MEASUREMENT OF MULTI-JOINT LOWER EXTREMITY EXTENSION POWER USING A CLINICALLY APPLICABLE LEG PRESS TOOL: THE CONCURRENT VALIDITY

by

Purva Prafullbhai Trivedi

Submitted in partial fulfilment of the requirements

for the degree of Master of Science

at

Dalhousie University

Halifax, Nova Scotia

November 2020

DEDICATION

I dedicate this project, in fulfilment of the requirements for my Master of Science degree, to

…my Parents, Prafull and Kashmira Trivedi, for sending me overseas away from you, for believing in me, and for always being my greatest inspiration and moral support

…my brother and friend, Rutvij and Shivani Trivedi, for always nurturing my interests and aspirations to follow my dreams

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ABSTRACT

Multi-joint leg extension power, a critical determinant of physical functioning, declines with age. Exercise can slow this decline and is usually prescribed based on maximum power. Currently available tests to assess maximum power can be unsafe for the elderly. This study assessed the concurrent validity of leg extension power measured with a new leg press + IMU system compared to that obtained using a squat jump on force plates. The load in each test equaled body weight. Bland-Altman analysis demonstrated a significant systematic difference, with the squat jump generating higher power in 21 young adults. The magnitude of difference was greater for 10 participants who used a countermovement in the squat test, which is known to increase power output. The difference in power between the 2 systems was negligible after accounting for the higher load created by additional weight of the legs in the leg press + IMU system.

ACKNOWLEDGEMENTS

Words cannot express my immense thankfulness and gratitude to my supervisor Dr. Gail Dechman for believing in me through this beautiful journey. I find myself delighted to be able to work under her guidance. I truly respect her patience with which she helped me in every step of my journey. Starting from narrowing down my research interests to giving me opportunity to grow as a researcher and expand my academic and personal knowledge she has been there with me every single time I needed. Her hard work and dedication throughout my journey to help me find my way in a totally new environment has been exemplary and has worked as an inspiration for me.

I would also like extend my deepest gratitude to my committee members Dr. Michel Ladouceur and Dr. Derek Rutherford for their valuable time and insightful directions which helped me understand some of the aspects of this project to which I was a total novice. I would not have been able to accomplish this research without their guidance.

I have a lot of people to thank in this journey. I am greatly thankful to James Course, Dr. Shaun Boe, Dr. Rebecca Moyer, Dr. Ryan Frayne, Dr. Janice Moreside, Carson Halliwell, for helping me understand all the instrumentation for my research.

Besides school, I would extend my endless thanks to my family and friends for always cheering, motivating and supporting me. This journey would not have been possible without you.

CHAPTER 1: INTRODUCTION

Canada is currently one of the top-ranked countries in the world in terms of average life expectancy. According to a recent report by World Health Organisation, the average life expectancy observed in Canada was 80.9 years for males and 84.7 years for females in the year 2018[1]. This increase in life expectancy is one of greatest achievements of society and health care services, but preserving the independence and quality of life of the elderly during these years remains a major clinical and public health challenge[2].

Aging is typically accompanied by progressive limitation of functional independence and decline in quality of life[3]. One of the major reasons for this decline is a progressive loss of skeletal muscle mass and function, known as sarcopenia[4,5]. This condition is characterised by the loss and atrophy of muscle fibers, a decline in the number innervating motor neurons[6], and a simultaneous increase in proportion of fat and fibrous tissue in muscles[7,8]. Sarcopenia has been addressed as a critical condition of elderly people and a significant factor responsible for the development of frailty[9,10]. It is also considered a potent predictor of a late-life disability[11]. The changes in skeletal muscle occurring with sarcopenia include the reduction in skeletal muscle strength and power. The American College of Sports Medicine defines muscle strength as the ability of a muscle to produce force during voluntary contraction against a resistance[12]. In clinical settings, it is usually quantified in terms of the one repetition maximum (1RM) described as the greatest load that can be moved through full range of motion, with good form in a single attempt[12]. Strength is typically assessed in one of three modes, either isometrically, isotonically, or isokinetically, using either concentric or eccentric muscle contractions. One way to assess strength clinically is manual muscle testing (MMT). During MMT, the clinician applies active or passive resistance to the body part being tested through the available range of motion[13]. The clinician determines the muscle strength as weak or normal based on several grading scales for MMT; chief among them are the Medical Research Council[14], Kendall et al[15], and Daniels and Worthingham[16]. This commonly used testing requires experience and can be imprecise because the grading of strength is dependent on the clinician's perception[17]. Tools to assess strength include free weights, and hand-held[17] and isokinetic dynamometers[18]. Muscle power is the product of the force applied by a person during the movement and the velocity of movement[19]. Assessment of power is complex because it requires measuring strength i.e., the force exerted during the movement and the velocity at which the movement is being performed[19]. This can be done using research grade force plates[20] or field tests such as the vertical jump test[21] or the stair climbing power test[22]. Reduction in muscle power is thought to be affected by the age-related change in skeletal muscle innervation. This includes the loss of fast motor neurons and associated fibre-type grouping of the type II muscle fibres supplied by them, called motor unit remodelling[23]. The type II muscle fibres are fast-twitch fibres, which are preferentially reduced with advancing age[24] leading to decline in muscle power. All of these changes collectively lead to the functional limitations amongst the elderly.

Functional limitations result in difficulty or inability to perform the basic activities of daily living (ADLs) like rising from chair, climbing a flight of stairs, walking several city blocks[3]. Traditionally, the age-related decline in muscle strength, that can be accentuated by the lack or reduction of physical activity with age, was considered to be responsible for the functional limitations in the elderly and the primary predictor of physical functioning in these individuals[25]. However, studies have proven the decline in skeletal muscle power is a more critical factor responsible for the functional limitations[26] and that it declines earlier and to a greater extent than the muscle strength[20,24,27,28]. In particular, lower extremity muscle power is considered to be the most important factor determining independent functioning in later life and, a central tenet of quality of life[26]. In community dwelling older adults, leg muscle power has been demonstrated to be a strong independent predictor of performance-based physical function[29,30] and self reported inabilities[31]. Hence, the assessment of lower extremity muscle power is an important factor when designing functional rehabilitation programs in the elderly.

In the literature, most of the assessments of lower extremity power have been limited to single joint assessments of the hip or knee with only a few examining the ankle. These assessments are usually performed on isokinetic dynamometers. But, a functional activity like chair rise requires hip, knee and ankle joint movements and this multi-joint action is not well represented by power at a single joint[32,33]. This thesis will focus on multi-joint lower extremity extension. Most of the studies in the literature have pointed to a strong relationship between the age-related reduced muscle power and functional limitations in activities of daily living based on single joint assessments. However, little research has examined the influence of age-related declines in multi-joint lower extremity extension power. The few studies that have assessed this activity have used a variety of instruments, including the laboratory force plate jump tests. Force plates are used to record the vertical ground reaction forces as a person jumps on them and these forces are used to calculate power. Despite the high precision of these instruments, they have limited applicability and feasibility in the older population due to comorbidities such as osteoporosis and poor balance[2]. The force plates are expensive, and it is not feasible to have them in an outpatient physiotherapy clinic. Other studies have used the Nottingham power rig[34] and the servo-controlled dynamometer[32] to address multi-joint power assessments but did not clearly report the protocols used for the validation of these instruments. Therefore, a new measurement method that can fill the present gaps in the assessment of lower extremity power is needed.

The Specific objective of the present study was to assess the concurrent validity of a new leg press + IMU system to measure multi-joint lower extremity power by comparing it with power measured during a force plate jump test using Bland-Altman analysis in healthy young adults.

CHAPTER 2: LITERATURE REVIEW

2.1: Aging

The World Health Organization (WHO) has documented population aging around the world as one of the most noteworthy challenges of the 21st century. The organization defined seniors as the population aged 60 years and above. According to a 2018 report by the WHO, the population of seniors was expected to outnumber that of children below 5 years old by the year 2020[35]. Canada reached WHO projection in the year 2017. The proportion of seniors has risen from 8% in the year 1960 to 14% in the year 2009[2]. According to the population projections by Statistics Canada, seniors are expected to account for around 23% to 25% of the population by the year 2036. The median age of the population was 26.2 years in the year 1960 and has risen to 39.5 years in the year 2009. This trend is expected to continue with the median being 42 – 45 years by the year 2036[36]. Figure 2.1 shows the population projections according to the data from Statistics Canada.

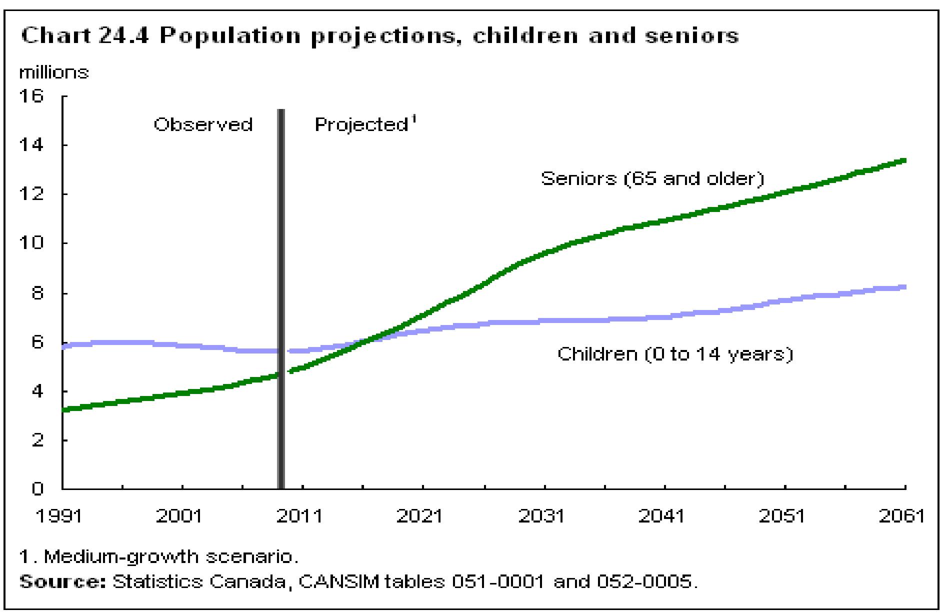


Figure 2.1: Canadian population projections for children and seniors[2]
The figure illustrates that the population of seniors outnumbered that of children in the year 2017 and it is expected to rise and remain higher than the population of children.

According to most biologists, aging in humans commences from the fourth decade of life and stops with the death of an individual[37]. At the biological level, aging is considered to occur as the result of the gradual accumulation of a wide variety of molecular and cellular damage[38,39]. The changes associated with aging are neither linear nor consistent, and are only loosely associated with the age in years, which makes it difficult to define the onset of old age[38]. Despite this, the WHO, has divided aging into 3 periods[37]:

1) aging (early old age): 'young-old' – 60–74 years old

2) old age (late age): 'old-old' – 75–90 years of age

3) longevity (long-lived) – 90 years and older

Although advancing age does not automatically mean ill health or disability, the risk of both does increase as people get older. During the year 2006, 33% of Canadians aged 65 and above had a disability and nearly 75% of Canadians above 65 years of age had at least one chronic health condition[2]. Arthritis is the second most common chronic condition among seniors after high blood pressure. Statistics Canada reported that 45% of Canadians aged 65 and older had osteoarthritis in the year 2017[40]. In particular, the osteoarthritis of knees was reported by 49% of population aged 65 and above in the year 2015[41]. Chronic back pain was the next most commonly reported condition in those older than 65[42]. Another important chronic condition in the older population is osteoporosis. According to a report by Statistics Canada, 20.3% of population aged 65 and older had osteoporosis in the year 2011[43]. The projections predict an increase in the proportion of chronic conditions as the number of elderly increases. These increasing rates of disability and chronic disease are expected to increase the demands on Canadian health care services.

The complex etiology of aging is difficult to understand however, some of the factors like physical inactivity, improper nutrition, and chronic medical conditions contribute to aging and lead to numerous changes in human body that are commonly associated with aging[44]. Some of the important structural changes described by Dziechciaz & Filip[37] are:

- Slowly developing atrophy of tissues and organs
- Internal and external cell dehydration, which leads to reduction in the total volume of body fluids
- Increased replacement of muscle tissue by fat tissue

These and other physiological changes associated with aging take place at different rates in body systems and individuals. For instance, the musculoskeletal system demonstrates a reduction in bone mass[5], degradation of articular cartilage, and narrowing of intervertebral discs[45]. There is also a noticeable decline in skeletal muscle mass, muscle strength and power with aging[46]. Such changes increase the risk of disabilities and ill health in older individuals.

2.1.1: Aging and Skeletal Muscle

Skeletal muscle is an elastic, contractile tissue under voluntary control of the somatic nervous system[47]. The basic function of skeletal muscle is voluntary contraction resulting in movement of the joints of the body. Skeletal muscle is highly adaptive to diverse stimuli including exercise, injury, disuse and aging. There are profound alterations in its form and function with advancing age which ultimately affects the health of older individuals. Peak skeletal muscle mass and strength is achieved by the third decade of life after which they begin to progressively decrease. A review by Aversa and colleagues reported a decline of 50% in the skeletal muscle mass by the ninth decade of life[7]. The loss in muscle mass and function, that accompany aging, is termed as sarcopenia[48,4]. Sarcopenia is characterised by the loss and atrophy of muscle fibers and a simultaneous increase in the proportion of fat and fibrous tissue in muscles[7,8]. The European Working Group on Sarcopenia in Older People (EWGSOP)[25] has categorized the severity of sarcopenia in their 2018 report, based on 3 criterions:

1. Low muscle strength measured using grip strength or chair stand test
2. Low muscle quantity or quality measured using DXA, CT or MRI
3. Low physical performance measured using gait speed, Short physical performance battery, Timed-up-and-go test or 400-meter walk test.

The presence of criterion 1 indicates probable sarcopenia while the presence of criterion 1 and 2 confirm the diagnosis. Presence of all three criterions suggests severe sarcopenia. Sarcopenia is a primary factor responsible for the development of frailty[9,10] and a potent predictor of a late-life disability[11].

While sarcopenia refers to age-related changes in muscle structure and function, comorbidities associated with aging enhance the severity of the disease. Common among these is diabetes. In 2012, Kirkman et al[49] reported that more than 25% of the U.S. population aged ≥65 years had diabetes, and the aging was a significant driver of the diabetes epidemic. The numbers are similar for Canada[50]. Tournadre and colleagues[51] describe how insulin resistance, particularly in the elderly, leads to decreased skeletal muscle protein synthesis and therefore greater depletion of muscle mass. Pacifico et al[52] performed a meta-analysis of 63 studies identifying presence of sarcopenia using the criterions of EWGSOP, and reported a prevalence of 31.1% in people over 50 years old with diabetes compared to only 16.2% in the non-diabetic cohorts[53]. Mori and colleagues used grip strength and DXA to identify sarcopenia in 308 elderly individuals (mean age: 63.5±11.0 years). Multivariate regression to examine the association between age, BMI, and diabetes and sarcopenia demonstrated that only age and the presence of diabetes were independent contributors to sarcopenia (Odds Ratio: 3.11; $p < 0.001$).

Other diseases, common in older people, are also associated with and increased risk or severity of sarcopenia. Dos Santos et al noted that sarcopenia was higher in people with chronic heart failure[54]. More recently, Springer and colleagues reported that in the elderly, the prevalence of sarcopenia was 20% higher in those with heart failure compare to an age-matched group without heart failure[55]. Several studies have described an increase in sarcopenia in smokers when compared to non-smokers[56,57]. The link between malnutrition, which is prevalent in the elderly, and sarcopenia has also been studied[58,59]. Yoo et al[58] assessed the association between malnutrition and chronic inflammation and the presence of sarcopenia and hip fracture in the elderly. They have also been cited as independent risk factors for sarcopenia. The rates of three indicators of malnutrition in men and women (low BMI, hypoalbuminemia, and hypoproteinemia) in sarcopenia patients with hip fractures were 23.4%, 31.9%, and 53.2% and 21.3%, 21.3%, and 37.3%, respectively. The prevalence of markers of chronic inflammation (increased C-reactive protein and erythrocyte sedimentation rate) in men and women with sarcopenia and hip fractures were 74.9% and 52.2%, and 49.3% and 85.1%, respectively. These rates were significantly higher than those in participants who were not diagnosed with sarcopenia. Taken together, it is clear that while it is not possible to halt sarcopenia, its rate of progression is increased by the presence of chronic diseases that are common in older people.

Figure 2.2 depicts the changes in skeletal muscle with aging. The reduction in muscle fibres is accompanied by a progressive decline in innervating motor neurons and capillaries. A review by Aagaard and colleagues[6] has reported an average loss of 25% in the number of spinal motor neurons at the lumbospinal segments (L1- S3) in a group of people 20 to 90 years old. In that study the people aged 60 years and older demonstrated up to 50% fewer motor neurons compared to individuals between 20 and 40 years old. Another major feature of aging skeletal muscle is the rearrangement of innervation. A motor neuron and the skeletal muscle fibres innervated by it are collectively called a motor unit. A recent systematic review by Wilkinson and colleagues[23] noted that loss of muscle fibres is associated with the age-related loss of motor units. This loss leaves a muscle fibre denervated and more susceptible to atrophy. Denervated fibres may be re-innervated by a nearby axonal terminal in a process termed motor unit remodelling[23]. Hence, older muscles tend to be comprised of motor units that are fewer in number and larger in size. The muscle fibres being innervated by the same motor neuron lie close to each other and are observed in clusters, in contrast to the typical random scattering commonly observed in a young muscle. This rearrangement is called fibre type grouping[23]. As a matter of interest, this grouping is characterized by a shift in fibre type composition (type I/II ratio)[23] which is discussed later in section 2.1.1.1 of this literature review. All the changes discussed here, collectively result in a reduction of muscle mass and muscle cross sectional area.

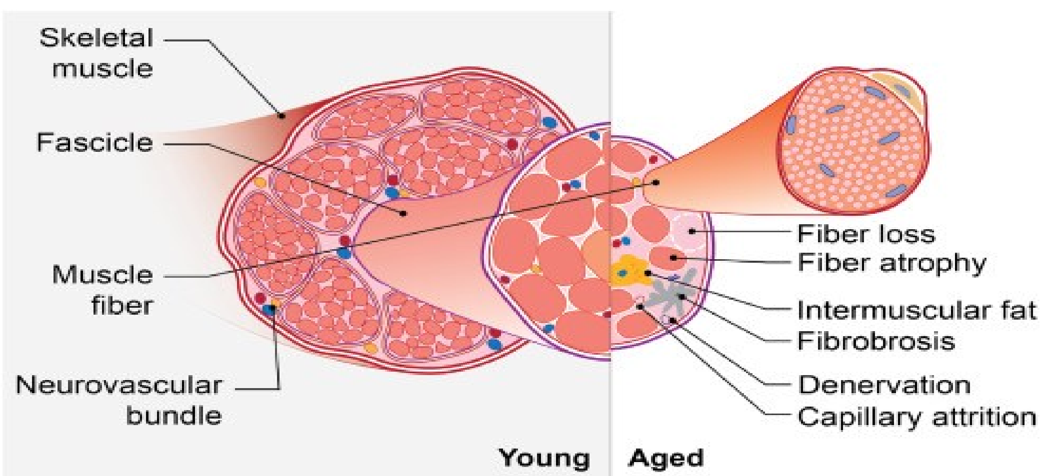


Figure 2.2: Age-related changes in skeletal muscle[7]
The age-related substantial loss of muscle mass is because of both the loss and atrophy of muscle fibers. The gradual diminution in functional contractile tissue is replaced by fat and fibrotic tissue. These changes, along with progressive decline in innervating motor neurons and capillaries, result in age-related loss of muscle strength and power.

The reduction in muscle mass increases with the advancing age. Many studies have attempted to quantify this loss. A review by Mitchell and colleagues[27] looked at cross-sectional as well as longitudinal studies. They reported the median rate of loss was 0.47% per year in men and 0.37% per year in women in cross-sectional studies comparing young (18–45 years) and old (>65 years) individuals. The longitudinal studies showed that in people aged 75 years and older, muscle mass was lost at a rate of 0.80–0.98% per year in men and 0.64–0.70% per year in women. A 12-year longitudinal study by Frontera and colleagues[60] explored the age-related changes in skeletal muscle size using computerized tomography. Their results for 77 people with an initial mean age of 65.4 +/- 4.2 years, demonstrated a significant reduction ($P < 0.05$) in the cross-sectional area of the thigh (12.5%), all thigh muscles (14.7%), and the quadriceps femoris muscle group (16.1%). Nilwik and colleagues[61] compared the quadriceps cross-sectional area in the older (n=26; 71±1 years) versus young men (n=25; 23±1 years) using computerised tomography. They observed that it was 14% smaller in the older group (68±2 cm^2 for older men vs 80±2 cm^2 for young men with $p < 0.001$). Recently, a review by Aversa and colleagues[7] reported a 40% reduction in the cross-sectional area of vastus lateralis muscle in people 20 to 80 years old and stated that the number and size of both the type I and type II fibers were reduced in the advanced age groups. This age-related loss and atrophy of the muscle fibers differs among fiber types and muscle groups.

2.1.1.1: Selective Fibre Type Involvement in Sarcopenia

A skeletal muscle consists of the type I (slow twitch) muscle fibres and type II (fast twitch) muscle fibres. The type I muscle fibres are responsible for low-intensity, long-duration aerobic activities. They are innervated by the slow motor neurons and form the slow motor units. The type II muscle fibres are responsible for anaerobic, powerful, short bursts of movements. They are innervated by the fast motor neurons and form the fast motor units. Overall, the reduction in muscle mass with age is characterized by preferential involvement of the type II muscle fibres. A large number of studies have supported this finding. A review by Andersen[62] stated that on a transverse section, muscle fibres show a change in shape from round to a shrunken flattened appearance with increasing age. This shape change was found to be more pronounced in the type II muscle fibres than the type I muscle fibres. He further stated that the age-related fibre atrophy is more common in the type II muscle fibres. He also reported that when the size of type I and type II muscle fibres were compared between a group with an average age of 88 years and another group with average age 25 years, the type I muscle fibre size reduced from 3822 ± 755 µm2 to 2891 ± 853 µm2 (reduced by 25%) whereas the type II fibre size reduced from 3974 ± 873 µm2 to 1704 ± 936 µm2 (reduced by 57%). Another review by Mitchel and colleagues[27] confirmed this preferential decline in the size of type II muscle fibres based on DXA, CT and MRI scans. A recent cross-sectional study by Nilwik and colleagues[61] also supported these findings using muscle biopsies. They studied the type II muscle fibers of vastus lateralis muscle in healthy young (n = 25; 23 ± 1y) and older (n = 26; 71 ± 1y) men and reported that the type II muscle fiber size was 29% smaller in the elderly vs the young (5050 ± 198 μm^2 vs 7136 ± 309 μm^2, respectively; $P < 0.001$). A more recent cross-sectional study by McPhee and colleagues[63] investigated the cross-sectional area of type I and type II muscle fibres in the vastus lateralis muscle in older (n = 20; age 72 ± 4 years) vs younger women (n = 15, age 22 ± 3 years) using single fibre muscle biopsies. The results of this study showed that there was no significant difference between the groups in the type I fibre cross-sectional area ($p = .487$) but, the type II fibers had 26% smaller cross-sectional area in the older participants ($p < .001$). These findings were confirmed in a recent review by Aversa and colleagues[7]. Therefore, the literature conclusively supports that age-related skeletal muscle atrophy is more prominent in type II than type I muscle fibres.

Several reasons have been proposed for such selective atrophy of type II muscle fibres. One plausible cause could be an age-related reduction in high intensity, anaerobic activities that recruit these fibres[11]. On the other hand, motor unit remodelling has also been noted to play a substantial role in type II fiber atrophy[64]. As remodelling accelerates with advancing age the pace of reinnervation does not match that of the denervation resulting in a loss of muscle fibres or at times the complete loss of motor units[62]. In their systematic review, Brunner and colleagues[24] concluded that fiber-type grouping was the major quantitative change observed in type II muscle fibre aging. They further stated that the motor unit remodelling and subsequent fibre type grouping associated with aging appears to be the most important cause of the age-related, preferential loss of type II muscle fibres. Therefore, it seems that the age-related reduction in physical activity that recruits fast-twitch fibres and the subsequent motor unit remodelling play an important role in the selective loss of type II muscle fibres.

2.1.1.2: Preferential Loss of Muscle Mass in The Lower Extremities

It is important to understand that the changes in muscle cross-sectional area and fiber type with aging are not consistent among the muscle groups. The muscles of lower extremity are preferentially affected compared to the muscles of upper extremities[23]. A cross-sectional study by Janssen and colleagues[65] examined the effects of age on whole body and upper and lower body muscle mass using MRI in 468 people (male = 268), ranging from 18 to 88 years old. The participants were divided into two age categories: 18 – 44 years and 45 years and older. Among men, older than 45, age was significantly ($p < 0.05$) and negatively related to the lower body ($r = -0.48$) but not the upper body muscle mass. In women, age was more strongly related ($p < 0.05$)

to the lower body (r = − 0.48) than the upper body skeletal muscle mass (r = − 0.26). Furthermore, a regression analysis of age and skeletal mass among women demonstrated that the slope of regression for lower body (r = − 0.09) was significantly ($p < 0.01$) greater than that for upper body skeletal muscle mass (r = − 0.02). A similar discrepancy in the reduction of skeletal muscle mass across various muscles of the body was found by comparing the results of two studies using the same muscle biopsy techniques. The cross-sectional study by McPhee and colleagues[63] compared the vastus lateralis fibre number and total muscle cross-sectional area using data from 31 young (mean age: 22years) and 40 old (mean age: 72 years) men and women. They reported that the muscle mass and muscle fibre numbers were significantly lower for the in the elderly compared to young subjects. The second study, also a cross-sectional design, revealed a non-significant difference in number of muscle fibres in bicep brachii between young (21 ± 2 years) and old (82 ± 2 years) individuals[66]. A recent review by Mitchel and colleagues[27] that included 20 cross-sectional studies and 5 longitudinal studies assessing the skeletal muscle mass using DXA, CT and MRI, affirmed that the age-associated loss of muscle mass affects lower limb muscle mass at more than twice the rate of loss in the upper limb.

