the determination of functional tasks that are sensitive to dissociating stages of frailty. No study has examined EMG during a set of discrete functional tasks for the purpose of frailty identification. Therefore, this study was designed to: a) Evaluate EMG differences between nine functional tasks, as each task becomes progressively more challenging to complete; b) Assess EMG during nine functional tasks across frailty phenotypes; and c) Determine whether a specific functional task, or progression of functional tasks, coupled with EMG, can identify non-frail, pre-frail, and frail older adults.

3.2 Methodology

Forty-nine non-frail, twenty pre-frail and seven frail older adult males and females aged 65 – 94 years participated in this study. This sample size is consistent with Roland et al. (2014) and Theou et al. (2010). Sixty-two were recruited from the local community and underwent testing in the Healthy Exercise and Aging Laboratory (HEAL) at UBC Okanagan. To access more frail persons, we conducted field assessments on fourteen older adults (73-94 years) living at a local assisted living facility. Fifteen middle-aged adults, aged 40-55 years, were included to examine how participants transition toward old age, and were used as a comparative between the frailty classifications. The exclusion criteria included: individuals unable to ambulate independently, those under the age of 65 years or over the age of 95 years, persons with current or previous neurological disorders, anyone engaged in physical activity greater than two times per week, and those unable to read or speak English fluently. A lifetime total physical activity (LT-PAQ) (Friedenreich et al. 1998) and Edinburgh handedness (Oldfield, 1971) questionnaires were administered. Written consent was obtained prior to participation in this study. Ethics was gained from the University of British Columbia Behavioral Research Ethics Board (H12-01560) (Appendix A), and in accordance with the Declaration of Helsinki.

3.2.1 Frailty Definition

The definition of frailty is controversial (Mitnitski et al. 2004, Sternberg et al. 2011), therefore, three frailty evaluation tools were used for this study: The Cardiac Health Study – frailty index (CHS-*fi*; Fried et al.2001), the Modified frailty index (Mod-*fi*; Theou et al. 2012), and gait speed (GS; Montero-Odasso et al. 2005). All participants

were classified according to each frailty assessment tool and evaluated to examine if differences between evaluation tools existed.

The CHS-*fi* assesses five physical criteria to determine a frailty phenotype classification, including: 1) Weight loss as a positive response to the question "In the last year, have you lost more than 4.5 kilograms (kg) (10 pounds) unintentionally (i.e., not due to dieting or exercise); 2) Reduced handgrip strength of the dominant hand using a hand-held dynamometer. Cut-off values were applied based upon body mass index (BMI ≤ 23, cutoff strength ≤ 17 kg; BMI 23.1-26 kg/m^2, cutoff strength ≤ 17.3 kg; BMI 26.1-29 kg/m^2, cutoff strength ≤ 18 kg; BMI > 29 kg/m^2 cutoff strength ≤ 21 kg); 3) Walking speed recorded over 4.6 meters (m) (15 feet). For males this was defined as ≥ seven s to perform the task when height was ≤ 173 centimetres (cm) or ≥ six s if height was > 173 cm. For females this was defined as ≥ 7 s when their height was ≤ 159 cm and ≥ 6 s when height was > 159 cm; 4) Physical activity assessment used a weighted score of kilocalories expended per week (kcal/wk) based upon participant's response to the short version of the Minnesota Leisure Time Activity Questionnaire. Cut-off values for males was < 383 kcal/wk) and for females this was defined as < 270 kcal/wk; and 5) An assessment of subjective fatigue was obtained relative to how the participant responds to the questions "How often in the last week did you feel that everything you did was an effort?" or "How often in the last week did you feel that you could not get going?" either for a moderate amount of the time or most of the time. Frailty phenotype was defined according to the number of criteria that the subject met across the five criteria (weight loss, handgrip, walking speed, physical activity, fatigue). The non-frail phenotype was

defined as meeting none of the criteria, one - two criteria was scored as pre-frail phenotype and three or more was defined as frail phenotype (Fried et al., 2001).

The Mod-*fi*, as described by Theou et al. (2012) provided a second assessment of frailty. This tool was derived from 54 physical deficits that might be reported within a health history questionnaire (Appendix, Table 2: Domains, measures and scores for the Mod-*fi*). A deficit was considered to be any symptom, disease, or disability that accumulates with age, and is associated with adverse outcomes. Variables were initially coded as deficits, which followed the convention of having a value of one when the deficit was present, and a zero value when it was absent. For example, absence of regular exercise was considered a deficit. Thus, it was coded as one if exercise was absent and zero if exercise was present. The number of recorded deficits was divided by the total deficits to give a Mod-*fi*. For example, if 10 deficits were present, the Mod-*fi* score was 10/54 = 0.19. A higher the score (closer to one) suggests a greater level of frailty. Although a useful indicator of frailty, the Mod-*fi* is comprised primarily from indirect measurements (i.e. self-report), which has been associated with greater measurement error (Prince et al. 2008, Shields et al. 2008). Due to validated cut points that were established by Hoover et al. (2013), the non-frail phenotype was defined as having a Mod-*fi* score less than or equal to 0.1, pre-frail phenotype defined as less than or equal to 0.21 and frail phenotype defined as greater than 0.21 (Hoover et al. 2013).

Gait speed, a direct measure of ambulatory performance is also a strong indicator of frailty status (van Kan et al. 2010). Participants were instructed to "walk as fast as possible" for a total of 4.6 m. A stopwatch was started when the participant began walking and was stopped when they crossed a 4.6 m marker. Two trials were given and

the fastest time to complete the task was then divided by 4.6 to give the final gait speed, which was measured in meters per second (m/s). The distance of 4.6 m or 15 feet was selected in accordance with the gait speed measurement used by Fried et al. (2001). While established cut-points predict incidence of adverse events in older adults (Montero-Odasso et al. 2005), no cut-points have yet been developed to identify the progressive stages of frailty. Individuals with a gait speed less than 1 m/s have the highest incidence of adverse events (van Kan et al. 2009), thus were used to identify frail participants. Due to the dispersion of the data as seen in Fig.3.3.1, further cut-points of 1.5 to 1.0 m/s and > 1.5 m/s were used to define non-frail and pre-frail phenotypes.

While CHS-*fi* has been used extensively in the literature (Theou et al. 2010, Roland et al. 2014), it has limitations; namely the cut-offs used to establish non-frail, pre-frail, and frail phenotypes. Current evidence suggests that assessing the accumulation of deficits and mobility are the best measures of frailty (Rockwood et al. 2004, van Kan et al. 2010). Gait speed and Mod-*fi* were therefore combined to establish frailty phenotype classifications. Non-frail were classified has having a gait speed of greater than 1.5 m/s and Mod-*fi* less than or equal to 0.1; gait speed of 1.5 to 1.0 m/s and Mod-*fi* less than or equal to 0.21 were classified as pre-frail; and gait speed less than 0.1 m/s and Mod-*fi* greater than 0.21 were classified as frail. In circumstances where individuals did not fit both Mod-*fi* and gait speed criteria, gait speed was then used for frailty phenotype classification.

3.2.2 Data Collection

Surface electrodes were placed on the biceps brachii, triceps brachii, vastus lateralis, and biceps femoris. Subsequent to electrode placement maximum voluntary

exertions (MVE) were executed for each muscle and EMG was recorded for these efforts. Participants were randomly allocated to complete sequences of three task groups (mobility, laundry and food). Each group had a series of progressively more challenging functional tasks (nine tasks total). Tasks were completed in order from easiest (BADL), to more challenging (IADL), to most difficult (AADL). A second MVE was executed at the end of the testing session to ensure integrity of the recording electrodes. Participants, who completed the testing at the assisted care facility, completed the same procedures as mentioned above.

3.2.3 Experimental Set-Up

Electromyography

Muscle activity and quiescence were measured with a portable surface EMG device (Biometrics DataLOG P3X8, Gwent, UK). The skin of the arm and thigh at the position of the desired muscle was exfoliated with 70% isopropyl alcohol swabs and low friction cleansing pads. Biometrics SX230 electrodes (Gwent, UK) were placed mid-belly of two major arm muscles (biceps brachii, and triceps brachii) and two major thigh muscles (vastus lateralis, and biceps femoris) with an inter-electrode distance of 20 mm. Electrodes were placed on both right and left limbs. Electrodes were adhered with Hypafix™ (BSN Medical Ltd., Laval, Canada). High conductivity electrode cream (Signa Creme, New Jersey, USA) was used with the reference electrode (R200, Biometrics), which was positioned on the lateral malleolus of the fibula. The cables from the electrodes were taped to the skin with Hypafix™, placed into the data logger (9.5 x 15.8 x 3.3 cm; 380 g) and the portable EMG unit was secured to a belt worn at the waist. Signals were sampled at 1,000 Hz, amplified (1,000x), band-pass filtered (20-450

Hz), and stored for offline analysis on a 512 MB MMC flashcard.

Fig. 3.2.1: Portable EMG Set-up. An image of the portable EMG set up during the experiment. The electrode wires were taped and fed through the participant's clothing. The portable EMG was placed on the right hip, and secured around the participant's waist.

3.2.4 Experimental Protocol

MVE Task

Isometric maximal voluntary exertions (MVE) were performed for the four muscles (vastus lateralis, biceps femoris, biceps brachii, triceps brachii) in order to normalize the functional task EMG recordings to a percentage of the participant's maximum EMG. Right and left arms and legs were tested. Verbal encouragement was provided during all maximal efforts (Simoneau et al. 2007). The MVE was recorded in the seated position during isometric knee and elbow extension and flexion against resistance performed manually by the same researcher who had extensive experience in assessing these MVE. The knee and elbow joint was bent to ~90° during the MVE of the thigh and arm muscles, respectively. Each muscle was tested in a randomized order two

times and each contraction was held for five seconds. Failure to maintain proper position warranted additional attempts until correct position was maintained throughout their maximal effort. The greater of the two trials was used for normalization of the functional task EMG data.

Functional Tasks

Functional tasks in this experiment were similar to those performed in the continuous-scale physical functional performance test (CS-PFP) (Cress et al. 1996). They consisted of nine everyday tasks that represent activities essential to independent living. Common activities were chosen to minimize the effects of learning or strategizing. The nine tasks were separated evenly into three domains, synonymous with common ADL: 1) Food; 2) Laundry; and 3) Mobility. For each group, the tasks were rank ordered for difficulty from easiest (BADL), to more challenging (IADL), to most difficult (AADL) (Fig. 3.2.2). Participants were asked to perform each task at their own pace and to the best of their capability. Each task was performed twice; however, failure to perform the task correctly resulted in a re-trial. Each domain was randomized. Within each group, participants performed the tasks in order of progressing difficulty (BADL, to IADL, to AADL). This was done to determine changes in muscle activity and quiescence with increased ADL difficulty, and if a threshold existed for discriminating frailty. The average time required to complete all nine functional tasks was approximately 30 minutes.

