RELATIONSHIPS BETWEEN ELECTRONIC HANDGRIP DYNAMOMETER DERIVED MUSCLE FUNCTION AND PURDUE PEGBOARD PERFORMANCE

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Purpose: To examine the relationships of electronic handgrip dynamometer and accelerometer derived maximal handgrip strength (HGS), sub-maximal control, and neuromuscular steadiness on Purdue Pegboard Test (PPT) performance in older adults.

Methods: The analytic sample included 30 generally healthy community-dwelling older adults (age: 72.4±5.3 years). An electronic handgrip dynamometer was used to collect the grip tasks. Standard protocols were used for the PPT.

Results: Right HGS was weakly, negatively, and insignificantly correlated with PPT performance ($r=-0.20$; $p=0.28$), while left HGS was negligibly correlated with PPT performance ($r=0.02$; $p=0.28$). Sub-maximal control showed a downward, but insignificant weak trend with PPT performance on the right ($r=-0.22$; $p=0.09$) and left hands ($r=-0.30$; $p=0.09$). Further, neuromuscular steadiness was negligibly correlated with PPT performance on the right ($r=-0.01$; $p=0.94$) and left hands ($r=0.14$; $p=0.43$).

Conclusions: Our findings suggest that a signal may exist between sub-maximal control and PPT performance.

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DEDICATION

My master's thesis is dedicated to my angel, Grandma Ruth. You are my sunshine.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

ADL ....Activity of Daily Living

BMI ....Body Mass Index

CI..Confidence Interval

CTS ....Carpal Tunnel Syndrome

HJT..Horizontal Jump Test

HGS..Handgrip Strength

MS...Multiple Sclerosis

OT ....Occupational Therapy

PD ....Parkinson’s Disease

PPT ....Purdue Pegboard Test

VJT..Vertical Jump Test

LIST OF SYMBOLS

† ....Corresponds with the hand in which the grip task was performed.

LIST OF APPENDIX TABLES

CHAPTER 1: INTRODUCTION

Handgrip strength (HGS) is a long-standing measure of overall muscle strength and function that is used in clinical and research settings (Mahoney et al., 2015). Hydraulic and spring-type handgrip dynamometers are often used for measuring HGS. During HGS measurements, persons squeeze the dynamometer with maximal effort, exhaling while squeezing, and then release the muscle contractions. Interviewers record the single highest HGS value from the 2-3 trials collected on each hand as maximal strength. As such, HGS is a convenient assessment of muscle function that is generally inclusive of wide-ranging ages and abilities (McGrath et al., 2021).

Measures of HGS are reflective of how overall muscle strength changes during aging (Ij, 2020). For example, lifespan HGS percentiles parallel how muscle strength peaks at about 30-years and declines starting at about middle-age (Okabe et al., 2021). Low HGS is also an indicator of muscle weakness, whereby HGS is below a pre-specified cut-point. Weakness is associated with several health conditions such as functional disability, cognitive impairment, and chronic cardiometabolic morbidities (McGrath et al., 2019). Therefore, HGS has robust predictive utility for health conditions related to muscle dysfunction.

Although HGS is used in clinical and research settings for examining how muscle dysfunction is linked to health, the prognostic value of HGS is limited (Martin et al., 2015). For example, given that low HGS is associated with several different types of health conditions, healthcare providers may experience challenges explaining how low HGS is a risk factor, and how referral to intervention can demonstrate efficacy. Moreover, HGS is only directly examining strength capacity, and maximal strength is being generalized to overall muscle function (McGrath, et al., 2020). Other important attributes of muscle function such as strength symmetry, sub-maximal force control, bilateral coordination, and neuromuscular steadiness are not examined (McGrath et al., 2021). Thus, more thoroughly evaluating muscle function by including more characteristics, while also maintaining feasibility, may help to increase the prognostic value of HGS.