2.1.2: Consequences of Aging Skeletal Muscle

The two crucial consequences of skeletal muscle ageing are the decline in muscle strength and power, which are associated with functional limitations.

2.1.2.1: Decline in Muscle Strength

The American College of Sports Medicine defines muscle strength as the ability of a muscle to produce force during voluntary contraction against a resistance[12]. In clinical settings, it is usually quantified in terms of the one repetition maximum (1RM) described as the greatest load that can be moved through full range of motion, with good form in a single attempt[12]. Strength is typically assessed in one of three modes, either isometrically, isotonically, or isokinetically, using either concentric or eccentric muscle contractions. One way to assess strength clinically is manual muscle testing (MMT). During MMT, the clinician applies active or passive resistance to the body part being tested through the available range of motion[13]. The clinician determines the muscle strength as weak or normal based on several grading scales for MMT; chief among them are the Medical Research Council[14], Kendall et al[15], and Daniels and Worthingham[16]. This commonly used testing requires experience and can be imprecise because the grading of strength is dependent on the clinician's perception[17]. Tools to assess strength include free weights, and hand-held[17] and isokinetic dynamometers[18]. Strength is related to the cross-sectional area of the muscle and the capacity of the innervating motor neurons to activate the muscle fibres[7]. Numerous cross-sectional and longitudinal studies have reported a decline in the muscle strength with aging and linked this to reductions in the muscle mass and motor units. A longitudinal study by Frontera and colleagues[60] illustrated a clear decrease in the muscle strength over a 12 year period. They studied twelve healthy sedentary men (initial mean age: 65.4 ±4.2 years) in the year 1985-86 and nine of them were reassessed in the year 1997-98. Isokinetic muscle strength of the flexors and extensors of the knee and the elbow were measured. The investigators reported a 2%/year and 2.5%/year loss of strength in the knee extensors and flexors, respectively and a 1.6%/year and 1.4-2.2%/year for the elbow extensors and flexors, respectively. The review by Figueiredo and colleagues[64] used cross-sectional studies and reported that the knee extensors of healthy older people (70-80 years old), were 20-40% weaker compared to participants who were 20 to 40 years old when assessed for isometric strength. The review by Mitchel and colleagues[27] in 2012 supported these findings. That group included 20 cross-sectional studies and 5 longitudinal studies. The longitudinal studies in this review documented that isokinetic knee extensor strength declined at 3 – 4%/year in men and 2.5 – 3%/year in women among the people aged 75 years. This review also reported that strength loss was 2 – 5 times faster than the rate of loss of muscle mass. Another 3 year longitudinal study by Goodpaster and colleagues[67] examined the changes in muscle mass and strength in 1880 healthy older (mean age: 73.5 ± 2.8 years) black and white men and women (n=929 men). They aimed to determine whether the change in lean appendicular mass was related to the change in muscle strength in older adults. They measured isokinetic knee extensor strength using an isokinetic dynamometer and the lean appendicular mass using DXA. The rates of strength decline reported by this longitudinal study were 3.4%/year and 4.1%/year in white and black men and 2.6%/year and 2.9%/year in white and black women, respectively. They further reported that these rates of strength decline were 3 times greater than the rate for loss of leg lean mass, which was about 1%/year across gender and race.

2.1.2.2: Decline in Muscle Power

Skeletal muscle power is the product of force and the velocity of movement[19]. Assessment of power is complex because it requires measuring strength i.e., the force exerted during the movement and the velocity at which the movement is being performed[19]. This can be done using research grade force plates[20] or field tests such as the vertical jump test[21] or the stair climbing power test[22]. As discussed, aging is associated with preferential involvement of the type II muscle fibres that are responsible for short burst movements, which may explain an earlier and greater decline in the muscle power as compared to the muscle mass and strength. Macaluso and De Vito[20] suggested that the selective loss of fast motor units with age and an increase in the number of slow motor units also contributes to an earlier and greater decline in the muscle power compared to strength. These findings were supported by a more recent systematic review by

Brunner and colleagues[24]. A study by Skelton and colleagues reported a 1-2% reduction in isometric knee extensor strength per year was associated with 3-4%/ year decline in multi-joint lower extremity power measured using the Nottingham power rig in men and women who were 65-89 years old[68]. Recently, a cross-sectional study by McKinnon and colleagues[28] studied the rates of decline in an isometric knee extensor strength and the knee extensor power among twelve older (6 men, mean age: 77±5 years) and twelve young adults (6 men, mean age: 24±3 years) using an isokinetic dynamometer. Despite a small number of participants in the comparison, their results demonstrated a greater loss of muscle power (44%) in comparison to muscle strength (40%) in older adults. A 3 year longitudinal study by Reid and colleagues[69] documented the age-related loss of lower extremity muscle power in the 26 healthy (mean age: 74.1±4, n = 12 females) and 22 mobility-limited (mean age: 77.2±4, n = 12 females) older adults. The researchers reported the rate of loss of muscle power to be 8.8% and 8.5% per year in the healthy and mobility-limited older adults, respectively.

2.2: Functional Limitations with Aging

Functional ability is the capacity to perform the activities and tasks in daily life. These basic activities of daily living (BADLs)[3] can be described as activities that allow people to take care of themselves (bathing, dressing, using the toilet,)[70]. The inability to carry out BADLs will affect quality of life and eventually lead to a lack of independence (Figure 2.3). Functional limitations increase noticeably with age[3] and many elderly people consider their ability to carry out BADLs to be more important than disease prevention [71]. Reductions in muscle strength, power and physical activity with increasing age are causes for the decline in functional ability. This inability to perform BADLs is also recognized as a risk factor for mortality in older adults[5]. Although muscle strength has been identified as the primary predictor of the limitation of function in elderly people, skeletal muscle power is now considered to be a more critical determinant of physical function with increasing age. As a matter of fact, Reid and Fielding concluded that the reduction in lower extremity muscle power is the primary determinant of the functional limitations and disability in the elderly[26].

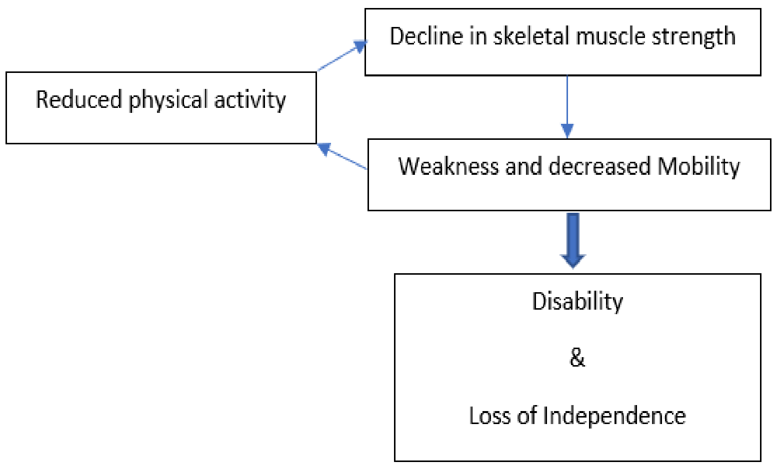


Figure 2.3: The vicious cycle of decline in muscle strength and reduced physical activity
The reduction in muscle strength leads to a decrease in abilities for physical functioning amongst the elderly people. This reduced physical activity ultimately serves as the cause for decline in muscle strength and worsens the condition, ultimately leading to a loss of independence[26].

2.3: Role of Lower Extremity Muscle Power in Functional Limitations

Several studies have addressed the association between lower extremity muscle power and functional limitations in older individuals. A study by Suzuki and colleagues[30] compared the associations between the ankle power and strength and performance-based functional tasks such as the ten time sit-to-stand test and the stair climb power test. They assessed 34 elderly women (age range: 65 – 84 years) with the self-reported limitations in function measured on the Medical Outcomes Study Short Form (SF-36) Health Status Survey. The investigators reported that muscle power was a stronger predictor of the chair rise time (muscle power: r = 0.58 vs. muscle strength: r = 0.32) and the stair climb performance (muscle power: r = 0.49 vs. muscle strength: r

= 0.37). A clinical trial by Foldvari and colleagues[31] assessed the association of leg muscle strength, power, endurance, and functional status in 80 community-dwelling elderly women (mean age 74.8 ± 5.0 years). The researchers assessed knee extensor strength and power using a computer-interfaced pneumatic resistance machine. The authors stated that multivariate analysis revealed that lower extremity power was the only factor that contributed independently to the functional status ($r = .64$, $p < .0001$), and that it accounted for 40% of the variance in functional status in the elderly women. Recently, a review by Reid and Fielding[26] confirmed these findings and concluded that the lower extremity muscle power is the most important determinant of functional limitations in the elderly subjects.

2.4: Role of Physical Activity and Exercise

There is growing evidence that the decline in muscle strength and power is highly dependent on physical activity levels[51]. Wall and colleagues[72] reported a 9% decrease in isometric knee extensor strength following 5 days of knee joint immobilization using a full leg cast in 24 healthy, young males (mean age: 23 ± 1 years). Another study by Kortebein and colleagues[73] analyzed the effect of 10 days of bed rest on the maximal isotonic knee extensor strength measures using a Cybex dynamometer in 11 healthy older adults with mean age of 67 ± 5 years. They also assessed lower extremity power using the stair-climbing power test. Their results demonstrated a decrease of 11% in isometric knee extensor strength ($p = 0.004$) and a decrease of 14% in lower extremity power ($p = 0.01$) over the 10-day assessment period.

The effects of aging are less pronounced among master athletes[74] compared to their sedentary cohorts, supporting the role of exercise in reducing the rate of decline in power with increasing age. Thé and colleagues[75] examined the records from the 2000 World Masters Weightlifting Championships and documented an age-related decline in power of 1.4–2.3 % per year in muscle power in lifters aged 60 years and older measured using laboratory assessments of muscle power. This is much less than the 8.8% per year decline in healthy sedentary older adults (mean age: 74.1±4) reported by Reid and colleagues[69]. Thus, exercise has a role in in combating the effects of aging and slowing the associated functional decline. Henwood and colleagues[76] studied the effects of 8 week of resistance training in 14 older subjects (mean age: 69.9±6.5 years) on knee extension power measured using an isokinetic dynamometer and on physical performance assessed using chair-rise time. Their results demonstrated a 33% increase ($p < 0.05$) in knee extension power and 10.4% decrease ($p < 0.05$) in chair-rise time following the training program. Another study by Yamauchi and colleagues[77] studied the effects of 10 months of body-weight based exercise training on leg muscle power in 27 healthy elderly subjects (66.0 ± 5.7 years). They assessed pre- and post-training leg muscle power using a servo-controlled dynamometer and reported an increase of 13% ($p < 0.01$). A recent review by Porter and colleagues[78] pooled results from 15 intervention studies demonstrating the effects of resistance training on lower extremity power and concluded that exercise can play an important role in helping improve muscle power in elderly. Accurate assessment of lower extremity power is important to prescribe exercises that can produce a noticeable improvement in muscle power and to investigate the most effective training protocols.

2.5: Assessment of Lower Extremity Muscle Power

Despite lower extremity muscle power being a crucial determinant of the physical functioning, there are few investigations of muscle power older people. Macaluso and De Vito[20] said this is because power is much more difficult to measure than strength. Most of the studies that have assessed power have used the knee extension power to represent lower extremity power. However, this is not an accurate representation as functional activities like rising from a chair, that involve the hip, knee and ankle joints. Samuel and colleagues[79] assessed the maximum isometric strength of the knee flexors and extensors, measured at 90, 60 and 20 degrees of knee flexion, and 45, 30 and 0 degrees of hip flexion in 84 healthy individuals aged 60 – 88 years old. They linked the findings to performance on the chair rise test. The functional demand was defined as the moment at a particular joint angle (Nm), divided by the maximum isometric strength (Nm) available at that joint angle, and was expressed as a percentage of maximum isometric strength. They performed a full body 3-D biomechanical assessment using the body markers, an 8-camera motion analysis system with 3 force plates and a standard height chair (460 mm). The results demonstrated that the mean knee extensor functional demand was 72.8% and the hip extensor functional demand was 88.2% of maximum isometric strength during a chair rise activity. Their results showed that the functional demands of both the knee and hip extensors increased with age, increasing from 72% in the participants between 60-70 years to 81.9% in those between 80-90. The functional demand of hip extensors increased from 88.2% to 94.7% in the same age groups. This investigation demonstrates the need to consider both the hip and knee extensors to fully understand the demands in a chair rise.

Isokinetic dynamometers are by far the most commonly used instruments to assess leg muscle power and typically knee extension power is used to represent the whole leg [20]. These devices control the speed of movement and assess power at a single joint eliminating the effects of proximal or distal joints through external stabilization. However, tasks like a chair rise do not occur at a constant speed and do not involve single joint movement therefore, isokinetic dynamometers do not simulate theses everyday multi-joint leg extension tasks. This was highlighted in the review by Macaluso and De Vito[20] and further supported by the findings of Yamauchi and colleagues[32]. Yamauchi and colleagues[32] developed a servo-controlled dynamometer to measure the steady state force – velocity relationship during multi-joint leg extension in 17 subjects (mean age 27.8±13.3 years). Their results demonstrated a linear force – velocity relationship instead of the typical hyperbolic force – velocity curve[80] expected for a single joint movement. This result clearly shows that the force – velocity relationship, and thus power, for multi-joint leg extension can not be accurately described by the relationship measured during single joint movement performed on an isokinetic dynamometer.

2.5.1: Assessment of Multi-joint Lower Extremity Extension Power

2.5.1.1: Field Tests to Assess Multi-joint Lower Extremity Power

A number of functional tests, most notably the sit-to-stand test[81,82,83] and the stair climbing power test[22,84,85] have been proposed as simple, valid methods of assessing multi-joint lower extremity power in older individuals. Many factors affect conclusions about the validity of these tools. For instance, variability of the seat height and the prescribed duration or number of rises in the test affect the outcome in the sit-to-stand test[86]. A landmark study by Lord et al concluded that quadriceps strength was the most important variable determining STS times but other factors such as proprioception, balance, and vision accounted for more than half the explained variance[82]. Most studies have validated the sit-to-stand test using measures of strength. However, Hardy et al[83] assessed the relationship between performance of the 10 time sit-to-stand test and lower extremity power and standing balance. Balance was a significant predictor of test performance and the investigators cautioned against using the test as proxy for leg power[83]. Lindemann and colleagues reported a poor correlation between lower extremity power and the 5 time sit-to-stand set[87]. The stair climbing power test assesses power that can be quantified in Watts. Interestingly, most validation studies for this test use lower extremity leg press strength as the comparator and do not control the velocity of the extension movement[84,85,88,89].

Cardiovascular and respiratory function are known to influence stair climbing performance[90,91] as is balance[22]. The number of stairs climbed varies greatly among testing protocols and affects the outcome[22]. Thus, these functional tests provide a useful way to track change in performance over time, but they have not been shown to measure lower extremity extensor power directly nor do they assess maximum performance.

The vertical jump test is commonly used to assess multi-joint lower extremity power in young individuals [92]. The jump height is documented as indicator of lower extremity power[93] and can be used to quantify power in Watts using predictive formulas. The most commonly used jump tests are: Countermovement jump (CMJ) test and Squat jump (SJ) test. In a countermovement jump, subjects perform a movement that increases knee flexion or decreases leg length or deepens the squat height before they jump[21]. In a squat jump, subjects jump from a semi squatting position without a countermovement[21]. Both tests are used extensively in research[94,21]. In their study, Markovic and colleagues[21] recruited 93 healthy males with a mean age of 19.6 ± 2.1 years to assess the psychometric properties of 7 different jump tests. Between-subject reliability was described using intra-class correlation and Cronbach's alpha coefficients. The results of this study indicated that out of 7 jump tests, the squat jump and the countermovement jump had the greatest between-subject reliability with Cronbach's alpha = 0.97 and 0.98 respectively. Principal component analysis was used to investigate the factorial validity of the tests. Results demonstrated that a single component, explosive power, explained 66.43% of the variance in performance among all 7 jumping tests. The countermovement jump showed the highest relationship with the explosive power factor ($r = 0.87$) and the squat jump had a correlation of $r = 0.81$, supporting the construct validity of the test. A paper by Graham and colleagues[92] discussed the predictive validity of the squat jump for basketball performance in young athletes. They stated that theoretically, athletes with higher squat jumps should have better basketball performance when compared to those with lower jumps. The Lewis formula is commonly used tool to convert jump height to power [95]. Surprisingly, despite of its wide use, the validity of the formula is in doubt[96]. Harman and colleages[96] reported that maximum lower extremity power during the squat jump in 17 young males (mean age: 28.5±6.9 years), estimated using Lewis formula, was 70.1 ± 3.5% less than that measured using laboratory force plates jump test in. Hence, more accurate assessment of power is needed if the goal is precision in exercise prescription.

2.5.1.2: Force Plate Jump Tests

Jump tests performed on force plates are considered to be accurate, standard laboratory tests for analysing lower extremity power[20,97,98]. Force plates measure the ground reaction forces when the body is standing on or moving across them. Vertical jump tests performed on force plates are reported to have construct, predictive, content and concurrent validity for determining the lower extremity power in young individuals[92]. Jump tests performed on force plates have also been used to assess multi-joint strength and power characteristics in older individuals[99]. A study by Ditroilo and colleagues[100] assessed intra- and inter-day reliability of countermovement jump performed on the laboratory force plates in 82 healthy middle-aged (55–65 years) and older (66–75 years) men and women. The researchers reported a coefficient of variance of less than 4% and the intra-class correlation coefficient was greater than 0.90 for peak lower extremity power. Hannan and colleagues[101] studied whether peak power measured using the force plate squat jump test could predict functional performance, quantified as the SPPB score, in 463 community dwelling women aged 71-87 years. The assessment was based on logistic regression and McFadden's pseudo R^2 value. The pseudo R^2 values ranging from 0.2 to 0.4 indicate a very good model fit and therefore, high predictive validity[102]. The investigators reported pseudo R^2 values of: SPPB score ($R^2 = 0.13$), gait speed ($R^2= 0.14$) and chair rise time ($R^2 = 0.18$) demonstrating relatively weak predictive validity of peak power for functional performance in older individuals. It is possible that the strength of the prediction was affected by the fact that the functional performance measures are influenced but factors other than lower extremity power. It is important to note that the older individuals in the studies by Ditroilo and colleagues[100] and Hannan and colleagues[101] were healthy elderly and did not have comorbidities affecting their functional capabilities. Thus, the findings are not immediately applicable to a typical elderly population.

Limitations of Force Plate Jump Tests:

Jump tests may be unsafe for older people with chronic health conditions. Jumping is a ballistic activity that requires postural adjustment and neuromuscular control[103]. Nearly 75% of Canadians above 65 years of age have at least one chronic health condition that can affect their balance[2] suggesting a jump test would be hazardous for them. Jumping is associated with highly compressive landing forces that makes it unsafe for elderly people with comorbidities such as osteoarthritis and osteoporosis[104]. According to a report by Statistics Canada, 20.3% of population aged 65 and older had osteoporosis in the year 2011[43]. Arthritis is the second most common chronic condition among people over 65 years older [40] and 49% of Canadians over 65 reported having osteoarthritis of the knees in 2015[41]. Apart from this, force plates are technically complex and expensive in which limits their use in outpatient physiotherapy clinics. Thus, alternatives to measure power are needed.

2.5.1.3: The Nottingham Power Rig

Bassey and Short developed the Nottingham power rig in 1990 to measure unilateral multi-joint leg extension power[34]. This instrument consists of an adjustable seat and a footplate connected to a flywheel with a lever and chain (Figure 2.4). The footplate can move 0.165m as an individual performs leg extension. The authors validated their instrument by comparing the leg extension power obtained from it with that from the isokinetic dynamometer and vertical jump tests on force plates. Spearman's ranked correlation demonstrated a strong relationship between power calculated using the newly developed 'rig' and that from the isokinetic dynamometer (rho = 0.82, p = <0.001). There was a similarly strong correlation between power from the rig and the jump test. (rho = 0.86, p =<0.001). Despite these high correlations, there were some methodological weaknesses in this study that affect confidence in the validity assessment.

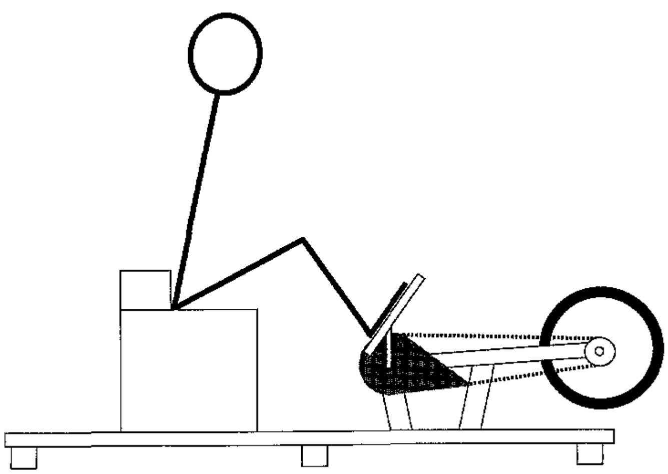


Figure 2.4: Schematic representation of the Nottingham power (LEP) rig[34]
The figure shows leg position of a seated subject at the start of the power measurement.

Bassey and Short claimed that the isokinetic dynamometer was configured to simulate the multi-joint leg extension movement of the power rig, stating that the angles of the hip, knee and ankle were matched to those that occurred during power rig extension. However, the reproducibility and therefor ethe validity of this tool has to be questioned because the authors did not include any information about the specific joint angles either in the power rig or the isokinetic dynamometer, or about testing procedures involved. As a part of this literature review, no studies were found that used an isokinetic dynamometer to produce a combined multi-joint movement such as the leg extension. Hence, we must assume that the authors compared their results with the components of leg extension i.e., the isolated movements of hip, knee and ankle joints or they might have used just knee extension power to represent lower extremity power.

The power and angular velocities were different for both the methods. Power measured on the isokinetic dynamometer is the peak instantaneous power whereas, the power obtained from the power rig was average leg extension power. While the leg extension peak power was calculated from the recorded peak torque at a constant angular velocity of 4 rad/s from the dynamometer, the angular velocity of leg extension on the power rig was dependent on the acceleration of the fly wheel, which in turn was dependent on the amount of push applied by the seated subject. For a combined multi-joint movement, the torque production depends on the combined effects of joint angles and angular velocities[33]. This makes it difficult to compare the torque produced during a multi-joint movement with changing angular velocity with that produced during movement on an isokinetic dynamometer at a constant angular velocity.

2.5.1.4: The Servo-Controlled Dynamometer

Yamauchi and colleagues developed a servo-controlled dynamometer[32] that controlled the force created during multi-joint leg extension in order to measure the steady state force-velocity relationship during the movement. The servo-controlled dynamometer system (Figure 2.5) consisted of a vertically placed tri-axial force plate, a servomotor, and a computer-assisted control unit to produce a servo loop. The force plate was connected to a servomotor, and a force clamp was created by using the servo-feedback to control the displacement of force plate. In this way, the force was kept constant during the movement. The authors used least-squares regression analyses to estimate the force-velocity relationship. They compared the force-velocity relationship obtained from the servo-controlled dynamometer with the estimated line of regression. Their results for 17 subjects (mean age 27.8±13.3 years), were an excellent fit to the line of regression ($r = -0.986$). The authors then extrapolated maximum force (Fmax) and maximum velocity (Vmax) from these results. These Fmax and Vmax were used to calculate the maximum power. In a subsequent study, Yamauchi and Ishii[105] compared power from the servo-controlled dynamometer with that from vertical jump performance, measured as vertical jump height in 67 untrained men and women (mean age: 19.54 ± 2.38 years). There was a significant correlation between the Fmax, Vmax, and Pmax from the dynamometer and the vertical jump performance (r = 0.48, 0.68, and 0.76, respectively, $p < 0.001$). Yamauchi and Ishii claimed that, the servo-controlled dynamometer was a useful tool for evaluating the multi-joint leg extension power; however, the instrument is not available commercially.