Physical activity (PA) was measured using an ActiTrainer accelerometer (Actigraph, LLC, Fort Walton Beach, FL) worn on the waist on the right side. The ActiTrainer (8.6 x 3.3 x 1.5 cm; 51 g) is a tri-axial solid-state accelerometer that was

programmed to record 60 s epochs of data. The data was downloaded into the ActiLife software (Actigraph, LLC, Fort Walton Beach, FL) and exported into Microsoft Excel spreadsheets for subsequent analysis. Physical activity intensity values were expressed as PA counts, which are defined by 30 Hz acceleration to 1 Hz PA count. PA counts were time locked to correct for differences in performance time. Equipment, procedures, instructions and measurement protocols were identical between sessions.

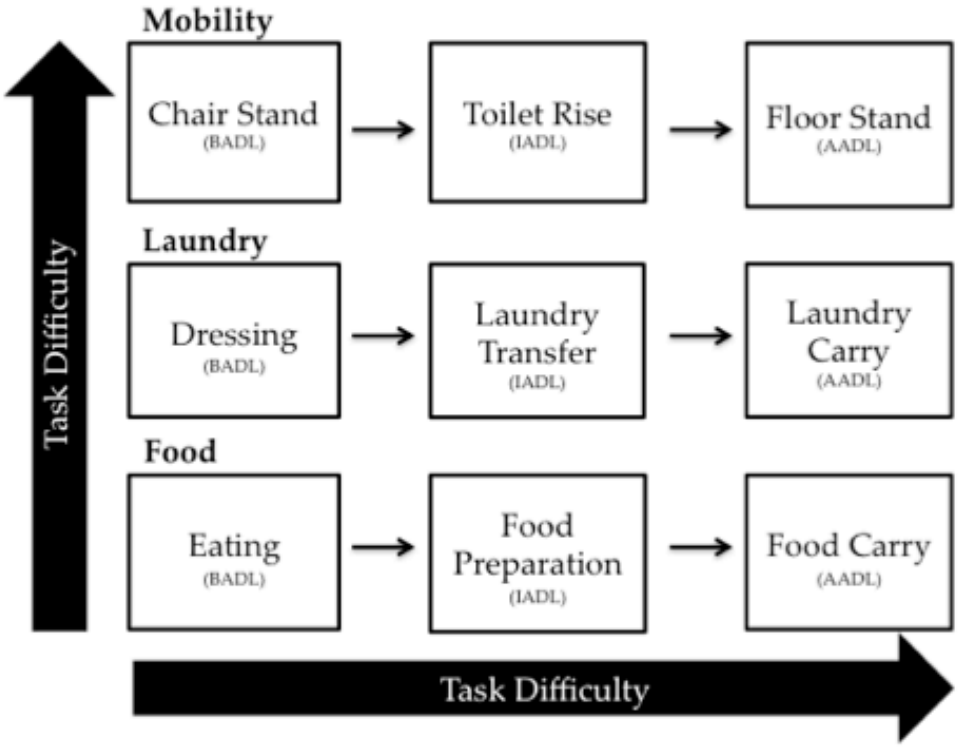

Fig. 3.2.2: Progressive ADL tasks. ADL task progression increased in difficulty starting with food domain being the easiest, and mobility domain being the hardest to perform (vertical increase in difficulty between tasks). Within each task group there was also progressive difficulty (horizontal progression); ADL, activities of daily living; BADL, basic activities of daily living; IADL, instrumental activities of daily living; AADL, advanced activities of daily living

Tasks quantified under the food domain in order from easiest to most difficult included: 1) Eating a total of six "spoonfuls" of canned soup using their dominant hand and two "bites" of bread using their dominant hand; 2) Food preparation required

opening a 540 mL can of soup using a non-electronic hand can opener, pouring the contents of the can of soup into a pot, lifting and moving the pot 68 cm to a marked burner on the simulated stove top (56 cm x 76 cm x 92 cm), turning on the stove, stirring the soup five rotations with a wooden spoon, turning off the stove, and returning the pot to a marked square on the counter; and a 3) Food carry task that required holding onto a cloth shopping bag, placing seven 540 mL soup cans from the table into the shopping bag (3.78 kg), walking two m, placing the shopping bag with soup cans onto a marked square on the counter, and placing all seven soup cans onto a shelf that was located 51 cm above the counter.

Tasks that were measured under the laundry domain included: 1) Dressing into a button-up shirt (male shirt had right sided buttons; female shirt had left sided buttons) that was lifted from a hook placed 125 cm up a wall, buttoning the shirt (8 buttons) unbuttoning the shirt, and placing the shirt back onto the hook (167 cm); 2) Laundry transfer required the participant to open a front loading washing machine (58 cm x 52 cm x 80 cm), transferring a load of towels (0.5 kg) 70 cm from the washing machine into a front loading dryer (83 cm x 59 cm x 55 cm), and closing the washing machine and dryer doors (31 cm off the floor) when completed; and the 3) Laundry carry that required participants to pick-up a laundry basket (65 cm x 43 cm) containing a load of towels (5.3 kg) from the floor, walk- up one flight of stairs (11 stairs x 16.5 cm x 30.5 cm each), turnaround while still holding onto the laundry basket, carrying the laundry basket back-down the flight of stairs, and placing the laundry basket back onto the floor. Tasks that were quantified under the mobility domain included: 1) Standing from a chair (44 cm x 48 cm x 44 cm) with arm rests, walking three m, turning around, walking back three m

towards the chair, and sitting back into the chair; 2) Toilet Rise from a standard height (41 cm x 36 cm x 40 cm) toilet, walking three m, turning around, walking back three m towards the toilet, and sitting back onto the toilet; 3) Floor Stand from a seated position on the floor, walking three m, turning around, walking back three m to the initial starting point, and sitting back onto the floor.

3.2.5 Data Analysis

All EMG data during the MVE and functional task testing were imported into Biometrics software (Biometrics DataLog version 3, Gwent, UK) for preliminary visual inspection and subsequently into Spike 2 Version 6 (Cambridge Electronics Design, Cambridge, UK) for analysis with custom scripts. Data artefacts, which arose from contact with the electrodes or device worn at the hip, were manually removed across all eight channels in a time-locked fashion. Signals were rectified, smoothed at a time constant of 0.01 s and down-sampled by a factor of 100. Bursts and gaps in the EMG signal were computed to quantify muscle activity and quiescence during each functional task. Bursts were defined as a period of EMG activity greater than 2% of MVE for duration longer than 0.1 s. The individual bursts were used to calculate the number of bursts, mean duration of each individual burst (s); average peak amplitude of all bursts (% MVE) and burst percentage (burst percent). Gaps were quantified as a period of EMG less than 1% of MVE for duration longer than 0.1 s (Harwood et al. 2011). The individual gaps were used to calculate the number of gaps, mean duration of each individual gap (s), and gap percentage (percentage of total time occupied by gaps).

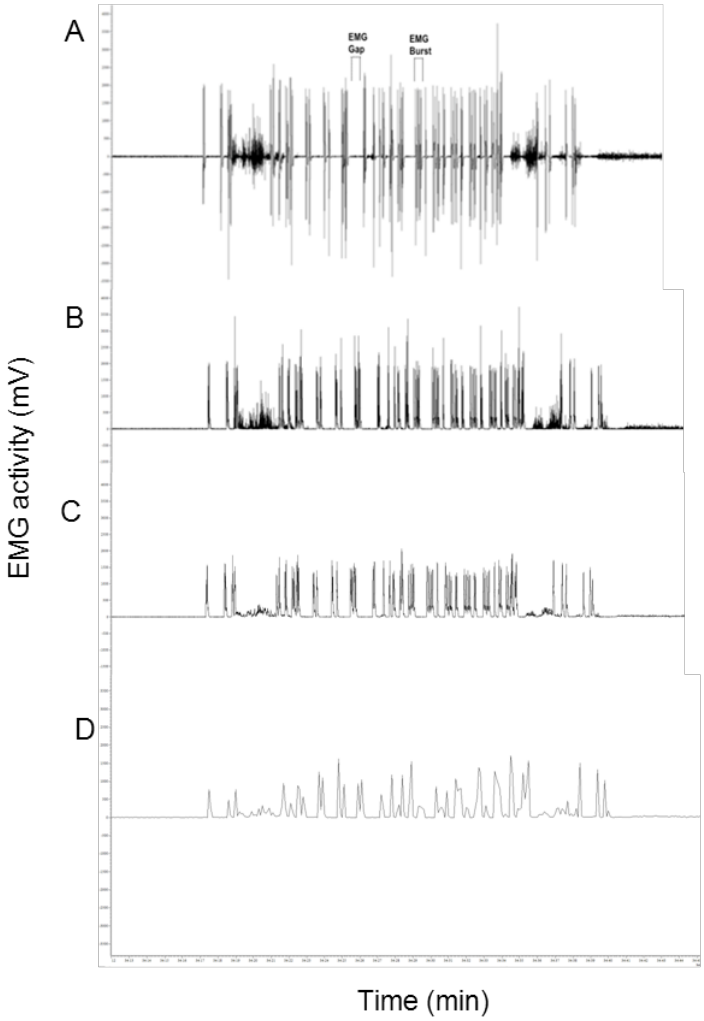

Fig. 3.2.3: Representative Burst and Gap Recording and Processing. A representative EMG recording from the left TB of an 81 year old non-frail male during the floor task. Interference EMG (A), rectified (B), smoothed (C), and down sampled (D); TB, triceps brachii; EMG, electromyography; mV, millivolt

3.2.6 Statistical Analyses

All statistical analyses were conducted with Statistical Package for Social Sciences (SPSS) version 20.0. A probability for significance was set at an Alpha level of 0.05 for all analyses. All data are presented as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) examined baseline characteristics (age, height, and weight, number of comorbidities and medications, and muscle strength) between the

middle-aged group and the older adult group. The older adult group was segregated into three phenotype groups' based-upon further frailty classification: (1) Non-frail; (2) Pre-frail; and (3) Frail.

A one-way ANOVA was used to examine nine variables in muscle activity and functional tasks. Burst and gap characteristics between groups for each ADL group and individual tasks were evaluated using 1 x 3 and 1 x 9 ANOVA respectively.

A 1 x 4 (task x group) ANOVA was used to examine differences between burst and gaps characteristics across middle-aged and non-frail, pre-frail and frail older adults phenotypes for each of the nine functional tasks.

Discriminant analysis determined which of the nine functional tasks, completed within a task group best-classified frailty. The analyses involved the determination of a linear equation like regression that predicted which task predicts frailty phenotype allocation. All EMG burst and gap characteristics were assessed individually for each of the three ADL groups. The analysis was first performed with upper and lower limb muscle groups combined. The same analysis was then performed independently for the upper and lower limb muscle groups. Finally, values, which discriminate classification results of greater than 70%, were separated by sex to determine if males or females were more sensitive to the influence of EMG changes upon functional task performance and frailty phenotype allocation. The functional tasks and muscle activity characteristics that provided the highest correspondence of real and predicted group allocations were used and reported in the results section.

