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USING ADDITIONAL MEASURES OF HANDGRIP STRENGTH TO PREDICT AEROBIC CAPACITY IN WHEELCHAIR USERS

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ABSTRACT

USING ADDITIONAL MEASURES OF HANDGRIP STRENGTH TO PREDICT AEROBIC CAPACITY IN WHEELCHAIR USERS

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Manual wheelchair users have been shown to have low physical capacity and impaired ability to perform activities of daily living. Current tests and protocols for assessing physical capacity in wheelchair users have specific boundaries. Measuring handgrip strength (HGS) with electronic handgrip dynamometers has been shown to be a reliable measure of muscle function and a convenient assessment of overall muscle strength. This study aimed to determine the correlation of maximal HGS, HGS rate of force development, HGS fatigability, HGS isometric control, and HGS asymmetry to a six-minute wheelchair propulsion (6MPT) test in ambulatory young adults. Thirty-four recreationally active ambulatory individuals aged 23.76±3.57yrs participated in this study. HGS was assessed using electronic handgrip dynamometry. Aerobic capacity was assessed using the 6MPT. Handgrip fatigability showed significant near moderate negative correlation ($r=-0.345$, $p<0.05$) with push test outcomes while the correlation with all other measures was insignificant. Evidence of weak to near moderate associations ($r=-0.12$; -0.28; -0.24; -0.32; $p>0.05$) were also shown between handgrip rate of force development, fatigue, isometric control and asymmetry respectively. Our findings that additional measures of HGS were correlated with aerobic capacity in ambulatory adults may suggest measures of HGS could be predictive of aerobic capacity in those who use manual wheelchairs. Additional research is necessary to further understand these relationships.

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This thesis follows the format prescribed by the *APA style manual*.

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Chapter One: Introduction

In the United States, there are roughly 3.6 million Americans that use wheelchairs as mobility aides, including but not limited to those with spinal cord injuries, multiple sclerosis, and cerebral palsy (Brault, 2010; Selph et al., 2021). Conditions deriving from motor function impairments, neurological deficits, and skeletal muscle limitations associated with manual wheelchair users experience strain during daily activities. The strain during wheelchair ambulation in household activities limits performing personal care tasks (Janssen et al., 1994). It is suggested that this strain is due to the predominant overuse of upper limb muscles during wheelchair propulsion (Katch, Katch, & McArdle, 1996). Because of these limitations paired with a greater susceptibility for upper extremity disorders associated with overuse, wheelchair users tend to have low physical health and decreased physical capacity, and impaired ability to perform both basic and instrumental activities of daily living (Anseew, 2007; Kasper, Chan, & Freedman, 2017; Macdonell et al., 2016).

Components of physical capacity in wheelchair users are currently assessed in laboratory settings with field tests that have been developed by modifying existing tests used in ambulatory individuals (Vinet et al., 1996; Goosey-Tolfrey & Tolfrey, 2008). Field tests are the current preferred method for assessing aerobic capacity in manual wheelchair users. However, in comparison with laboratory protocols, specific boundaries exist and are associated with the cost of specialized equipment, lack of specificity with traditional wheelchair propulsion, and external factors inducing propulsion variability (Cowen et. al., 2012; Franklin et al., 1990; Goosey-Tolfrey et al., 2008; Vanlandewijk, Daly & Theisen, 1999). Knowing the limitations of current field tests, the development of a valid and accessible protocol for assessing physical capacity in manual wheelchair users is clinically important.

The measurement of handgrip strength using electronic handgrip dynamometers has been shown to be a reliable measure of muscle function and a convenient assessment of overall muscle strength (Klawitter et al., 2020; McGrath et al., 2020). Due to its relatively low cost and ease of assessment, handgrip strength has been recognized to be easily applicable in both clinical and research settings and is the most widely used, non-fatiguing method to measure muscle strength (Beaudart et al., 2019; McGrath et al., 2020). Maximum handgrip strength alone is only a single aspect of muscle function, and the inclusion of additional measures of grip strength, such as handgrip asymmetry, fatiguability, rate of force development, and isometric control, may support aspects of further understanding muscle function. (Mahoney et al., 2020). Maximal handgrip strength, hand grip asymmetry, handgrip rate of force development, handgrip isometric control, and handgrip fatiguability have not been well assessed in manual wheelchair users. However, it is known that the upper extremities have limited capacity and fatigue more easily, indicating a possible link between additional measures of muscle function measured with electronic handgrip dynamometry such as fatigability and aerobic capacity. Therefore, the purpose of this study is to determine the correlations between maximal hand grip strength, handgrip rate of force development, handgrip fatigability, handgrip isometric control, and handgrip asymmetry to a six-minute push test in ambulatory young adults using wheelchairs. Ambulatory adults will be used as they will all be equally experienced in wheelchair propulsion, decreasing variability in propulsion test outcomes when trying to find the initial relationship with handgrip strength. A secondary purpose is to evaluate the concurrent validity of handgrip rate of force development, handgrip fatiguability, handgrip isometric control, and handgrip asymmetry on maximal handgrip strength in young ambulatory adults using wheelchairs. The researcher postulates that increased maximal handgrip strength, handgrip rate of force development, handgrip fatigability, handgrip isometric control, and no handgrip asymmetry will be valid predictors for assessing functional capacity measured via the six-minute push test and that there will be a positive correlation between handgrip rate of force development, handgrip isometric control, and handgrip asymmetry on maximal handgrip strength, as well as a negative correlation between handgrip fatiguability and maximal grip strength in young ambulatory adults using wheelchairs.

Chapter Two: Literature Review

Introduction

As of 2010, nearly 3.6 million people, roughly 1.5% of Americans, use wheelchairs as mobility aids, including individuals with spinal cord injuries (SCI) (Brault, 2010). Spinal cord injuries can occur in a variety of ways, including falls, accidents during recreational activities, vehicle accidents, or violence. Currently, there is an estimated population of 183,000 to 230,000 individuals living with a traumatic SCI in the United States (McDonald & Sadowsky, 2002). A significant number of SCIs can result in tetraplegic and neurological complete deficits requiring many individuals with an SCI to use a wheelchair for all mobility (Chen, Tang, Vogel, & DeVio, 2013; Selph et al., 2021). Motor function impairments of the lower extremities associated with SCIs cause individuals to depend on the upper extremities, as well as trunk musculature, in low lesion injuries. In SCI individuals with low physical capacity, the ability to carry out activities of daily living in areas such as balance, range of motion, stamina, and strength is compromised. The limited capacity of the small muscle mass in the upper extremities combined with low physical capacity can cause high physical strain during wheelchair propulsion and other ADLs. Strain from limited capacity may possibly decrease activity levels even further and impact physical capacity and aerobic fitness, as well as quality of life (Kasper, Chan, & Freedman, 2017; Janssen et al., 1994).

Another condition associated with the use of a wheelchair is multiple sclerosis (MS). Multiple sclerosis is one of the most common non-traumatic disabling diseases affecting young adults and is more common in females (Dobson & Giovannoni, 2019; Kobelt et al., 2017). The cause of MS is often stated to be unknown, but environmental and genetic factors play important roles in the development of the disease. MS is viewed as a two-staged autoimmune disease, the first being early inflammation which is responsible for relapsing-remitting disease with relapses developing sub-acutely over hours to days and plateauing over several weeks before gradually recovering. As MS develops, these relapses leave behind lasting damage and loss of neuronal reserve, leading to sustained disability. The second stage is delayed neurodegeneration, causing non-relapsing progression, and generally develops 10 to 15 years after the onset of relapse-remitting MS (Dobson & Giovannoni, 2019). Due to neurological deficits, up to 93% of individuals with MS experience decreased mobility within 15 years of disease onset. The mobility impairments associated with MS have been shown to lead to decreased health-related quality of life and the ability to perform ADLs (Macdonell et al., 2016; Souza et al., 2010).

A third population that may use a wheelchair are individuals with cerebral palsy (CP). Cerebral palsy is the most common childhood physical disability affecting two to two and a half children per 1,000 live births in the United States and is best described as a group of permanent disorders. Permanent disorders may consist of the development of movement and posture abnormalities causing activity limitation, which are attributed to nonprogressive disturbances occurring in the development of the young brain (Krigger, 2006). The motor disorders of CP are often accompanied by disturbances of sensation, perception, cognition, communication, and behavior, by epilepsy, and by secondary musculoskeletal problems (Anseeuw, 2007). The skeletal muscle limitations associated with CP such as spasticity and increased muscle tone can restrict joint range of motion and lead to tremors and muscle weakness, contributing to reduced functional capacity (Barrett & Lichtwark, 2010). Increased muscle spasticity and low physical activity rates in children with CP are also thought to cause meaningfully lower peak oxygen consumption (VO_2 peak) values compared to typical developed children (Verschuren & Takken, 2010). With the knowledge of the physical limitations associated with wheelchair use, the development of an accessible and valid protocol to assess physical capacity in wheelchair users is clinically relevant; physical limitations are associated with negative health outcomes in addition to decreases in functional capacity and quality of life.

Instrumental Activities of Daily Living/Basic Activities of Daily Living

Activities of daily living can be split into two categories, basic activities of daily living (BADLs), and instrumental activities of daily living (IADLs). Performance of BADLs can be assessed by asking individuals if they have difficulty with activities such as bathing, dressing, eating, getting in and out of chairs, toileting, or walking. In IADLs, the aim is to assess difficulty with activities including preparing meals, grocery shopping, managing money, performing light and heavy housework, and medication management (Pavela, 2015). Instrumental activities of daily living are considered necessary for independent living and require higher neuropsychological functioning, while BADLs are considered necessary for self-care and require more physical fitness (Liang et al., 2017; Mlinac & Feng, 2016). The ability to perform IADLs and BADLs is essential to older adults, as IADL autonomy plays a vital role in "successful" aging (Depp & Jeste, 2006). Currently, assessment of IADLs and BADLs includes the use of questionnaires such as the Katz Index of Independence in Activities of Daily Living, to measure functional capacity regarding an individual's ability to complete a series of IADLs and BADLs (Shelkey & Wallace, 2001).