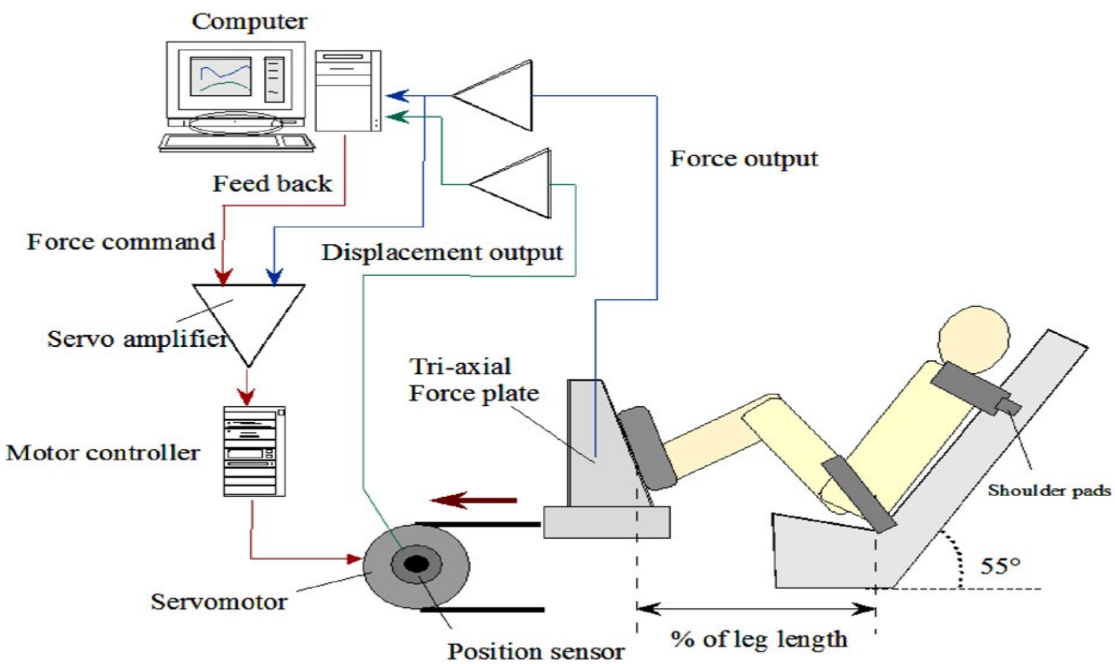


Figure 2.5: Schematic design of the servo-controlled dynamometer[32]
The force command was generated by a personal computer and sent to a servo amplifier. The output from the force plate was sent to the computer and fed back to the servo amplifier, which generated a signal for controlling the servomotor so as to cancel the difference between force command and actually measured force.

2.5.2: Feasible Alternatives

Lower extremity power assessment in older individuals should assess multi-joint extension and be safe for people with poor balance, osteoporosis and other age-related comorbidities. Furthermore, it should be suitable for use in rehabilitation clinics. A leg press machine is commonly used in physiotherapy clinics. When using the leg press, multi-joint extension movement is performed in sitting which is a well supported position that reduces joint impact compared to a jump test. A leg press machine could be used to assess lower extremity muscle power in older individuals if the velocity of the foot plate movement could be measured. An Inertial Measurement Unit (IMU) consists of an accelerometer, a gyroscope, and a magnetometer and measures acceleration, angular velocity and magnetic fields. Recently IMUs have been used by researchers to determine movement characteristics like jump height[106] that can be used to measure multi-joint leg extension power. It is possible that leg press + IMU combination, could be used to measure multi-joint lower extremity power. Adding an IMU to the leg press could facilitate measurement of power by quantifying acceleration of the movement that can be used to calculate the force and velocity of the movement. The leg press + IMU system could be used in a clinical setting because both the leg press and the IMU are commercially available. In fact, most of the outpatient clinics usually have a leg press machine and adding an IMU could be feasible because it is inexpensive and easily available.

Summary of The Literature Review

The proportion of seniors in Canada is increasing, presenting a challenge for the health care system to preserve the quality of life in this population. Aging is associated with a decrease in muscle mass due to a decrease in fiber size and number. These changes are more common in type II skeletal muscle fibres and result in a decline in muscle strength and power that results in limitations in the ability to carry out functional activities. Lower extremity muscle power, which decreases markedly with advancing age, is the strongest physical determinant of functional activities in elderly. Rehabilitation to slow this decline and improve function in the elderly depends on being able to prescribe exercise based on an accurate assessment of power. Currently available tests to assess the multi-joint leg extension power may be unsafe for older individuals, some have questionable validity, while still others are not commercially available. Therefore, an alternative assessment, suitable to the rehabilitation setting, is needed. The purpose of this study is to assess the concurrent validity of a new leg press + IMU system to measure multi-joint lower extremity power by comparing it with power measured during a force plate jump test using Bland-Altman analysis. As jumping presents a problem for older people, we aimed to assess the validity of the new tool in young individuals so that we could use a strong comparator like the force plate jump test.

CHAPTER 3: OBJECTIVE & HYPOTHESIS

Objective:

The objective of this study was to determine the concurrent validity of the leg press (HOIST H4400) + IMU (a Notch inertial measurement unit) system to measure the multi-joint lower extremity extension power in healthy young adults. This was done by measuring the agreement between the results of lower extremity power obtained from this system with that obtained from a squat jump on force plates using Bland-Altman analysis.

Hypothesis:

The hypothesis of this study was that the lower extremity power measured using the leg press (HOIST H4400) + IMU (a Notch inertial measurement unit) system, would be in agreement with that measured using the force plate jump tests on a Bland-Altman analysis.

CHAPTER 4: METHODS

4.1: Study Design

This study examined the concurrent validity of the leg press (HOIST 4400) + inertial measurement unit (Notch IMU) system to measure the multi-joint lower extremity extension power. To do this, the maximum power produced during the multi-joint lower extremity extension on the leg press + IMU system was compared with that produced during a squat jump on the force plates.

4.2: Participant Selection

4.2.1: Inclusion Criteria

1. Healthy young adults aged 18 or older
2. Individuals with the ability to perform a squat jump without any discomfort
3. Individuals with the ability to perform full leg extension on the leg press system without any discomfort
4. Individuals with the ability to understand verbal commands for the test
5. Individuals with the ability to provide a written informed consent

4.2.2: Exclusion Criteria

1. Individuals with any musculoskeletal conditions or injuries that could be exacerbated by a jump
2. Individuals who have reported any instances of loss of balance resulting in an unplanned descent on the floor (fall) with or without injury
3. Individuals under any ongoing rehabilitation program for lower limb injuries

4.3: Sample Size

The sample size for this study was based on work by Harman and colleagues[96]. They compared the lower extremity peak muscle power derived by the Lewis formula with that obtained from the vertical jump test on force plates in 17 healthy young males (mean age: 28.5±6.9 years). The standard deviation of force plate measured peak jump power in this study was 686 Watts. We used the standard deviation and sample size from this study to calculate the margin of error (MOE) using the formula MOE = Z(standard deviation / √N) where Z = the z-statistic value for the determined confidence interval, standard deviation = the sample standard deviation, √N = the square root of the sample size. The alpha value was set to 0.05 with confidence intervals of 95%. Calculations were made using Minitab's (Minitab, LLC, USA) estimate sample size function. A sample size of 17 was obtained for the current study. Four additional participants were recruited to compensate for any breach in the data quality or participant dropout. Thus, 21 healthy young participants were recruited in the study.

4.4: Participant Recruitment

The following method was used to recruit participants in this study:

1. The study posters (Appendix B) were displayed at DalPlex, the Forrest, Dentistry, Tupper and CHEB buildings, and the Killam library and Sexton library
2. The study poster (Appendix B) was sent to the students from School of Health and Human Performance, Dalhousie University using the weekly announcements email correspondence

Individuals interested in participating in the study were asked to contact the principal investigator by phone or email. The investigator contacted these people via telephone to conduct a screening interview (Appendix C) and to provide a description of the study. Those who met the participation criteria and expressed continued interest in participating in the study were given the consent form (Appendix D) by email for their review. People who were still interested in participating in the study after reviewing the consent form were asked to contact the investigator to arrange a 1.5-hour study appointment.

In preparation for the appointment, the participants were advised to: (i) have a light meal or snack before the appointment, (ii) wear comfortable tight-fitting shorts and shoes appropriate for jumping.

At the appointment: the investigator reviewed the consent form with the participants and answered all their questions. Participants were then asked to sign the form and was given a copy for their records.

4.5: Measurement Setup

4.5.1: Measurement 1: Leg Press + Inertial Measurement Unit System

The Hoist 4400 (HOIST Fitness Systems, USA) is a multigym with a leg press component housed in Room 415 at School of Physiotherapy, Dalhousie University. A Notch (Notch Interfaces Inc., New York, USA) inertial measurement unit (IMU) was used with the Hoist 4400 leg press machine to measure the lower extremity muscle power. The Notch IMU is a 3-D motion tracking sensor that consists of an accelerometer, a magnetometer, and a gyroscope. The accelerometer data from this sensor was used in the calculation of muscle power for this study. The Notch IMU sensor was attached to the front of the moving stack of weights of the leg press machine. As the participants performed leg press trials, the stack of weights and IMU lifted vertically and the vertical acceleration of the weight stack along the y-axis was recorded by using the Notch phone application.

4.5.2: Measurement 2: Force Plate Jump Test

The force plates in the Joint Action Research (JAR) lab at School of Physiotherapy, Dalhousie University were used for this part of the study. Squat jumps performed on the force plates were used to measure the lower extremity extension power. The force plates recorded the vertical ground reaction forces (VGRF) generated as a result of the jump. These VGRF were processed and analyzed to calculate the lower extremity power.

4.6: Standardizations Between the Two Measurement Methods

4.6.1: Foot Placement

Standard foot placement marks were made using tape on the footplate of a leg press (Figure 4.1). Foot placement marks, of the same dimensions (length: 22 cm and breadth: 27 cm) were placed on the force plates (Figure 4.1).

4.6.2: Leg Length

Leg length (cm) was calculated as the straight distance from the right greater trochanter to the surface that supported the feet (Figure 4.2). The leg length measured on leg press + IMU system was used as a reference for the starting squat position on the force plates. This was to standardize the distance between hip and foot of each participant during all the trials for both the measurement methods.

4.6.3: Knee Angle

The centre of the strain gauge of Biometrics twin axis electronic goniometer (Biometrics Ltd - Motion Lab Systems, Inc.) was positioned over the center of rotation of the right knee joint (Figure 4.2). One end of the goniometer was aligned with the greater trochanter and other end was aligned with the center of lateral malleolus[107] and secured to the leg to maintain this position using adhesive tape. This positioning was used during both the measurement methods to standardize the initial knee angle during all the trials for both the measurements.

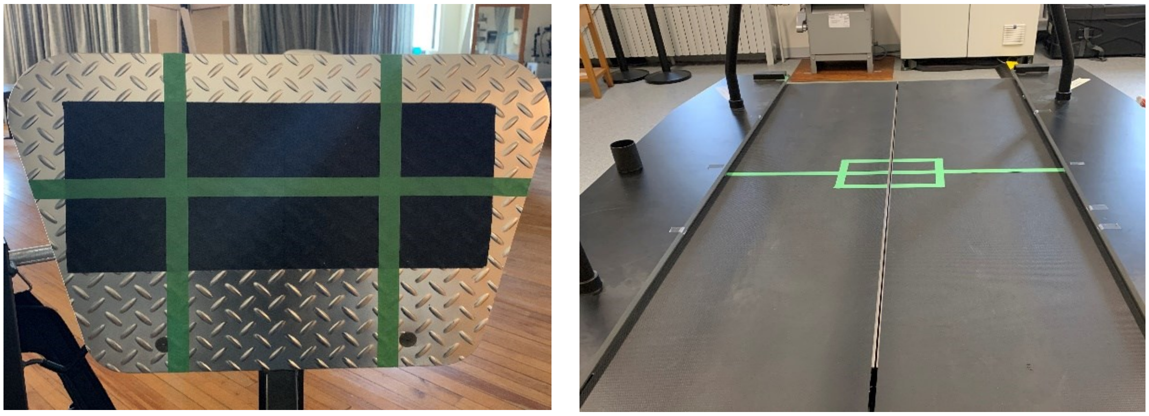


Figure 4.1: Foot Placement
The figure shows foot placement marks on the leg press foot plate (left) and the force plates (right). Dimensions of foot markings were same for both the surfaces (length: 22 cm and breadth: 27 cm). For leg press, the feet were placed on the vertical green tapes with the heel at the bottom of black rectangular mat. For the force plates, the feet were placed on the vertical green borders of the box with heels at the bottom of the box.

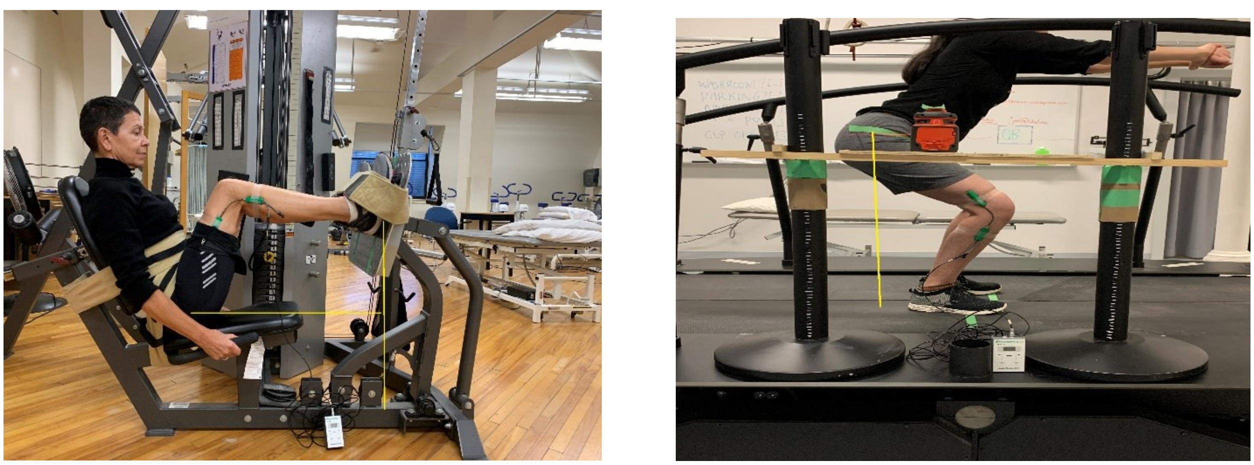
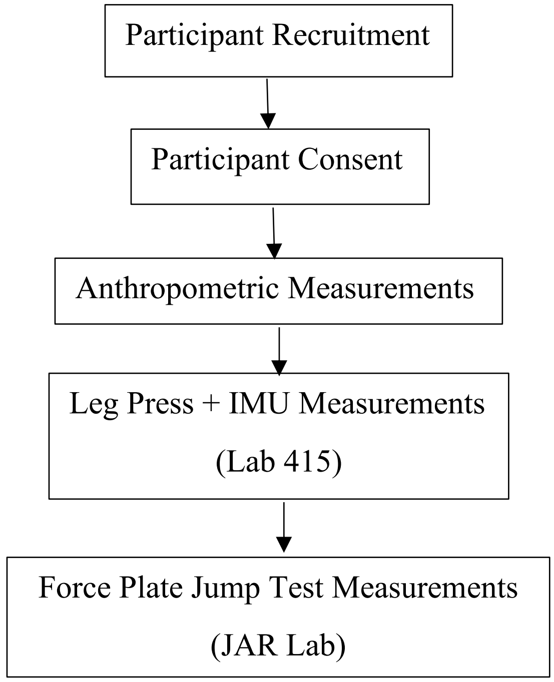


Figure 4.2: Leg Length and Electronic Goniometer attachment to right knee
The figure represents leg length measurements on the leg press (left) and the force plates (right). For leg press, the vertical yellow line represents a wooden stick placed vertically, with one end adjacent to center of participants' foot contact with foot plate and the other end touching the floor. This stick was marked with the distance equal to the distance from participant's greater trochanter to the ground. The horizontal yellow line represents the leg length with the greater trochanter as a starting point and the mark on the vertically placed wooden stick as an end point. For force plates, the leg length was equal to the distance from right greater trochanter (marked with green tape) to the surface of the force plates, represented by vertical yellow line. The greater trochanter was aligned with the adjustable laser light mounted on 2 uprights. The laser light was set to the height equal to leg length measured on leg press. The figure also shows electronic goniometer attached to the right knee.

4.7: Overview of Procedures



After recruiting the participants and obtaining their consent, the data collection procedures began. First, we measured weight for all the participants, which was used to determine the load on the leg press.

4.7.1: Leg Press + IMU System

A biometric twin axis electronic goniometer was attached to the participant's right knee (Figure 4.2) and their right greater trochanter was marked using a colored tape before they sat on the leg press machine (Figure 4.1). The participant sat in the leg press and put their feet on the vertically marked green tapes with the heel at the bottom of black rectangular mat. Next, the backrest was adjusted according to the participant's comfort while aiming to maintain the knee angle at 60 ± 10 degrees. A firm strap was used to stabilize the pelvis with respect to backrest to prevent any forward sliding in the seat during the test. Participants' feet were fastened (Figure 4.2) to the footplate using straps to prevent any loss of contact with the footplate during the fast and forceful leg press movement. In this position the leg length was measured using a measuring tape (Figure 4.2). The vertical distance from the right greater trochanter to the ground was measured using a measuring tape. This distance was marked on a vertical wooden stick. The stick was then placed vertically, with its one end adjacent to the center of participants' foot contact with foot plate and the other end touching the ground as shown by the vertical yellow line in Figure 4.2 so that it marks the height of greater trochanter form the ground. Next, the leg length (cm) was measured using a measuring tape with greater trochanter as a starting point and the mark on the vertically placed wooden stick as an end point, as shown by horizontal yellow line in Figure 4.2. Following this, the weight to be lifted on leg press was set equal to the participant's body weight[108]. Each of the leg press weight plates is 10 lb. and the pulley cam system converts this to 21.5 lb. We performed a calibration to verify this weight translation (Appendix G). Additional weight increments of 2.5 and 5 lb. were added to the weight stack to match the leg press weight with participant's body weight if needed.

The participants then performed 3 familiarization leg press trials (Commands: Push the footplate as fast and as forcefully as possible). After the familiarization trials, the data collection trials began. Initially a "calibration trial" was performed in which the participants simply placed their feet on the foot plate without preforming any movement. This was done to measure and subtract the bias in the acceleration values recorded by the IMU. Three "leg press trials" followed the calibration trial. Standard verbal encouragements 'On the count of 3 push as fast and as forcefully as possible. 1, 2, 3, push' were given during all the leg press trials. These were performed with a 2-minute rest between trials. This time allowed the Notch smartphone application to download the recorded file. The details and sequence of the data collection trials can be found in the data collection sheet (Appendix F).

4.7.2: Force Plate Squat Jump

Participants moved to the JAR lab where the force plate jump measurements were conducted. The electronic goniometer attached to the right knee was used to assess the knee angle during the squat position. The participants were asked to step on the standardized foot markings (see Figure 4.1) for the jump trials. All the participants assumed a squat position using the knee angle and leg length that were measured for starting position of the leg press trials (Figure 4.2). Leg length (cm) was calculated as the distance from the right greater trochanter to the surface of force plates. The leg length was determined using 2 uprights and a laser light source placed besides the force plates on the participants' right side, which was focused on their greater trochanter (Figure 4.2). The 2 uprights were marked with increments of 1 cm. The height of the laser light source was adjusted to equal the leg length measured on the leg press. The participant was asked to squat to a position so that their greater trochanter aligned with the laser light that gave the same leg length as that used during the leg press trial (vertical yellow line in Figure 4.2). Next the knee angle was measured in this squat position to ensure it was same as that measured on the leg press. For all the participants, the recorded knee angle was ± 5 degrees compared to the angle recorded on leg press; therefore, no adjustments were performed.

Once the required squatting position was achieved, the participants held that start position for a period of 3 seconds. The participants then jumped from this start position as fast and forcefully as possible. They were asked not to use a countermovement, which was defined as any movement that further increased knee flexion or decreased leg length or otherwise deepened the squat. Specific instructions were given to the participants to avoid this. Participants were monitored visually and if they performed any countermovement, those jump trials were repeated. The participants performed 3 familiarization trials. After this, the data collection trials began. An initial “standing calibration trial” was done before the 3 jump trials. Participants simply stood on the force plates to measure and subtract the bias in recorded VGRF. This was used to represent the baseline force and thereby the mass of the participant. The 3 jump trials were performed with a 2-minute rest between trials. Standard verbal encouragements ‘On the count of 3 jump as fast and as forcefully as possible. 1, 2, 3, jump’ were given during all the 3 jump trials. A second, “zero calibration trial” was done after the jump trials. In this case the force plates were empty (participant not standing on the force plates). The details and sequence of the data collection trials can be found in the data collection sheet (Appendix F).

4.8: Data Collection

4.8.1: Anthropometrics

The weight (kg) was measured for the participants using research grade digital weight measurement scale.

4.8.2: Measurement 1: Leg Press + Inertial Measurement Unit System

The acceleration data for the calibration trial was recorded for a period of 2 seconds at the sampling frequency of 500 Hz. The acceleration of leg press weight stack during the leg press trials was recorded for a period of 10 seconds at a sampling frequency of 500 Hz. The recording was begun and 3 seconds later following the ‘1,2,3 push’ command described in 4.7.1.

4.8.3: Measurement 2: Force Plate Jump Test

The vertical ground reaction forces for the jump trials were recorded for a period of 10 seconds at a sampling frequency of 500 Hz using the Qualysis Software (Qualisys, Sweden). Vertical ground reaction forces were filtered using a 30 Hz - low pass, 4th order Butterworth, zero-phase digital filter prior to processing. The recording was begun and 3 seconds later following the

‘1,2,3 jump’ command described in 4.7.2. The data for two calibration measurement trials were recorded for a period of 2 seconds at the sampling frequency of 500Hz.

4.9: Data Processing

4.9.1: Leg Press + IMU System

We used the trapezoidal method, the steps of which are described below, for calculation of lower extremity muscle power.

Acceleration data for all the trials was recorded by the Notch smart phone application and downloaded to an Excel file.

Bias Correction:

The mean acceleration value of the calibration trail was calculated and subtracted from each of the acceleration values of the leg press trials.

Calculation of Velocity:

The average acceleration was calculated by taking the average of two consecutive acceleration values. For instance, average acceleration corresponding to the time point 0.004 equals:

Average Acceleration_0.004 (m/s^2) = Acceleration_0.002 (m/s^2)+ Acceleration_0.004 (m/s^2)/2.

Next, the change in velocity (ΔV) was calculated by multiplying the average acceleration with the sampling interval (0.002).

Change in velocity (m/s) = Average_Acceleration (m/s^2) * 0.002 (s).

The Absolute stack velocity was calculated and updated after each sampling interval. This was done by adding the new ΔV and the previous absolute velocity, assuming the absolute stack velocity for the first sampling interval equals to 0. For instance, the absolute stack velocity corresponding to the time point 0.004 equals:

Absolute Velocity_0.004 **(m/s)** = Absolute_Velocity_0.002 (m/s) + ΔV_0.004 (m/s).

Calculation of Force:

The force applied to perform a leg press was calculated by multiplying the participant's body mass with the acceleration of weight stack after accounting for gravity.

Force (Newtons) = Participant_mass (kg) *(Acceleration-(-9.81)) (m/s^2)

Calculation of Power:

Power was calculated as the product of the force and the absolute velocity.

Power (Watts) = Force (N) * Absolute_Velocity (m/s)

Maximum Force, Velocity and Power:

Force –, velocity – and power – time curves were used to determine maximum force, velocity and power for the leg press movement. The Y – axes represented force (N), velocity (m/s) and power (W) and x - axes represented time (s). The beginning of leg press movement was identified as a positive deflection of more than 2 standard deviations from the average baseline on the y – axes. The end of the movement was marked as a return to the value used to identify the start of the leg press. This was done using the conditional formatting feature in Excel that highlighted all the values greater than 2 standard deviations above the average baseline values. The maximum function in Excel was used to determine the peak value on the curve. These curves were used to identify the maximum values corresponding to the leg press movement and to avoid misinterpreting the values corresponding to the impacts created by the collision of weight stack. This data processing was performed for all the participants for all the 3 trials. The mean of the three; maximum force, velocity and power values was calculated and used for subsequent statistical analysis.

4.9.2: Force Plate Jump Test

We used the trapezoidal method, the steps of which are described below, for calculation of lower extremity muscle power. These calculations were demonstrated by Harman and colleagues[96] to calculate lower extremity muscle power during a jump test.

Bias Correction:

The ‘zero calibration trial’ recorded during data collection was used to calculate the bias in recorded VGRF. A custom program, written in MatLab™ 2016b (The Mathworks Inc., USA), was used to correct this bias.

The data files for the jump trials were then downloaded to Excel. These files consisted of vertical ground reaction forces (VGRF) from the left (L_Fz) and the right (R_Fz) force plate.

Calculation of Force:

The total VGRF was calculated by the sum VGRF from the left (L_Fz) and right (R_Fz) force plates.

Total VGRF (N) = L_Fz (N) + R_Fz (N)

Calculation of Velocity:

A series of calculations, similar to those described for the leg press + IMU system, were required to calculate the absolute velocity of a jump. First, the average VGRF was calculated by taking the average of two consecutive total VGRF values. For instance, average VGRF corresponding to the time point 0.004 equals:

Average VGRF_0.004 (N) = Total VGRF_0.002 (N) + Total VGRF_0.004 (N) / 2.

Next, the net force was calculated. This is the force applied by participant resulting in upward movement of the body. This was calculated by subtracting the mean static VGRF from the corresponding average VGRF. The mean static VGRF was calculated as an average of 1000 Total_VGRF values for initial 2 seconds of data recording when the person is in the squat position on the force plates.