Scores were computed from each of the above discriminant functions. A one-way ANOVA and pairwise comparisons of the frailty groups on the discriminant function

scores were then used to support the above findings. The linear combinations and pairwise comparisons from the discriminant function with the largest effect were reported.

A 4 x 9 (group x task) repeated measures MANOVA was used to determine differences between recorded physical activity counts between groups. This data was used to support the differences in EMG found between middle-aged and older adult groups.

Finally, a discriminant analysis was run to determine if all BADL, IADL and AADL tasks individually were required for frailty allocation. This data was used to determine if there is a minimal threshold of PA counts coupled with EMG to distinguish differences found in middle-aged and older adult phenotypes.

3.3 Results

3.3.1 Frailty Classification and Participant Characteristics

Participants were classified according to the frailty phenotype (Fried et al. 2001), where 52 older adults were classified as non-frail, 22 as pre-frail, and two as frail (Table 3.3.1). However, it was apparent that some participants tested at the assisted care facility were misclassified as pre-frail as they opted not to report fatigue. This was likely due to the most challenging tasks being physically adapted (raised toilet seats, ground level housing) and facility staff executing these tasks for the older adult (weekly housekeeping). This assistance enables these residents to remain independent within their assistive environment. However, these individuals would be unable to thrive

independently in the community and would likely be classified as frail and rather than pre-frail.

Due to the assistive support offered participants that influenced perceptions of fatigue frailty status was re-classified using gait speed (Montero-Odasso et al. 2005) and modified frailty index (Mod-*fi*), which are known to be more objective tools (Hoover et al. 2013, Theou et al. 2012) (Fig. 3.3.1). Forty-nine older adults were classified as non-frail, 20 as pre-frail, and seven as frail (Table 3.3.1). Non-frail had a faster gait speed, lower Mod-*fi* score, and stronger grip strength than pre-frail and frail ($p < 0.001$) phenotypes. Pre-frail had a faster gait speed, lower Mod-*fi* score, and stronger grip strength than frail ($p < 0.001$) phenotype (Table 3.3.2). Non-frail were younger than pre-frail and frail in age ($p < 0.001$) but pre-frail did not differ from frail. Non-frail and pre-frail were taller than frail ($p < 0.05$). Weight and BMI were similar among the four groups ($p > 0.05$).

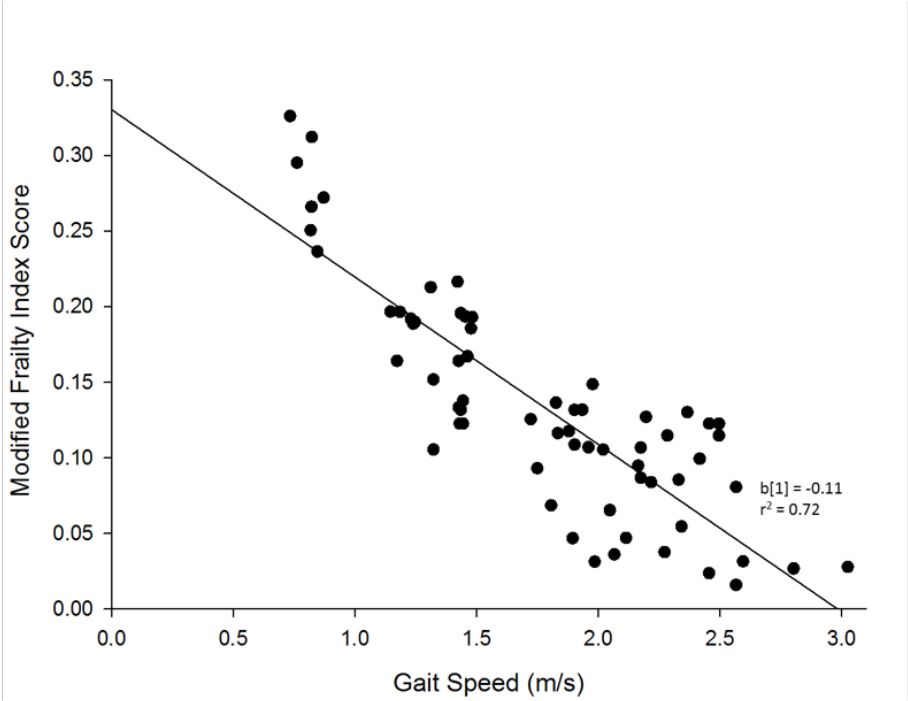

Fig. 3.3.1 Gait speed and FI-*mod* scores used for frailty classification. Non-frail were classified with a gait speed > 1.5 m/s and frailty index score ≤ 0.1; pre-frail were classified with a gait speed 1.5 to 1.0 m/s and frailty index score > 0.1 to ≤ 0.21; frail were classified with a gait speed < 1.0 m/s and frailty index score ≥ 0.21; m, meters; s, second

Table 3.3.1 Frailty Status: Number of participants classified per frailty assessment tool

Classification	Non-frail	Pre-frail	Frail
CHS-*fi*	52	22	2
Gait Speed	51	18	7
Mod-*fi*	43	26	7
Gait Speed and Mod-*fi* Combination	49	20	7

CHS-*fi*, Cardiovascular Health Study frailty index; Mod-*fi*, modified frailty index

Table 3.3.2 Participant Characteristics

Characteristics		Frailty Classification		
	Middle-Aged (*N* = 15)	**Non-frail (Gait Speed > 1.5 m/s; Mod-*fi* ≤ 0.1)** (*N* = 49)	**Pre-frail (Gait Speed 1.0– 1.5 m/s; Mod-*fi* > 0.1 to ≤ 0.21)** (*N* = 20)	**Frail (Gait Speed < 1.0 m/s; Mod-*fi* ≥ 0.21)** (*N* = 7)
Age (years),	49 ± 5	73 ± 6	83 ± 6	87 ± 3*
Sex (male/female)	8/7	21/28	7/13	0/7
Height (cm),	169.6 ± 0.09	168.7 ± 0.08	164.6 ± 0.09	154.3 ± 0.04*
Weight (kg),	74 ± 16	75 ± 15	72 ± 15	64 ± 15
Body mass index,	27.5 ± 8.1	26.2 ± 4.7	26.6 ± 4.8	26.8 ± 5.8
Modified Frailty Index Score, mean ± SD	N/A	0.08 ± 0.04	0.18 ± 0.05	0.28 ± 0.04**
Grip strength (kg),	48.82 ± 15.26	34.57 ± 9.31	23.41 ± 8.1	15 ± 4.8*

m, meters; s, seconds; *N*, number; cm, centimeters; Nm, newton-meters; kg, kilograms; MVE, maximal voluntary exertion; BB, biceps brachii; TB, triceps brachii; VL, vastus lateralis; BF, biceps femoris; * Significantly different from non-frail;
** Significantly different from non-frail and pre-frail ($p < 0.05$)

3.3.2 Task Progression

Muscle Activity

Getting-up from a chair in the mobility ADL category had a shorter burst duration than the toilet task, and a lower peak amplitude, burst percentage, and burst number than the floor task ($p < 0.05$). The toilet task had a shorter burst duration, lower peak amplitude, burst percentage, and burst number than the floor task ($p < 0.05$). There was no difference in burst duration between the chair and floor task, and no difference in peak amplitude, burst percentage, and burst number between the chair and toilet tasks ($p > 0.05$).

Within the laundry ADL, dressing exhibited shorter burst duration, lower peak amplitude, and fewer bursts than the transfer task ($p < 0.001$), while burst number was higher in dressing than the laundry carry task ($p < 0.001$). The transfer task had shorter burst duration, smaller peak amplitude, burst percentage, and greater burst number than the laundry carry task ($p < 0.05$). No differences were observed in burst duration between the dressing and carry tasks or for burst percentage between the dressing and transfer tasks.

Eating within the food ADL task grouping exhibited shorter burst duration, lower burst percentage, and fewer burst numbers than the food preparation ($p < 0.001$) and food carry task ($p < 0.001$). No differences were observed in burst duration, burst percentage, and burst number between the food preparation and food carry task ($p > 0.05$). There was no difference in peak amplitude between the eating, food preparation, and food carry tasks ($p > 0.05$).

Muscle Quiescence

Getting up from a toilet had a higher gap percentage than getting up off the floor within the mobility ADL task group ($p < 0.05$). The chair task exhibited no differences in gap percentage between the toilet and floor task ($p > 0.05$). There were no differences in overall gap characteristics, gap duration, and number of gaps between chair, toilet, and floor tasks ($p > 0.05$).

Gap duration was longer, burst percentage higher and the number of gaps greater in the dressing task than the transfer and laundry carry task within the mobility task grouping ($p < 0.001$). The transfer task had longer gap duration, higher gap percentage, and greater number of gaps than the laundry carry task ($p < 0.05$).

Eating exhibited longer mean gap duration, higher gap percentage, and greater number of gaps than the food preparation and food carry task ($p < 0.001$). The food preparation task had longer mean gap duration, higher gap percentage, and greater number of gaps than the food carry task ($p < 0.05$).

3.3.3 Phenotype differences

Muscle Activity

As the task progression increased within each ADL group, the net muscle activity increased from middle-aged to frail. For all tasks except dressing and laundry transfer, the number of bursts for the middle-age group were lower than that recorded in the frail group. With the exception of the floor and laundry carry tasks, mean burst duration in the middle-age group was lower than frail. The percentage of bursts and mean peak amplitude recorded for all tasks was less in middle-aged than frail. Non-frail exhibited a

smaller number of bursts than frail during toilet, floor, laundry transfer, laundry carry, and eating tasks. During the chair, toilet, and eating tasks non-frail had shorter mean burst duration than frail. Mean peak amplitude recorded for all tasks was less in non-frail than frail. For all tasks except laundry carry, eating, and food carry, mean peak amplitude was less in non-frail than pre-frail. For all tasks except the laundry transfer task, burst percentage was smaller in non-frail than frail. Pre-frail was found to have a smaller number of bursts than frail during toilet, floor, and food carry tasks. Pre-frail exhibited less mean burst duration than frail during the laundry carry task. Mean peak amplitude recorded for all tasks was less in pre-frail than frail. The percentage of bursts for chair and toilet tasks was less in pre-frail than frail ($p < 0.05$) (Fig. 3.3.4).