As age increases, individuals can experience IADL and BADL disabilities from a catastrophic event such as an injury or a progressive decline in brain functions (Pashmdarfard & Azad, 2020). Using data from the National Health and Nutrition Examination Survey

(NHANES) from 1988 to 1994 and 1999 to 2004, Seeman and colleagues (2010) examined the prevalence of reported disability trends in adults aged 60 to 69, 70 to 79, and 80 years and older. Using logistical regression models for each age group assessing relative odds of each type of disability as a function of time. When comparing prevalence in 1988-1994 with 1999-2004, they found an increase of 40% to 70% of reported prevalence for all disability types. When additional controls for health status and health behaviors were added reported prevalence of all types of disability other than functional remained significantly high among respondents aged 60 to 69 years in 1999 to 2004. Odds ratios of 1.7, 1.8, and 1.6 were shown for ADL, IADL, and mobility disability prevalence in respondents aged 60 to 69 respectively. The results are concurrent with the findings of Stevens and colleagues (2016) using data from the National Health Interview Survey (NHIS) for the years 2011-2014. Overall, 22.6 million (11.9%) working-age adults (18-64 years) who completed the survey were found to have any disability, with 56.6% having only one disability type. Of the 22.6 million, 51.0% had a mobility disorder, and approximately 42.9% had two or more disabilities, with the most common types being mobility, independent living, and cognition. As the number of disability types increased, the percentage of adults aged 45-64 years increased as well. Although we see a decline in both basic and instrumental ADLs as individuals age, more middle-aged and older adults are living with IADL impairments than with BADL limitations. The increased prevalence of IADL impairments is due functions assessing IADLs represent higher-level cognitive tasks that typically decline in aging individuals before self-care tasks, where greater physical function is required (McGrath et al., 2019).

Impairments in IADL and BADL functions have been highly associated with negative health outcomes such as chronic morbidity and premature mortality (Dunlay et al., 2015; Hennessy et al., 2015). Although a majority of research on ADL disability and limitations has used samples of working-aged and older adults, they are not the only group to have negative health implications associated with ADL function. Due to loss of motor function, it has been suggested that wheelchair users with an SCI live a relatively sedentary life, leading to low physical fitness (Janssen et al., 1994; Nooijen et al., 2012). Due to an increased sedentary lifestyle and decreased physical capacity, wheelchair users have been shown to experience physical strain while performing daily ADLs. Physical strain increases in individuals who have experienced a cervical or high thoracic lesion. Periods of peak strain in wheelchair users occur in daily activities such as wheelchair ambulation, transfers, household activities, and personal care. The physical strain during daily activities not only have negative implications on physical health but on quality of life as well (Janssen et al., 1994). The preservation of functional capacity should be a major public health priority as it could have the ability to decrease healthcare costs and increase quality of life for the affected individual and their family (Hoffman et al., 1996; McGrath et al., 2019).

Physical health of wheelchair users

Although individuals may use wheelchairs as their primary base of support, means of transportation, and physical activity, wheelchairs can also limit the user’s ability to exercise and be physically active (Ellapen, Hammil, Sawnepoel, & Srtydom 2017). The limited ability to exercise in wheelchair users may be due to increased muscle fatigue, due to the predominant use of upper limb muscles during wheelchair propulsion. Warms and colleagues (2008) analyzed community-based free-living physical activity of 50 adult manual wheelchair users between the ages of 18 and 74 years (46.3±13.6 years) and found that 56% of their sample population did not meet the physical activity guidelines of 150 hours of weekly activity as compared to 33% of individuals without disability and wheelchair use (Healthy People, 2010). Limitations arise in manual wheelchair users during exercise as they are more susceptible to upper extremity disorders such as carpal tunnel, impingement, and rotator-cuff syndrome when compared to able-bodied individuals. Upper extremity disorders can lead to an even greater decrease in already low physical activity levels, reducing IADLs and BADLs (Janssen et al., 1994).

A sedentary lifestyle in manual wheelchair users has been shown to lead to negative health effects, such as a heightened risk for cardiovascular disease and metabolic syndrome (Nooijen et al., 2012; Ellapen et al., 2017). Although there is little research with manual wheelchair users, a direct relationship between lipid profile and coronary artery disease in the general population is shown. Multiple studies report decreased levels of high-density lipoprotein (HDL), increased low-density lipoprotein (LDL), total cholesterol (TC), and triglycerides in individuals with an SCI (de Groot et al., 2008; Bauman et al., 1992; Maki et al., 1995; Demirel et al., 2001; Storch et al., 2005). A significant relationship between physical capacity parameters and HDL ($p<0.01$), TC/HDL ($p<0.05$), LDL/HDL ($p<0.05$), and TG ($p<0.01$) has also been shown. When comparing sedentary SCI populations with active SCI populations, it was found that HDL and VO_2 peak were significantly higher ($p<0.05$) in the active group, which also had lower TC/HDL ratios (de Groot et al., 2008).

Regular physical activity has been shown to improve cardiovascular and metabolic health in wheelchair users. Cardiometabolic improvements associated with physical activity include increased HDL, increased metabolic health with reduced type 2 diabetes development, increased cardiovascular function, improved hemodynamics, and decreased risk of heart failure by decreasing stress through physiological adaptations (Pinckard, Baskin, & Stanford, 2019). Associations between health risks, physical capacity, and activity levels in manual wheelchair users reiterate the importance of a valid method to predict physical capacity, specifically aerobic capacity, in manual wheelchair users.

Current Wheelchair Tests

Aerobic capacity is a measure of cardiorespiratory fitness and a major component of physical ability, which has been robustly assessed in laboratory settings in wheelchair users (Vinet et al., 1996). However, the feasibility of laboratory protocols is quite low as the cost of specialized equipment is prohibitive, and laboratory availability is limited. Field tests are the current preferred method for assessing aerobic capacity because they require minimal equipment, time, and are cost-effective (Goosey-Tolfrey & Tolfrey, 2008). Field tests for wheelchair users have been developed by modifying versions of existing tests used in ambulatory individuals, like the 25-m shuttle run, the Leger and Boucher test, and Cooper's 12-minute run (Cowan, Callahan & Nash, 2012). Although field tests have shown positive, moderate-to-high correlations (r=0.84, modified Cooper's 12-minute run) with aerobic capacity, in the modified 12-minute push test, Franklin and colleagues (1990) reported pacing was important for optimal performance. Vanlandewijck and colleagues (1999) reported despite the positive, moderate correlation between distance covered and peak aerobic capacity in the modified 25-m shuttle test (r=0.64), it is only valid when using a laboratory arm crank ergometer protocol. However, crank arm ergometer protocols lack specificity with wheelchair propulsion because of upper limb position (Goosey-Tolfrey & Tolfrey, 2008). With the known limitations and challenges of laboratory and current field tests, it is essential to find a reliable, valid, and inexpensive test for assessing aerobic capacity and understanding functional capacity in wheelchair users.

The six-minute walk (6MPT) test is a valid and reliable field test for estimating aerobic capacity in healthy older adults (Mänttäri, Suni, Sievänen, Husu & Vähä-Ypyä, 2018). A modified version was created to assess aerobic capacity in individuals with an SCI. The 6MPT has been deemed a valid and reliable test for assessing aerobic capacity in wheelchair users (Solanki, Chaudhari & Bhise, 2016). In a cross-sectional study measuring the aerobic response during the 6MPT and its parallel reliability with the maximal arm crank ergometer test (ACET), it was found that the 6MPT yielded peak values of heart rate and VO_2 that were strongly and positively associated with values of the ACET ($r=0.92$). The total distance traveled during the 6MPT was also strongly associated with VO_2 peak ($r=0.86$, $p<0.05$), implying total distance covered during the 6MPT may represent a clinical alternative for estimating aerobic fitness in manual wheelchair users (Bass et al., 2020).

Although the 6MPT has been shown to be a valid assessment protocol for aerobic capacity, it has limitations similar to other field tests that rely on manual wheelchairs. Limitations include factors that affect propulsion performance, such as chair configuration, propulsion skill, and surface resistance, which introduce variance and affect prediction precision. The limitations presented by wheelchair propulsion variability demonstrate the importance of a more accessible protocol for manual wheelchair users (Cowen et al., 2012). Differences in external conditions such as turning capacity and mechanical resistance have been shown to lead to meaningfully different wheelchair shuttle run performances due to variability from wheelchair to wheelchair. In a cross-sectional study, Vanlandewijk and colleagues (2006) had participants complete a 25 m shuttle run (SR) adapted for wheelchair users from Leger and Lambert (1982), where SR performance was reported in seconds. The study consisted of three different testing conditions: in condition one the wheelchairs had normal turning capacity and mechanical resistance (SR performance mean ± SD= 536±119.09s; r=0.53; p<0.05), wheelchairs in condition two had increased mechanical resistance and normal turning capacity (488.82±199.84s; r=0.52; p<0.05) and the wheelchairs in condition three had both increased mechanical resistance and decreased turning capacity (404.91±88.41s; r=0.37; p<0.05). Across the three conditions, as resistance increased and turning capacity decreased, SR performance decreased. The findings from this study represent the negative impact of increased mechanical resistance and decreased turning capacity on SR performance. The increased resistance and decreased turning capacity can be attributed to factors such as chair configuration, and external factors such as testing surface (Léger & Lambert, 1982). Therefore, determining an assessment of functional capacity in wheelchair users that is valid and reliable is needed.