Net Force (N) = Average_VGRF (N) – mean static VGRF (N)

The change in velocity (ΔV) was calculated as:

Change in Velocity (m/s) = (Net_Force (N) * Sampling_interval (s)) / Participant_mass (kg)

Lastly, the absolute velocity was calculated for each time point. This was done by adding the new ΔV and the previous absolute velocity. For instance, absolute velocity corresponding to the time point 0.004 equals to:

Absolute Velocity_0.004 (m/s) = Absolute_Velocity_0.002 (m/s) + ΔV_0.004 (m/s)

Calculation of Power:

The calculated total_VGRF and the absolute velocity were multiplied to obtain Power.

Power (Watt) = Total_VGRF (N) * Absolute_Velocity (m/s)

Maximum Force, Velocity and Power:

Force –, velocity – and power – time curves were used to determine maximum force, velocity and power for the squat jump movement. Y – axes represented force (N), velocity (m/s) and power (W) and x - axes represented time (s). The beginning of squat jump movement was identified as a positive deflection of more than 2 standard deviations from the average baseline on the y – axes. The end of the movement was marked as a return to the value used to identify the start of the squat jump. This was done using the conditional formatting feature in Excel that highlighted all the values greater than 2 standard deviations above the average baseline values. The maximum function in Excel was used to determine the peak value on the curve. These curves were used to identify the maximum values corresponding to the squat jump movement and to avoid misinterpreting the values corresponding to the impacts created by participant landing on the force plates. This data processing was performed for all the participants for all the 3 trials. The mean of the three; maximum force, velocity and power values was calculated and used for subsequent statistical analysis.

4.10: Statistical Analysis

Descriptive statistics for lower extremity maximum power, maximum force, and maximum velocity (means and standard deviations) were used to describe the study population. All three parameters were analysed for normal distribution using histograms and the Shapiro-Wilk statistical test. To explore and understand the data, comparisons between parameters from the 2 measurement systems were made using Pearson's product moment correlation test and paired t-tests. The maximum power from the two measurement systems was also compared using the boxplots. The difference between maximum power from the two systems was assessed for normal distribution using histograms and the Shapiro-Wilk statistical test. To serve the objective of this study, Bland and Altman analysis was used to determine the agreement between power determined using the leg press + IMU system and the force plate jump test. The presence of any statistically significant systematic or proportional bias in the Bland and Altman plot, was analysed using t-test and general linear regression analysis, respectively. Statistical Package for the Social Sciences (IBM SPSS Statistics 25) was used for all the statistical analyses of this study.

CHAPTER: 5 RESULTS

A total of 21 participants were recruited for this study. The participant characteristics are presented in Table 5.1.

Table 5.1: Participant Characteristics

N	21
Females (%)	38
Age (years)	23.7 ± 2.8
Mass (kg)	76.6 ± 17.0
Leg length (cm)	66 ± 4

Participant characteristics presented as the mean ± SD
Leg length (cm) was calculated as the straight distance from the right greater trochanter to the surface that supported the feet (See Section 4.6.2)

5.1: Maximum Lower Extremity Power

Table 5.2 presents the mean ± SD values of maximum power, maximum force and maximum velocity for all the participants measured using the force plate jump test and the leg press + IMU system. Individual participant values of maximum force, velocity and power are presented in Appendix H, I and J, respectively. The individual participant values of maximum power calculated using the force plate jump test and the leg press + IMU system were analysed to confirm that they were normally distributed. The Shapiro-Wilk test demonstrated that the results were not significantly different from the normal distribution with a significance value of 0.69 and 0.44 for the force plate jump test and the leg press + IMU system, respectively. The histograms and test results for normality are presented in Appendix K, L, M and N. The correlation between the mean maximum force, velocity and power between the 2 measurement systems was assessed using Pearson's product moment correlation. This analysis demonstrated that maximum power and force were correlated whereas the maximum velocity was not (Table

5.2). Paired t-tests were used to assess whether there were significant differences between the parameters from the 2 measurement systems. Maximum power and force were significantly different whereas the velocity was not (Table 5.2). The maximum power from the two measurements was also compared graphically using boxplots (Figure 5.1). The box plot comparison compliments the results in Table 5.2, showing that the median and the range of the maximum power calculated from the force plate jump test was greater than that for the leg press + IMU system. The greater range and longer whiskers for the force plate jump test indicates greater variability among the participants compared to the leg press + IMU system measured power. The box plots also revealed that no outliers were present in the data for either measurement.

Table 5.2: Force, Velocity and Power

	Force Plate Jump Test	**Leg Press + IMU System**	**t - test**	**Correlation Coefficient**
Maximum Force (N)	1693.9 ± 394.4	1393.5 ± 319.9	$p < 0.001$	$r = 0.9$*
Maximum Velocity (m/s)	2.3 ± 0.2	2.2 ± 0.3	$P = 0.130$	$r = 0.2$
Maximum Power (W)	3278.1 ± 955.7	2438.2 ± 777.8	$P < 0.001$	$r = 0.7$*

Values represent the mean ± SD of the maximum lower extremity force (Newtons), velocity (meters/second) and power (Watts), measured using the force plate jump test and the leg press + IMU system. Paired-sample t-test and Pearson's product moment correlation coefficients were used to compare the results. '*' indicates a statistically significant result at $p \leq 0.05$.

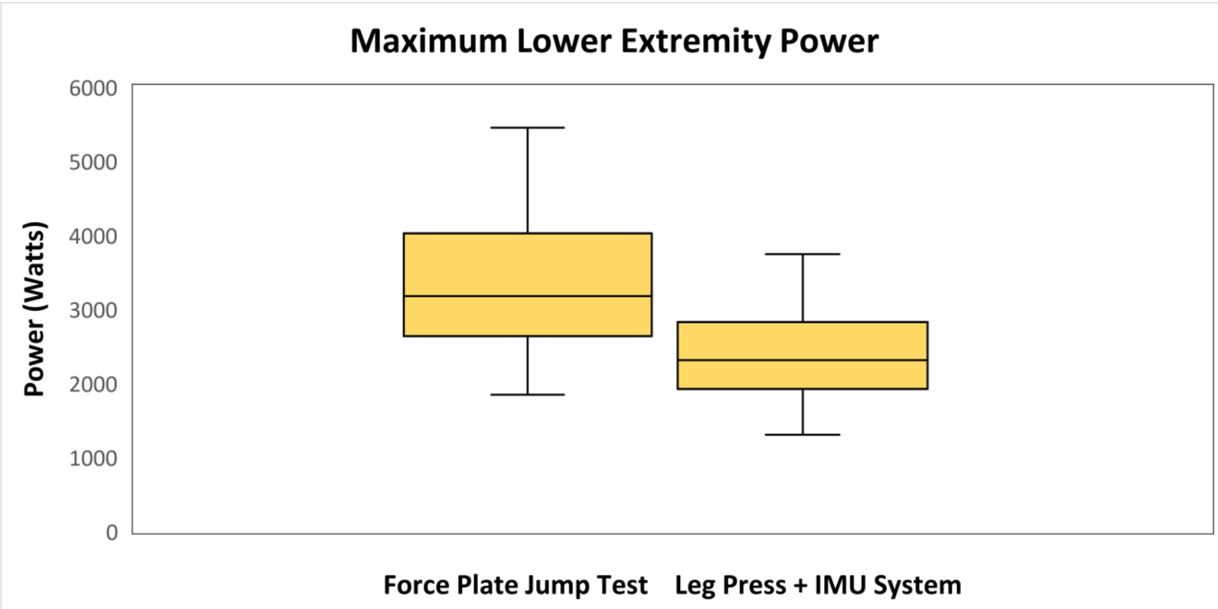


Figure 5.1: Box plots of the maximum lower extremity power (Watts)
The plot presents power from the force plate jump test (left) and leg press + IMU system (right). The box represents the median (solid horizontal line inside the box), and the 2nd and 3rd quartiles (the boxes on either side of median) of the leg power data. The upper and lower whiskers represent the 1st and 4th quartiles.

Bland-Altman analysis (Figure 5.2) was performed to determine the agreement between the two power measurements. The maximum lower extremity power for all the participants measured by both methods lies within the limits of agreement and are spread equally on both sides of the mean. The mean difference between both the measurement methods was 839.94 Watts with a standard deviation of 644.71 Watts. This difference is positive for all the participants indicating that power calculated from the force plate measurements was always higher than that calculated using data from the leg press + IMU system, identifying a systematic bias in the data. The bias is called a proportional bias when the difference between the two measurement methods is observed to increase or decrease by an amount that is proportional to the mean value. We did not find any signs of proportional bias on our Bland – Altman plot. To further confirm our interpretation regarding the systematic and the proportional biases, post – hoc analyses were performed.

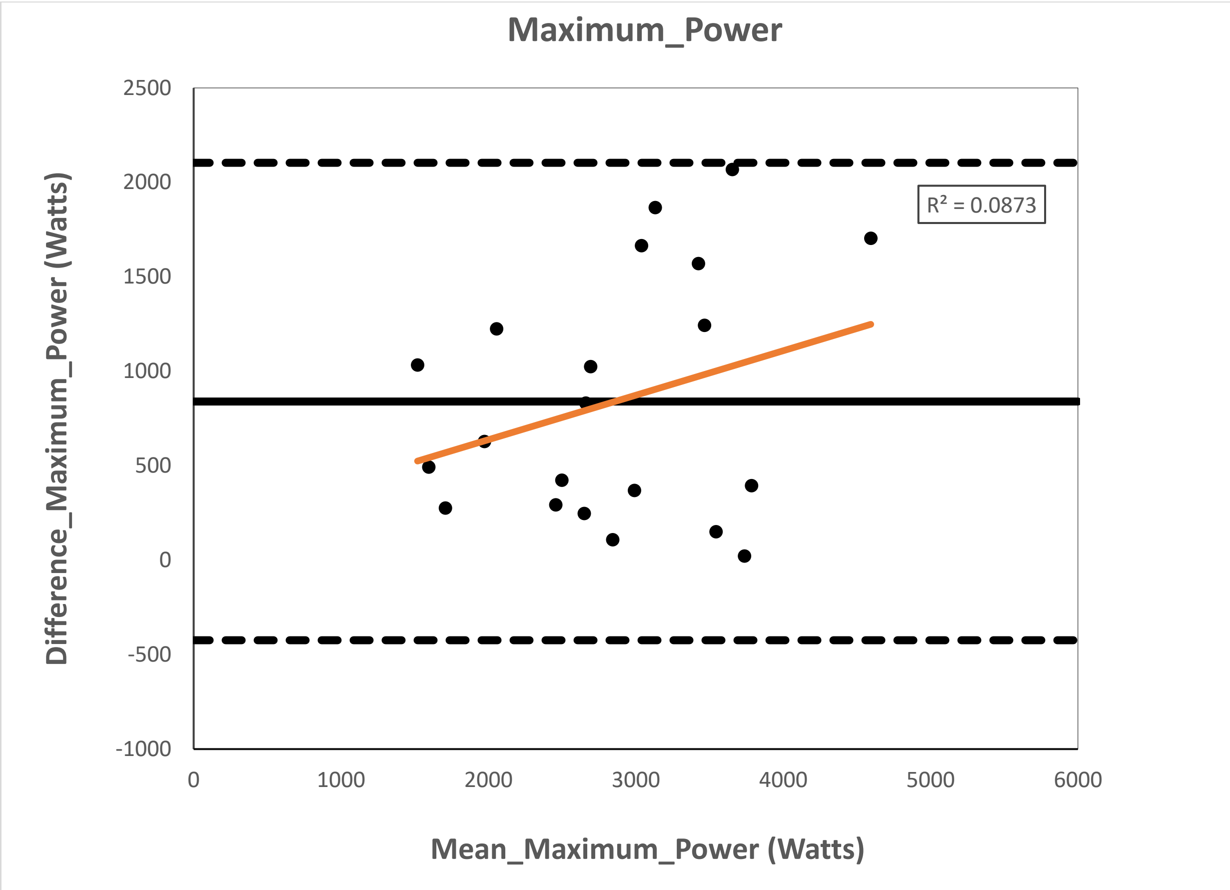


Figure 5.2: Bland-Altman Plot of the maximum lower extremity power (Watts) comparing force plate jump test and the leg press + IMU system
The x-axis represents the mean of force plate and leg press power for all the participants and the y-axis represents the difference between the means of the force plate and leg press power. The solid line represents this mean difference across the range of maximum power values. The dotted lines represent the limits of agreement which were set to ± 1.96 SD. The orange line represents the linear regression of the mean_maximum_power with respect to the difference_maximum_power for the two measurement methods. R^2 indicates the proportion of variance explained by the mean_maximum_power.

Proportional Bias: To confirm the absence of proportional bias, a post-hoc analysis was performed using simple linear regression. The difference between the force plate and leg press power was set as the dependent variable and the mean of force plate and leg press power was set as the independent variable. The linear regression line can be seen in Figure 5.2. The results of the regression (F = 1.88, $p = 0.19$) demonstrate that there was no significant proportional bias present between the two measurement methods. A power analysis of the regression, using the G-

Power software (Heinrich-Heine-Universität Düsseldorf), returned a power of 0.3, which suggests that the study sample size was too small to confirm the lack of proportional bias.

Systematic Bias: The magnitude of the difference in maximum power between the two measurements was substantially different among the participants (Appendix I). The force-time curves for all the participants were examined to explore the reasons for this difference. This revealed that 10 of the 21 participants appeared to have performed a countermovement, arm-swing or trunk movement before the squat jump. This was defined as a negative deflection of more than 2SD from the average baseline force before the jump on a force – time curve[109]. The jump was defined as a positive deflection of more than 2SD from the average baseline force on a force – time curve. Figure 5.3 and 5.4 demonstrate the force – time curve (x – axis represents force (Newtons) and y – axis represents time (seconds)) for two representative participants who did and did not perform a countermovement.

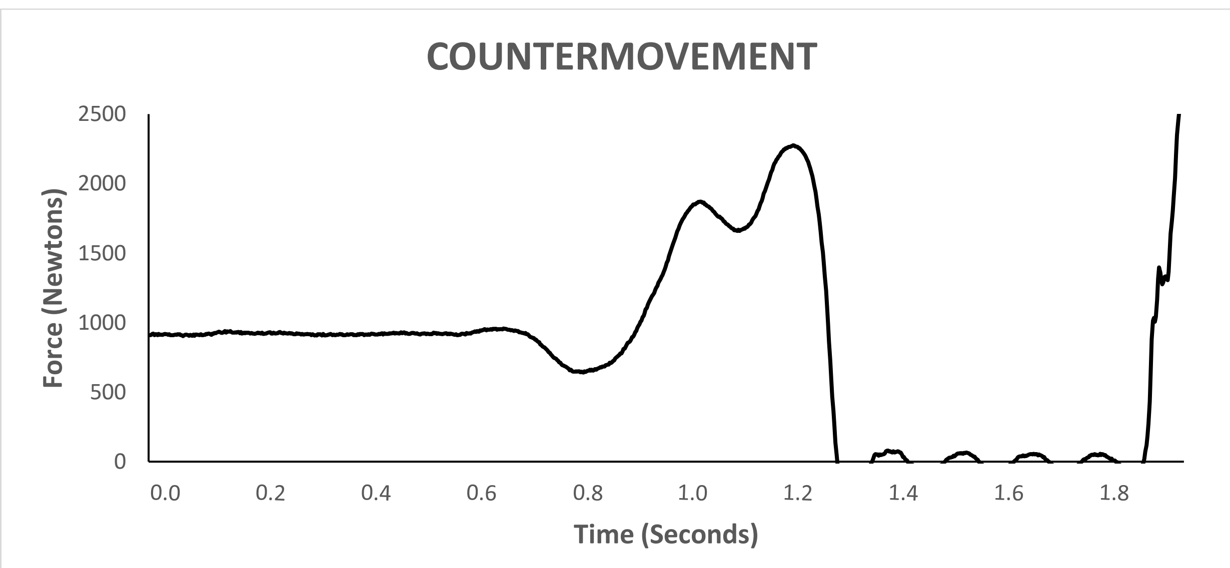


Figure 5.3: Force – Time curve of a participant demonstrating a countermovement
The x-axis represents time in seconds and the y-axis represents the force in Newtons. The countermovement is visible as a negative deflection in baseline force preceding the jump. The jump is visible as a positive deflection in the baseline force.

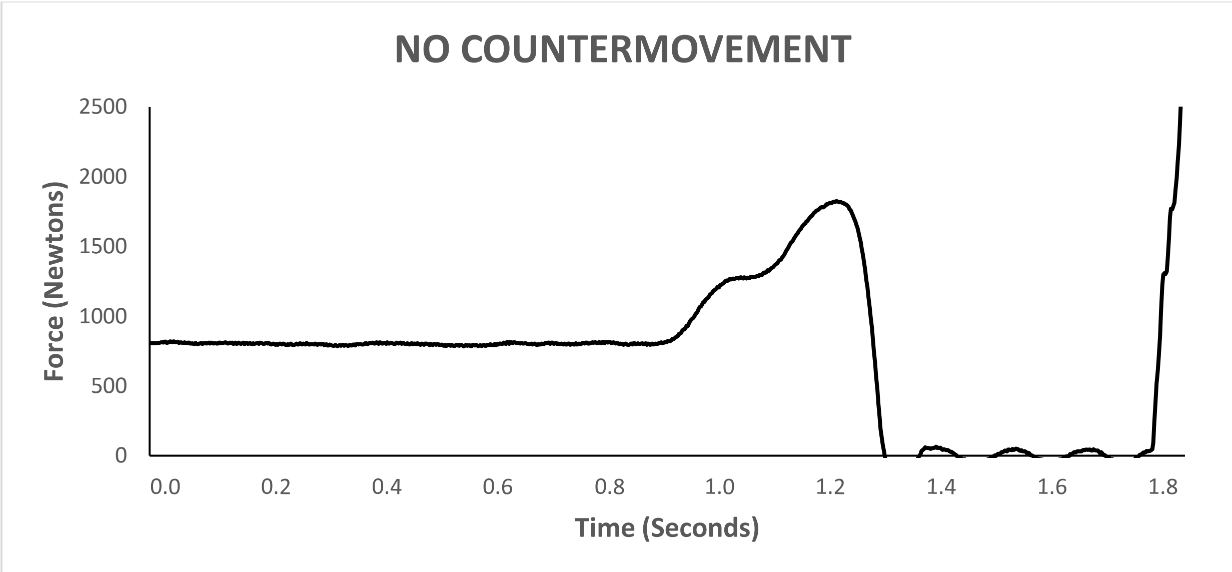


Figure 5.4: Force – Time curve of a participant who does not use a countermovement
The x-axis represents time in seconds and the y-axis represents the force in Newtons. The absence of a countermovement is visible as no negative deflection in the baseline force preceding the jump. The jump is visible as a positive deflection in the baseline force.

We performed a subgroup analysis for the participants who did and did not perform a countermovement to determine whether this difference affected the maximum power obtained from the two measurement tools. The analysis revealed that the difference in maximum power between the two tools was 1423.30 ± 408.7 Watts for the participants who performed the countermovement (Appendix O) compared to only 309.61 ± 176.89 Watts for participants who did not (Appendix P). This study aimed at determining the concurrent validity based on the Bland-Altman analysis by comparing the maximum power for the squat jump without a countermovement, arm-swing or trunk movement and the leg press performed on our new leg press + IMU system. Bland-Altman analysis (Figure 5.5) for the subgroup of 11 participants that did not use countermovement demonstrated the agreement between the two power measurements. The maximum lower extremity power for all of these participants measured by both methods lies within the limits of agreement and the data points are spread equally on both sides of the mean. The mean difference between both the measurement methods was 309.61 ±

176.89 Watts. This difference was positive for all the participants indicating that power calculated from the force plate measurements was still higher than that calculated using data from the leg press + IMU system, identifying a systematic bias in the data. The maximum force, velocity, and power measured by the force plate jump test and the leg press + IMU system were compared for the participants who did not perform the countermovement (Table 5.3). The results show that the difference in maximum power observed between our two measurements remained statistically significant ($p<0.05$). To further explore the reasons for the significant difference in maximum power between the two measurements among the subgroup who did not perform a countermovement, arm-swing or trunk movement, several additional analyses were performed for this subgroup.

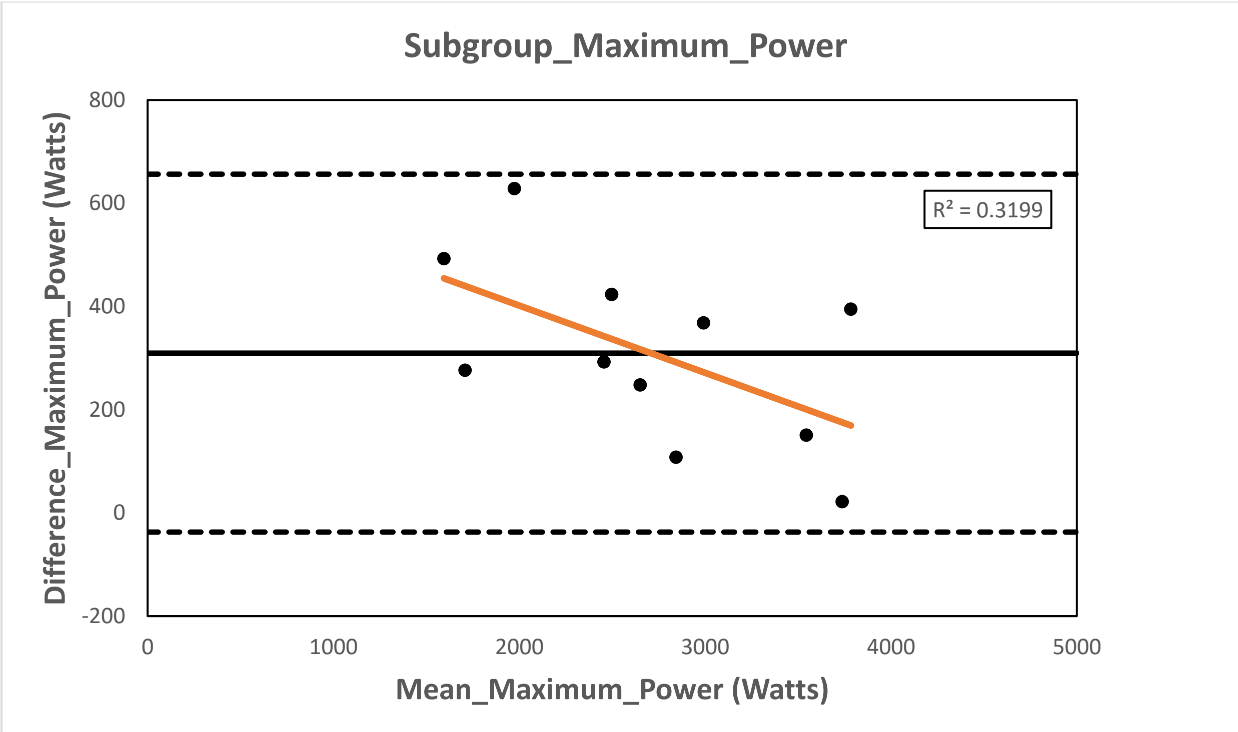


Figure 5. 5: Bland-Altman Plot of the maximum lower extremity power (Watts) comparing force plate jump test and the leg press + IMU system in a subgroup that did not use countermovement

The x-axis represents the mean of force plate and leg press power for all the participants and the y-axis represents the difference between the means of the force plate and leg press power. The solid line represents this mean difference across the range of maximum power values. The dotted lines represent the limits of agreement which were set to ± 1.96 SD. The orange line represents the linear regression of the mean_maximum_power with respect to the difference_maximum_power for the two measurement methods. R^2 indicates the proportion of variance explained by the mean_maximum_power.

Table 5.3: Participants not using a Countermovement: Force, Velocity and Power

	Force Plate Jump Test	**Leg Press + IMU System**	**t - test**	**Correlation Coefficient**
Maximum Force (N)	1580.3 ± 359.2	1364.7 ± 318.3	$p < 0.001$	$r = 0.9$*
Maximum Velocity (m/s)	2.1 ± 0.2	2.0 ± 0.3	$p = 0.031$	$r = 0.8$*
Maximum Power (W)	2862.1 ± 722.0	2552.5 ± 821.6	$p < 0.001$	$r = 0.9$*

Values represent the mean ± SD of the maximum lower extremity force (Newtons), velocity (meters/second) and power (Watts) measured using the force plate jump test and the leg press + IMU system. Paired-sample t-tests and Pearson's product moment correlation coefficients were used to compare the results. '*' indicates a statistically significant result at $p \leq 0.05$.

5.2: Reasons for Power Differences in Participants Who Did Not Use a Countermovement, arm swing or trunk movement in the Squat Jump

Maximum power is the product of maximum force and velocity. In this study, maximum force corresponds to the amount of weight being pushed/lifted times the acceleration at which it is pushed. The weight to be pushed/lifted was the same in both tests but, our results show that maximum force was significantly different between the two measurements (Table 5.3). Therefore, the acceleration during the two movements must have been different, which could account for the differences in maximum power. Acceleration is the rate of velocity development for the movement. Velocity is how fast the movement was performed. Our results show that maximum velocity was significantly different between the two measurements (Table 5.3). This indicates that one movement must have been performed in less time than the other. To better understand this and the difference in acceleration (rate of velocity development), the duration and the rate of maximum force, velocity and power development between the 2 assessment techniques were examined. All analyses in the subsequent sections are limited to the concentric phase of the movement. For the squat jump, this was defined as the time from movement initiation to the time the participant left the ground. For the leg press, the concentric phase was defined as the time from movement initiation to the time at which the legs were fully extended.