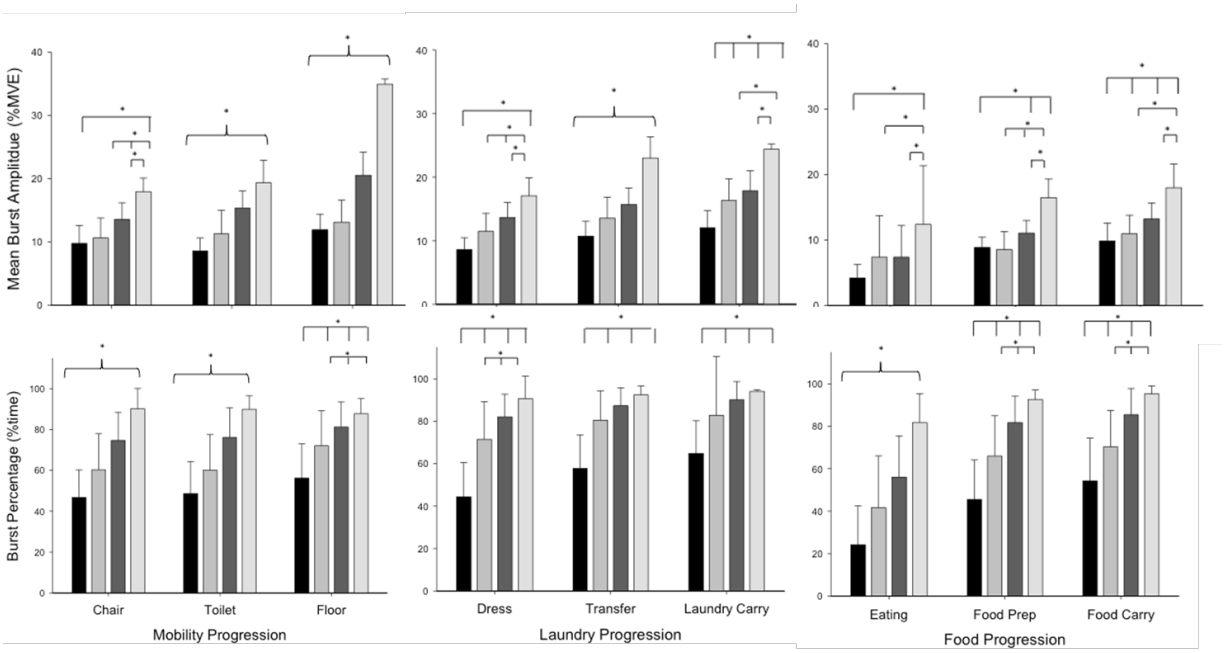

Fig. 3.3.4 ADL differences in burst amplitude and percentage across groups. The graph progression was reorganized vertically, thus the task progression increased within each ADL group (vertical), the mean burst amplitude and burst percentage increased from middle-aged to frail. Middle-aged (black bars), Non-frail (medium grey bars), pre-frail (dark grey bars) and frail (light bars) during the mobility tasks. %, percent, MVE, maximum voluntary exertion.*, significantly different ($p < 0.05$)

Muscle Quiescence

For all tasks except the laundry carry tasks middle-aged had more gaps than frail. Similarly, non-frail recorded more gaps during chair, toilet, eating, and food preparation tasks than frail. During all nine tasks middle-aged experienced greater mean gap duration than frail and non-frail and also had greater mean gap duration for all tasks except for the floor, laundry transfer, and laundry carry tasks than frail (Fig. 3.3.5). The percentage of gaps recorded for all tasks was greater in middle-aged than frail. Non-frail experienced greater gap percentage for chair and toilet tasks ($p < 0.05$)

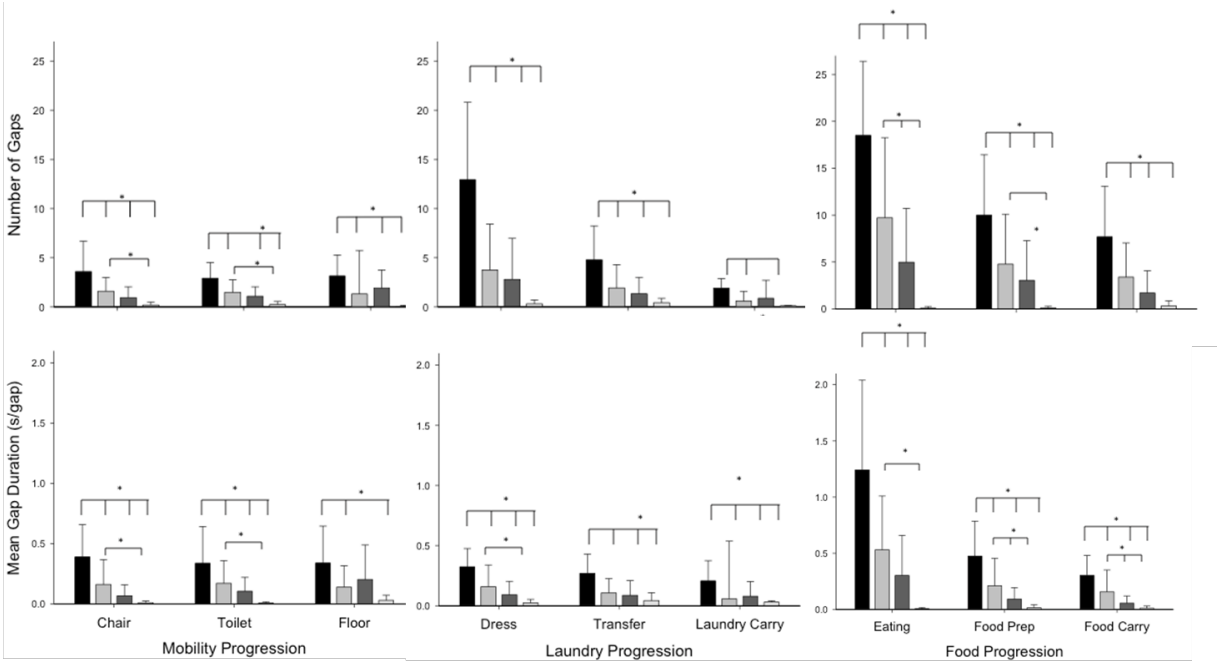

Fig . 3.3.5 ADL differences in number of gaps and mean gap duration across groups. As the task progression increased within each ADL group, the number of gaps and mean gap duration decreased from middle-aged to frail. Middle-aged (black bars), Non-frail (medium grey bars), pre-frail (dark grey bars) and frail (light bars) during the mobility tasks. s, seconds. *, significantly different ($p < 0.05$)

3.3.4 Task Identification in Frailty

Discriminant analysis determined that overall, the phenotypes differentiated among the three progressive ADL groups accounted for muscle activity ($\Lambda = 0.361$, χ^2 (9) = 83.005, $p < 0.001$) and for quiescence ($\Lambda = 0.501$, χ^2 (9) = 54.897, $p < 0.001$). Closer analysis of the structure matrix however revealed only two significant predictors, namely mobility ADL (muscle activity = 0.961, quiescence = 0.926) and laundry ADL (muscle activity = 0.872, quiescence = 0.888).

When testing the three progressive ADL groups individually, discriminant analysis indicated that phenotype allocation (i.e., middle-aged, non-frail, pre-frail or frail) was best predicted by number of gaps recorded in the upper limb muscles during mobility ADL (rising from the floor, toilet and chair), where 80.2% (kappa= 0.685) of the original grouped cases were correctly classified in this sample (middle-aged 11/15, non-frail 44/49, pre-frail 12/20, frail 6/7). Three discriminant functions were revealed; the first included all three mobility tasks, which explained 89.7% of the variance, canonical R^2= 0.539, whereas the second, containing only the chair and floor task, explained 6.7%, canonical R^2= 0.173, and the third, containing just the chair task, explained 3.6%, canonical R^2= 0.127. In combination, these discriminant functions significantly differentiated frailty phenotype groups ($\Lambda = 0.677$, χ^2 (9) = 33.746, $p < 0.001$).

To determine if sex had an influence on frailty phenotype allocation with number of gaps, a discriminant analysis was performed separately for males and females. There were no frail males in this study; therefore the analysis was conducted for middle-aged, non-frail, and pre-frail males only. All of the male subjects in this sample were correctly classified (kappa=1.00) and females were correctly classified 81.8% for the original

grouped cases (middle-aged 7/7, non-frail 24/28, pre-frail 8/13, frail 6/7) (kappa= 0.731) (Fig. 3.3.2).

Discriminant function scores were computed on the first function (mobility structure matrix = 0.961). The discriminant functions revealed a frailty phenotype effect in males (η^2=0.274, 95% CI [-0.208, 0.554], $p < 0.001$), and females (η^2=0.420, 95% CI [-0.077, 0.557], $p < 0.001$). For males, pre-frail (1.19 ± 1.797) had greater discriminant scores than non-frail (-0.228 ± 0.544) (95% CI [-2.484, -0.341], $p < 0.05$), and middle-aged (-0.439 ± 1.048) (95% CI [-2.894, -0.354], $p < 0.05$). For females, frail (1.506 ± 0.554) had greater discriminant scores than non-frail (-0.348 ± 0.564) (95% CI [0.873, 3.112], $p < 0.001$), and middle-aged (-0.567 ± 1.086) (95% CI [0.774, 3.613], $p < 0.05$); pre-frail (1.114 ± 1.861) exhibited greater scores than non-frail (95% CI [0.5334, 2.316], $p < 0.05$), and middle-aged (95% CI [0.378, 2.868], $p < 0.05$).

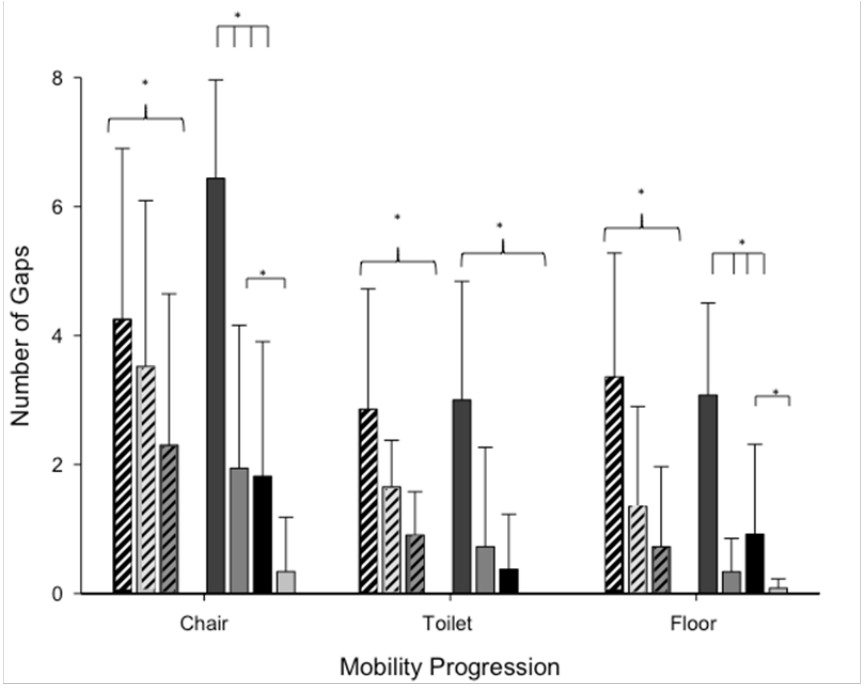

Fig. 3.3.2 Mobility ADL differences in number of gaps of the upper limbs between males and females. Pre-frail males had a lower gap number than middle-aged and non-frail. Frail females had a lower gap number than middle-aged and non-frail. The first three columns of each task are males and the second groupings of four bars in each task are females. Black bars for males represent middle-aged, light bar = non-frail, darker grey = pre-frail. For females, darker grey = middle-aged, medium-grey = non-frail, black = pre-frail, light grey= frail. *, Significantly different ($p < 0.05$)

Discriminant analysis also indicated that frailty group allocation (i.e., middle-aged, non-frail, pre-frail or frail) was predicted by burst amplitude in the lower limbs during the mobility tasks, where 72.5% (middle-aged 10/15, non-frail 37/49, pre-frail 14/20, frail 5/7) (kappa= 0.563) of the original grouped cases were correctly classified in this sample. Three discriminant functions were revealed; the first included all three mobility tasks and explained 88.8% of the variance, canonical R^2= 0.459, whereas the second, containing only the chair and toilet task, explained 8.1%, canonical R^2= 0.154, and the third, using only the toilet task, explained 3.1%, canonical R^2= 0.096. In combination, these discriminant functions differentiated the groups ($\Lambda = 0.764$, $\chi^2 (9) = 23.310$, $p < 0.05$).