Utility of Handgrip Strength

Measuring handgrip strength (HGS) using electronic dynamometry is a reliable measure of muscle function and is considered a convenient assessment of overall muscle strength (Klawitter et al., 2020; McGrath et al., 2020). Before discussing HGS further, it is important to clarify the term muscle function. Muscle function consists of three concepts: muscular endurance, the ability of muscles to exert force against resistance over a sustained period of time; muscular power, the ability to exert a maximal force in as short a time as possible, as in accelerating, jumping and throwing implements; and finally, muscular strength, the amount of force a muscle can produce with a single maximal effort (Beaudart et al., 2019). Handgrip Strength is measured during a muscular isometric contraction and is the most widely used method to measure muscle strength as it has been recognized to be easily applicable in both clinical and research settings due to its relatively low cost and ease of assessment (Beaudart et al., 2019; McGrath et al., 2020).

Low HGS is classified as a combined score for the right and left hands of ≤83 kg of force in males and ≤51 kg of force in females between the ages of 20 and 29 years. Low HGS is an important component of decision algorithms for determining sarcopenia and dynapenia as it is a well-validated protocol for assessing muscle strength (ACSM, 2018; Cruz-Jentoft & Sayer, 2019; Manini & Clark, 2012). Assessing muscle strength and function is imperative to understand during the aging process, as aging is linked to loss of muscle mass and strength (McGrath et al., 2018). Identifying low HGS in individuals is also important because it is highly predictive of many adverse health outcomes including increased risk of all-cause and cardiovascular mortality, body mass index, comorbidities, dietary intake, and physical activity levels, as well as stroke, type 2 diabetes, functional limitations, and many others (Dufner, Fitzgerald, Lang, & Tomkinson, 2020).

Although maximal HGS has been shown to be reliable, clinically relevant, and is the most widely used method to measure muscle strength, it is argued that maximal HGS alone should not be assumed a proxy for overall muscle strength. Yeung and colleagues (2018) used a cross-sectional design consisting of 960 healthy young and old individuals as well as geriatric outpatients and older individuals post-hip fracture (49.8% male) to determine the associations between maximal HGS and overall muscle strength. They found the correlation with knee extensor strength was low and positive in healthy young males ($r=0.36-0.45$; females, $r=0.45$), healthy old individuals (males, $r=0.35-0.337$; females, $r=0.44$) and moderate and positive in geriatric outpatients ($r=0.54$) and individuals post-hip fracture (males, $r=0.44$; females, $r=0.57$). A significant relationship was determined for young males, healthy old males, and geriatric outpatients ($p<0.05$) (Yeung et al., 2018). However, although the use of isokinetic dynamometers to measure KES is usually the preferred method in clinical studies, their use is limited in largescale epidemiological studies as the equipment is costly and not portable (Martin et al., 2006). Knee Extensor Strength is also not practical in manual wheelchair users and individuals with limited lower limb mobility.

Handgrip Tests

As described above, measures of HGS are characterized as a maximal isometric grip force task, whereas muscle function includes other aspects, including but not limited to: fatiguability, rate of force development, asymmetry, and isometric control (Klawitter et al., 2020). Although more research is warranted, findings suggest that including additional HGS measurements related to the other aspects of muscle function and better resemble muscle function may improve how we assess muscle function for age-related health conditions when compared to maximal HGS alone (Mahoney et al., 2020). A pilot study evaluating additional aspects of muscle function in older adults (n=13; 53.9% female, 70.9 ± 4.0 years) sought to determine the role of handgrip strength and function on cognitive function. Although there were no statistical significance individuals with cognitive impairments generally had lower mean scores in nearly all HGS measurements. Statistical insignificance is thought to be due to the small sample size (Klawitter et al., 2020). The possible relationship between additional measures of HGS and cognitive function again elicits the need for further research on these additional HGS measurements as higher-level cognitive tasks required for completing IADLs typically decline in aging individuals leading to IADL impairment and limitations (McGrath et al., 2019).

Handgrip Strength in Different Populations

There are many populations where the various assessments of HGS are clinically relevant, one of which is older adults. It is well known that poor muscle function due to loss of muscle mass and strength during the aging process can lead to mobility impairments and other adverse health events in older adults. Therefore, experts advise handgrip strength to be used to measure muscle strength in adults aged 65 years and greater (Beaudart et al., 2019). Handgrip strength is highly recommended due to the applicability of the tools in clinical practice, the required test time, and the availability of robust cut points (Beaudart et al., 2019). Sallinen and colleagues (2010) looked to determine optimal HGS cut points for the likelihood of mobility limitations in older adults (55-99 years; males n=1,084; females n=1,562) and whether cut points differed according to BMI classification. They found a significant interaction effect between HGS and BMI in males ($p<0.05$) with no significant interaction in females ($p>0.05$). Optimal cut points were determined as: 33 kg of force for normal-weight males (BMI of 20.0-24.9 kg/m^2), 39 kg for overweight males (BMI of 25.0-29.9 kg/m^2), 40 kg for obese males (BMI ≥30.0 kg/m^2), and 21 kg of force for females when assessing the risk of mobility limitation in older adults.

Although there is limited research on the topic, another population that may benefit from HGS assessments are manual wheelchair users. When comparing HGS between wheeled mobility users and non-disabled adults, researchers found female manual wheelchair users (n=14) aged 20 to 34 years had a mean maximal HGS of 21.0 kg ± 8.3 (classified as poor by ACSM), with (n=32), while male manual wheelchair users had a mean maximal HGS of 38.7 kg ± 15.3 (classified as poor by ACSM). The reported values fell below the 95% confidence interval of the healthy ambulatory adult population reported previously (Bohannon, Peolsson, Massy-Westropp, Desrosiers, & Bear-Lehman, 2006; Joseph, D'Souza, & Paquet, 2010). The findings that both male and female manual wheelchair users had poor average maximal grip strength are clinically significant as it is known that low HGS is associated with functional limitations. A cross-sectional study of 947 older adults aged at least 65 years and older showed that for every

10 kg of force increase in HGS, the odds for IADL impairment was decreased by 39% ($p<0.05$) (Gopinath, Kifley, Liew, & Mitchell, 2017). Likewise, Neto and colleagues (2021) aimed to determine optimal HGS cut points for males with SCI (n=54) to attain greater functional independence scores on the Spinal Cord Independence Measure version III (SCIM-III), a self-reported measure where higher scores represent greater skill and independence. They determined that the sum of the highest HGS values of the left and right sides needs to be 102.5 kg of force to achieve a score of 70/100 on the SCIM-III.

Additional measures of HGS that incorporate various aspects of muscle function, such as asymmetry, fatiguability, and rate of force development, may be beneficial to wheelchair users as well. It is known that the strain of wheelchair propulsion is often at its peak during different ADLs, and it has been shown that handgrip asymmetry and weakness together were associated with 81% increased odds for future functional disability in a national sample of aging Americans (Janssen et al., 1995). The association between HGS asymmetry and functional disability is also noteworthy due to the bilateral nature of wheelchair propulsion. Power production during wheelchair propulsion comes from the work of the upper body, mainly the arms. Due to the relatively small muscle mass of the upper extremities and an increased tendency for local fatigue, a much lower maximal work capacity is experienced by wheelchair users. Increased local fatigue associated with wheelchair propulsion highlights the importance of assessing fatiguability in manual wheelchair users as the measurement of power output in wheelchair exercise testing combined with physiological measurements of the cardiorespiratory strain, gives additional information on the physical capacity of the person (van der Woude, Veeger, Dallmeijer, Janssen, & Rozendaal, 2001).

When compared to pure maximal voluntary contraction (MVC), rate of force development has been shown to be better related to most performances of functional daily tasks. Rate of force development is also more sensitive to acute and chronic changes in neuromuscular function, which is significant in wheelchair user sub-populations. Individuals with MS experience neurodegeneration and individuals with SCI tend to have motor function impairments associated with their injury, demonstrating the importance of the additional assessments of HGS in manual wheelchair users (Dobson & Giovannoni, 2019; Janssen et al., 1994; Maffiuletti et al., 2016). Assessing fatigue and other aspects of muscle function using electronic dynamometry may also help estimate aerobic capacity as is known that muscle mass, strength, and muscular endurance influence aerobic capacity greatly (Kujala et al., 2019).

Conclusion

Roughly 3.6 million Americans use wheelchairs as mobility aides, including those with SCI, MS, and CP. Manual wheelchair users have been shown to experience barriers associated with IADLs and BADLs, as well as low physical capacity when compared to able-bodied individuals. The barriers to ADL performance experienced by manual wheelchair users stem from the strain of wheelchair propulsion and the nature of their diagnosis and can lead to declines in physical health and well-being. The current tests to assess physical capacity in manual wheelchair users have been shown to have limitations; therefore, a more accessible protocol needs to be developed. In the general population and in older individuals, measures of HGS have been shown to be accurate, reliable, and accessible for estimating muscle strength and function. If an association is present between the maximal HGS and additional measures of HGS and current physical tests, then HGS may be used as a more accessible estimate of physical capacity in manual wheelchair users.

Chapter Three: Methods

Participants

A cross-sectional design was utilized to complete this investigation. The Northern Michigan University Institutional Review Board has approved all study protocols (HS23-1374). To account for any missing data and adhere to the recommended minimum number of individuals for 80% power in a single group cross-sectional design to obtain a correlation coefficient of ≥0.50, the researcher recruited 34 participants from July 2023 through October 2023 in Marquette, Michigan, USA. Sample size was calculated using collected pilot data. The researcher recruited by word of mouth, email list serves, flyers, and oral presentations in the School of Health and Human Performance.