5.2.1: Duration: Squat Jump and Leg Press Movement

The duration of movements was determined using the power – time curves. A power – time curve was plotted for all the three trials for each of the 11 subgroup participants. The x – axis represented power (Watts) and the y – axis represented time (seconds). On the power time curve, the concentric phase of the movements was determined as the power data points greater than 2SD from the average baseline power on y – axis. The x – axis values corresponding to this part of curve was considered as the duration of the concentric phase of movements in seconds. The duration was calculated for each of the three trials for each participant for both the measurements. The mean of the three durations were compared between the two measurements. The comparison revealed that the duration of the squat jump was significantly less ($p < 0.05$) than that of the leg press movement (Table 5.4). The individual participant values for the duration of the concentric phase of the squat jump and leg press time are presented in Appendix Q and R, respectively.

Table 5.4: Analysis of Squat Jump and Leg Press Movement Duration

Movement	Total Time (s)
Leg Press	0.8 ± 0.2
Squat Jump	0.4 ± 0.1
Difference	0.4 ± 0.1*

Values represent the mean ± SD values for the duration of the concentric phase (seconds) of the squat jump and the leg press movements. All values are expressed as mean time ± SD. '*' indicates a statistically significant difference at the $p \leq 0.05$.

5.2.2: Rate of Maximum Force, Maximum Velocity and Maximum Power Development

We analysed the rate of maximum power (Figure 5.5), maximum force (Figure 5.6) and maximum velocity (Figure 5.7) development for both the squat jump and the leg press movements. This was done using power –, force –, and velocity – time curves where x – axes represented time and y – axes represented power (Watts), force (Newtons) and velocity (m/s), respectively. The concentric phase of the movement was identified using the method described in section 5.2.1 for each parameter independently on all the three curves. The mean of the 3 trials was plotted against time for each participant for each measurement system. (Figure 5.5, 5.6 and 5.7) The maximum value for each parameter was identified from the mean curve. The rate of development was calculated as the maximum for the parameter divided by the time taken to achieve that maximum[110]. The Table 5.5 presents the comparison of the rate of maximum power (W/s), force (N/s) and velocity (m/s^2) development for the squat jump and leg press assessments. These analyses demonstrate that the rate of power and velocity development were significantly faster during the squat jump than the leg press movement whereas, the rate of force development was quite similar between the two. The power –, force –, and velocity – time curves (Figure 5.8, 5.9, 5.10, respectively) for one representative participant not using the countermovement were also plotted for easier comparison of the two movements.

Table 5.5: Rate of Maximum Force, Maximum Velocity and Maximum Power Development

Rate of Development			
	Squat Jump	**Leg Press**	**t - test**
Maximum Force (N/s)	2707.2 ± 1427.4	2511.2 ± 1186.6	$p = 0.371$
Maximum Velocity (m/s^2)	6.67 ± 2.6	5.05 ± 1.6	$p = 0.002$
Maximum Power (W/s)	9883.9 ± 4481.0	6072.1 ± 2546.9	$p = 0.002$

Values represent the mean ± SD of the rate of maximum force (Newtons/Second), velocity ($meters/Second^2$) and power (Watts/Second) development during the squat jump and leg press movements for participants not using a countermovement. Paired-sample t-test was used to compare the results.

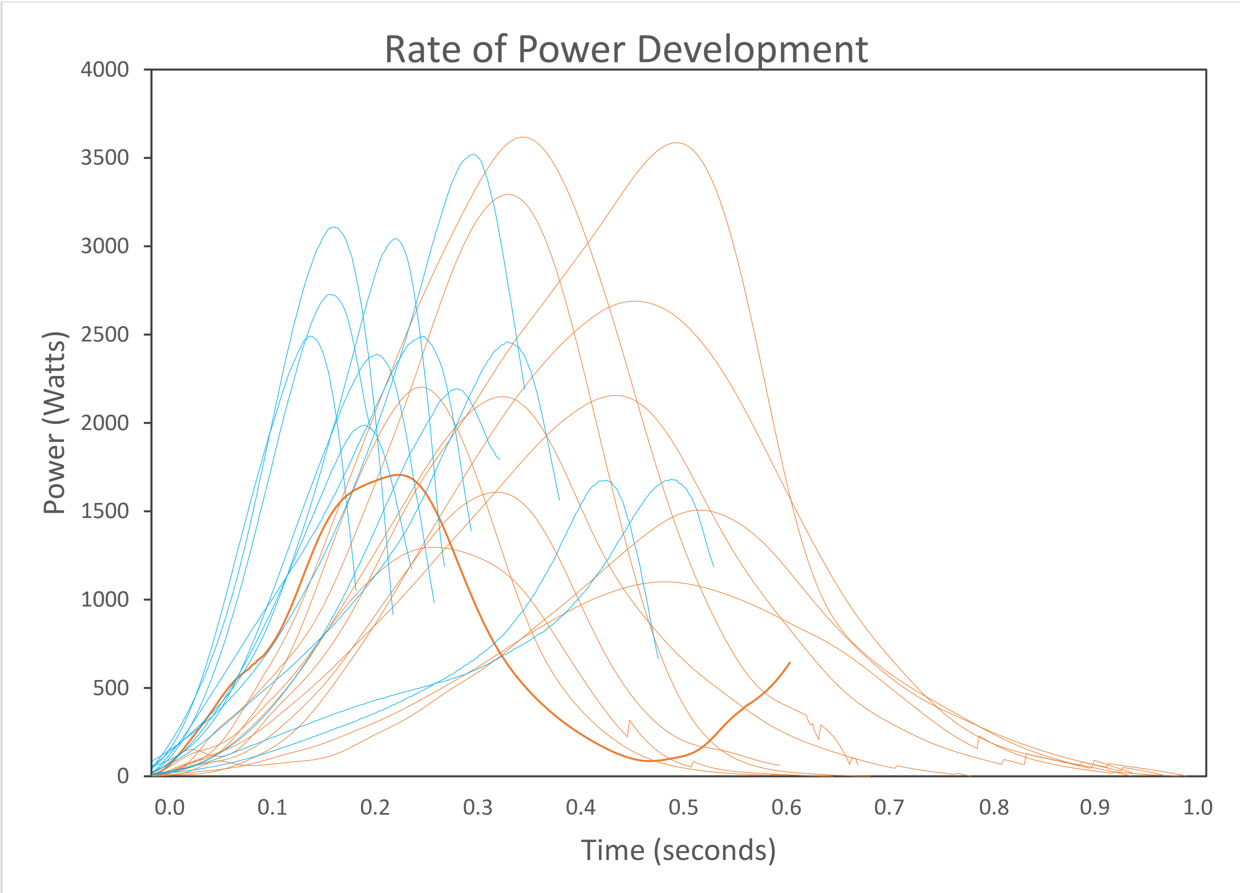


Figure 5.6: Rate of maximum power development for the concentric phase of the squat jump and leg press for participants not using countermovement

The x-axis represents time in seconds and the y-axis represents the lower extremity power in Watts. The power during the squat jump is represented by the blue lines and that for the leg press is represented by the orange lines. Each line represents the mean power – time curve for the three trials.

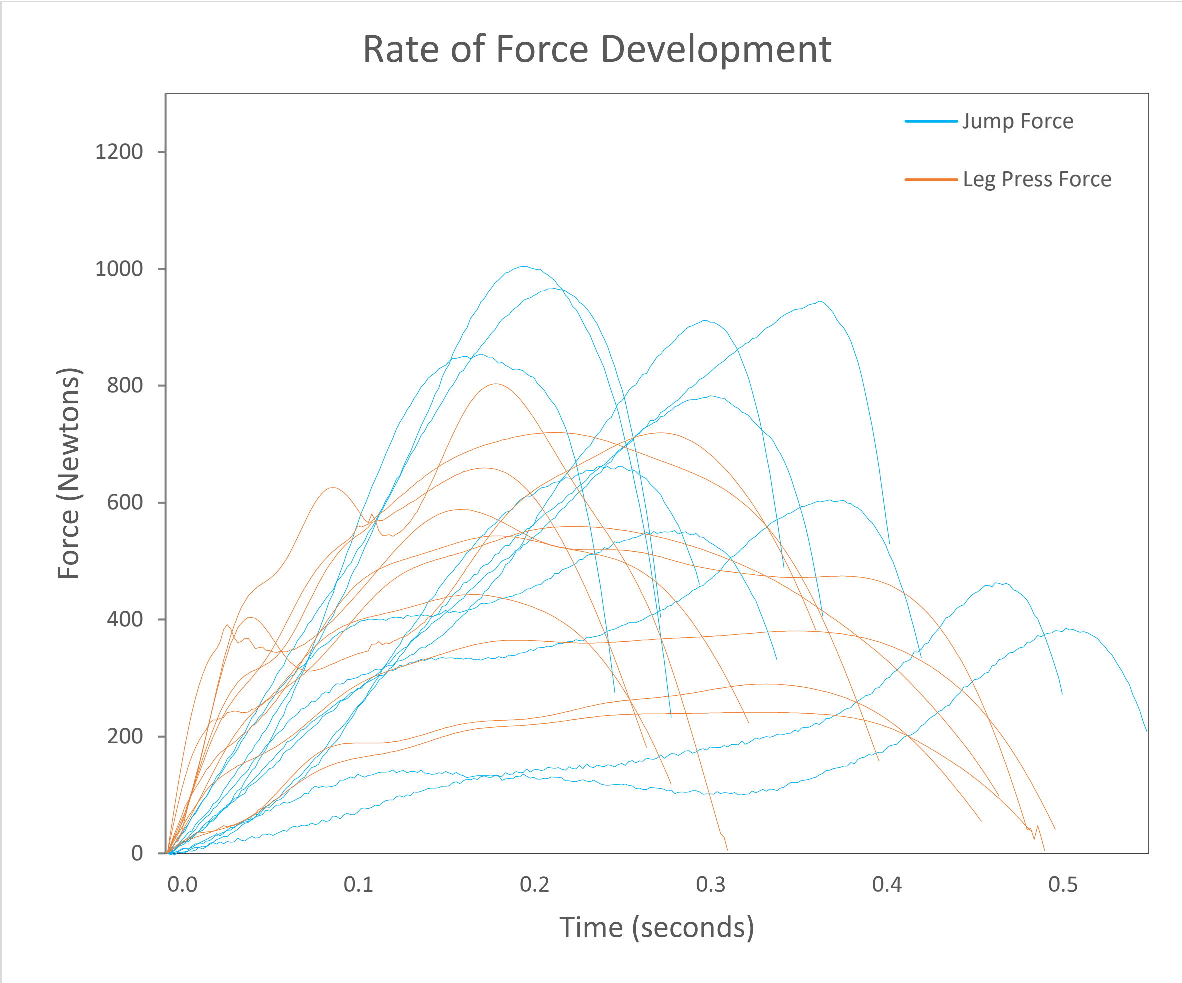


Figure 5.7: Rate of maximum force development for the concentric phase of the squat jump and leg press for participants not using countermovement
The x-axis represents time in seconds and the y-axis represents the force in Newtons. The force during the squat jump is represented by the blue lines and that during the leg press is represented by the orange lines. Each line represents the mean force – time curve for the three trials.

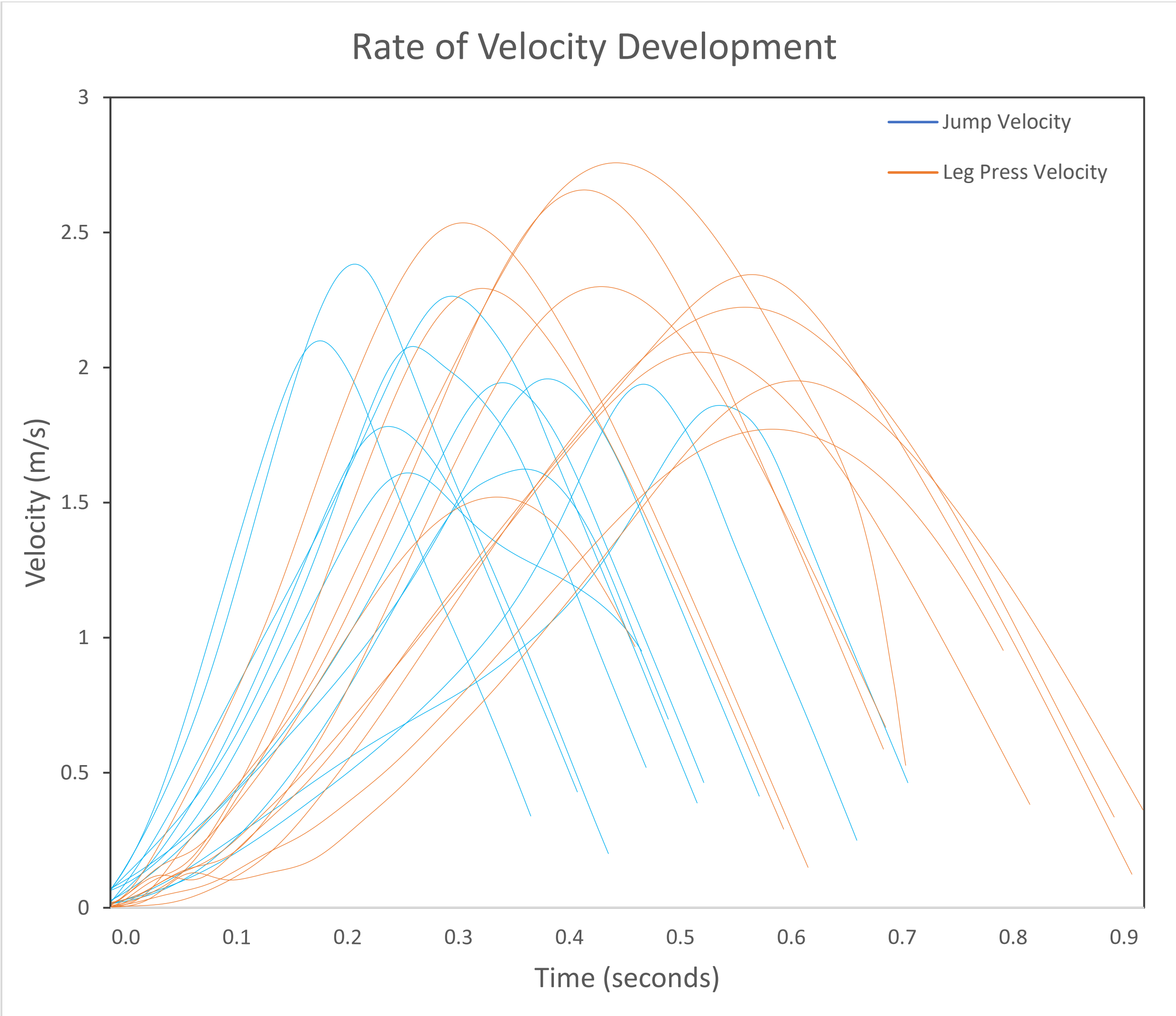


Figure 5.8: Rate of maximum velocity development for the concentric phase of the squat jump and leg press for participants not using countermovement
The x-axis represents time in seconds and the y-axis represents the velocity in meters/second. The velocity during the squat jump is represented by the blue lines and that of the leg press is represented by the orange lines. Each line represents the mean force – time curve for the three trials.

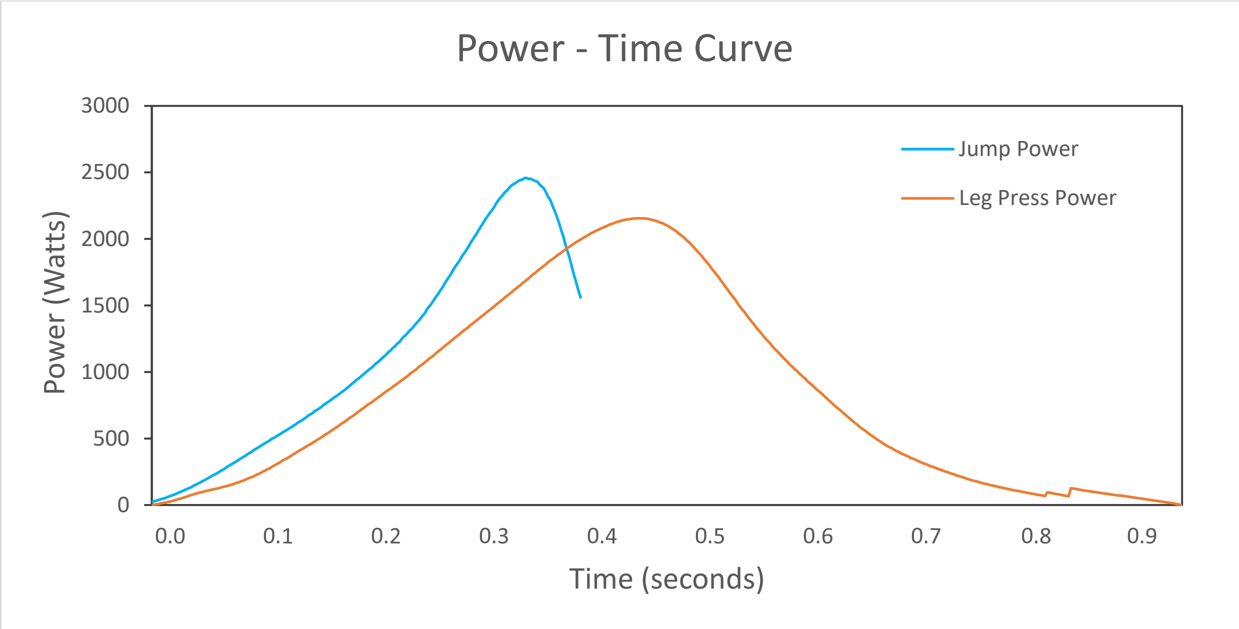


Figure 5.9: Power–Time Curve of a representative participant not using countermovement The curves represent rate of power development in a representative participant during the concentric phase of the squat jump and the leg press movement. The x-axis represents time in seconds and the y-axis represents the power in watts. Each line represents the mean force – time curve for the three trials.

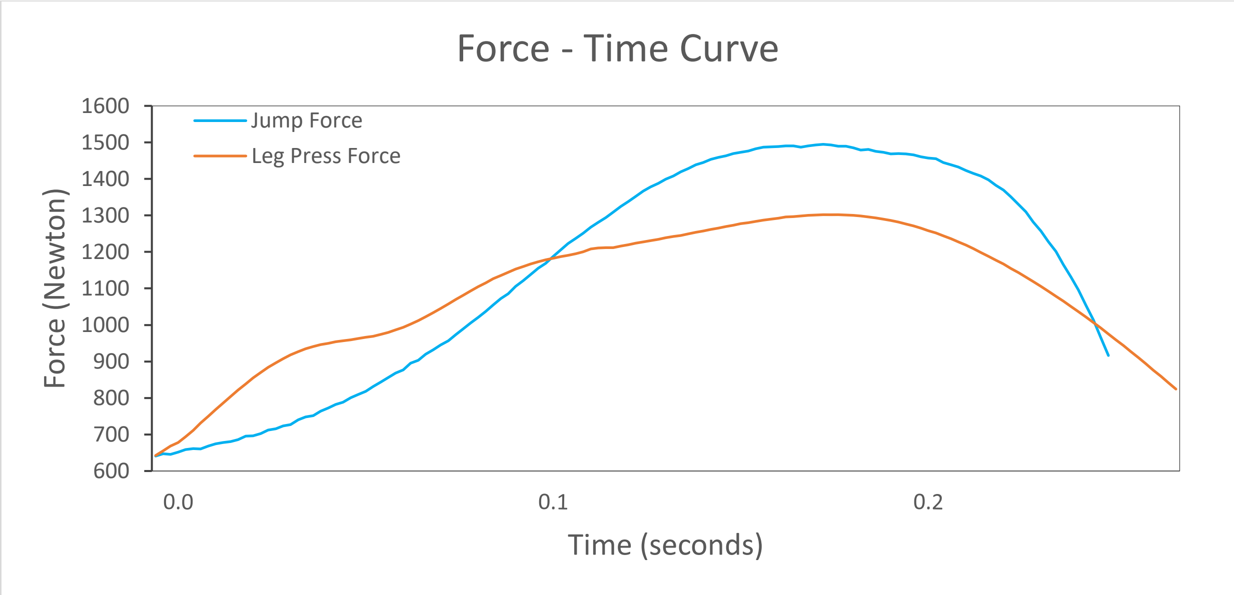


Figure 5.10: Force–Time Curve of a representative participant not using countermovement The curves represent rate of force development in a representative participant during the concentric phase of the squat jump and the leg press movement. The x-axis represents time in seconds and the y-axis represents the force in Newtons. Each line represents the mean force – time curve for the three trials.

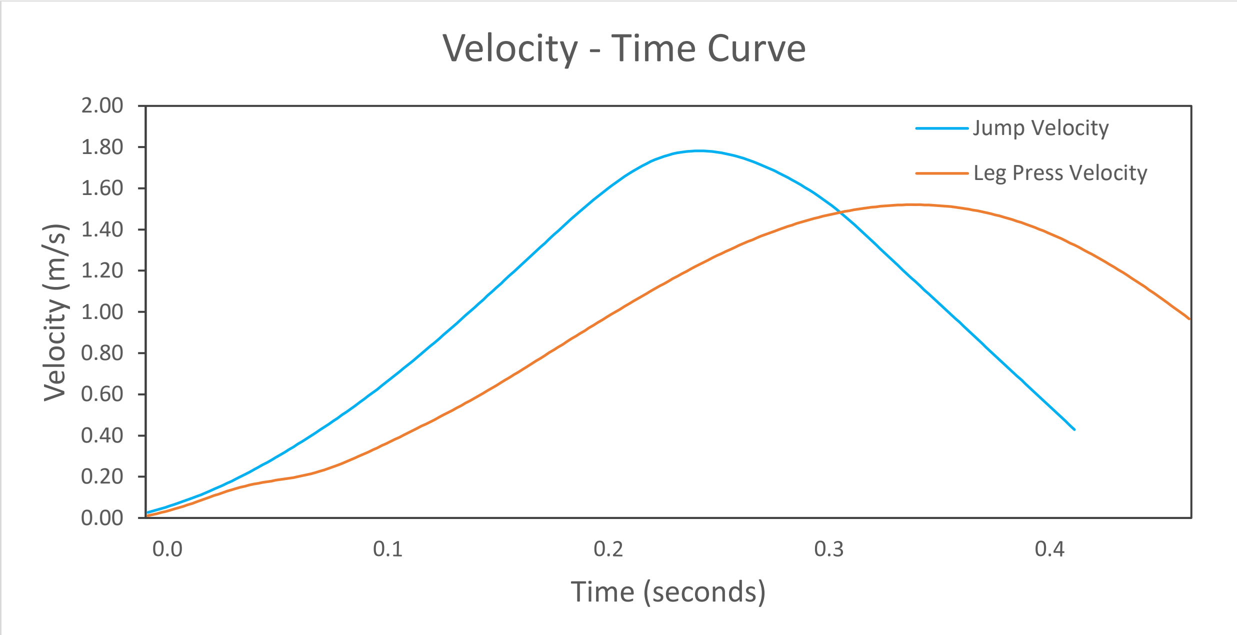


Figure 5.11: Velocity–Time Curve of a representative participant not using countermovement The curves represent rate of velocity development in a representative participant during the concentric phase of the squat jump and the leg press movement. The x-axis represents time in seconds and the y-axis represents the velocity in meters/second. Each line represents the mean force – time curve for the three trials.

CHAPTER: 6 DISCUSSION

This study aimed to use Bland-Altman analysis to evaluate the concurrent validity of a new method for measuring maximum lower extremity extension power by comparing values calculated using data from our newly developed leg press + IMU system with those obtained from a squat jump test on research-grade force plates. The load in each test equaled body weight. The objective was to determine if the new method could replace the force plate jump test and be used for exercise prescription. Bland-Altman analysis demonstrated a systematic difference of 840 Watts, with the force plate jump test power always being higher than our new leg press + IMU system. However, the magnitude of this difference was not consistent among the participants. Inconsistencies in jump technique and the load between the two systems appeared to account for much of the difference in maximum power. Accounting for these discrepancies, the difference in maximum power measured by the two systems was negligible and unlikely to have any significant effect on exercise prescription.