To determine if sex had an influence on frailty allocation with burst amplitude, a discriminant analysis was performed separately for males and females. For males, 77.8% (middle-aged 6/8, non-frail 16/21, pre-frail 6/7) (kappa= 0.625) of the original grouped cases were correctly classified in this sample. For females, 78.2% of original grouped cases were correctly classified (middle-aged 6/7, non-frail 22/28, pre-frail 10/13, frail 5/7) (kappa= 0.674) (Fig. 3.3.3).

When run for BADL, IADL, and AADL tasks separately, discriminant analysis indicated that the eating task was not required for group allocation for the BADL. Chair stand and dressing BADL tasks collectively differentiated the groups ($\Lambda = 0.873$, $\chi^2 (9) = 11.775$, $p= 0.006$). For IADL and AADL tasks, all were required for group allocation ($p > 0.05$).

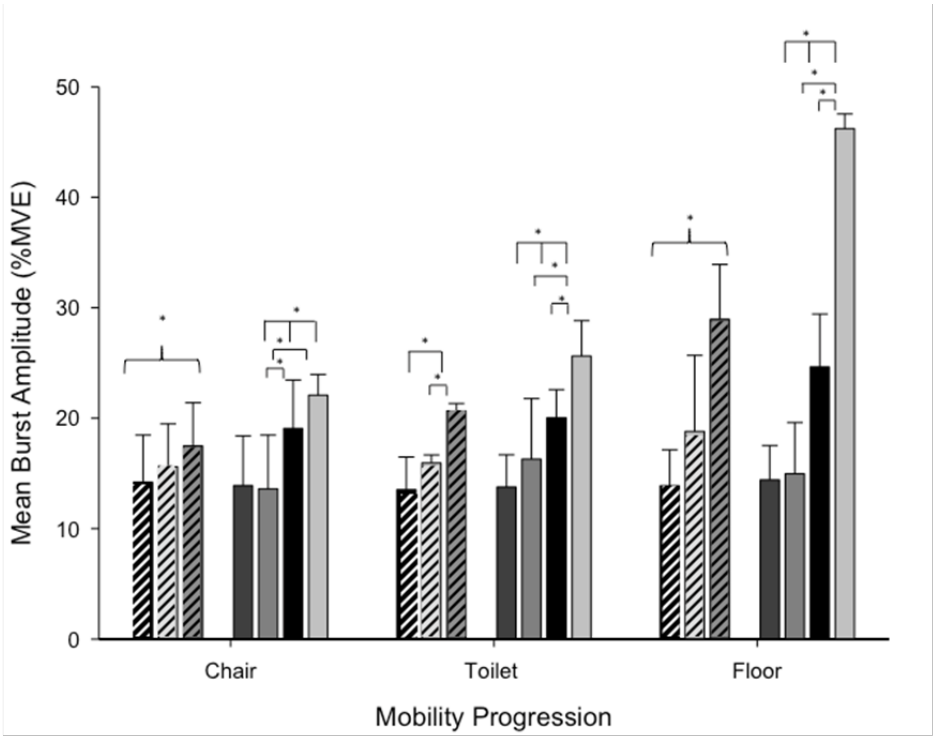

Fig. 3.3.3 Mobility ADL differences in burst amplitude of the lower limbs between males and females. Pre-frail males had higher mean burst amplitude than middle-aged and non-frail. Frail females had higher mean burst amplitude than middle-aged and non-frail. The first three columns of each task are males and the second grouping of four bars in each task are females; Black bars for males represent middle-aged, light bar = non-frail, darker grey = pre-frail. For females, darker grey = middle-aged, medium-grey = non-frail, black = pre-frail, light grey= frail. %, percent, MVE, maximum voluntary exertion. *, Significantly different ($p < 0.05$)

3.3.5 Accelerometer Data

The two-way interaction between groups (middle-aged, non-frail, pre-frail and frail) and task (chair, toilet, floor, dress, transfer, laundry carry, eating, food preparation, and food carry) was significant ($p < 0.05$). Overall, the middle-aged group recorded greater physical activity (PA) counts than non-frail, pre-frail, and frail groups ($p < 0.001$), and non-frail and pre-frail groups had greater activity counts than frail participants ($p < 0.05$) for all functional tasks. There were no differences in PA counts observed between the non-frail and pre-frail groups ($p > 0.05$). Greater PA counts were recorded across all

mobility tasks compared with the laundry and food tasks ($p < 0.001$). The laundry tasks required greater PA counts than food tasks ($p < 0.001$) (Fig. 3.3.6)

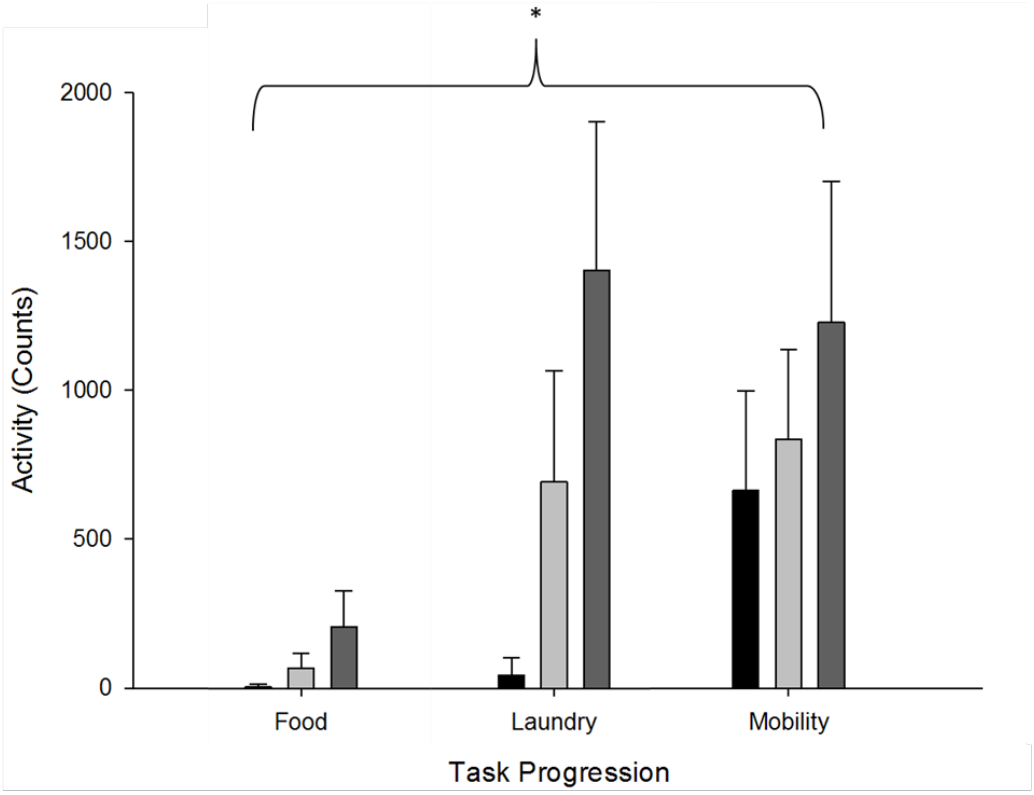

Fig. 3.3.6 ADL group differences in accelerometer counts. PA for BADL, IADL, and AADL with middle-aged and frailty groups combined. Three AADL tasks of floor, laundry carry, and food carry, had a greater PA count than BADL tasks of chair, dressing, and eating. IADL tasks of toilet, laundry transfer, and food preparation had a greater PA count than BADL tasks. Mobility ADL had greater PA counts than laundry and food ADL and laundry had greater PA counts than food ADL. Easiest group (black bars), moderate tasks (light shaded bars), and difficult tasks (medium shaded bars) during the mobility, laundry and food ADL. *, Significant ($p < 0.05$)

3.4 Discussion

The purpose of this thesis was to compare low threshold EMG between middle-aged, non-frail, pre-frail and frail older adults during a set of discrete functional tasks and to determine whether a particular task or set of progressive tasks could predict frailty in older males and females. Results from this study corroborates previous investigations

reporting that EMG burst activity increased and gap frequency decreased as persons progressed from non-frail to frail. However, data from this current study extends prior work as this is the first study to measure EMG activity across progressive ADL, where EMG burst activity was observed to increase and gap activity decrease as tasks became progressively more difficult. The most interesting observation from this study is that frailty phenotype allocation was best predicted by number of gaps in the upper limbs and burst peak amplitude in the lower limbs during mobility tasks; particularly when groups were separated by sex. Thus, this study is to our knowledge the first to indicate that EMG is sensitive to discriminating sex-differences between non-frail, pre-frail, and frail individuals. Undertaking progressive mobility tasks coupled with low-threshold EMG is an achievable measure that when used in a clinical setting is likely to assist in frailty identification.

3.4.1 Task Progression

This is the first study to compare muscle activity and quiescence between tasks that progress in difficulty across three domains BADL, IADL and AADL. Burst activity increased and quiescence decreased as the functional tasks progressed from BADL to AADL irrespective of whether the task was within the eating, laundry or mobility ADL domain. In the mobility domain, differences in EMG burst activity were observed between all three task progressions of standing from a chair, rising from a toilet, and getting-up off the floor. The increase was not due to walking as all tasks involved a three m walk and return to place of origin. The increase in muscle activity occurred due to advancing the workload between tasks by standing from a standard height chair, rising from a toilet and ultimately getting-up of the floor. The increase in muscle activity

relative to greater task demand was demonstrated across burst variables. For example, the toilet task exhibited burst durations 15% longer than the chair task. When completing the floor task participants exhibited increased burst duration (10%), larger mean peak amplitudes (25%), burst percentage (5%), and number of bursts (33%) than chair and toilet tasks. The toilet was four cm lower than the chair and no assistive devices (grab bar, chair arms) were allowed, while the distance between toilet and floor was 40 cm. Thus, as the task progressed in difficulty due to lifting body weight from a lower position muscle activity also increased. Physical activity data paralleled the EMG results. Easier tasks were detected as fewer PA counts compared with the more challenging tasks and this was evident both within task groupings (BADL, IADL, AADL) as well as between task domains (eating, laundry, mobility. Therefore, the increase in EMG paralleled the PA data.