We recruited individuals between the ages of 18 and 35 years old who met the current physical activity guidelines for Americans (HHS, 2018), and had no prior manual wheelchair experience. Persons were excluded if they 1) had any musculoskeletal injuries, health conditions, or surgical procedures within the last six-months that limited physical functioning (e.g., fractures, sprains, arthritis); 2) were not ready to participate in physical activity as determined by the PAR-Q+ (Warburton et al., 2001); 3) were not ambulatory; or 4) were unable to complete dynamometer testing on both hands due to pain, arthritis, or a surgical procedure. Each session lasted between 30- and 60-minutes in duration.

Procedures

Prior to study testing, individuals were asked to avoid strenuous physical activities for 48 hours prior to their visit and maintain habitual sleeping, eating, and hydration patterns. All data collection took place in the Exercise Science Lab (PEIF 146) in the Physical Education

Instructional Facility on Northern Michigan University's campus. Participants attended one session that lasted up to 60 minutes, beginning with a review of an informed consent form (Appendix A) explaining all aspects of the study prior to taking part in any study procedures. Participants were also asked to complete a PAR-Q+, and the International Physical Activity Questionnaire (IPAQ-SF) to screen for risk associated with performing physical activity and assess physical activity, respectively (Appendix B; Appendix C). Once written informed consent was given, and if the participant met all inclusion criteria, data collection began with obtaining all measures of HGS. Measures of HGS were recorded using a Biopac handgrip dynamometer (Biopac Systems; Goleta, CA) and MP36 Student Lab software. Previous research suggests that Biopac handgrip dynamometers are highly reliable and valid for estimating grip force (Wiles, Boyson, Balmer & Bird, 2001). The Biopac dynamometer allows for kilograms of force to be digitally recorded in real-time for the duration of a grip task (Park, Baek, Kim, Park, & Kang, 2017). Guidelines for measuring HGS informed our procedures (Roberts et al., 2011). Specifically, participants were comfortably seated in a chair with forearms in a 90-degree resting position, wrist neutral, and hand slightly over the arm of the chair with thumbs facing upwards. The researcher explained and demonstrated all HGS protocols before participants completed a practice trial. Standardized verbal encouragement was provided for all participants. Block randomization was used to determine hand start. Participants performed two trials on both hands for each task at a sampling rate of 50 hz with a minimum of 60-seconds rest.

For maximal HGS, participants were seated in a chair with their elbow rested at 90-degrees. The researcher advised the participant to squeeze the dynamometer as hard as possible, exhaling while squeezing before releasing the muscle contraction. The greatest recorded HGS value on either hand was used for analysis. Next, the rate of HGS force development was calculated by instructing the participant to squeeze the dynamometer as fast as possible, and delta t was determined from rest to the single highest-performing measure (D'Emanuele et al., 2021). The highest-performing continuous score was included for the purposes of the analysis with one-minute of rest between trials.

Thirdly, the HGS fatigability was measured by having participants squeeze the dynamometer at maximal effort for as long as possible or until they could no longer maintain 75% of their maximal effort (De Dobbeleer et al., 2017). A corresponding grip force curve was generated from the collected data. Fatigability was then calculated from the fatigability index equation, which utilizes the area under the curve (kg/s), peak force (kg), and duration of contraction (sec). The equation being used is fatigue index = {1- [area / (peak force * duration)]} * 100.

Thereafter, isometric control was measured by having the participant squeeze the dynameter at 25% of their maximal value determined by their maximal hand grip for each hand for a total of 10-seconds with a force tracing visible to participants. The coefficient of variation was determined over the middle eight-seconds using the best-performing submaximal HGS force control value for analysis. Lastly, the highest recorded HGS values on either hand were used to calculate the HGS asymmetry ratio (non-dominate HGS (kilograms)/dominant HGS (kilograms)). Since asymmetry ratios could be <1.0, any asymmetry ratios <1.0 were inversed to make all ratios ≥1.0 to improve interpretability (Mahoney et al., 2020).

The 6-Minute Push Test (6MPT) was conducted on a course consisting of a 30-m loop marked by two cones 15-m apart with 30 in. wide lanes marked between the cones on either side to ensure between-subject reliability. The 6MPT was modeled after the 6-Minute Walk Test (6MWT), therefore, American Thoracic Society (ATS) administration instructions and guidelines for the 6MWT were followed, including the standard patient instruction script (ATS, 2002). A Quickie 2 manual wheelchair donated from Bay Cliff Health Camp was used to conduct the propulsion test. Once in the wheelchair, participants were given five-minutes to become acclimated to wheelchair propulsion and the mechanics of making turns. After the acclimation period, participants rested for an additional five-minutes; once they returned to a near resting state, they were instructed to position themselves at the designated starting position on the test course. Once at the starting position, a pretest script was used to instruct the participant to propel as far as possible within the six-minute time frame at a comfortable pace as if they were pushing around the grocery store (Cowan, Callahan & Nash, 2012). Participants were also advised that they may slow down or stop at any point during the test but time would not stop until the test was completed or the participant requested to end the test. A stopwatch began the moment the participant began propulsion, and the participants were instructed to stop where they were as soon as the stopwatch reached six-minutes. Total distance was measured by counting the number of laps completed and the distance from the end cone to the stopping point.

Statistical Analysis

SPSS Software version 28.0 (IBM; Armonk, NY) was used for the analyses. Descriptive statistics were reported as mean ± standard deviation for continuous variables. Data was visually inspected for outliers and to determine whether parametric assumptions are met using histograms and scatter plots. To accomplish Purpose 1, individual Pearson correlation analyses were used to measure the associations between maximal HGS, rate of handgrip force development, handgrip fatigability, handgrip isometric control, handgrip asymmetry, and six-minute wheelchair propulsion distance. To complete Purpose 2, Pearson correlation analyses were used to evaluate the concurrent validity between maximal HGS and 1) rate of handgrip force development and 2)

HGS handgrip fatigability. The strength of the associations was interpreted as: <0.10 is negligible, 0.10-0.39 is weak, 0.40-0.69 is moderate, and ≥ 0.70 is strong (Schober & Schwarte, 2018).

Chapter Four: Results

The descriptive statistics of the participants are shown in Table 1. In general males (n=14) ranked in the good category for maximal HGS (95-103kg) and outperformed females (n=20; M=50.78±7.75 kg; 35.61±4.56 kg), who ranked in the very good category for their age group. Males also had higher average values than females in handgrip rate of force development (0.139±0.041 sec; 0.141±0.034 sec), handgrip isometric control (2.12±1.01%; 2.52±1.32%), and hand grip asymmetry (1.08±0.061; 1.11±0.094), while females outperformed males in fatiguability (21.98±9.08%; 23.00±11.78%) and 6MPT distance (1129.70±86.05 ft; 1087.84± 99.54 ft).In general individuals that were left hand dominant (n=5) performed better for maximal HGS (48.19±12.87 kg; 40.76±8.81 kg), handgrip rate of force development (0.135±0.037 sec; 0.141±0.037 sec), handgrip fatiguability (17.74±1.86%; 23.20±10.76%) and handgrip asymmetry (1.05±0.037; 1.11±0.085) while right handed (n=29) individuals recorded more favorable outcomes for handgrip isometric control (2.33±1.17%; 2.49±1.54%) and 6MPT distance (1120.05±94.12 ft; 1064.98±76.36 ft).

There were weak to near moderate negative associations between maximal HGS, rate of force development, fatigue, isometric control, and asymmetry (Purpose 1) shown in Table 2. The association between fatiguability and the 6MPT was the only relationship shown to be significant. Weak associations were found between the additional measures of grip strength assessing muscle function and maximal HGS, although insignificant. Concurrent validity of the additional measures of grip strength cannot be determined due to the statistical findings. All validity data is shown in Table 2.

Table 1. Participant Descriptive Statistics.

	n=34
Participant Age (years)	20-34
Height (centimeters)	173.23±8.28
Weight (kilograms)	76.11±12.62
Right Hand Dominant	n=29
Left Hand Dominant	n=5
Male	n=14
Female	n=20
Weekly MVPA (min)	685.19±655.19*
Maximal Handgrip Strength (kilograms)	41.85±9.65
Handgrip Rate of Force Development (seconds)	0.140±0.037
Handgrip Fatiguability (%)	22.40±10.12
Handgrip Isometric Control (% variation)	2.35±1.20
Handgrip Asymmetry (OR)	1.10±0.08

*n=33, one outlier removed

Table 2. Results for Correlation of all Measures of Handgrip Strength on 6-Minute Push Test (6MPT) Performance and Concurrent Validity of the Additional Measures of Grip Strength.