A careful examination of participant force – time curves demonstrated a negative deflection in force prior to the jump in a subgroup of 10 (9 males) participants. This deflection could have been due to participants using a countermovement prior to the jump. A squat jump should be a purely concentric activity that does not incorporate a countermovement, arm-swing or trunk movements that results into eccentric contraction prior to the jump[111]. Visual checks facilitated by a laser light focused on the greater trochanter did identify some people who used a countermovement. In these cases, participants repeated the jump to produce a pure squat jump. It is possible other countermovement were missed. The study protocol did not have specific instructions to limit arm or trunk movements which may have caused negative deflections on the force-time curves[112]. It is well established that the initial rapid eccentric contraction of a stretchshortening cycle prior to jumping accentuates the subsequent jump performance[113]. Numerous investigations have demonstrated this using jump height as an outcome measure[114,115,116]. Jump height is an indicator of the ability to produce maximum lower extremity power in healthy young adults[93]. A study by Hara and colleagues in 5 males (mean age: 27.6±3.8 years) documented that use of arm-swing increased vertical jump height by 18% (p<0.05) when used during a squat jump[117]. Another study by Floría and colleagues reported a significant increase of 18.7% in vertical jump height with the use of arm-swing during a countermovement jump in 20 females (mean age: 22.3±3.1 years)[118]. There are inconsistencies in the literature regarding the magnitude of difference in power between the countermovement + arm-swing jump and the squat jump. However, the countermovement jump + arm-swing is always reported to produce greater power than the squat jump. Harman and colleagues[119] assessed the difference in power during a squat jump and a countermovement jump with arm-swing by recording the VRGF measured on force plates in 18 males (mean age: 28.5±6.9 years). They reported a difference of 634 Watts between maximum lower extremity power during a countermovement jump with arm-swing as compared to a squat jump. Another study by Walsh and colleagues[120] reported a difference of 683 Watts between the countermovement jump with arm-swing and the squat jump power in 25 healthy young males (mean age: 21.4±1.7 years). On the other hand, Bosco and colleagues[121] reported a much larger difference of 1158 Watts in muscle power between the countermovement and a squat jumps among healthy young males. The present study demonstrated a mean difference of 1423 Watts between the two measurement systems in participants who performed a countermovement compared to only 310 Watts in those who did not, consistent with literature demonstrating enhanced power with a countermovement jump and countermovement + arm-swing jump. Bland-Altman analysis using data from participants who did not use a countermovement demonstrated that two methods were in agreement and may be used interchangeably.

Despite this, the 310 Watts difference between the two measurement systems was statistically significant. One plausible cause for the difference in the power in those who did not use the countermovement may be the difference in acceleration observed between the 2 movements. Acceleration produced during the leg press was less than that for the squat jump. In hindsight, it appears that participants had to push more weight during the leg press movement than in the squat jump. We used the maximum dynamic output theory[108] to determine the optimum load for maximum power development during the squat jump. This theory states that power is greatest when the jump load is equal to a person's body weight. Therefore, to standardize the testing conditions we set the leg press load equal to the participant's body weight. However, we did not consider that the subject not only pushes the load of weight stack but also the weight of their lower extremities. Plagenhoef and colleagues[122] report that the legs account for nearly 35% of body weight. Therefore, we hypothesize that this higher load for the leg press system may have led to lower acceleration, and therefore lower power when compared to the jump test.

Several studies have examined the effect of changes in load on acceleration and power during a squat jump. They reported significantly lower values for acceleration and power under positive loading conditions[108,123,124]. Positive loading has been achieved by using a pulley cam or overhead harness[108], weighted vests[123], or with the help of a barbell over the shoulders[124]. Cormie and colleagues[124] applied a positive load equal to 25%, 50%, 75% and 100% of the body weight in 18 young males using a barbell and reported a linear decrease (R^2=1) in acceleration in the squat jump. By extrapolation, setting the additional load to 35% of the body weight reduced the acceleration by 2 m/s^2. This reduction is similar to the 1.6 m/s^2 difference between the leg press + IMU system and the force plate jump test seen in the current study. Driss and colleagues[123] examined the effects of positive loading on maximum lower extremity power in 20 young males and females. They used a weighted vest equal to 7% and 14% of the body weight during the squat jump and reported a linear ($R^2 = 1$) decrease in muscle power of nearly 69 Watts (7% body weight) and 137 Watts (14% body weight) under the two weighted conditions. By extension, muscle power would be decreased by 342 Watts with a positive load of 35% of body weight, which accounts for the weight of lower extremities in this study. This decrease in power is very close to the difference between the two measurement systems in the subgroup of participants who did not perform a countermovement in the present study.

An advantage of the leg press + IMU system compared to a jump test is the supported position during the test, which improves testing safety for people with impaired balance. Another concern is that the explosive nature of jump tests may make them unsafe for people with balance issues[103] and osteoporosis[104]. The duration of the concentric phase of squat jump in this study was 50% shorter than that of the leg press movement. Also, although significant ($p = 0.03$), the difference in maximum velocity between the two measurement systems was only 0.1 m/s. This suggests that the participants were able to achieve similar maximum velocities during both measurements but the return to baseline, after achieving the maximum velocity, was much slower during the leg press movement. Therefore, the leg press movement was more controlled compared to the squat jump, which was more explosive in nature. These features make the leg press + IMU system safer than a squat jump for assessing lower extremity multi-joint extension power in older and frail individuals.

6.1: Limitations and Future Directions

- **Load differences between the 2 systems:** The weight pushed/lifted by participants in the two measurement systems was different, which led to the systematic difference in maximum power. The impact of this difference was estimated by assigning 35% of subject's body weight to the legs. Using the estimate, power calculated by the leg press + IMU system was essentially the same as that from the squat jump. Future research should assess the leg weight to determine the accuracy of our estimated power.

- **Undetected countermovement, arm-swing, trunk motion:** The presence of what appeared to be an undetected countermovement contributed to a discrepancy in power between the two measurement systems. A future study should use real-time analysis of the force – time relationship during the jump to overcome this limitation and confirm the positive findings of the current study.

- **Sample size:** The sample size estimate for this study was 17 participants but we had only 11 participants who did not use a countermovement in the squat jump. In these participants, the estimated power, accounting for the effect of leg weight, suggested that there was no difference in power between the leg press + IMU system and squat jumps performed on force plates. This result should be confirmed in a larger group of participants.

- **Leg Press Seating:** The Hoist leg press has a partially reclined back support which may cause some level of low back discomfort. Studies have shown that prolonged sitting in a reclined position may contribute to low back pain[125] but there is no published evidence that sitting for a short duration as required for testing using the leg press + IMU system creates low back pain. The incidence and intensity of low back pain should be assessed when the new tool is initially used in older individuals.

6.2: Strengths

Despite its limitations, this study had several strengths.

- The leg press + IMU system can be used in a clinical setting. It was easy and inexpensive to modify the leg press to assess power. The kit of 6 Notch IMUs cost only $379 USD and works with a smartphone application to provide the acceleration used to calculate power. Those calculations can be entered in an Excel spreadsheet providing a quick and easy method of obtaining power.

- The leg press + IMU system provides stability and reduced joint compressive forces compared to jump tests, making it safer for older or frail people.

- The leg press movement is similar to functional activities and allows for congruence between testing and training.

- The leg press + IMU system provides an accurate assessment of maximum lower extremity multi-joint extension power, which can facilitate the ability to prescribe power training. Currently, the American College of Sports Medicine[126] recommends training at 60% of the 1 RM, which only quantifies strength. Furthermore, the best approach to training lower extremity power and its translation to functional activities is unclear. The leg press + IMU system will facilitate research on this important question.

CHAPTER: 7 CONCLUSION

This study aimed to determine the concurrent validity of the new leg press + IMU system to measure multi-joint lower extremity extension power in young adults. This was done by measuring the agreement between the results of lower extremity power obtained from this system with that obtained from a squat jump on force plates using Bland-Altman analysis. In the subgroup of participants that did not perform a countermovement, the maximum power measured by our new leg press + IMU system was not different from that measured by the force plate squat jump test after accounting for the additional load of lower extremities on the Bland-Altman analysis. Therefore, the leg press +IMU shows concurrent validity with multi-joint power assessed using a squat jump on research-grade force plates in young adults. The results of this study should be followed up to determine if the tool is applicable in an older population for whom jump tests, another assessment of multi-joint lower extremity power, are not applicable.

REFERENCES

1. World Health Organization. Life Expectancy in Canada. World Health Rankings. https://www.worldlifeexpectancy.com/canada-life-expectancy. Published 2018.

2. Statistics Canada. Seniors. Canada year book. https://www150.statcan.gc.ca/n1/pub/11-402-x/2011000/chap/seniors-aines/seniors-aines-eng.htm. Published 2011.

3. Kirch W. Functional ability - *Encyclopedia of Public Health*.; 2008:466. doi:10.1007/978-1-4020-5614-7_1209

4. Trombetti A, Reid KF, Hars M, et al. Age-associated declines in muscle mass, strength, power, and physical performance: impact on fear of falling and quality of life. *Osteoporos Int*. 2016;27(2):463-471. doi:10.1007/s00198-015-3236-5.

5. Curtis E, Litwic A, Cooper C, Dennison E. Determinants of muscle and bone aging. *J cell Physiol.* 2016;230(11):2618-2625. doi:10.1002/jcp.25001.

6. Aagaard P, Suetta C, Caserotti P, Magnusson SP, Kjaer M. Role of the nervous system in sarcopenia and muscle atrophy with aging: strength training as a countermeasure. *Scand J Med Sci Sports*. 2010;20(1):49-64. doi:10.1111/j.1600-0838.2009.01084.

7. Aversa Z, Zhang X, Fielding RA, Lanza I, LeBrasseur NK. The clinical impact and biological mechanisms of skeletal muscle aging. *Bone*. 2019;127:26-36. doi:10.1016/j.bone.2019.05.021

8. Visser M, Goodpaster BH, Kritchevsky SB, et al. Muscle mass, muscle strength, and muscle fat infiltration as predictors of incident mobility limitations in well-functioning older persons. *J Gerontol A Biol Sci Med Sci*. 2005;60(3):324-333. doi:10.1093/gerona/60.3.324

9. Morley JE, Kim MJ, Haren MT, Kevorkian R, Banks WA. Frailty and the aging male. *Aging Male*. 2005;8(3-4):135-140. doi:10.1080/13685530500277232

10. Morley JE. Anorexia, sarcopenia, and aging. *Nutrition*. 2001;17(7-8):660-663.

11. Fielding RA, Vellas B, Evans WJ, et al. Sarcopenia: an undiagnosed condition in older adults. Current consensus definition: prevalence, etiology, and consequences. International working group on sarcopenia. *J Am Med Dir Assoc*. 2011;12(4):249-256. doi:10.1016/j.jamda.2011.01.003

12. American College of Sports Medicine. *Guidelines for Exercise Testing and Prescription - 10th Edition.*; 2019.

13. Magee DJ. *Orthopedic Physical Assessment - 6th Edition*.; 2013.

14. M. O. O'Brien. *Aids to the Examination of the Peripheral Nervous System - 5th Edition*.; 2010.

15. F. P. Kendall, E. K. McCreary, P. G. Provance, M. M. Rodgers and WAR. *Muscles: Testing and Function, with Posture and Pain - 5th Edition*.; 2005.

16. D. Avers and M. Brown. *Daniels and Worthingham's Muscle Testing - 10th Edition*.; 2018.

17. Bohannon RW. Considerations and practical options for measuring muscle strength: A narrative review. *Biomed Res Int*. 2019;2019. doi:10.1155/2019/8194537

18. Reed RL, Den Hartog R, Yochum K, Pearlmutter L, Ruttinger AC, Mooradian AD. A comparison of hand-held isometric strength measurement with isokinetic muscle strength measurement in the elderly. *J Am Geriatr Soc*. 1993;41(1):53-56. doi:10.1111/j.1532-5415.1993.tb05949.

19. Sapega AA, Drillings G. The definition and assessment of muscular power. *J Orthop Sports Phys Ther*. 1983;5(1):7-9. doi:10.2519/jospt.1983.5.1.7

20. Macaluso A, De Vito G. Muscle strength, power and adaptations to resistance training in older people. *Eur J Appl Physiol*. 2004;91(4):450-472. doi:10.1007/s00421-003-0991-3

21. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. *J strength Cond Res*. 2004;18(3):551-555. doi:10.1519/1533-4287(2004)18<551:RAFVOS>2.0.CO;2

22. Nightingale EJ, Pourkazemi F, Hiller CE. Systematic review of timed stair tests. *J Rehabil Res Dev*. 2014;51(3):335-350. doi:10.1682/JRRD.2013.06.0148

23. Wilkinson DJ, Piasecki M, Atherton PJ. The age-related loss of skeletal muscle mass and function: Measurement and physiology of muscle fibre atrophy and muscle fibre loss in humans. *Ageing Res Rev*. 2018;47:123-132. doi:10.1016/j.arr.2018.07.005

24. Brunner F, Schmid A, Sheikhzadeh A, Nordin M, Yoon J, Frankel V. Effects of aging on type II muscle fibers: A systematic review of the literature. *J Aging Phys Act*. 2007;15(3):336-348. doi:10.1123/japa.15.3.336

25. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: Revised European consensus on definition and diagnosis. *Age Ageing*. 2019;48(1):16-31. doi:10.1093/ageing/afy169

26. Reid KF, Fielding RA. Skeletal muscle power: a critical determinant of physical functioning in older adults. *Exerc Sport Sci Rev*. 2012;40(1):4-12. doi:10.1097/JES.0b013e31823b5f13

27. Mitchell WK, Williams J, Atherton P, Larvin M, Lund J, Narici M. Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. *Front Physiol*. 2012;3:260. doi:10.3389/fphys.2012.00260

28. McKinnon NB, Montero-Odasso M, Doherty TJ. Motor unit loss is accompanied by decreased peak muscle power in the lower limb of older adults. *Exp Gerontol*. 2015;70:111-118. doi:10.1016/j.exger.2015.07.007

29. Bean JF, Kiely DK, Herman S, et al. The relationship between leg power and physical performance in mobility-limited older people. *J Am Geriatr Soc*. 2002;50(3):461-467.

30. Suzuki T, Bean JF, Fielding RA. Muscle power of the ankle flexors predicts functional performance in community-dwelling older women. *J Am Geriatr Soc*. 2001;49(9):1161-1167.

31. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol A Biol Sci Med Sci*. 2000;55(4):M192-9.

32. Yamauchi J, Mishima C, Fujiwara M, Nakayama S, Ishii N. Steady-state force-velocity relation in human multi-joint movement determined with force clamp analysis. *J Biomech*. 2007;40(7):1433-1442. doi:10.1016/j.jbiomech.2006.06.010

33. Hahn D, Herzog W, Schwirtz A. Interdependence of torque, joint angle, angular velocity and muscle action during human multi-joint leg extension. *Eur J Appl Physiol*. 2014;114(8):1691-1702. doi:10.1007/s00421-014-2899-5

34. Bassey EJ, Short AH. A new method for measuring power output in a single leg extension: feasibility, reliability and validity. *Eur J Appl Physiol Occup Physiol*. 1990;60(5):385-390.

35. World Health Organization. Ageing and health. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health. Published 2018.

36. Statistics Canada. *Population and Demography*.; Published 2010. https://www150.statcan.gc.ca/n1/pub/11-402-x/2010000/pdf/population-eng.pdf.

37. Dziechciaz M, Filip R. Biological psychological and social determinants of old age: bio-psycho-social aspects of human aging. *Ann Agric Environ Med*. 2014;21(4):835-838. doi:10.5604/12321966.1129943

38. Steves CJ, Spector TD, Jackson SHD. Ageing, genes, environment and epigenetics: what twin studies tell us now, and in the future. *Age Ageing*. 2012;41(5):581-586. doi:10.1093/ageing/afs097

39. Vasto S, Scapagnini G, Bulati M, et al. Biomarkes of aging. *Front Biosci (Schol Ed)*. 2010;2:392-402.

40. Statistics Canada. Arthritis, by age group. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310009606. Published 2017. https://doi.org/10.25318/1310009601-eng

41. Statistics Canada. Prevalence of osteoarthritis, by age group and site of joint pain, household population aged 20 or older diagnosed with arthritis, Canada excluding territories, 2009. Statistics Canada Health Reports 82-003-x. https://www150.statcan.gc.ca/n1/pub/82-003-x/2014009/article/14087/tbl/tbl1-eng.htm. Published 2015.

42. Statistics Canada. *Canadian Community Health Survey (2008/2009)-Healthy Aging*.; Published 2008. http://www.statcan.gc.ca/pub/11-631-x/11-631-x2016001-eng.htm.

43. Statistics Canada. Figure 1: Percentage diagnosed with osteoporosis, by age group and household income quintile, female household population aged 50 or older, Canada excluding territories, 2009. 2009 Canadian Community Health Survey—Healthy Aging. https://www150.statcan.gc.ca/n1/pub/82-003-x/2011003/article/11515/tbl/tbl1-eng.htm. Published 2011.

44. Kirkwood TBL. A systematic look at an old problem. *Nature*. 2008;451(7179):644-647. doi:10.1038/451644a

45. Roberts S, Colombier P, Sowman A, et al. Ageing in the musculoskeletal system. *Acta Orthop*. 2016;87(sup363):15-25. doi:10.1080/17453674.2016.1244750

46. Frontera WR. Physiologic changes of the musculoskeletal system with aging: A brief review. *Phys Med Rehabil Clin N Am*. 2017;28(4):705-711. doi:10.1016/j.pmr.2017.06.004

47. Birbrair A, Zhang T, Wang Z-M, et al. Role of pericytes in skeletal muscle regeneration and fat accumulation. *Stem Cells Dev*. 2013;22(16):2298-2314. doi:10.1089/scd.2012.0647

48. Rosenberg IH. Sarcopenia: origins and clinical relevance. *Clin Geriatr Med*. 2011;27(3):337-339. doi:10.1016/j.cger.2011.03.003

49. Sue Kirkman M, Briscoe VJ, Clark N, et al. Diabetes in older adults: A consensus report. *J Am Geriatr Soc*. 2012;60(12):2342-2356. doi:10.1111/jgs.12035

50. Statistics Canada. cases_by_age_group. *Table 13-10-0096-07 Diabetes, by age Gr*. 2020:1. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310009607.

51. Tournadre A, Vial G, Capel F, Soubrier M, Boirie Y. Sarcopenia. *Jt Bone Spine*. 2019;86(3):309-314. doi:10.1016/j.jbspin.2018.08.001

52. Pacifico J, Geerlings MAJ, Reijnierse EM, Phassouliotis C, Lim WK, Maier AB. Prevalence of sarcopenia as a comorbid disease: A systematic review and meta-analysis. *Exp Gerontol*. 2020;131:110801. doi:10.1016/j.exger.2019.110801

53. Mori H, Kuroda A, Matsuhisa M. Clinical impact of sarcopenia and dynapenia on diabetes. *Diabetol Int*. 2019;10(3):183-187. doi:10.1007/s13340-019-00400-1

54. dos Santos MR, Saitoh M, Ebner N, et al. Sarcopenia and endothelial function in patients with chronic heart failure: Results from the studies investigating comorbidities aggravating heart failure (SICA-HF). *J Am Med Dir Assoc*. 2017;18(3):240-245. doi:10.1016/j.jamda.2016.09.006

55. Springer J, Springer JI, Anker SD. Muscle wasting and sarcopenia in heart failure and beyond: update 2017. *ESC Hear Fail*. 2017;4(4):492-498. doi:10.1002/ehf2.12237

56. Castillo EM, Goodman-Gruen D, Kritz-Silverstein D, Morton DJ, Wingard DL, Barrett-Connor E. Sarcopenia in elderly men and women: The Rancho Bernardo study. *Am J Prev Med*. 2003;25(3):226-231. doi:10.1016/S0749-3797(03)00197-1

57. Samper-Ternent R, Reyes-Ortiz C, Ottenbacher KJ, Cano CA. Frailty and sarcopenia in Bogotá: results from the SABE Bogotá Study. *Aging Clin Exp Res*. 2017;29(2):265-272. doi:10.1007/s40520-016-0561-2

58. Yoo J Il, Ha YC, Choi H, et al. Malnutrition and chronic inflammation as risk factors for sarcopenia in elderly patients with hip fracture. *Asia Pac J Clin Nutr*. 2018;27(3):527-532. doi:10.6133/apjcn.082017.02

59. Bloom I, Shand C, Cooper C, Robinson S, Baird J. Diet quality and sarcopenia in older adults: A systematic review. *Nutrients*. 2018;10(3):308 doi:10.3390/nu10030308

60. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. *J Appl Physiol*. 2000;88(4):1321-1326. doi:10.1152/jappl.2000.88.4.1321

61. Nilwik R, Snijders T, Leenders M, et al. The decline in skeletal muscle mass with aging is mainly attributed to a reduction in type II muscle fiber size. *Exp Gerontol*. 2013;48(5):492-498. doi:10.1016/j.exger.2013.02.012

62. Andersen JL. Muscle fibre type adaptation in the elderly human muscle. In: *Scand J of Med Sci Sports*. Vol 13. ; 2003:40-47. doi:10.1034/j.1600-0838.2003.00299.

63. McPhee JS, Cameron J, Maden-Wilkinson T, et al. The contributions of fiber atrophy, fiber loss, in situ specific force, and voluntary activation to weakness in sarcopenia. *Journals Gerontol - Ser A Biol Sci Med Sci*. 2018;73(10):1287-1294. doi:10.1093/gerona/gly040

64. Figueiredo PA, Mota MP, Appell HJ, Duarte J. Ceasing of muscle function with aging: is it the consequence of intrinsic muscle degeneration or a secondary effect of neuronal impairments? *Eur Rev Aging Phys Act*. 2006;3(2):75-83. doi:10.1007/s11556-006-0011-9

65. Janssen I, Heymsfield SB, Wang ZM, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol*. 2000;89(1):81-88. doi:10.1152/jappl.2000.89.1.81

66. Klein CS, Marsh GD, Petrella RJ, Rice CL. Muscle fiber number in the biceps brachii muscle of young and old men. *Muscle and Nerve*. 2003;28(1):62-68. doi:10.1002/mus.10386

67. Goodpaster BH, Park SW, Harris TB, et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci*. 2006;61(10):1059-1064. doi:10.1093/gerona/61.10.1059

68. Skelton DA, Greig CA, Davies JM, Young A. Strength, power and related functional ability of healthy people aged 65-89 years. *Age Ageing*. 1994;23(5):371-377. doi:10.1093/ageing/23.5.371

69. Reid KF, Pasha E, Doros G, et al. Longitudinal decline of lower extremity muscle power in healthy and mobility-limited older adults: influence of muscle mass, strength, composition, neuromuscular activation and single fiber contractile properties. *Eur J Appl Physiol*. 2014;114(1):29-39. doi:10.1007/s00421-013-2728-2

70. Cornelis E, Gorus E, Beyer I, Bautmans I, De Vriendt P. Early diagnosis of mild cognitive impairment and mild dementia through basic and instrumental activities of daily living: Development of a new evaluation tool. *PLoS Med*. 2017;14(3):e1002250. doi:10.1371/journal.pmed.1002250

71. Paterson DH, Warburton DER. Physical activity and functional limitations in older adults: a systematic review related to Canada's physical activity guidelines. *Int J Behav Nutr Phys Act*. 2010;7(1):38. doi:10.1186/1479-5868-7-38

72. Wall BT, Dirks ML, Snijders T, Senden JMG, Dolmans J, Van Loon LJC. Substantial skeletal muscle loss occurs during only 5 days of disuse. *Acta Physiol*. 2014;210(3):600-611. doi:10.1111/apha.12190

73. Kortebein P, Symons TB, Ferrando A, et al. Functional impact of 10 days of bed rest in healthy older adults. *Journals Gerontol - Ser A Biol Sci Med Sci*. 2008;63(10):1076-1081. doi:10.1093/gerona/63.10.1076

74. Hawkins SA, Wiswell RA, Marcell TJ. Exercise and the master athlete - a model of successful aging? *Journals Gerontol - Ser A Biol Sci Med Sci*. 2003;58(11):1009-1011. doi:10.1093/gerona/58.11.m1009

75. Thé DJ, Ploutz-snyder L. Age, body mass, and gender as predictors of masters olympic weightlifting performance. *Med Sci Sports Exerc*. 2003;35(7):1216-1224. doi:10.1249/01.mss.0000074582.55220.1c

76. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. *Gerontology*. 2005;51(2):108-115. doi:10.1159/000082195

77. Yamauchi J, Nakayama S, Ishii N. Effects of bodyweight-based exercise training on muscle functions of leg multi-joint movement in elderly individuals. *Geriatr Gerontol Int*. 2009;9(3):262-269. doi:10.1111/j.1447-0594.2009.00530.