Increased muscle activity was not only evident in the burst variables but fewer gaps were also observed. For example, there were fewer EMG gaps and when present they were of shorter duration for more challenging tasks. When completing IADL tasks participants exhibited 42% shorter gap duration than BADL tasks, and when performing AADL tasks, participants had 16% shorter gap duration than IADL tasks. These findings, across the three progressions of ADL demonstrated that as the difficulty to execute a task increased there was an increased demand placed upon the neuromuscular system to execute the movement. Laboratory studies clearly indicate that EMG increases as the load of isometric and anisometric contractions increase (Bigland-Ritchie et al. 1981, Kyröläinen et al. 2005, Moritani and Muro 1987). Data from our laboratory (Cornett 2013) from controlled lab-based movements have also identified that as task complexity

increases motor unit recruitment is earlier and discharge rates higher. Because contractile force is governed by a specific recruitment sequence in order of increasing motor neuron and motor unit (MU) size (DeLuca et al. 1982, Henneman et al. 1965, Milner-Brown et al. 1973) that is coupled to a linear increase in discharge rates (Kukulka et al. 1981), it is likely that the changes observed in surface EMG reflect underlying activity of MUs. It is important to acknowledge that the above studies were performed during standardized laboratory tasks. The results from the current study were able to demonstrate that the relationship of EMG to force not only applies to these controlled tasks but also to functional activities of daily life.

3.4.2 Frailty

Muscle activity was found to increase and quiescence decreased in frail compared with middle-aged and non-frail older adults, which is consistent with the literature (Theou et al. 2010, Roland et al. 2014). Previous work where EMG was recorded over an entire day indicates that frail older adults exhibit greater burst duration (Theou et al. 2010) and fewer gaps than non-frail older adults (Roland et al. 2014), which was also observed in this study. Relative strength differences between the groups likely contributed to the observation of greater muscle activity in frail. Frail were found to have 69% lower grip strength than middle-aged, 57% lower than non-frail, and 34% lower than pre-frail. The loss of motor units (Kaya et al. 2013), and sarcopenia (Morley et al. 2001) with advancing age contributes to muscle weakness exhibited by older adults. Decreased strength likely resulted in the frail having to work at a higher workload, which was detectable through EMG burst and gap analysis, in order to perform the same tasks as pre-frail, non-frail and middle-aged.

Longer duration of bursts in frail might be attributed to rate of movement. Frail were found to take 46% longer than middle-aged, 45% longer than non-frail and 34% longer than pre-frail older adults to complete the mobility tasks. This effect of time was supported by the PA counts that were expressed by frail in comparison to non-frail. Counts were registered based on the rate of movement for each task. The faster the participant was able to move, the more counts were registered. Thus, the slower movements and longer task durations were detected as lower PA counts and this was evident in frail. Fast velocity movements are known to be affected by aging more than slow velocity movements (Candow and Chillibeck, 2005, Petrella et al. 2005) which suggests that frail older adults may move slower during the performance of activities of daily living than younger non-frail and pre-frail adults (Theou et al. 2010). These slower movements expressed by frail older adults are generally detected as more EMG bursts (Theou et al. 2010). This increase in muscle activity is in part due to muscle weakness that can be associated with the loss in size and number of type II muscle fibers (Kanda et al. 1986, Lexell et al. 1988) and reduced muscle activation (Narici et al. 1999). Moreover, the number of gaps and gap duration were fewer in frail older adults during each progressive task, which can be interpreted as reduced muscle recovery time (Harwood et al. 2008). Roland et al. (2014) associated gaps with muscle rest and suggested that decreased gaps are related to earlier onset fatigue (Blangsted et al. 2003, Laursen et al. 2001), which lead to declines in functional performance (Garber & Friedman, 2003). This decrease in muscle rest coupled with the increase in muscle activity observed in these functional tasks in frail persons likely contributed to increased self-reporting exhaustion.

While distinct differences were found between frail and non-frail, similarities were evident between middle-aged, non-frail, and pre-frail groups. Some middle-aged adults transition to characteristics of older adults sooner than others. Thus, some of the middle-aged participants may have exhibited characteristics of non-frail older adults. Theou et al. (2010) demonstrated that the number of gaps was greater in frail and pre-frail but no differences were observed between pre-frail and non-frail. When pre-frail participants that exhibited burst and gap characteristics within the range of non-frail were removed, Theou (2010) was able to demonstrate that the remaining pre-frail participants fell close to the frail grouping. This data blurring across persons is because pre-frail is the "transitioning" group between non-frail and frail. Some exhibited characteristics similar to non-frail while others exhibited characteristics similar to frail, which masked differences (Theou 2010), and demonstrated that the phenotype classification is not sensitive. A similar case was found in this study where some pre-frail exhibited characteristics close to that of non-frail and others of frail. Other frailty assessment tools lack the sensitivity required to identify discrete changes in frailty status. By being able to identify subtle differences through recordings of EMG within the pre-frail group, pre-frail persons are likely to be identified earlier before transitioning to frail.

A novel finding of this study is that only two of the seven frail participants were able to perform the get-up off the floor and laundry carry tasks. While unable to collect data from these five individuals for these specific tasks, mean burst amplitude was found to be higher in the chair stand (BADL; 20%) and toilet rise tasks (IADL; 30%) during mobility ADL (Fig. 3.4.1) and higher in dressing (BADL; 28%) and laundry transfer (IADL; 25%) than the two frail participants that were able to complete the floor rise and

laundry carry tasks. The inability to execute the most difficult tasks (AADL) is likely associated with declines in muscle function that were not detected in the questionnaires but evident through physiological recordings of muscle activity through the measure of bursts and gaps. These participants were working at a higher workload during the BADL and IADL as evident by higher muscle activity; therefore attempting to perform an AADL surpassed their individual physiological threshold hindering the successful completion of the challenging tasks. BADL and IADL during mobility and laundry progressions were therefore more sensitive to changes in the frailty phenotype. In addition, the five individuals that were unable to perform the floor and laundry carry tasks were classified by CHS-*fi* as pre-frail rather than frail. This demonstrates the importance of using progressive ADL tasks coupled with EMG to identify frail individuals.

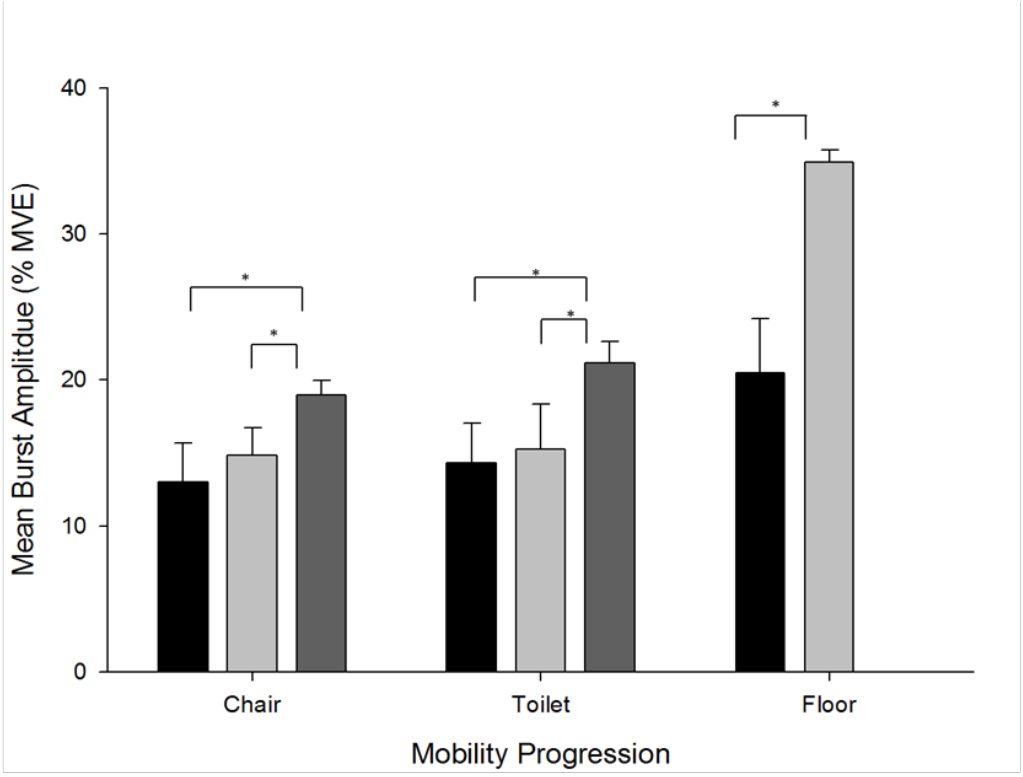

Fig. 3.4.1 ADL differences in burst amplitude based on AADL completion. Five out of the seven frail were unable to complete the floor task. These individuals exhibited higher mean burst amplitude during chair and toilet tasks than the two frail participants that were able to complete the floor. Pre-frail (black bars), Frail that executed all tasks (light bars), Frail that could not perform the floor task (dark grey bars). %, percent, MVE, maximum voluntary exertion.*, significantly different ($p < 0.05$)

While mobility and laundry ADL tasks were able to identify differences across frailty progressions, the mobility ADL was found to be the most sensitive to these differences. All mobility ADL were required for frailty allocation. Discriminant analysis was able to determine that all three tasks collectively accounted for 89.7% of the variance, demonstrating that testing a progression of ADL tasks is beneficial in identifying the different stages of frailty. As participants transitioned towards increased frailty, they used more of their upper limbs to perform each of the mobility tasks. For example, frail exhibited 51% fewer gaps in the upper limb muscles than non-frail during

the chair task, followed by 60% fewer during the toilet tasks, and 63% less in the floor task. The change in strategy by frail persons to perform mobility tasks with arms is consistent with the literature (Ulbrich et al. 2000). This is the first study to identify the increased prevalence of upper limb use across the frailty spectrum during a progression of ADL tasks.

When running the discriminant function scores, for the purpose of this thesis, only the discriminant function with the largest effect (number of gaps during the mobility task when separated by limbs and sex) was reported. These discriminant function scores further supported the differences found by the number of gaps between frailty groups, where a main effect was present for frailty phenotype for these socres. Frail demonstrated greater discriminant scores than middle-aged, non-frail and frail. This identified that prediction of frailty was evident not by a specific task, but rather the linear combinations that are generated from the mobility ADL progression.

The mobility ADL likely discriminated frailty with greater sensitivity than the other domains due to the low PA count that was found during tasks such as eating. Eating exhibited less activity counts than the dress (90%) and chair (99%) BADL tasks, which provides evidence that this task is too low for frailty detection. This is further supported by the discriminant analysis statistic, where it was determined that the eating task was not required for frailty allocation. The eating task therefore illustrates that there is a minimal level of physical exertion for threshold identification of frailty. The biomechanics required for the mobility ADL were also very similar across the three tasks. The primary difference was the difficulty of each task, which was induced by varying the surface heights participants had to stand up from (Wheeler et al. 1985). The greater sensitivity

found by the progressive mobility ADL is a novel finding demonstrating that the laundry and food domains do not provide sufficient sensitivity to identify frailty, thus reducing the number of variables necessary for frailty identification.