Outcome Measure	6MPT	95% CI	Maximal Handgrip Strength	95% CI
Maximal Handgrip Strength	r=-0.14; p=0.42	-0.458 – 0.206	r=1.00	
Handgrip Rate of Force Development	r=-0.10; p=0.58	-0.422 – 0.249	r=-0.12; p=0.49	-0.442 – 0.226
Handgrip Fatiguability	r=-0.35; p=0.05*	-0.612 – 0.008	r=-0.28; p=0.10	-0.568 – 0.060
Handgrip Isometric Control	r=-0.19; p=0.27	-0.500 – 0.154	r=-0.24; p=0.18	-0.531 – 0.112
Handgrip Asymmetry	r=0.20; p=0.27	-0.155 – 0.499	r=-0.32; p=0.06	-0.597 – 0.015

* denotes significance

Chapter Five: Discussion

The purpose of this study was to determine the correlations between maximal handgrip strength, handgrip rate of force development, handgrip fatigability, handgrip isometric control, and handgrip asymmetry to a 6MPT test in ambulatory young adults using wheelchairs. We hypothesized that increased maximal HGS, handgrip rate of force development, handgrip fatigability, handgrip isometric control, and no handgrip asymmetry will be valid predictors for assessing functional capacity measured via the 6MPT. Handgrip fatiguability and aerobic capacity as measured by the 6MPT were negatively associated with one another, and this association was of weak approaching moderate strength. Although there were no statistically significant correlations between the other measures of handgrip strength (i.e., rate of force development, fatigue, isometric control, and asymmetry) and the 6MPT, there is some evidence suggesting weak association between measures of handgrip assessing muscle function and estimated aerobic capacity in manual wheelchair users. The secondary purpose was to evaluate the construct validity of the additional measures of handgrip to maximal HGS. We hypothesized that that there would be a positive correlation between handgrip rate of force development, handgrip isometric control, and handgrip asymmetry on maximal handgrip strength, as well as a negative correlation between handgrip fatiguability and maximal grip strength. No statistically significant differences were found when comparing the four additional measures to maximal grip strength. However, there is some evidence of weak negative relationships between all additional measures and maximal HGS. When considering these findings, handgrip fatiguability may be a useful estimate of aerobic capacity in clinical populations. While clinicians should continue to use gold standard methods such as laboratory procedures utilizing metabolic data, or field tests such as the validated 6MPT when assessing aerobic capacity in manual wheelchair users whenever possible, the findings of this study suggests, handgrip fatiguability may have utility.

We found a negative weak association between maximal HGS and the outcome of the 6MPT distance which is used to estimate aerobic capacity. Although there is a lack of evidence existing that shows the relationship between measures of handgrip measured with electronic handgrip dynamometry on aerobic capacity, there are proposed mechanisms as to why HGS and aerobic exercise may be associated. It has been stated that aerobic exercise induces mitochondrial adaptations and elicits changes in different growth factor levels in skeletal muscle tissue leading to positive protein turnover balance and improves muscular strength and hypertrophy (Seong et al., 2020; Sung et al., 2022). The mechanisms of strength gains from aerobic activity can be supported from the findings in a study by Crane and colleagues (2012) aiming to observe the effects of long-term aerobic exercise on muscle strength in sedentary and highly aerobically active ambulatory men and women. It was found that the active subjects had higher relative grip strength compared to those in the sedentary group. These findings were thought to be derived from greater upper limb habitual activity similarly seen in high mechanical loads on the upper extremity during wheelchair propulsion (van der Woude, Veeger, Dallmeijer, Janssen, & Rozendaal, 2001). Similarly, in a study aiming to evaluate the effects of maximum aerobic capacity and ratings of perceived exertion on muscular strength via handgrip and endurance in 83 male students and office workers, a strong significant relationship ($r = 0.871$, $p \leq 0.001$) between HGS and VO_2 max as well as a near moderate relationship ($r = 0.399$, $p \leq 0.001$) between HGS endurance and VO_2 max were found (Ordudari & Habibi, 2019). Ordudari and Habibi's finds show much stronger associations than those reported in our study but they help to demonstrate the relationship between maximal HGS and aerobic capacity.

In parallel to our results that show associations between handgrip rate of force development and isometric control, r=-0.12; p=0.49; r=-0.24; p=0.18 respectively, with maximal HGS respectively, Klawitter and colleagues (2020) found positive moderate and negative moderate relationships between handgrip rate of force development ($r = 0.63$, $p < 0.05$), and handgrip submaximal force control ($r = -0.46$, $p < 0.05$), to handgrip maximal strength respectively. The associations found in Klawitter and colleagues pilot utilizing the same methods with electronic handgrip dynamometry examining the aspects of muscle function in master's age endurance athletes were strong than those found in our study but help to further strengthen the evidence of a relationship between additional measures of handgrip strength to assess muscle strength and function as well as the validity of utilizing electronic handgrip dynamometry.

With the evidence of a relationship between the additional measures of HGS measuring muscle strength and function, this information may have clinical significance in the manual wheelchair population. Rate of force development can be considered as an important factor for the performance of motor tasks and activities of daily living. Rodrìguez-Rosell and colleagues (2018) stated that the rate of force development following the onset of a muscle contraction and evaluated at different time intervals (0-300 ms) can provide insight into the physical conditions of individuals such as the influence of neural and intrinsic contractile properties on rate of force development changes. For example, the early phase of rate of force development (<100 ms) has been shown to be mainly influenced by neural drive and intrinsic muscle properties, whereas the rate of force development after 100 ms may be more related to adaptive mechanisms promoting increases in maximal muscle strength (Rodríguez-Rosell et al., 2018). This knowledge is important for subpopulations that use manual wheelchairs including individuals with MS, which leads to neurodegeneration and loss of motor control (Dobson & Giovannoni, 2019). In addition, Uyguar and colleagues investigated handgrip rate of force development and relaxation scaling factors in 12 individuals with MS and twelve controls to determine if upper extremity motor impairments could be detected. They found that handgrip rate of force development was reduced in those with MS, indicating a reduced ability to produce high handgrip rate of force development over submaximal ranges. A reduced ability to produce high handgrip rate of force development is thought to be due to central neuromuscular systems rather than peripheral, which include muscle fiber type. With this knowledge, we can now possibly use handgrip rate of force develop to assess the disease progression in those with MS.

Although not statistically significant, we found there was evidence supporting a weak association between handgrip asymmetry and maximal HGS, which is also clinically relevant to wheelchair users. Individuals with handgrip asymmetry alone have been shown to have 9% greater odds for future accumulating morbidities and when asymmetry is also combined with weakness the odds of future accumulating morbidities increases to 46% (Klawitter et al., 2022). Researchers suggest the combination of asymmetry assessments with strength assessments may help to improve the concurrent validity of handgrip dynamometry as a screening tool for chronic diseases related to poor muscle function as well as aid in the prediction of morbidity status (Klawitter et al., 2022). Handgrip asymmetry has also been shown to be associated with functional disability in aging Americans. A study utilizing data of over 18,000 Americans aged ≥50 years from 2006-2016 found increased odds for future ADL disability to be 11% in individuals with any handgrip asymmetry alone and 81% for both handgrip asymmetry and weakness (McGrath et al., 2021). Knowing the risk of functional disability is important as impairments to both instrumental and basic activities of daily living are shown to be highly associated with negative health outcomes including premature mortality and chronic morbidity

(Dunlay et al., 2015; Hennessy et al., 2015). It is especially important to assess manual wheelchair users as individuals in this population report approximately nine ADL-IADL limitations, which impacts their ability to live independently and is higher than that of individuals who use walkers (8), crutches (6), or canes (5.5) (Allen, Resnik, & Roy, 2006).

Limitations

This study had some limitations with the first being that participants were not manual wheelchair users. Therefore, our findings may not be generalizable to manual wheelchair users as a whole. Additionally, a pacing strategy is often required to perform well during the 6MPT and we observed that several participants struggled with maintaining the same pace throughout the test. Also, one wheelchair was used for all participants and may not have been the appropriate size for some of the larger participants which made regulating tire pressure difficult. Finally, we had a limited sample size which may have lead to statistically insignificant findings

Future Applications

Future research should utilize individuals who are manual wheelchair users now that there appears to be evidence of an initial relationship between additional measure of HGS and aerobic capacity. The relationships shown between the additional measures of HGS and maximal HGS indicate the need for more research to further validate electronic handgrip dynamometry as a tool to measure muscle function.

Conclusion

We found that handgrip fatiguability has a negative association of weak, approaching strength with aerobic capacity, as estimated by the 6MPT. Additionally, we found there is evidence of associations between all additional measures of handgrip and maximal handgrip strength. The findings of this thesis study may be useful for informing clinicians to implement electronic handgrip dynamometry measurements to not only assess muscle function in manual wheelchair users, but also aerobic capacity. Handgrip rate of force development and asymmetry are variables that show promise for assessing muscle function and predicting functional limitations in manual wheelchair user's population.

REFERENCES

Allen, S., Resnik, L., & Roy, J. (2006). Promoting Independence for Wheelchair Users: The Role of home accommodations. *The Gerontologist*, *46*(1), 115–123. https://doi.org/10.1093/geront/46.1.115

American College of Sports Medicine., Ehrman, J. K., Liguori, G., Magal, M., & Riebe, D. (2018). *ACSM's guidelines for exercise testing and prescription* (Tenth edition.). Wolters Kluwer.