78. Porter MM. Power training for older adults. *Appl Physiol Nutr Metab*. 2006;31(2):87-94. doi:10.1139/h05-034

79. Samuel D, Rowe P, Nicol A. The functional demand (FD) placed on the knee and hip of older adults during everyday activities. *Arch Gerontol Geriatr*. 2013;57(2):192-197. doi:10.1016/J.ARCHGER.2013.03.003

80. Holmes JW. Teaching from classic papers: Hill's model of muscle contraction. *Adv Physiol Educ*. 2006;30(2):67-72. doi:10.1152/advan.00072.2005

81. Jones CJ, Rikli RE, Beam WC. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Res Q Exerc Sport*. 1999;70(2):113-119. doi:10.1080/02701367.1999.10608028

82. Lord SR, Murray SM, Chapman K, Munro B, Tiedemann A. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *Journals Gerontol - Ser A Biol Sci Med Sci*. 2002;57(8). doi:10.1093/gerona/57.8.M539-543

83. Hardy R, Cooper R, Shah I, Harridge S, Guralnik J, Kuh D. Is chair rise performance a useful measure of leg power? *Aging Clin Exp Res*. 2010;22(5-6):412-418. doi:10.1007/BF03324942

84. Bean JF, Kiely DK, LaRose S, Alian J, Frontera WR. Is Stair Climb Power a Clinically Relevant Measure of Leg Power Impairments in At-Risk Older Adults? *Arch Phys Med Rehabil*. 2007;88(5):604-609. doi:10.1016/j.apmr.2007.02.004

85. Ni M, Brown LG, Lawler D, Bean JF. Reliability, validity, and minimal detectable change of four-step stair climb power test in community-dwelling older adults. *Phys Ther*. 2017;97(7):767-773. doi:10.1093/ptj/pzx039

86. Vaidya T, Chambellan A, de Bisschop C. Sit-to-stand tests for COPD: A literature review. *Respir Med*. 2017;128:70-77. doi:10.1016/j.rmed.2017.05.003

87. Lindemann U, Claus H, Stuber M, et al. Measuring power during the sit-to-stand transfer. *Eur J Appl Physiol*. 2003;89(5):466-470. doi:10.1007/s00421-003-0837-z

88. Roig M, Eng JJ, MacIntyre DL, Road JD, Reid WD. Associations of the Stair Climb Power Test with muscle strength and functional performance in people with chronic obstructive pulmonary disease: a cross-sectional study. *Phys Ther*. 2010;90(12):1774-1782. doi:10.2522/ptj.20100091

89. Butcher SJ, Pikaluk BJ, Chura RL, Walkner MJ, Farthing JP, Marciniuk DD. Associations between isokinetic muscle strength, high-level functional performance, and physiological parameters in patients with chronic obstructive pulmonary disease. *Int J COPD*. 2012;7:537-542. doi:10.2147/COPD.S34170

90. Shiomi T. Effects of different patterns of stairclimbing on physiological cost and motor efficiency. *J Hum Ergol (Tokyo)*. 1994;23(2):111-120.

91. Teh KC, Aziz AR. Heart rate, oxygen uptake, and energy cost of ascending and descending the stairs. *Med Sci Sports Exerc*. 2002;34(4):695-699. doi:10.1097/00005768-200204000-00021

92. Graham J. Guidelines for providing valid testing of athletes' fitness levels. *Strength Cond*. 1994;16(6):7-14. doi:10.1519/1073-6840(1994)016<0007:GFPVTO>2.3.CO;2

93. Gajewski J, Michalski R, Buśko K, Mazur-Różycka J, Staniak Z. Countermovement depth – A variable which clarifies the relationship between the maximum power output and height of a vertical jump. *Acta Bioeng Biomech*. 2018;20(1):127-134. doi:10.5277/ABB-01058-2017-02

94. Dias JA, Dal Pupo J, Reis DC, et al. Validity of two methods for estimation of vertical jump height. *J strength Cond Res*. 2011;25(7):2034-2039. doi:10.1519/JSC.0b013e3181e73f6e

95. Keir PJ, Jamnik VK, Gledhill N. Technical-Methodological Report: A Nomogram for Peak Leg Power Output in the Vertical Jump. *J Strength Cond Res*. 2003;17(4):701-703. doi:10.1519/1533-4287(2003)017<0701:TRANFP>2.0.CO;2

96. Harman EA, Rosenstein MT, Frykman PN, Rosenstein RM, Kraemer WJ. Estimation of Human Power Output from Vertical Jump. *J Strength Cond Res*. 1991;5(3):116-120

97. Tenelsen F, Brueckner D, Muehlbauer T, Hagen M. Validity and reliability of an electronic contact mat for drop jump assessment in physically active adults. *Sport (Basel, Switzerland)*. 2019;7(5). doi:10.3390/sports7050114

98. Buckthorpe M, Morris J, Folland JP. Validity of vertical jump measurement devices. *J Sports Sci*. 2012;30(1):63-69. doi:10.1080/02640414.2011.624539

99. Holsgaard Larsen A, Caserotti P, Puggaard L, Aagaard P. Reproducibility and relationship of single-joint strength vs multi-joint strength and power in aging individuals. *Scand J Med Sci Sports*. 2007;17(1):43-53. doi:10.1111/j.1600-0838.2006.00560.x

100. Ditroilo M, Forte R, McKeown D, Boreham C, De Vito G. Intra- and inter-session reliability of vertical jump performance in healthy middle-aged and older men and women. *J Sports Sci*. 2011;29(15):1675-1682. doi:10.1080/02640414.2011.614270

101. Hannam K, Hartley A, Clark EM, Sayer AA, Tobias JH, Gregson CL. Feasibility and acceptability of using jumping mechanography to detect early components of sarcopenia in community-dwelling older women. *J Musculoskelet Neuronal Interact*. 2017;17(3):246-257.

102. Fadden DM. Conditional logit analysis of qualitative choice behavior. *Frontiers in Econometrics*.1973:105–142.

103. Izquierdo M, Aguado X, Gonzalez R, López JL, Häkkinen K. Maximal and explosive force production capacity and balance performance in men of different ages. *Eur J Appl Physiol Occup Physiol*. 1999;79(3):260-267. doi:10.1007/s004210050504

104. Katz WA, Sherman C. Exercise for osteoporosis. *Phys Sportsmed*. 1998;26(2):43.

105. Yamauchi J, Ishii N. Relations between force-velocity characteristics of the knee-hip extension movement and vertical jump performance. *J strength Cond Res*. 2007;21(3):703-709. doi:10.1519/R-20516.1

106. Grainger M, Weisberg A, Stergiou P, Katz L. Comparison of two methods in the estimation of vertical jump height. *J Hum Sport Exerc*. 2020;15(3):623-632. doi:10.14198/jhse.2020.153.12

107. Clarkson. *Musculoskeletal Assessment: Joint Motion and Muscle Testing - 3rd Edition.;* 2012.

108. Pazin N, Berjan B, Nedeljkovic A, Markovic G, Jaric S. Power output in vertical jumps: Does optimum loading depend on activity profiles? *Eur J Appl Physiol*. 2013;113(3):577-589. doi:10.1007/s00421-012-2464-z

109. Linthorne NP. Analysis of standing vertical jumps using a force platform. *Am J Phys*. 2001;69(11):1198-1204. doi:10.1119/1.1397460

110. Haff GG, Ruben RP, Lider J, Twine C, Cormie P. A comparison of methods for determining the rate of force development during isometric midthigh clean pulls. *J Strength Cond Res*. 2015;29(2):386-395. doi:10.1519/JSC.0000000000000705

111. Mcbride JM, Mccaulley GO, Cormie P. Influence of preactivity and eccentric muscle activity on concentric performance during vertical jumping. *J Strength Cond Res.*; 2008; 22(3): 750-757.

112. Vaverka F, Jandačka D, Zahradník D, et al. Effect of an Arm Swing on Countermovement Vertical Jump Performance in Elite Volleyball Players: FINAL. *J Hum Kinet*. 2016;53(1):41-50. doi:10.1515/hukin-2016-0009

113. Van Hooren B, Zolotarjova J. The Difference between Countermovement and Squat Jump Performances: A Review of Underlying Mechanisms with Practical Applications. *J Strength Cond Res*. 2017;31(7):2011-2020. doi:10.1519/JSC.0000000000001913

114. Bobbert MF, Casius LJR. Is the effect of a countermovement on jump height due to active state development? *Med Sci Sports Exerc*. 2005;37(3):440-446. doi:10.1249/01.MSS.0000155389.34538.97

115. Bobbert MF, Gerritsen KGM, Litjens MCA, Van Soest AJ. Why is countermovement jump height greater than squat jump height? *Med Sci Sports Exerc*. 1996;28(11):1402-1412. doi:10.1097/00005768-199611000-00009

116. Komi P V., Bosco C. Utilization of stored elastic energy in leg extensor muscles by men and women. *Med Sci Sports*. 1978;10(4):261-265.

117. Hara M, Shibayama A, Takeshita D, Hay DC, Fukashiro S. A comparison of the mechanical effect of arm swing and countermovement on the lower extremities in vertical jumping. *Hum Mov Sci*. 2008;27(4):636-648. doi:10.1016/j.humov.2008.04.001

118. Floría P, Harrison AJ. The effect of arm action on the vertical jump performance in children and adult females. *J Appl Biomech*. 2013;29(6):655-661. doi:10.1123/jab.29.6.655

119. Harman EA, Rosenstein MT, Frykman PN, Rosenstein RM. The effects of arms and countermovement on vertical jumping. *Med Sci Sports Exerc*. 1990;22(6):825-833. doi:10.1249/00005768-199012000-00015

120. Walsh Ms, Böhm H, Butterfield Mm, Santhosam J. Gender bias in the effects of arms and countermovement on jumping performance. *J Strength Cond Res*. 2007;21(2):362-366. doi:10.1519/00124278-200705000-00012

121. Bosco C, Komi P V., Ito A. Prestretch potentiation of human skeletal muscle during ballistic movement. *Acta Physiol Scand*. 1981;111(2):135-140. doi:10.1111/j.1748-1716.1981.tb06716.x

122. Plagenhoef et al. 1983. ExRx.net : Body Segment Data. https://exrx.net/Kinesiology/Segments. Published 1983.

123. Driss T, Vandewalle H, Quièvre J, Miller C, Monod H. Effects of external loading on power output in a squat jump on a force platform: A comparison between strength and power athletes and sedentary individuals. *J Sports Sci*. 2001;19(2):99-105. doi:10.1080/026404101300036271

124. Cormie P, McBride JM, McCaulley GO. Power-time, force-time, and velocity-time curve analysis during the jump squat: Impact of load. *J Appl Biomech*. 2008;24(2):112-120. doi:10.1123/jab.24.2.112

125. Bikbov MM, Kazakbaeva GM, Zainullin RM, et al. Prevalence of and factors associated with low Back pain, thoracic spine pain and neck pain in Bashkortostan, Russia: The Ural Eye and Medical Study. *BMC Musculoskelet Disord*. 2020;21(1). doi:10.1186/s12891-020-3080-4

126. Esco Michael R. Resistance training for health and fitness various types of resistances. *Am Coll Sport Med*. 2011. https://www.prescriptiontogetactive.com/static/pdfs/resistance-training-ACSM.pdf

Appendix A: Ethics Approval

DALHOUSIE UNIVERSITY
Research Services

Health Sciences Research Ethics Board
Letter of Approval

January 15, 2020

Purva Trivedi
Health\School of Physiotherapy

Dear Purva,

REB #: 2020-5042
Project Title: Measurement of Multi-Joint Lower Extremity Extension Power Using a Clinically Applicable Leg Press Tool: The Concurrent Validity

Effective Date: January 15, 2020
Expiry Date: January 15, 2021

The Health Sciences Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans.* This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Lori Weeks, Chair

Appendix B: Study Advertisement Poster

DALHOUSIE UNIVERSITY

Participants Needed

Developing a Clinically Useful Method of Measuring Leg Muscle Power

Purpose: To compare muscle power assessed using a leg press machine and a squat jump test

Task: You will perform a small number of squat jumps and leg presses

You should be:

- Of age between18-40 years
- Able to perform a squat jump and leg press without any discomfort

Length of study: 1.5 hours (one visit study)

Location: 4th floor, Forrest Building, 5869 University Avenue

For more information, or to volunteer, please contact: Purva Trivedi (MSc candidate) at pr840293@dal.ca

Appendix C (I): Participant Screening Phone Call Interview Script

DALHOUSIE UNIVERSITY

Hello, my name is Purva Trivedi. I am a graduate student at School of Physiotherapy, Dalhousie University. This phone call is in response to your interest in my research.

Is this a good time to talk to you about the research? It will probably take about 10 minutes.

***No*:** That is fine. When would be a better time to contact you?
***Yes*:** Continue conversation

My research project compares the results of leg muscle power assessed using a leg press machine versus using a squat jump test on force plates in young healthy people. A squat jump is jumping from a half squat position. Half squat is an action like sitting in an imaginary chair placed behind you.

Participation in this research will involve performing 6 squat jumps on the force plates and 6 leg presses with rests between each. Your entire visit will take approximately 1.5 hour. All the testing will take place at School of Physiotherapy, Dalhousie University.

Do you have any questions about the study so far?

Yes: Answer these.
No: Continue.

If you are still interested in participating in the research, I need to ask you some questions to make sure that it is safe for you. There are seven questions in total. I will read all the questions. Please listen to them carefully and note down your answer, either YES or NO to all of them.

1. Do you, or would you have difficulty doing a half squat?
   (Half squat is an action like sitting in an imaginary chair placed behind you.)
2. Do you, or would you have difficulty jumping from a half squat position?
3. Have you had any loss of balance resulting in a fall in the past?
4. Have you had any muscle, bone or joint injuries treated with or without surgery in past 16 weeks?

5. Do you have any muscle, bone or joint problems that would affect your ability to perform a half squat jump?

6. Are you receiving any treatment for any of your muscle, bone or joint injuries or problems?

7. Do you have any allergies to adhesive tapes?

Did you answer 'YES' to any of the questions?

Yes: I would like to inform you that this study might not be safe for you and **we cannot include you in this study**. Thank you for expressing you interest in this research and giving your time today.

No: I would like to inform you that you meet all the criteria for this study. If you wish to continue participating, I will send you the informed consent form which explains the study, its procedures, the risks and benefits associated with in detail. Please go through the consent form thoroughly, do not hesitate to ask any question that you have about the study. Thank you for expressing your interest in this research and giving your time today. You can reach me at the email address provided in the study advertisement.

Appendix C (II): Participant Screening Form

Title: Measurement of multi-joint lower extremity extension power using a clinically applicable leg press tool: The Concurrent Validity

Participant Screening Form
1. Do you, or would you have difficulty doing a half squat? Half squat is an action like sitting in an imaginary chair placed behind you.
2. Do you, or would you have difficulty jumping from a half squat position?
3. Have you had any loss of balance resulting in a fall in the past?
4. Have you had any muscle, bone or joint injuries treated with or without surgery in past 16 weeks?
5. Do you have any muscle, bone or joint problems that would affect your ability to perform a half squat jump?
6. Are you receiving any treatment for any of your muscle, bone or joint injuries or problems?
7. Do you have any allergies to adhesive tapes?

Appendix D: Consent Form

DALHOUSIE
UNIVERSITY

Project title: Measurement of Multi-Joint Lower Extremity Extension Power Using A Clinically Applicable Leg Press Tool: The Concurrent Validity

Lead researcher:
Purva Trivedi, MSc RRPT (Candidate)
School of Physiotherapy
Dalhousie University.
Email: pr840293@dal.ca
Tel: +1(902)-329-8867

Research Supervisor
Gail Dechman BSc PT, PhD
Assistant Professor
School of Physiotherapy and School of Health and Human Performance
Affiliate Scientist, Department of Medicine – Respirology, NSHA
Rm 430, Forrest Building
Dalhousie University
Halifax, NS B3H 2R4
Email: gdechman@dal.ca
Tel: 902-494-2734

Funding provided by: Unfunded

Introduction

We invite you to take part in a research study being conducted by Purva Trivedi, a graduate student at Dalhousie University as part of her MSc Rehabilitation Research Physiotherapy program. Choosing whether to take part in this research is entirely your choice. Before you decide, you need to understand few important things like what is involved in the research, what you will be asked to do and about any benefit, risk, inconvenience or discomfort that you might experience. This consent form explains all these things in detail.

Please read this consent form carefully. Take your time, mark anything you don't understand or want explained better. After you have read it, please ask questions about anything that is not clear.

The researchers will:

- Discuss the study with you
- Answer your questions
- Be available during the study to deal with problems and answer your questions

You are being asked to take part in this study because you replied to our study advertisement and you meet the study requirements.

Purpose and Outline of the Research Study

We perform numerous activities in our daily life like walking, climbing stairs, and rising from a chair or bed. These activities depend on leg muscle power. Muscle power is the capacity of our muscles to perform fast and forceful movements. Unfortunately, this muscle power begins to decrease as people age, and this may result in a loss of independence. We can exercise our muscles to delay this decrease in power but, we need to be able to measure the baseline muscle power before we start exercising. Hence, the measurement of muscle power is important.

Force plates are instruments available in research laboratories that measure the forces produced when someone stands or moves (walking, jumping, etc.) on them. These forces can be used to calculate leg muscle power. Squat jumps (explained later) performed on force plates are commonly used to measure leg muscle power. However, jumping may not be safe in an older population and these force plates are very expensive. Therefore, force plates not appropriate for use in physiotherapy clinics.

The purpose of this study is to develop a new method of measuring leg muscle power that is affordable, can be used in a physiotherapy clinic and is safe in all age groups. Power determined using this new method must be accurate so we will compare it to power assessed with a force plate. Currently we are assessing leg muscle power in young individuals as jump tests are safe to be used in this population. Once we establish that the new method can assess leg muscle power correctly, future research can be performed to determine whether the technique is accurate and safe in older individuals.

Our new method of assessing leg muscle power uses a leg press machine like the ones in gyms and an inertial measurement unit (IMU). IMU is a sensor that measures how fast any movement was performed. We will attach this sensor to the weight stack of the leg press machine and use this information to calculate muscle power. We will compare the results of this method with power calculated during a squat jump on a force plate. We will have 22 people take part in the study. Each person will have 1 assessment visit that will take 1.5 hours. During the visit you will be asked to complete 6 leg presses and 6 squat jumps.

Who Can Take Part in the Research Study?

You may participate in the study if you:

- are between 18 to 40 years
- are able to perform a squat jump (jump from a body position like figure 4) without any discomfort
- are able to perform a leg press (push a weight away from your body with your legs like figure 1) without any discomfort

You may **NOT** participate in this study if you:

- have had a loss of balance that resulted in a fall with or without injury
- have any history of leg muscle, bone or joint injuries in past 4 months
- are receiving care for leg injuries
- have allergies to adhesive tapes

What You Will Be Asked to Do?

All testing will be done in Room 414, lab 415 and lab 314 at the School of Physiotherapy in the Forrest Building, Dalhousie University. This is a single visit study. The duration of you visit will be 1.5 hours.

We will meet you in Room 414, School of Physiotherapy in the Forrest Building, Dalhousie University. At that time, we will discuss the study procedures in detail and answer all your questions. If you are still interested in participating, you will sign this consent form. Then we will begin the study measurements. For all the study measurements we will need you to be dressed in running shorts and shoes. There is a private space in Room 414 to change your clothes. We will first measure your weight using a digital scale like one you might have in your bathroom. Then, we will move on to our first measurement – the Leg press.

<u>Leg Press Method</u>

This will take place in lab 415. We will first clean the area around your right knee with an alcohol swab. We will then attach an instrument called an electronic goniometer at your right knee (see figure 1) using an adhesive tape. This measures the knee angle. Then you will sit in the leg press seat and place your feet on specific markings (see figures 1 & 2). In this position we will wrap 2 straps across your waist and hip joints to make sure that you do not move during the test. We will use another strap to secure your feet to the footplate (see figure 1). In this position, we will measure your leg length - the distance between your hip joint and the leg press footplate, using a measuring tape. We will also record your right knee joint angle in this position.

You will then perform a short warm-up session. For this, we will set the weight to be pushed on the leg press machine equal to half of your measured body weight. You will perform 4-6 leg press at this weight. Next, we will change the weight to 70% of your body weight and you will perform 2-4 leg press at this weight. Then, we will change it to 90% of your body weight and you will perform 1 leg press at this weight.

Following this, we will begin with the study trials. For this, we will set the weight to be pushed on the leg press machine. This will equal to your measured body weight. You will then be asked to perform 3 practice leg presses to get used to the action and the weight to be pushed. Following this you will perform another 3 leg press actions in which we will record your data. For all the leg press actions you will have to push the footplate as fast and forcefully as possible. You will have a 2-minute rest between each of the leg presses. At the end we will perform one more measurement in which you remain seated in the leg press with your feet flat on the footplate and do not perform any movement with your legs. This will take less than 5 seconds. Following this measurement, you can stand up from the leg press. We will not remove the goniometer from to your knee as we need it for the force plate measurements.


Figure 1: Participant seated on the leg press seat with an electronic goniometer attached, feet placed on the markings, waist-hip-feet stabilized with the belts.


Figure 2: Foot markings on the leg press footplate.

Force Plate Method

This will take place in lab 314. You will have to step on the markings of force plates (see figure 3). There are two force plates placed adjacent to each other. You will have to place one foot on each force plate. The researcher will give you clear instructions about this. Once you are in position, we will attach a colored paper tape on outer part of your right hip joint over your clothing. You will then perform a short warm-up session. For this, you will perform 5-7 toe raises (raising your body by standing on your toes), you will perform an action of running on the same spot for 30 seconds, 5-7 half squats and 5-7 squat jumps.

Following this we will begin with the study measurements. For this, you will be asked to squat to a specific height marked with the laser light source (see figure 4). The researcher will give you the feedback and directions on bending or straightening your knees in order to meet the marked laser height. This height is equal to your leg length measured on leg press machine. Once you are in this position, we will record your right knee joint angle using the goniometer to make sure it is the same as it was in the leg press. You will perform 3 practice jumps from this squat position to get used to this action. You will be asked to jump as fast and forcefully as possible. After this, we will ask you to perform 3 more jumps from the same squat position. We will record the data from these 3 jumps. You will have a 2-minute rest between each jump. At the end we will perform one more measurement in which you will stand on the force plates without performing any movement for 2 seconds. We will then detach the electronic goniometer from your knee and clean the area of adhesive tapes with an alcohol swab. This will end your session. You can change your clothes before leaving if you wish.

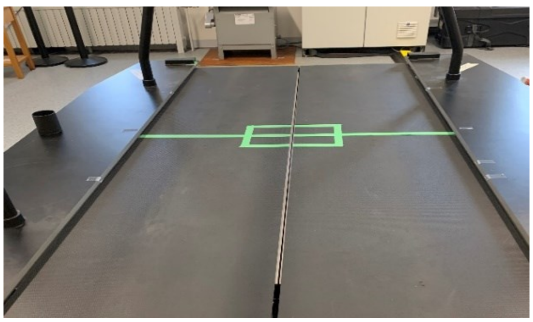


Figure 3: Force plate foot markings

Figure 4: Participant performing a squat on the force plate with electronic goniometer recording the right knee angle and squat height matched with the laser light.

Possible Benefits, Risks and Discomforts

There are risks with this, or any study. The risks and discomforts associated with this study are minimal, as you will be performing activities that someone might do in the gym. We do not want to alarm you, but we do want to make sure that if you decide to participate in the study, you have had a chance to think about the risks carefully.

Risks and Discomforts:

Maintaining your safety and comfort is one of our concerns. You have verified that you are able to perform a squat jump, therefore, there is little chance that you would lose your balance and fall during testing. For the same reason, there is a very small chance that you would twist your ankle while landing the jump. In order to minimize these risks, we have handrails along the length of force plates that you can use to steady yourself in case any loss of balance.

Beyond this, being bored or fatigued might be one possible discomfort. However, you will have breaks between the activities to reduce this.

You may feel that the electronic goniometer attached to your knee and its wires restrict your leg movement. We make sure that you can fully straighten your knee when we place the goniometer

on your leg so this should not be a concern. Please speak to the researcher if you are worried about this.
We will fold the extra length of wire and keep it away from you while jumping in order to prevent any trips or falls.

There is a very small chance (0.033% of people) of having a skin reaction to the adhesive tape used for attaching the goniometer. By answering "No" to the question about skin allergies on the screening form, you would have an even small chance of having such a reaction.

Benefits:

Participating in this study might not benefit you directly, but we might learn things that will be of benefit to others. Accurate assessment of muscle power can help to prescribe exercise to improve power. This is particularly important in older individuals for whom impaired lower extremity power affects the ability to perform essential activities of daily living and the ability to live independently.

Compensation / Reimbursement:

You will **not** receive any compensation for participating in this study.

How your information will be protected:

Privacy:

Keeping your information private is an important concern of this study. Every effort will be made to protect your privacy. No identifying information (e.g., your name) will be sent outside of Dalhousie University. If in case when the results of this study are to be presented at conferences or in journals, we will only present group data so nobody will be able to tell that you were a part of this study.

If you decide to participate in this study, the research team will collect the following information:

- Name
- Age
- Body weight

Confidentiality:

To safeguard your privacy and keep your participation in the study confidential, you will be assigned a specific participant code for this study (e.g., p01) and your study data will only be identified using this code instead of your name. The document linking your name to your participant code will be stored separately in a locked filing cabinet in Dr. Dechman's office. Only the lead researcher and supervisor will have access to this information. All the documentation having your study data will be identified using participant code only.

All paper copies of data associated with this study (including this consent form) will be stored in a locked filing cabinet separate from your identifying information in Dr. Dechman's office that is accessible only to the lead researcher and Dr. Dechman via personalized pin codes. All electronic files will be stored on a secure, password-protected computer that will be stored in a locked filing cabinet in Dr. Dechman's office. We will secure a back-up of all the electronic data of our study on the lead researcher's OneDrive account.

Data retention:

Only the research team at Dalhousie University will have access to study information. We will describe and share our findings in thesis, conference presentations, and journal articles. We will be very careful to only talk about group results so that no one will be identified. This means that ***you will not be identified in any way in our reports***. Also, we will use a participant number (not your name) in our written and computer records so that the information we have about you contains no names.

All the hard copy and electronic records will be kept secure in a locked filing cabinet for 7 years after which we will destroy it according to Dalhousie's Policy at that time.

If You Decide to Stop Participating:

You may choose to discontinue participating in the study at any time. If you decide not to take part in the study or if you leave the session early, your data will be automatically withdrawn from the study. If you complete the full session and then decide later to not let us include your data into the analysis, you will have to indicate this within 2 weeks after completion of your session.