The finding that group allocation was best predicted by separating EMG by upper and lower limbs parallels literature regarding limb use differences between non-frail and frail older adults during daily activity (Theou et al. 2010). Discriminant analysis was able to determine that the number of gaps in the upper limbs during the mobility ADL served as the best indicator of frailty. Number of gaps in the upper limbs indicated that the number of rest periods present during mobility tasks declines as the older adult transitions toward frailty. These findings demonstrate that EMG can be useful at earlier identification of frailty. Muscle activity changes are known to occur before observable changes in muscle strength (Ferucci et al. 2004). When measuring muscle activity during mobility ADL, compensatory strategies were identified that may arise from muscle weakness. Age-related loss of strength and power in lower limbs is greater than upper limbs (Aoyagi et al. 1992, Candow et al. 2005, Frontera et al. 1991) and older individuals are known to complement weaker lower body movements with upper body movements, such as arm contractions when rising from a chair (Macaluso et al. 2004). Therefore, the upper limb muscles that maintain strength longer with increasing age are progressively required to execute mobility tasks from getting up off a chair, to the toilet and ultimately the floor. This upper body assistance that was used to compensate for lower body decline, results in less muscle quiescence in the arms. This change in muscle strategy during these tasks could be monitored over time to determine if advanced changes occur, potentially indicating the increased risk of frailty.

3.4.3 Sex

Low-threshold EMG during a set of discrete functional tasks was able to determine that the mobility tasks were able to discriminate stages of frailty better when separated for males and females. When combined for sex, it was determined that 80.2%, and 72.5% of the middle-aged, non-frail, pre-frail, and frail were correctly classified by the number of gaps and burst peak amplitude during mobility ADL. Yet, when separated for sex the identification increases 20% in males and 12% in females. This is supported by Harwood et al. (2008) where it was demonstrated that females exhibited fewer EMG burst periods compared with males during a discrete functional task (bag carry). Thus, separation of males and females is necessary to enhance identification of frailty.

Strength differences likely contribute to the sex-differences observed in this study of frailty identification (Brown et al. 2010, Harwood et al. 2008), as well as sex differences observed in gerontological disorders, such as Alzheimer's disease (Carter et al. 2012), peripheral artery disease (Hiramoto et al. 2013), and sarcopenia (Castillo et al. 2003). Muscle weakness likely contributes to the incidence of frailty being more common and occurring sooner in females than males (Fried et al. 2001). The use of EMG in this study improved the classification of frailty due to its ability to identify progressive decline that differs between the sexes. This is the first frailty measure to-date to consider sex differences when classifying different stages of frailty. Other frailty tools do not account for these sex differences, thus potentially increasing the risk of frailty misclassification.

Frailty alters the individual characteristics of muscle activity (bursts) and quiescence (gaps), which assists in dissociation between stages of frailty. As task

difficulty increases, and as an individual becomes more frail, muscle activity increases and quiescence decreases. The number of gaps in the upper limbs during the mobility ADL served as the best indicator of frailty. By requiring all three mobility tasks for group allocation, this demonstrates the importance of using progressive ADL tasks coupled with EMG to identify frail individuals. The sensitivity of the classification increased when separated by sex. This is the first study to consider sex as a unique component of frailty classification. Undertaking progressive mobility tasks coupled with low-threshold EMG therefore is an achievable measure that when used in clinical setting is likely to assist in frailty identification.

Chapter 5: Conclusions and Recommendation

5.1 Conclusions

Overall the objectives of this study were met. Muscle activity was recorded on ninety-one persons to assess whether EMG burst and gap measures are sensitive to dissociate difficulty of a functional task and discriminate between stages of frailty. Low-threshold EMG was recorded during nine discrete functional tasks in middle-aged, non-frail, pre-frail, and frail males and females. The hypothesis that difficult functional tasks would exhibit more frequent and longer bursts and fewer gaps than more basic tasks was accepted. This progression of difficulty was marked by an increase in burst activity and decrease in gaps as tasks became progressively more difficult. The hypothesis muscle activity would be greater and quiescence less in frail compared with non-frail individuals was also accepted, as frail persons had greater muscle activity and decreased gap activity. The hypothesis of frailty identification was achieved through determination that measures of the upper limb in progressive mobility tasks are best predictors of frailty classification and this prediction is enhanced when females and males are evaluated independently.

5.2 Implications

It is evident from the current investigation that the best prediction of frailty is not achieved from a specific task, but rather a discriminant function/ linear combination of mobility tasks of sequential progression. Undertaking mobility tasks coupled with low-threshold EMG is likely a readily achievable measurement in a clinical setting to detect frailty. However, the identification of persons across the frailty spectrum must be in accordance with sex. Females have lower percentages and differential rates of decline in strength, muscle mass, bone mineral density (Cesari et al. 2006, Fried et al. 2001, Morley

et al. 2005) and anabolic hormones (Phillips et al. 1993). Sex differences are known to arise in gerontological disorders, such as Alzheimer's disease (Carter et al. 2012), and peripheral artery disease (Hiramoto et al. 2013), and sarcopenia (Castillo et al. 2003), which may lead to the incidence of frailty being more common and occurring sooner in females than males (Fried et al. 2001).Sex related increases in bursts and decreases in gaps may result in greater muscle fatigue and functional decline in females compared with males (Roland et al. 2014). Interventions to prevent/prolong frailty must therefore account for these differential rates in decline. For example, females should be monitored earlier for frailty than males since females undergo primary aging events (menopause) leading to rapid decline in muscle strength. Investigators studying frailty should also test males and females separately to account for these sex differences.

5.3 Strengths and Limitations

The methodological strength of the current study was the large sample size for an EMG study, the stringent subject exclusion criteria and the effort made to control for extraneous variables. For example, all subjects were recreationally active as intensive training has been shown to influence EMG activity (Narici et al. 1989). All functional tasks were standardized so that all participants were getting up from the same height of toilet, transferring the same load of laundry, etc to ensure a controlled lab based environment. The physiological strength of this study is that it was the first to assess EMG between males and females during a progression of functional tasks to identify frailty.

One limitation of this study is that many of the frail participants assessed in this study were recruited and tested at a local assisted care facility and not in our laboratory at

UBC Okanagan. Individuals at this facility did not perceive themselves as frail due to the adaptive environment that was provided to them (i.e. weekly housekeeping, raised toilet seats, ground-level housing). This assistance enabled these residents to remain independent within their assistive environment, which potentially hindered the classification found using the CHS-*fi*.

Gait speed for this study was measured according to the frailty phenotype where a timer was started when the participant began walking and was stopped when they passed a 4.6 m (15 feet) marker. Most gait speed measurements account for a 1 meter acceleration phase, and a 1 meter deceleration phase (Lenardt et al. 2013, Montero-Odasso et al. 2005). This serves as a limitation to this study, as acceleration, and deceleration phases were not accounted for, limiting the values that were determined.

Restrictions were not placed as to how the participant could perform each functional task. For example, during the laundry carry task, participants were allowed to use the handrails if needed to carry a loaded laundry basket up and down a set of stairs. This encouraged participants to perform each task using adaptive techniques. Some participants were able to complete tasks that they would have been unable to perform if such adaptive techniques were restricted. Making use of assistive devices may have influenced some of the differences in muscle activity observed between frailty groups.

Finally, no frail males were included in this study. Group allocation was best predicted by mobility ADL when separated by limbs, and sex. All males were correctly classified for the number of gaps in the upper limbs and 77.8% correctly classified for the burst peak amplitude of the lower limbs. But, these classifications were only for middle-aged, non-frail and pre-frail male participants. We are therefore making scoping

statements for these findings when we have yet to determine the effect of EMG and progressive ADL tasks on frail males.

5.4 Future Directions

From this study, males exhibited fewer EMG bursts and more gaps than females during functional tasks. No frail males were included in this study. Future research should compare low threshold EMG between frail males and females during these functional tasks. Adaptive techniques used to perform each functional task should be restricted. This would be of significant use as it would provide further control for the muscle activity changes seen and would identify those that can not do each task. Thus, the easier ADL, such as BADL and IADL might become more sensitive and the prediction of frailty transition may be found to occur earlier. Finally, while cross-sectional studies are useful at determining changes across various groups, they do not provide definite information about cause and effect relationships. Therefore, to quantify the rate at which muscle activity and quiescence changes as individual transitions from non-frail, to pre-frail, to frail a longitudinal study is ideal.

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Appendices

Appendix A: Ethics Approval

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - MINIMAL RISK

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
Gareth R. Jones	UBC/UBCO Health & Social Development/UBCO Health and Exercise Sciences	H12-01560

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Okanagan

CO-INVESTIGATOR(S):
Judah Campbell
Noelannah Neubauer

SPONSORING AGENCIES:
Canadian Institutes of Health Research (CIHR) - "Measurement of Muscle Activity in Functional Tasks"
Natural Sciences and Engineering Research Council of Canada (NSERC) - "Supraspinal and Sensory Contributions to Motoneuron Modulation during Steady Contractions in Men and Women"
UBCO Internal Research Funds - "Measurement of Muscle Activity in Functional Tasks"

PROJECT TITLE:
Measurement of Muscle Activity in Functional Tasks

CERTIFICATE EXPIRY DATE: June 26, 2013

DOCUMENTS INCLUDED IN THIS APPROVAL:	DATE APPROVED: June 26, 2012	
Document Name	Version	Date
Protocol:		
Project Summary	1	June 6, 2012
Consent Forms:		
Consent Form	1	June 5, 2012
Advertisements:		
Tentative list of community presentations	N/A	June 15, 2012
Poster for Functional Tasks Study	N/A	June 15, 2012
Letter of Initial Contact:		
Letter of Information	1	June 5, 2012

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

This study has been approved either by the full Behavioural REB or by an authorized delegated reviewer