Anseeuw, K. (2007). A report: The definition and classification of cerebral palsy April 2006. *Developmental Medicine Child Neurology, 49*, 8–14. https://doi.org/10.1111/J.1469-8749.2007.TB12610.X

ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories (2002). ATS statement: guidelines for the six-minute walk test. *American journal of respiratory and critical care medicine*, 166(1), 111–117. https://doi.org/10.1164/ajrccm.166.1.at1102

Barrett, R. S., & Lichtwark, G. A. (2010). Gross muscle morphology and structure in spastic cerebral palsy: A systematic review. *Developmental Medicine & Child Neurology*, *52*(9), 794–804. https://doi.org/10.1111/j.1469-8749.2010.03686.x

Bass, A., Brosseau, R., Décary, S., Gauthier, C., & Gagnon, D. H. (2020). Comparison of the 6-min propulsion and arm crank ergometer tests to assess aerobic fitness in manual wheelchair users with a spinal cord injury. *American Journal of Physical Medicine & Rehabilitation*, *99*(12), 1099–1108. https://doi.org/10.1097/PHM.0000000000001534

Bauman, W. A., Spungen, A. M., Zhong, Y.-G., Rothstein, J. L., Petry, C., & Gordon, S. K. (1992). Depressed serum high density lipoprotein cholesterol levels in veterans with spinal cord injury. *Spinal Cord*, *30*(10), Article 10. https://doi.org/10.1038/sc.1992.136

Beaudart, C., Rolland, Y., Cruz-Jentoft, A. J., Bauer, J. M., Sieber, C., Cooper, C., Al-Daghri, N., Araujo de Carvalho, I., Bautmans, I., Bernabei, R., Bruyère, O., Cesari, M., Cherubini, A., Dawson-Hughes, B., Kanis, J. A., Kaufman, J.-M., Landi, F., Maggi, S., McCloskey, E., Petermans, J., Rodrigues Mañas, L., Reginster, J-Y., Roller-Wirnsberger, R., Schaap, L.A., Uebelhart, D., Rizzoli, R., Fielding, R. A. (2019). Assessment of muscle function and physical performance in daily clinical practice. *Calcified Tissue International*, *105*(1), 1–14. https://doi.org/10.1007/s00223-019-00545-w

Bohannon, R. W., Peolsson, A., Massy-Westropp, N., Desrosiers, J., & Bear-Lehman, J. (2006). Reference values for adult grip strength measured with a Jamar dynamometer: A descriptive meta-analysis. *Physiotherapy*, *92*(1), 11–15. https://doi.org/10.1016/j.physio.2005.05.003

Chen, Y., Tang, Y., Vogel, L., & DeVivo, M. (2013). Causes of spinal cord injury. *Topics in Spinal Cord Injury Rehabilitation*, *19*(1), 1–8. https://doi.org/10.1310/sci1901-1

Cowan, R. E., Callahan, M. K., & Nash, M. S. (2012). The 6-min push test is reliable and predicts low fitness in spinal cord injury. *Medicine & Science in Sports & Exercise*, 44(10), 1993–2000. https://doi.org/10.1249/MSS.0b013e31825cb3b6

Crane, J. D., MacNeil, L. G., & Tarnopolsky, M. A. (2013). Long-term aerobic exercise is associated with greater muscle strength throughout the life span. *The Journals of Gerontology: Series A*, *68*(6), 631–638. https://doi.org/10.1093/gerona/gls237

Cruz-Jentoft, A. J., & Sayer, A. A. (2019). Sarcopenia. *The Lancet*, *393*(10191), 2636–2646. https://doi.org/10.1016/S0140-6736(19)31138-9

D'Emanuele, S., Maffiuletti, N. A., Tarperi, C., Rainoldi, A., Schena, F., & Boccia, G. (2021). Rate of force development as an indicator of neuromuscular fatigue: A scoping review. *Frontiers in Human Neuroscience*, 15, 1–11. https://doi.org/10.3389/fnhum.2021.701916

De Dobbeleer, L., Beyer, I., Njemini, R., Pleck, S., Zonnekein, N., Mets, T., & Bautmans, I. (2017). Force-time characteristics during sustained maximal handgrip effort according to age and clinical condition. *Experimental Gerontology*, 98, 192–198. https://doi.org/10.1016/j.exger.2017.08.033

de Groot, S., Dallmeijer, A. J., Post, M. W. M., Angenot, E. L. D., & van der Woude, L. H. V. (2008). The longitudinal relationship between lipid profile and physical capacity in persons with a recent spinal cord injury. *Spinal Cord*, *46*(5), Article 5. https://doi.org/10.1038/sj.sc.3102147

Demirel, Ş., Demirel, G., Tükek, T., Erk, O., & Yilmaz, H. (2001). Risk factors for coronary heart disease in patients with spinal cord injury in Turkey. *Spinal Cord*, *39*(3), Article 3. https://doi.org/10.1038/sj.sc.3101135

Depp, C. A., & Jeste, D. V. (2006). Definitions and predictors of successful aging: A comprehensive review of larger quantitative studies. *The American Journal of Geriatric Psychiatry*, *14*(1), 6–20. https://doi.org/10.1097/01.JGP.0000192501.03069.bc

Dobson, R., & Giovannoni, G. (2019). Multiple sclerosis – a review. *European Journal of Neurology*, *26*(1), 27–40. https://doi.org/10.1111/ene.13819

Dufner, T. J., Fitzgerald, J. S., Lang, J. J., & Tomkinson, G. R. (2020). Temporal trends in the handgrip strength of 2,592,714 adults from 14 countries between 1960 and 2017: A systematic analysis. *Sports Medicine*, *50*(12), 2175–2191. https://doi.org/10.1007/s40279-020-01339-z

Dunlay, S. M., Manemann, S. M., Chamberlain, A. M., Cheville, A. L., Jiang, R., Weston, S. A., & Roger, V. L. (2015). Activities of daily living and outcomes in heart failure. *Circulation: Heart Failure*, *8*(2), 261–267. https://doi.org/10.1161/CIRCHEARTFAILURE.114.001542

Ellapen, T. J., Hammill, H. V., Swanepoel, M., & Strydom, G. L. (2017). The health benefits and constraints of exercise therapy for wheelchair users: A clinical commentary. *African Journal of Disability*, *6*. https://www.proquest.com/docview/1938730471/abstract/42315D66A5B94503PQ/1

Franklin, B. A., Swantek, K., Grais, S., Johnstone, K., Gordon, S., & Timmis, G. (1990). Field test estimation of maximal oxygen consumption in wheelchair users. *Archives of Physical Medicine and Rehabilitation*, *71*(8), 574–578.

Gopinath, B., Kifley, A., Liew, G., & Mitchell, P. (2017). Handgrip strength and its association with functional independence, depressive symptoms and quality of life in older adults. *Maturitas*, *106*, 92–94. https://doi.org/10.1016/j.maturitas.2017.09.009

Healthy People 2010 (Understanding and Improving Health). (2000). *Healthy people 2010* (Vol. 2). US Department of Health and Human Services.

Hennessy, S., Kurichi, J. E., Pan, Q., Streim, J. E., Bogner, H. R., Xie, D., & Stineman, M. G. (2015). Disability stage is an independent risk factor for mortality in medicare beneficiaries aged 65 years and older. *PM&R*, *7*(12), 1215–1225. https://doi.org/10.1016/j.pmrj.2015.05.014

HHS. (2018). Physical activity guidelines for Americans 2nd edition.

Hoffman, C., Rice, D., & Sung, H. Y. (1996). Persons with chronic conditions. Their prevalence and costs. *JAMA*, *276*(18), 1473–1479.

IBM Corp. Released 2021. IBM SPSS statistics for windows, version 28.0. Armonk, NY: *IBM Corp*

Janssen, T. W. J., Van Oers, C. a. J. M., Van Der Woude, L. H. V., & Hollander, A. P. (1994). Physical strain in daily life of wheelchair users with spinal cord injuries. *Medicine & Science in Sports & Exercise*, *26*(6), 661–670.

Janssen, T. W. J., Van Oers, C. a. J. M., Veeger, H. E. J., Hollander, A. P., van der Woude, L. H. V., & Rozendal, R. H. (1994). Relationship between physical strain during standardized ADL tasks and physical capacity in men with spinal cord injuries. *Spinal Cord*, *32*(12), Article 12. https://doi.org/10.1038/sc.1994.131

Joseph, C., D'Souza, C., Paquet, V., & Feathers, D. (2010, July 1). Comparison of hand grip strength between wheeled mobility device users and non-disabled adults. https://doi.org/10.1201/EBK1439835012-71

Kasper, J. D., Chan, K. S., & Freedman, V. A. (2017). Measuring physical capacity: An assessment of a composite measure using self-report and performance-based items. *Journal of Aging and Health*, *29*(2), 289–309. https://doi.org/10.1177/0898264316635566

Katch, V. L., Katch, F. I., & McArdle, W. D. (1996). Exercise physiology: study guide (No. Ed. 4). *Williams & Wilkins*.

Klawitter, L., Mahoney, S. J., Dahl, L., Hackney, K. J., Herrmann, S. D., Edwards, B., & McGrath, R. (2020). Evaluating additional aspects of muscle function with a digital handgrip dynamometer and accelerometer for cognitive functioning in older adults: A pilot study. *Journal of Alzheimer's Disease Reports*, *4*(1), 495–499. https://doi.org/10.3233/ADR-200225

Klawitter, L., Vincent, B. M., Choi, B.-J., Smith, J., Hammer, K. D., Jurivich, D. A., Dahl, L. J., & McGrath, R. (2022). Handgrip strength asymmetry and weakness are associated with future morbidity accumulation in Americans. *Journal of Strength and Conditioning Research*, *36*(1), 106–112. https://doi.org/10.1519/JSC.0000000000004166

Kobelt, G., Thompson, A., Berg, J., Gannedahl, M., Eriksson, J (2017). New insights into the burden and costs of multiple sclerosis in Europe. *Multiple Sclerosis Journal*, *23*(8), 1123–1136. https://doi.org/10.1177/1352458517694432

Krigger, K. W. (2006). Cerebral palsy: An overview. *Cerebral Palsy*, *73*(1), 10.