How to Obtain Results:

If you would like to obtain your results, we will provide you with a short description about the study results by email. You can obtain these results by indicating your interest and including your email address at the end of the signature page. We will not be able to provide you with your individual results.

Questions:

We are happy to talk with you about any questions or concerns you may have about your participation in this research study. For further information about the study, you may call or email the principal investigator, who is the person in charge of this study.

The principal investigator is Purva Trivedi.

Telephone: (902) 329-8867

Email: pr840293@dal.ca

We will also tell you if any new information comes up that could affect your decision to participate.

If you have any ethical concerns about your participation in this research, you may also contact Research Ethics, Dalhousie University at (902) 494-1462, or email: ethics@dal.ca (and reference REB file # 2020-5042).

Signature Page

Project Title: Measurement of Multi-Joint Lower Extremity Extension Power Using A Clinically Applicable Leg Press Tool : The Concurrent Validity

Lead Researcher:
Purva Trivedi, MSc RRPT (Candidate)
School of Physiotherapy
Dalhousie University.
Email: pr840293@dal.ca
Tel: +1(902)-329-8867

Research Supervisor
Gail Dechman BSc PT, PhD
Assistant Professor
School of Physiotherapy
Dalhousie University
Email: gdechman@dal.ca
Tel: 902-494-2734

I ______________________________ , have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I understand that this data will be recorded, analyzed and the results of this study will be shared in thesis, conference presentations and journal articles. I agree to take part in this study. My participation is voluntary. I understand that I am free to withdraw from the study at any time and that I may withdraw my data at any time prior to 2 weeks after the completion of my experimental session. I understand I will be given a copy of this consent form.

____________________________	____________________________	___________
Name of Participant	Signature of participant	Date
____________________________	____________________________	___________
Name of Investigator	Signature of Investigator	Date

Do you wish to obtain the results of study? [Yes / No]

If yes, provide your contact information here: Email: ______________________________.

Appendix E: Participant Information Sheet

DALHOUSIE UNIVERSITY

Title: Measurement of multi-joint lower extremity extension power using a clinically applicable leg press tool: The Concurrent Validity

Participant Code:

Name:

Age:

Appendix F: Data Collection Sheet

DALHOUSIE UNIVERSITY

Title: Measurement of multi-joint lower extremity extension power using a clinically applicable leg press tool: The Concurrent Validity

DATA COLLECTION SHEET

Anthropometrics:

Height(cm): ___________. Weight(lb): ___________.

Measurement 1 (Leg press + IMU system):

Leg length measurement on leg press machine:

- Distance between right hip greater trochanter and the footplate (cm):______.

Trial 1: Calibration trial (similar to standing reading on a force plate)

- **Instructions for the participants:** Simply place your feet on the foot plate markings. DO NOT push the foot plate at all.
- ☐ Recording time: 2 seconds
- ☐ Sampling rate: 500 Hz

Trial 2: Leg Press trial 1

- **Instructions for the participants:** On the count of 3, **p**ush the footplate as fast and as forcefully as possible. "1,2,3,push."
- ☐ Recording time: 10 seconds
- ☐ Sampling rate: 500 Hz
- Right Knee Angle: ________degrees

Trial 3: Leg Press trial 2

- ☐ Recording time: 10 seconds
- ☐ Sampling rate: 500 Hz
- Right Knee Angle: ________degrees

Trial 4: Leg Press trial 3

- ☐ Recording time: 10 seconds
- ☐ Sampling rate: 500 Hz
- Right Knee Angle: ________degrees

Measurement 2 (Force plate jump test):

Trial 1: Standing Calibration trial (standing reading on a force plate)

- **Instructions for the participants:** Simply place your feet on the force plates markings and stand on it. DO NOT move during the recording.
- ☐ Recording time: 2 seconds
- ☐ Sampling rate: 500 Hz

Trial 2: Jump trial 1

- **Instructions for the participants:** On the count of 3, jump from the same squatting position as fast and forcefully as possible. DO NOT perform any movement before jumping that further increases your knee bending; or decreases the height of your squat; or deepens your squat. “1,2,3,jump.”
- ☐ Recording time: 10 seconds
- ☐ Sampling rate: 500 Hz
- Right Knee Angle: ________degrees

Trial 3: Jump trial 2

- ☐ Recording time: 10 seconds
- ☐ Sampling rate: 500 Hz
- Right Knee Angle: ________degrees

Trial 4: Jump trial 3

- ☐ Recording time: 10 seconds
- ☐ Sampling rate: 500 Hz
- Right Knee Angle: ________degrees

Trial 5: Zero Calibration

- ☐ Recording time: 2 seconds
- ☐ Sampling rate: 500 Hz

Appendix G: Leg Press Weight Calibration

Weight translation on the Hoist: Hoist leg press consists of 20 weight plates, each weighing 10 lb. The weights are connected to the foot plate by a pulley and cam system that the manufacturer states creates 21.5 lb of force for each 10 lb plate (Table G.1). The following describes the process and results used to assess the accuracy of the weight translation.

Table G.1: Hoist Leg Press Weight Translation

Plate #	Total weight (lb)	Total Pulley Converted weight (lb)
1	10	21.5
2	20	43.0
3	30	64.5
4	40	86.0
5	50	107.5
6	60	129.0
7	70	150.5
8	80	172.0
9	90	193.5
10	100	215.0
11	110	236.5
12	120	258.0
13	130	279.5
14	140	301.0
15	150	322.5
16	160	344.0
17	170	365.5
18	180	387.0
19	190	408.5
20	200	430.0

The manufacturer's provided weight translation for the Hoist leg press. Each 10 lb plate is converted to 21.5 lb force.

Calculation of Load Cell Constant:

A load cell (Harold G. Schaevitz Industries, USA) was used to convert force to a voltage signal that was amplified (Technical University of Nova Scotia, Canada) and displayed**,** in volts, on a multimeter (Fluke Corporation, USA).

Load cell calibration was performed as follows. The load cell was mounted vertically on a wooden frame. Pre-calibrated weights from a Cybex NORM dynamometer (CSMi Solutions, Stoughton, MA) were placed on a weight pan suspended from the load cell using an S-hook (Figure G.1). The load cell voltage for the empty weight pan was recorded to provide a zero-reading to be subtracted from subsequent measurements. Following this, 4 free weights (Table G.2) were added consecutively to the weight pan and the associated voltages recorded. The constant for each weight was calculated by dividing the weight by the associated voltage. This demonstrated a relatively linear change in voltage with weight with the r – squared value of 1. The constant used for assessment of the Hoist weight stack was determined by dividing the total weight of 100.23 lb added to the weight pan the corresponding voltage change of 2.63 volts. This yielded a constant of 38.14 lb/V.

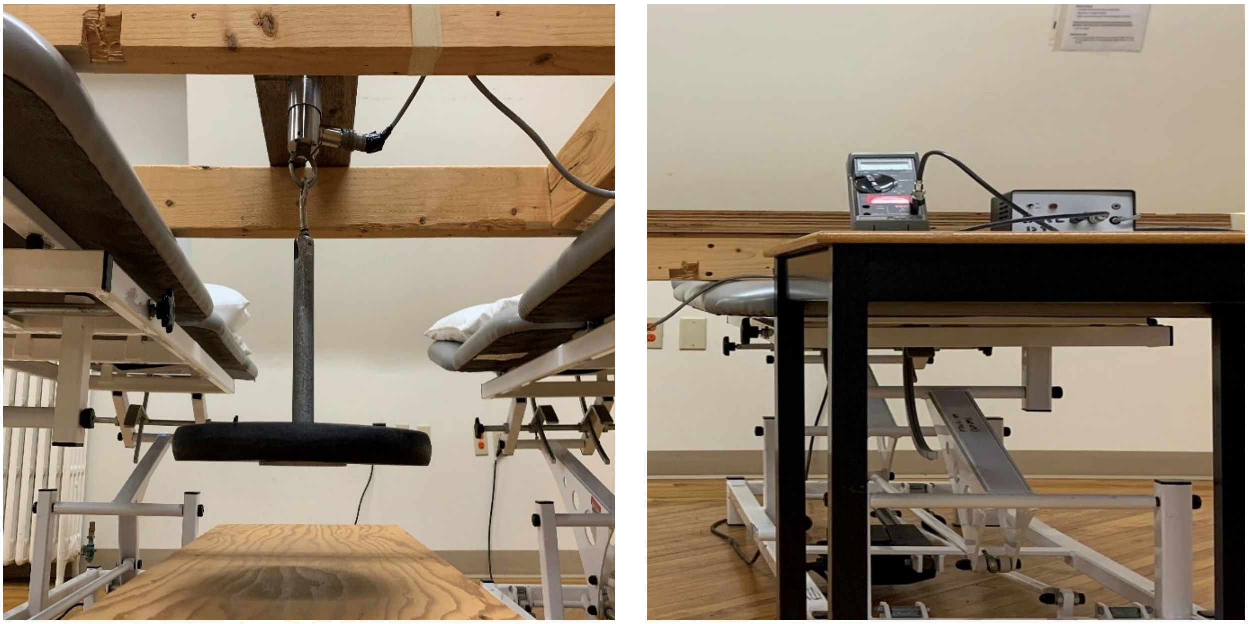


Figure G.1: Free weight supported by the weight pan suspended from a load cell. (left) The load cell is connected to an amplifier and multimeter (right).

Table G.2: Load Cell Calibration Constant

	Total Weight (lb)	Load cell recorded Voltage (V)
A	Empty weight pan	1.00
B	24.40	0.36
C	50.72	-0.33
D	75.56	-0.97
E	100.24	-1.63

Weights and corresponding voltages used to determine the load cell calibration constant.

Assessment of the Accuracy of the Hoist Weight Stack:

The load cell was secured to a wood frame and connected to the footplate of the Hoist leg press by a length of chain (Figure G.2). Voltage corresponding to this zero weight condition was recorded from the load cell. The footplate was then moved to a position that approximated full leg extension for the majority of participants in the study, which raised the weight stack from the supported position. A wooden pole was then inserted below the stack to support it. This allowed us to safely take up the slack in the chain connecting the footplate to the load cell. The pole was then removed exposing the load cell to the weight of the stack. This process was completed for plates 1 through 9 of the leg press, consecutively. Thus, the final weight was 193.5 lb according to the Hoist specifications. The assessment was limited to only 9 plates as the load cell limit was 200 lbs. The maximum weight lifted by any participant in the study was 256 lbs.

Figure G.2: The leg press configuration to assess the accuracy of the Hoist weight plates. The metal chain connects the leg press foot plate and the load cell. The load cell is connected to the voltmeter via the amplifier.

Figure G.3: The leg press weight plates being lifted up with the help of wooden plank support.

The voltage for each weight plate was documented. The voltage for the zero-weight condition was subtracted from the voltage for each subsequent weight plate to create the zero corrected voltage. The absolute value for that voltage was multiplied by the load cell constant, generating the Load Cell Weight. That weight was compared to the weight provided in the Hoist specifications. This information is provided in Table G.3.

Table G.3: Error in Hoist Weight translation

A	B	C	D	E	F
Leg Press weight plate (lb)	**Load cell recorded Voltage (V)**	**Load cell recorded Voltage Zeroed (V')**	**Load cell Measured Weight (lb)**	**Hoist Labelled Weight (lb)**	**Error in Weight translation (lb)**
0	1.06	0.00		0.00	
10	0.60	-0.47	17.77	21.50	-3.73
20	-0.03	-1.09	41.50	43.00	-1.50
30	-0.58	-1.64	62.43	64.50	-2.07
40	-1.14	-2.21	84.10	86.00	-1.90
50	-1.72	-2.78	106.14	107.50	-1.36
60	-2.28	-3.34	127.42	129.00	-1.58
70	-2.84	-3.90	148.78	150.50	-1.72
80	-3.40	-4.46	170.25	172.00	-1.75
90	-4.01	-5.08	193.56	193.50	0.06

Table represents the error in Hoist leg press weight translation. Load cell recorded voltage zeroed (V'): recorded voltage for the weight plates – recorded voltage without weight.

Interpretation:

Load cell recorded 1.06 volts under zero weight conditions which could be because of the weight of the chain. This was considered as a baseline error in voltage and was accounted for by subtracting 1.06 volts form the voltage recordings for the wight plates. A negligible average error of 1.73 lb. was found indicating that Hoist labelled weight was 1.73 lb. greater than the load cell measured weight.

Appendix H: Maximum Power for Individual Participants

Maximum Power (Watts)			
Participant Code	**Force Plate Jump Test**	**Leg Press + IMU System**	**Difference**
LP01	4066.0	2199.7	1866.3
LP02	4088.7	2845.0	1243.7
LP03	2709.5	2285.9	423.6
LP04	2896.7	2788.7	108.0
LP05	4208.8	2639.4	1569.4
LP06	1846.3	1569.8	276.5
LP07	2035.6	1002.2	1033.4
LP08	5446.9	3742.3	1704.7
LP09	1841.4	1348.6	492.8
LP10	4689.9	2621.3	2068.6
LP11	2774.5	2526.6	247.9
LP12	3747.9	3726.3	21.6
LP13	2602.3	2309.8	292.6
LP14	3870.4	2205.4	1664.9
LP15	2668.4	1443.6	1224.8
LP16	3077.7	2245.5	832.3
LP17	3619.5	3468.5	150.9
LP18	3174.9	2806.5	368.4
LP19	2288.1	1659.7	628.4
LP20	3981.9	3587.0	394.9
LP21	3205.7	2180.7	1025.0
MEAN ± SD	**3278.1 ± 955.8**	**2438.2 ± 777.8**	**839.9 ± 644.7**

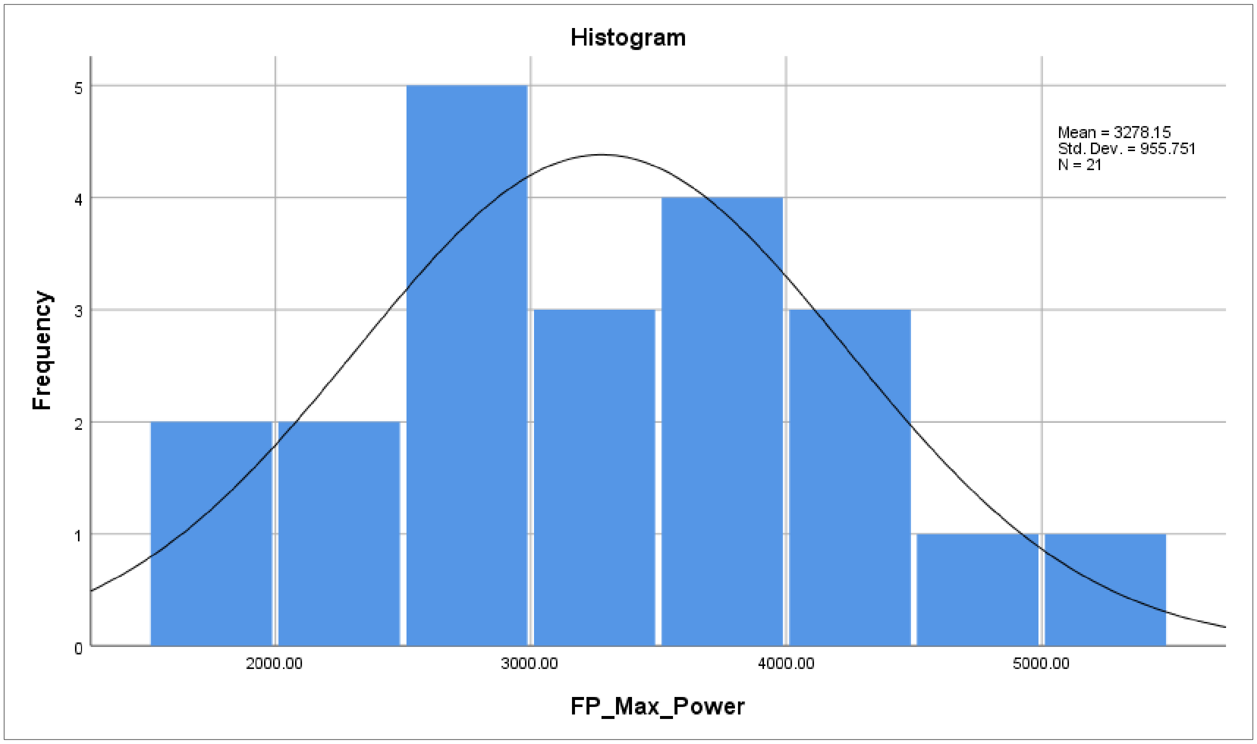
Appendix I: Maximum Force for Individual Participants

Maximum Force (N)			
Participant Code	**Force Plate Jump Test**	**Leg Press + IMU System**	**Difference**
LP01	2007.0	1356.0	651.0
LP02	2029.7	1510.7	519.0
LP03	1516.6	1251.8	264.8
LP04	1803.5	1578.9	224.6
LP05	2011.2	1820.2	190.9
LP06	1066.0	933.5	132.5
LP07	984.9	868.7	116.2
LP08	2246.6	2036.6	210.0
LP09	1050.8	804.4	246.4
LP10	2219.8	1597.0	622.9
LP11	1327.9	1291.5	36.4
LP12	1955.9	1688.5	267.4
LP13	1500.3	1312.5	187.8
LP14	2037.1	1372.3	664.8
LP15	1289.0	1126.5	162.5
LP16	1714.9	1271.4	443.5
LP17	1830.8	1609.2	221.5
LP18	1729.5	1532.8	196.7
LP19	1415.2	1176.5	238.7
LP20	2187.1	1832.3	354.9
LP21	1649.9	1293.5	356.4
MEAN ± SD	**1694.0 ± 394.5**	**1393.6 ± 319.9**	**300.4 ± 180.2**

Appendix J: Maximum Velocity for Individual Participants

Maximum Velocity (m/s)			
Participant Code	**Force Plate Jump Test**	**Leg Press + IMU System**	**Difference**
LP01	2.6	2.2	0.5
LP02	2.6	2.4	0.2
LP03	2.1	2.1	-0.1
LP04	1.9	2.3	-0.4
LP05	2.6	2.0	0.7
LP06	2.0	2.0	0.0
LP07	2.4	1.7	0.7
LP08	2.9	2.5	0.5
LP09	2.0	2.0	0.0
LP10	2.5	2.2	0.3
LP11	2.4	2.5	0.0
LP12	2.3	2.8	-0.5
LP13	2.2	2.3	-0.2
LP14	2.6	2.1	0.5
LP15	2.4	1.8	0.7
LP16	2.2	2.2	0.1
LP17	2.4	2.7	-0.4
LP18	2.4	2.6	-0.2
LP19	2.0	1.7	0.2
LP20	2.1	2.3	-0.3
LP21	2.3	2.1	0.2
MEAN ± SD	**2.3 ± 0.3**	**2.2 ± 0.3**	**0.1 ± 0.4**

Appendix K: Histogram for Force Plate Jump Test Power



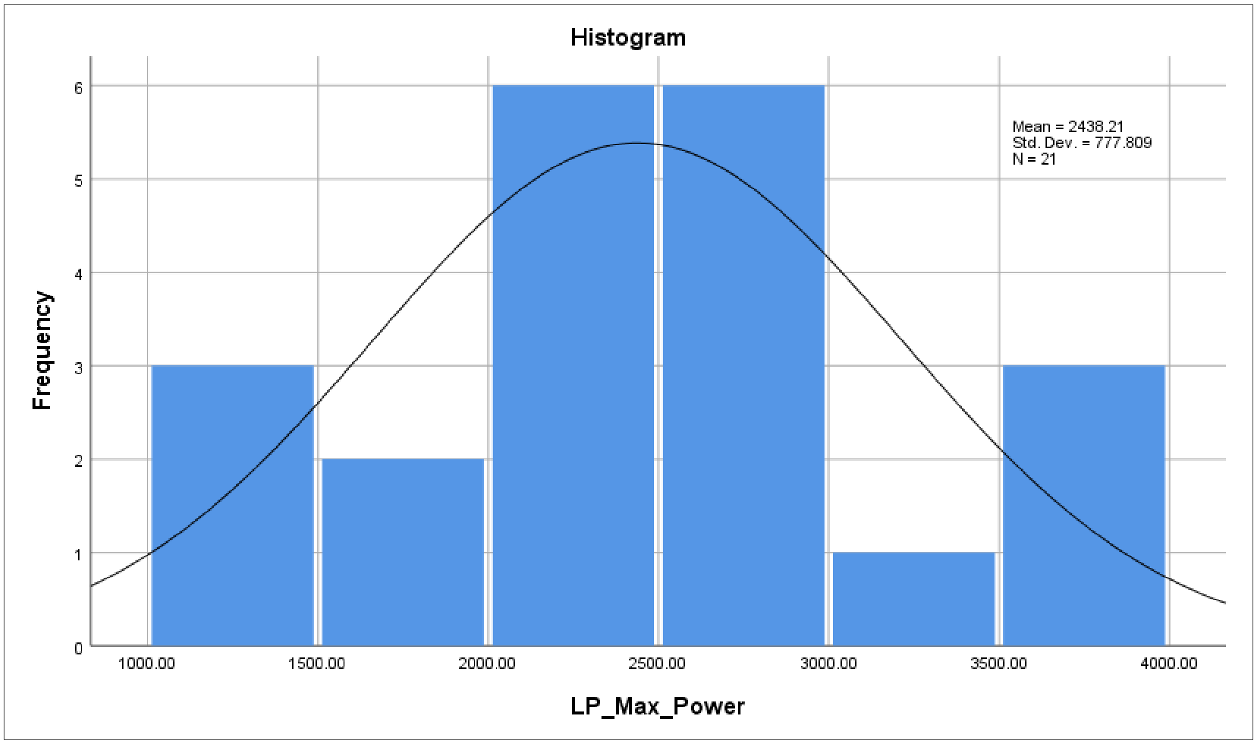
Histogram plot showing the normal distribution of the force plate jump test measured maximum lower extremity power (Watts).

Appendix L: Shapiro- Wilk Test of Normality for Force Plate Jump Test Power

	Shapiro-Wilk		
	Statistic	df	Sig.
Force Plate Jump Test Maximum Power	.968	21	.686

The Shapiro-Wilk test assessing the force plate jump test measured maximum lower extremity power (Watts) data for its difference from a normal distribution.

Appendix M: Histogram for Leg Press + IMU System Power



Histogram plot showing the normal distribution of the leg press + IMU system measured maximum lower extremity power (Watts).

Appendix N: Shapiro- Wilk Test of Normality for Force Plate Jump Test Power

Test of Normality			
	Shapiro-Wilk		
	Statistic	df	Sig.
Leg Press + IMU Maximum Power	.956	21	.444

The Shapiro-Wilk test assessing the leg press + IMU measured maximum lower extremity power (Watts) data for its difference from a normal distribution.

Appendix O: Difference in Maximum Power for Participants using a Countermovement

Participant Code	Maximum Jump Power (Watts)	Maximum Leg Press Power (Watts)	Difference
LP01	4066.0	2199.7	1866.3
LP02	4088.7	2845.0	1243.7
LP05	4208.8	2639.4	1569.4
LP07	2035.6	1002.2	1033.4
LP08	5446.9	3742.3	1704.7
LP10	4689.9	2621.3	2068.6
LP14	3870.4	2205.4	1664.9
LP15	2668.4	1443.6	1224.8
LP16	3077.7	2245.5	832.3
LP21	3205.7	2180.7	1025.0
Mean ± SD	**3735.8 ± 1003.2**	**2312.5 ± 748.9**	**1423.3 ± 408.7**

Values represent the mean ± SD of the maximum lower extremity power (Watts) measured using the force plate jump test and the leg press + IMU system.

Appendix P: Difference in Maximum Power for Participants not using a Countermovement

Participant Code	Maximum Jump Power (Watts)	Maximum Leg Press Power (Watts)	Difference
LP03	2709.5	2285.9	423.6
LP04	2896.7	2788.7	107.9
LP06	1846.3	1569.8	276.5
LP09	1841.4	1348.6	492.8
LP11	2774.5	2526.6	247.9
LP12	3747.9	3726.3	21.6
LP13	2602.4	2309.8	292.5
LP17	3619.5	3468.5	150.9
LP18	3174.9	2806.5	368.5
LP19	2288.1	1659.7	628.4
LP20	3981.9	3587.0	394.9
Mean ± SD	**2862.1 ± 722.0**	**2552.5 ± 821.6**	**309.6 ± 176.8**

Values represent the mean ± SD of the maximum lower extremity power (Watts) measured using the force plate jump test and the leg press + IMU system.

Appendix Q: Analysis of Squat Jump Movement Duration

Squat Jump Movement Duration	
Participant Code	**Total Time (seconds)**
LP03	0.4
LP04	0.4
LP06	0.5
LP09	0.5
LP11	0.3
LP12	0.4
LP13	0.2
LP17	0.3
LP18	0.3
LP19	0.3
LP20	0.4
MEAN ± SD	**0.4 ± 0.1**

Appendix R: Analysis of Leg Press Movement Duration

Leg Press Movement Duration	
Participant Code	**Total Time (seconds)**
LP03	0.8
LP04	0.9
LP06	0.9
LP09	0.9
LP11	0.9
LP12	0.7
LP13	0.6
LP17	0.7
LP18	0.8
LP19	0.6
LP20	0.9
MEAN ± SD	**0.8 ± 0.2**

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