Appendix B: Summary of Current Measures to Determine Frailty

Table 1: Summary of Current Measures to determine Frailty

Tool	Protocol	Pro	Con
Fried's Frailty Phenotype (Fried et al. 2001)	Consists of 5 measurements: 1) Walk time: measured and calculated according to height 2) Grip strength: measured according to BMI 3) Physical activity: calculated using the Minnesota Leisure Time Physical Activity Questionnaire 4) Exhaustion: participants are asked if in the last week they felt that everything they did was an effort, and how often they felt that they could not get going 5) Weight loss: whether they have lost more than 10 lbs unintentionally in the last year Characterized as non-frail when they do not have any of the component indexes, pre-frail when they have 1 to 2 of the component indexes, and frail when they have 3 or more of the 5 component indexes	• Has been extensively validated in the research literature and has achieved an international reputation	• Increased risk of misclassification error due to dichotomization of criteria that are measured on a continuous scale. • Handgrip strength as an indicator of frailty only measures upper limb strength, which may not capture lower limb strength • Inability to determine discrete changes in an individual's frailty status
Rockwood Frailty Index (Rockwood et al. 2005)	• Counts the number of positive identifiers and proposes a frailty index based on a count of accumulated deficits (70 total clinical deficits from the Canadian Study of Health and Aging (CSHA)) • Items include the presence and severity of current diseases, ability in the activities of daily living, and neurological and physical signs from clinical examinations • Variables coded as deficits. Follow the convention of having a value of 1 when the deficit is present, and a 0 value when it is absent. More deficits result in a higher score for the frailty index	• Reveals a gradient in degrees of fitness and frailty • Does not assume that the groups of elements that make up frailty are statistically independent	• Clinical use of this measure remains to be fully demonstrated
Clinical Frailty Scale (Rockwood et	• Individual is assigned to a category after a comprehensive geriatric assessment has taken place	• Effective measure of frailty and provides predictive	• Requires specialized training to make appropriate selections

al. 2005)	• Consists of 7 different categories: 1) Very fit: exercise regularly and are in the most fit group for their age 2) Well: without disease, but less fit than people in category 1 3) Well, with treated comorbid disease: disease symptoms that are well controlled 4) Apparently vulnerable: individuals that commonly complain of having disease symptoms 5) Mildly frail: limited dependence in instrumental activities of daily living 6) Moderately frail: help is needed with instrumental and non-instrumental activities of daily living 7) Severely frail: completely dependent on others for the activities of daily living	information similar to that of other established tools, such as the Frailty Index • Easy to use in a clinical setting	
Edmonton Frailty Scale (Rolfson et al. 2006)	Samples 10 domains: • Two domains are tested using performance- based items such as the Clock test and the 'Timed Get Up and Go' test • Other domains are mood, functional independence, medication use, social support, nutrition, health attitude, continence, quality of life, and burden of medical illness Points ranging from 0-2 are given based on the physical performance tasks, and based-on the answers provided for the remaining domains. Points from all ten of the domains are then totaled where the maximum score for this test is 17, representing the highest level of frailty	• Good construct validity, good reliability and acceptable internal consistency • Includes social support suggesting an endorsement of the dynamic model of frailty • Can complete this scale without specialized training	
Gait Velocity (Montero-Odasso et al. 2005)	• Gait velocity measured as the time to walk the middle 8 meters of 10 meters • First and last meter are considered as warm-up and deceleration phases, which, which are not included in the calculation • Total time to perform task is then divided by 8m to give a score measured in meters per second (m/s) • Final score is placed into one of 3	• Suggested as the best single indicator of frailty and that a slow gait velocity alone in well functional adults in enough to predict risk for further adverse events • Quick to perform • Can be administered	• Idea remains to be tested in further studies with larger samples

	groups: high gait velocity (>1.1 m/s), median gait velocity (0.7-1 m/s), and low gait velocity (<0.7 m/s) • Scores greater than 1 m/s is deemed as "normal" gait velocity for older adults without disability, whereas scores less than 0.7 m/s is a powerful predictor of adverse events	without specialized training	

Appendix C: Pre-Study Questionnaires

Modified Frailty Index

Subject Code: _____

Date: _____

Domain	54 variables	Cut point
Comorbidities	Do you have one of the following health conditions: (answer as either yes or no) Cardiovascular disease: _____ Peripheral vascular disease: _____ Diabetes: _____ Respiratory disease: _____ Stroke: _____ Osteoporosis: _____ Arthritis: _____ Joint Replacement: _____ Vision problems: _____ Hearing problems: _____ Cancer: _____ Cognitive disorders: _____ Depression: _____ Arrhythmia: _____ Vertigo: _____ High cholesterol: _____ High Glucose: _____	Yes = 1, no = 0

Leg/feet symptoms	Numbness: _____ Tingling: _____ Swelling: _____	Yes = 1, no = 0
General health status	Hospitalization in past year: _____ ≥2 falls in past year: _____ For the following, list as either poor, fair, good, very good, or excellent: Self rating of health: _____ For the following, list your fear of falling with 1 being no fear, and 7 being your greatest fear: Fear of falling: _____	Yes = 1, no = 0 Poor = 1, fair = 0.75, good = 0.5, very good = 0.25, excellent = 0 7 = 1, 6 = 0.83, 5 = 0.67, 4 = 0.5, 3 = 0.33, 2 = 0.17, 1 = 0
Quality of life	For the following, list your Self rating of quality of life with 1 being the lowest quality of life and 7 being the highest quality of life: Self rating of quality of life: _____	1 = 1, 2 = 0.83, 3 = 0.67, 4 = 0.5, 5 = 0.33, 6 = 0.17, 7 = 0
Mobility	Do you use an assistive device for walking? (List as yes or no): _____ How would you describe your average walking pace? (List as either strolling, average, fairly brisk): _____	Yes = 1, no = 0 Strolling = 1, average = 0.5, fairly brisk = 0
Nutrition	Have you lost more than 5 kg in the past year? (List as yes or no): _____	Yes = 1, no = 0
Functional Independence	For the following activities list as either cannot do, can do with help or can do:	

	Take care of personal needs: _____ Bathing: _____ Climb stairs: _____ Walk 1 – 2 blocks: _____ Walk 6 – 7 blocks: _____ Do own shopping for groceries or clothes: _____ Lift and carry a full bag of groceries: _____ Do light household activities: _____	Cannot do = 1, can do with help, 0.5, can do = 0
	How would you describe your overall function in activities of daily living (0-24 score): _____	
	Do you have limitations in activities of daily living due to health problems? (List as either extremely, quite a bit, moderately, slightly, or not at all): _____	< 16 = 1, ≥ 16 = 0 (Rikli and Jones, 1998)
Mood and subjective fatigue	Do you (list as either yes or no): Experience any form of bodily pain? _____ Feel depressed? _____	Extremely = 1, quite a bit = 0.75, moderately = 0.5, slightly = 0.25, not at all = 0
	Feel easily tired? _____ List the following activity as either every day, 3-4/week, 1-2/week, or <1/week: Are bothered by fatigue? _____ At any point do you (list as either yes or	Extremely= 1, quite a bit = 0.75, moderately = 0.5, slightly = 0.25, not at all = 0

	no): Feel everything is an effort? _____ Have trouble getting going? _____	Every day = 1, 3-4/week = 0.67, 1-2/week = 0.33, <1/week = 0
Education	Feel tired after: Transfer, walk outdoors, walk outdoors: _____	Yes = 1, no = 0
Social	Have you (list as either yes or no): Completed primary school? _____	
Financial Status	Do you (list as either yes or no) Live alone? _____	
	Do you (list as either yes or no) Feel comfortable with financial status? _____	No = 1, yes = 0 No = 1, yes = 0
	Able to save money after all expenses? _____	
	Have enough money for the needs in the future? _____	No = 1, yes = 0

(Theou et al. 2012)

Minnesota Leisure Physical Activity Questionnaire

ACTIVITY	Did you perform this activity the last 2 weeks?		How many times did you do this activity the last 2 weeks?	How long did you usually do the activity each time?	
	NO	YES		Hrs	Min
Walking for exercise					
Moderate strenuous house chores					
Mowing the lawn					
Raking the lawn					
Gardening					
Hiking					
Jogging					
Biking					
Exercise Cycle					
Dancing					
Aerobics					
Bowling					
Golf					
Single Tennis					
Doubles Tennis					
Racquetball					
Calisthenics/Weights					
Swimming					

(Taylor et al. 1978)

Edinburgh Handedness Inventory

Subject Code:
Date of Birth: _____ Sex: _____

Please indicate your preference in the use of hands in the following activities by *putting* + in the *appropriate column.* Where the preference is so strong that you would never try to use the other hand unless forced to, *put* ++. If in any case you are really indifferent put + in *both columns.*

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking a Match (Match hand)		
10	Opening box (Lid)		
I	Which foot do you prefer to kick with?		
Ii	Which eye do you use when using only one?		

Leave these spaces blank:

L.Q.	

DECILE	

(Oldfield et al. 1971)

Background Questionnaire

Date of Experiment: Experimenter Name(s):

Subject Name: Subject Code:

Sex: Date of Birth (mm/yyyy):

Weight (kg): Height (cm):

Dominant Hand: Right Left

Mailing Address (For Experiment Findings Only):

Phone Number:

1. Are you a regular smoker? ☐ YES ☐ NO
If yes, how often? _____

2. Have you had surgery in the past year? ☐ YES ☐ NO

If yes, what type? _____

3. Have you been diagnosed by a health professional as having any of the following? (Check all that apply, and be specific where applicable)

Heart Trouble _____
Arthritis _____
High Blood Pressure _____
High Cholesterol _____
Cardiac Pacemaker _____
Electronic Implant _____
Back problems _____
Foot problems _____
Muscle problems _____
Bone or Joint disorder _____
Previous Injury _____
Alcoholism _____
Diabetes _____

4. Do you suffer from any allergies? (Include hay fever and sinus problems)

_____

_____

_____

5. Do you have difficulty hearing? _____

6. Do you have difficult seeing? _____

7. Other health problems? _____

_____

8. Are you currently using any medications? _____

_____

_____

9. Do you use any walking/gait aids? (ie: walker, cane) ☐ YES ☐ NO

If yes, how often and for what purposes? (ie: long distances, outside travel etc.)

_____

_____

10. In the last year, have you lost more than 10 pounds unintentionally (i.e., not due to dieting or exercise)?

☐ YES ☐ NO

11. How often in the last week did you feel that everything you did was an effort?

☐ rarely or none of the time (<1 day) ☐ some or a little of the time (1–2 days)
☐ moderate amount of the time (3–4 days) ☐ most of the time

12. How often in the last week did you feel that you could not get going?

☐ rarely or none of the time (<1 day) ☐ some or a little of the time (1–2 days)
☐ moderate amount of the time (3–4 days) ☐ most of the time

Thank you for your participation

The Lifetime Total Physical Activity Questionnaire

Description of Occupational Activity	Age Started	Age Ended	No. of Months/ Year	No. of Days/Week	Time/Day		Intensity of Activity (1, 2, 3, 4)*
					Hours	Minutes	
1.							
2.							
3.							
4.							
5.							
6.							
7.							

Description of Exercise/Sport Activities	Age Started	Age Ended	No. of Months/ Year	No. of Days/ Week	Time/Day		Intensity of Activity (1,2, 3, 4)*
					Hours	Minutes	
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							

Description of Household Activities	Age Started	Age Ended	No. of Months/ Year	No. of Days/ Week	Time/Day		Intensity of Activity (1,2, 3, 4)*
					Hours	Minutes	
1.							
2.							
3.							
4.							
5.							
6.							
7.							

*Intensity of activity
1. Activities that are done sitting. Only include activities in this category for the occupational chart.
2. Activities that require minimal effort
3. Activities that are not exhausting, that increase heart rate slightly and may cause some light perspiration.
4. Activities that increase heart rate and cause heavy sweating.

(Friedenreich et al. 1998)