Kujala, U. M., Vaara, J. P., Kainulainen, H., Vasankari, T., Vaara, E., & Kyröläinen, H. (2019). Associations of aerobic fitness and maximal muscular strength with metabolites in young men. *JAMA Network Open*, *2*(8), e198265. https://doi.org/10.1001/jamanetworkopen.2019.8265

Léger, L. A., & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict VO2 max. *European Journal of Applied Physiology and Occupational Physiology*, *49*(1), 1–12. https://doi.org/10.1007/BF00428958

Liang, Y., Welmer, A.-K., Möller, J., & Qiu, C. (2017). Trends in disability of instrumental activities of daily living among older Chinese adults, 1997-2006: Population based study. *BMJ Open*, *7*(8), e016996. https://doi.org/10.1136/bmjopen-2017-016996

Macdonell, R., Nagels, G., Laplaud, D.-A., Pozzilli, C., de Jong, B., Martins da Silva, A., Nicholas, R., Lechner-Scott, J., Gaebler, J. A., Agarwal, S., Wang, P., Yeh, M., Hovenden, M., & Soelberg Sørensen, P. (2016). Improved patient-reported health impact of multiple sclerosis: The ENABLE study of PR-fampridine. *Multiple Sclerosis Journal*, *22*(7), 944–954. https://doi.org/10.1177/1352458515606809

Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force development: Physiological and methodological considerations. *European Journal of Applied Physiology*, *116*, 1091–1116. https://doi.org/10.1007/s00421-016-3346-6

Mahoney, S., Klawitter, L., Hackney, K. J., Dahl, L., Herrmann, S. D., Edwards, B., & McGrath, R. (2020). Examining additional aspects of muscle function with a digital handgrip dynamometer and accelerometer in older adults: A pilot study. *Geriatrics*, *5*(4), 86. https://doi.org/10.3390/geriatrics5040086

Maki, K. C., Briones, E. R., Langbein, W. E., Inman-Felton, A., Nemchausky, B., Welch, M., & Burton, J. (1995). Associations between serum lipids and indicators of adiposity in men with spinal cord injury. *Spinal Cord*, *33*(2), Article 2. https://doi.org/10.1038/sc.1995.24

Manini, T. M., & Clark, B. C. (2012). Dynapenia and aging: An update. *The Journals of Gerontology: Series A*, *67A*(1), 28–40. https://doi.org/10.1093/gerona/glr010

Martin, H. J., Yule, V., Syddall, H. E., Dennison, E. M., Cooper, C., & Aihie Sayer, A. (2006). Is hand-held dynamometry useful for the measurement of quadriceps strength in older people? A comparison with the gold standard Biodex dynamometry. *Gerontology*, *52*(3), 154–159. https://doi.org/10.1159/000091824

McDonald, J. W., & Sadowsky, C. (2002). Spinal-cord injury. *The Lancet*, *359*(9304), 417–425. https://doi.org/10.1016/S0140-6736(02)07603-1

McGrath, R. P., Clark, B. C., Erlandson, K. M., Herrmann, S. D., Vincent, B. M., Hall, O. T., & Hackney, K. J. (2019). Impairments in individual autonomous living tasks and time to self-care disability in middle-aged and older adults. *Journal of the American Medical Directors Association*, *20*(6), 730-735.e3. https://doi.org/10.1016/j.jamda.2018.10.014

McGrath, R., Johnson, N., Klawitter, L., Mahoney, S., Trautman, K., Carlson, C., Rockstad, E., & Hackney, K. J. (2020). What are the association patterns between handgrip strength and adverse health conditions? A topical review. *SAGE Open Medicine*, *8*, 2050312120910358. https://doi.org/10.1177/2050312120910358

McGrath, R., Vincent, B. M., Jurivich, D. A., Hackney, K. J., Tomkinson, G. R., Dahl, L. J., & Clark, B. C. (2021). Handgrip Strength Asymmetry and Weakness Together Are Associated With Functional Disability in Aging Americans. *The Journals of Gerontology: Series A*, *76*(2), 291–296. https://doi.org/10.1093/gerona/glaa100

Mlinac, M. E., & Feng, M. C. (2016). Assessment of activities of daily living, self-care, and independence. *Archives of Clinical Neuropsychology*, *31*(6), 506–516. https://doi.org/10.1093/arclin/acw049

Neto, F. R., Gomes Costa, R. R., Dorneles, J. R., Gonçalves, C. W., Veloso, J. H. C. L., & Carregaro, R. L. (2021). Handgrip strength cutoff points for functional independence and wheelchair ability in men with spinal cord injury. *Topics in Spinal Cord Injury Rehabilitation*, 27(3), 60–69. https://doi.org/10.46292/sci20-00040

Nooijen, C. F. J., de Groot, S., Postma, K., Bergen, M. P., Stam, H. J., Bussmann, J. B. J., & van den Berg-Emons, R. J. (2012). A more active lifestyle in persons with a recent spinal cord injury benefits physical fitness and health. *Spinal Cord*, *50*(4), 320–323. https://doi.org/10.1038/sc.2011.152

Ordudari, Z., & Habibi, E. (2019). The effects of maximum aerobic capacity and ratings of perceived exertion on muscular strength and endurance. *Iranian Journal of Health, Safety and Environment*, *6*(3), Article 3.

Park, H.-W., Baek, S., Kim, H. Y., Park, J.-G., & Kang, E. K. (2017). Reliability and validity of a new method for isometric back extensor strength evaluation using a hand-held dynamometer. *Annals of Rehabilitation Medicine Original Article Ann Rehabil Med*, 41(5), 793–800. https://doi.org/10.5535/arm.2017.41.5.793

Pashmdarfard, M., & Azad, A. (2020). Assessment tools to evaluate activities of daily living (ADL) and instrumental activities of daily living (IADL) in older adults: A systematic review. *Medical Journal of the Islamic Republic of Iran*, *34*, 33. https://doi.org/10.34171/mjiri.34.33

Pavela, G. (2015). Functional status and social contact among older adults. *Research on Aging*, *37*(8), 815–836. https://doi.org/10.1177/0164027514566091

Pinckard, K., Baskin, K. K., & Stanford, K. I. (2019). Effects of exercise to improve cardiovascular health. *Frontiers in Cardiovascular Medicine*, *6*, 69. https://doi.org/10.3389/fcvm.2019.00069

Roberts, H. C., Denison, H. J., Martin, H. J., Patel, H. P., Syddall, H., Cooper, C., & Sayer, A. A. (2011). A review of the measurement of grip strength in clinical and epidemiological studies: Towards a standardized approach. *Age and Ageing*, 40(4), 423–429. https://doi.org/10.1093/ageing/afr051

Rodríguez-Rosell, D., Pareja-Blanco, F., Aagaard, P., & González-Badillo, J. J. (2018). Physiological and methodological aspects of rate of force development assessment in human skeletal muscle. *Clinical Physiology and Functional Imaging*, *38*(5), 743–762. https://doi.org/10.1111/cpf.12495

Sallinen, J., Stenholm, S., Rantanen, T., Heliövaara, M., Sainio, P., & Koskinen, S. (2010). Hand-grip strength cut points to screen older persons at risk for mobility limitation. *Journal of the American Geriatrics Society*, *58*(9), 1721–1726. https://doi.org/10.1111/j.1532-5415.2010.03035.x

Schober, P., & Schwarte, L. A. (2018). Correlation coefficients: Appropriate use and interpretation. Anesthesia and Analgesia, 126(5), 1763–1768. https://doi.org/10.1213/ANE.0000000000002864

Seeman, T. E., Merkin, S. S., Crimmins, E. M., & Karlamangla, A. S. (2010). Disability trends among older Americans: National health and nutrition examination surveys, 1988–1994 and 1999–2004. *American Journal of Public Health*, *100*(1), 100–107. https://doi.org/10.2105/AJPH.2008.157388

Selph, S. S., Skelly, A. C., Wasson, N., Dettori, J. R., Brodt, E. D., Ensrud, E., Elliot, D., Dissinger, K. M., & McDonagh, M. (2021). Physical activity and the health of wheelchair users: A systematic review in multiple sclerosis, cerebral palsy, and spinal cord injury. *Archives of Physical Medicine and Rehabilitation*, *102*(12), 2464-2481.e33. https://doi.org/10.1016/j.apmr.2021.10.002

Seong, J. Y., Ahn, H. Y., Park, Y., Shin, S., & Ha, I.-H. (2020). Association between aerobic exercise and handgrip strength in adults: A cross-sectional study based on data from the Korean national health and nutrition examination survey (2014–2017). *The Journal of Nutrition, Health and Aging*, *24*(6), 619–626. https://doi.org/10.1007/s12603-020-1372-x

Shelkey, M., Wallace, M. (2001). Katz index of independence in activities of daily living. *Home Healthcare Nurse* 19(5):p 323-324.

Souza, A., Kelleher, A., Cooper, R., Cooper, R. A., Iezzoni, L. I., & Collins, D. M. (2010). Multiple sclerosis and mobility-related assistive technology: Systematic review of literature. *The Journal of Rehabilitation Research and Development*, *47*(3), 213. https://doi.org/10.1682/JRRD.2009.07.0096

Stevens, A. C., Carroll, D. D., Courtney-Long, E. A., Zhang, Q. C., Sloan, M. L., Griffin-Blake, S., & Peacock, G. (2016). Adults with one or more functional disabilities—United States, 2011–2014. *Morbidity and Mortality Weekly Report*, *65*(38), 1021–1025.

Storch, M.-J., König, D., Bültermann, D., Blum, A., Vogt, S., Baumstark, M., Berg, A., & Schmid, A. (2005). Lipid profile in spinal cord-injured women with different injury levels. *Preventive Medicine*, *40*(3), 321–325. https://doi.org/10.1016/j.ypmed.2004.06.006

Sung, J. H., Son, S. R., Baek, S.-H., & Kim, B.-J. (2022). The association of aerobic, resistance, and combined exercises with the handgrip strength of middle-aged and elderly Korean adults: A nationwide cross-sectional study. *BMC Geriatrics*, *22*, 676. https://doi.org/10.1186/s12877-022-03293-z

Uygur, M., de Freitas, P. B., & Barone, D. A. (2020). Rate of force development and relaxation scaling factors are highly sensitive to detect upper extremity motor impairments in multiple sclerosis. *Journal of the Neurological Sciences*, *408*, 116500. https://doi.org/10.1016/j.jns.2019.116500

van der Woude, L. H. V., Veeger, H. E. J., Dallmeijer, A. J., Janssen, T. W. J., & Rozendaal, L. A. (2001). Biomechanics and physiology in active manual wheelchair propulsion in adapted form, published as Woude et al. [1].1. *Medical Engineering & Physics*, *23*(10), 713–733. https://doi.org/10.1016/S1350-4533(01)00083-2

Vanlandewijck, Y. C., Van De Vliet, P., Verellen, J., & Theisen, D. (2006). Determinants of shuttle run performance in the prediction of peak VO2 in wheelchair users. *Disability and Rehabilitation*, *28*(20), 1259–1266. https://doi.org/10.1080/09638280600554769

Verschuren, O., & Takken, T. (2010). Aerobic capacity in children and adolescents with cerebral palsy. *Research in Developmental Disabilities*, *31*(6), 1352–1357. https://doi.org/10.1016/j.ridd.2010.07.005

Warburton, D. E. R., Jamnik, V. K., Bredin, S. S. D., Burr, J., Charlesworth, S., Chilibeck, P., Gledhill, N. (2011). Executive summary the 2011 physical activity readiness questionnaire for everyone (PAR--Q+) and the electronic physical activity readiness medical examination (ePARmed--X+). *Health & Fitness Journal of Canada*, 4(2), 24–25.

Warms, C. A., Whitney, J. D., & Belza, B. (2008). Measurement and description of physical activity in adult manual wheelchair users. *Disability and Health Journal*, *1*(4), 236–244. https://doi.org/10.1016/j.dhjo.2008.07.002

Yeung, S. S. Y., Reijnierse, E. M., Trappenburg, M. C., Hogrel, J.-Y., McPhee, J. S., Piasecki, M., Sipila, S., Salpakoski, A., Butler-Browne, G., Pääsuke, M., Gapeyeva, H., Narici, M. V., Meskers, C. G. M., & Maier, A. B. (2018). Handgrip strength cannot be assumed a proxy for overall muscle strength. *Journal of the American Medical Directors Association*, *19*(8), 703–709. https://doi.org/10.1016/j.jamda.2018.04.019

APPENDIX A

Informed Consent

Northern Michigan University
School of Health and Human Performance
PROJECT TITLE: Using Additional Measures of Handgrip Strength to Predict Aerobic Capacity in Wheelchair Users
IRB Approval Number: HS23-1374
Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study:

The purpose of this study is to determine the correlation between five different measures of handgrip strength and the distance covered in a standardized wheelchair propulsion test with the aim of using various measures of handgrip strength as an estimator of aerobic capacity.

It is important to understand the aerobic capacity of wheelchair users as it is a major component of physical capacity, the ability to carry out activities in areas such as balance, range of motion, stamina, and strength with decreased levels of physical capacity being associated with limitations to activities of daily living and negative health outcomes such as the increased risk of cardiovascular disease. The proposed utility of handgrip strength to predict aerobic capacity is clinically significant as it is non-fatiguing and is shown as a valid predictor of total muscle function.

What you will be asked to do in the study:

- Record five measures of handgrip strength including maximal handgrip strength, isometric control, handgrip fatiguability, rate of force development, and handgrip strength asymmetry.
- Perform a six-minute wheelchair propulsion test which involves propelling a wheelchair at a moderate as far as you can in six minutes.

Time required:

Up to one-hour

Risks and Benefits:

Risks to this study are minimal. Risks to this study may involve muscle soreness associated with the physical activities.

The benefits of this study could be a better understanding of the correlation between multiple measures of handgrip strength and the distance covered in a wheelchair propulsion test to develop a non-fatiguing test to estimate aerobic capacity in clinical populations

Incentive or Compensation:

Participants in this study may be eligible for compensation of $10 at successful completion of visit.

Confidentiality:

Your identity will be kept confidential to the extent provided by law. Your information will be de-identified by an assigned code number. Your name will not be used in any report or publication.

Voluntary participation:

Your participation in this study is completely voluntary. You have the right to withdraw from the study at any time without consequence or penalty.

Whom to contact if you have questions about the study:

If you have any further questions regarding your rights as a participant in a research project you may contact Dr. Lisa Schade Eckert of the Human Subjects Research Review Committee of Northern Michigan University (906-227-2300) leckert@nmu.edu. Any questions you have regarding the nature of this research project will be answered by the principal researcher who can be contacted as follows: Dr. Lukus Klawitter lklawitt@nmu.edu.

Agreement:

If you wish to participate in this study, please sign the form below. A signature will indicate agreement to participate.

Participant's Name: (Print) ____

Signature_____________________________________(Date) __________________

APPENDIX B

PAR-Q+

2020 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	**YES**	**NO**
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://apps.who.int/iris/handle/10665/44399).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION
If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______________________ DATE ______________

SIGNATURE ______________________ WITNESS ______________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

2020 PAR-Q+

6.	**Do you have any Mental Health Problems or Learning Difficulties?** This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7	
6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	**YES** ☐ **NO** ☐
7.	**Do you have a Respiratory Disease?** This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8	
7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	**YES** ☐ **NO** ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	**YES** ☐ **NO** ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	**YES** ☐ **NO** ☐
8.	**Do you have a Spinal Cord Injury?** This includes Tetraplegia and Paraplegia If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9	
8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	**YES** ☐ **NO** ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	**YES** ☐ **NO** ☐
9.	**Have you had a Stroke?** This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10	
9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
9b.	Do you have any impairment in walking or mobility?	**YES** ☐ **NO** ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	**YES** ☐ **NO** ☐
10.	**Do you have any other medical condition not listed above or do you have two or more medical conditions?** If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations	
10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	**YES** ☐ **NO** ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	**YES** ☐ **NO** ☐
10c.	Do you currently live with two or more medical conditions?	**YES** ☐ **NO** ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ____________________

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

2020 PAR-Q+

If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:
You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______________________________ DATE ______________________________

SIGNATURE ______________________________ WITNESS ______________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

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Key References

1. Jamnik VK, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.
3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

APPENDIX C

International Physical Activity Questionnaire – Short Form

Evaluation Measures

YOUTHREX
Research & Evaluation eXchange

International Physical Activity Questionnaire - Short Form

OVERVIEW

- This measure assesses the types of intensity of physical activity and sitting time that people do as part of their daily lives are considered to estimate total physical activity in MET-min/week and time spent sitting.

SUBSCALES

- None
- Sample items from the scale:

» During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?

STEPPING UP THEME(S) & OUTCOME(S)

- Health & Wellness

» Youth are physically healthy

TARGET POPULATION

- Youth 15 years of age and older

LENGTH & HOW IT IS MEASURED

- 7 items
- Open-ended questions surrounding individuals' last 7-day recall of physical activity
- Self-report, paper-pencil version or orally
- Available in: English and many other languages

DEVELOPER

- International Physical Activity Questionnaire, 1998

GOOD TO KNOW

- Used by the Ontario Trillium Foundation

- Click here for Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ) - Short Form

PSYCHOMETRICS

- Reliability

Test-rest reliability indicated good stability High reliability (α <.80)

- Validity

Predictive validity Concurrent validity Convergent validity Criterion validity Discriminant validity

LEARN MORE

- International Physical Activity Questionnaire. (2016). Home. Retrieved from https://sites.google.com/site/theipaq/

- C.L. Craig, A. Marshall, M. Sjostrom, A. Bauman, M. Booth, B. Ainsworth, *et al*. International Physical Activity Questionnaire: 12-country reliability and validity. Med Sci Sports Exerc, 35 (2003), pp. 1381–1395

- Lee, P.H., Macfarlane, D.J., Lam, T.H., Stewart, S.M. (2011). *Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review*. International Journal of Behavioral Nutrition and Physical Activity. 8:115.

- van Poppel MNM, Chinapaw MJM, Mokkink LB, van Mechelen W, Terwee CB: Physical activity questionnaires for adults: A systematic review of measurement properties. Sports Medicine. 2010, 40: 565-600. 10.2165/11531930-000000000-00000.

(August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ
The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ
Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation
Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ
International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information
More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

________________ **days per week**

☐ No vigorous physical activities ➡ ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

________________ **hours per day**

________________ **minutes per day**

Don't know/Not sure ☐

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

________________ **days per week**

☐ No moderate physical activities ➡ ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

________________ **hours per day**

________________ **minutes per day**

Don't know/Not sure ☐

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

________________ **days per week**

No walking ☐ → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

________________ **hours per day**

________________ **minutes per day**

Don't know/Not sure ☐

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

________________ **hours per day**

________________ **minutes per day**

Don't know/Not sure ☐

This is the end of the questionnaire, thank you for participating.

Appendix D

IRB Approval Form

Graduate Studies and Research
Marquette, MI 49855-5301
906-227-2300
www.nmu.edu/graduatestudies/

MEMORANDUM

TO: Lukus Klawitter
Eric Naugle
Megan Nelson
School of Health and Human

Performance Kira Smith

DATE: September 7, 2023

FROM: Lisa Schade Eckert

Dean of Graduate Studies and Research

RE: Modification to HS23-1374
Original IRB Approval Date: 3/32/2023
Modification Approval Date: 9/7/2023
"Using Additional Measures of Handgrip Strength to Predict Aerobic Capacity in Wheelchair Users"

Your modification for the project “Using Additional Measures of Handgrip Strength to Predict Aerobic Capacity in Wheelchair Users” has been approved by the Northern Michigan University Institutional Review Board. Please include your proposal number (HS23-1374) on all research materials and on any correspondence regarding this project.

Any additional personnel changes or revisions to your approved research plan must be approved by the IRB prior to implementation. Unless specified otherwise, all previous requirements included in your original approval notice remain in effect.

If you have any questions, please contact the IRB at hsrr@nmu.edu.