Traditional hydraulic and spring-type handgrip dynamometers are only able to collect maximal force. New electronic handgrip dynamometers allow for HGS to be collected in real-time and displayed on a monitor. Given these sophisticated technologies enable grip tasks to be observed on a force-time curve, opportunities exist for examining other attributes of muscle function apart from strength capacity, while also maintaining feasibility (McGrath et al., 2021). Although electronic handgrip dynamometers may allow for muscle function to be assessed beyond maximal strength, the role of how hand dexterity may factor into these new assessments is not well-known.

Hand dexterity is an indicator of handgrip performance. The fine motor skills of the hands, and the ability of the hand flexors to synergistically contract is a marker of neuromuscular functioning (Liu et al., 2016). Further, the neural systems mediating the control of fine motor movement are associated with age-related health conditions such as cognitive impairment (Martin et al., 2015). While hand dexterity and function are linked to HGS performance, there is a crucial need to evaluate the role of hand dexterity on electronic handgrip dynamometer derived aspects of muscle function for understanding how dexterity factors into these new grip tasks.

A tool commonly used to measure hand dexterity is the Purdue Pegboard Test (PPT). The PPT is a practical and economical evaluation instrument to examine hand dexterity. Further, the PPT is inclusive of several ages and abilities, and relates to basic self-care tasks such as dressing and eating. Accordingly, the PPT is a great candidate tool for examining how electronic handgrip dynamometer derived characteristics of muscle function are related to hand dexterity.

Statement of Purpose

The purposes of this thesis study were to determine the relationships of electronic handgrip dynamometer derived 1) maximal strength, 2) strength asymmetry, 3) sub-maximal control, 4) bilateral coordination, and 5) neuromuscular steadiness on PPT performance in older adults.

Background

HGS is a reliable indicator of overall muscle strength (McGrath et al., 2021). There are many tools available to test HGS including hydraulic, spring-type, and electronic handgrip dynamometry. The Biopac dynamometer is valid for permitting digital real-time force measurement during a grip task. This type of dynamometer has also been used in recent studies for collecting HGS (Wiles et al., 2001) (Singh et al., 2013) (Huma S.K. et al., 2014).

The PPT was developed as a practical and valid evaluation instrument to examine hand dexterity (Tiffin & Asher, 1948). Specifically, the PPT was designed to assess fine motor hand function using three common objects, pins, washers, and collars to be inserted on a pegboard in a simulation of an industrial setting (Rule et al., 2021). Given the test's use of tasks that reflect activities of daily living (ADL), ease of administration, and affordability, it has become more utilized as a dexterity assessment tool in medical research and the PPT has been used as an outcome measurement tool for many health conditions. Additionally, with this test’s long history and wide usage, normative values and test-retest reliability in healthy subjects are well-established (Amirjani et al., 2010). Scoring of the PPT is likewise used from the PPT Scoring Application. The tablet-based app assisted the administrators in the testing process by standardizing the set-up test batteries, creating organizational norms, and keeping track of individualized data.

Significance of Review

HGS is a reliable measure to examine overall muscular strength. Electronic handgrip dynamometry is a novel tool that has shown promise for more comprehensively examining muscle function while also maintaining feasibility. Hand dexterity is similarly an important metric for grip tasks. The PPT is a valid and reliable tool to measure hand dexterity and fine motor skills. However, the link between electronic handgrip dynamometry derived muscle function and fine motor skills of the hands has not been thoroughly examined in most populations, including middle-aged and older adults.

CHAPTER 2: LITERATURE REVIEW

Little evidence exists for the relationships between HGS, hand dexterity, and fine motor skills in middle-aged and older adults. Examining these relationships is important for identifying linkage among these characteristics because such linkages can advance on how we utilize muscular function assessments. HGS is a clinically viable tool for evaluating overall muscular strength. Weakness, which is operationalized from low HGS, is associated with many health conditions during aging. Different types of tools are used to measure muscle function, but this review will aim to focus on handgrip dynamometers.

Despite HGS being a robust predictor of health during aging, dexterity and fine motor control of the hands are important for executing a grip force task. While various instruments and methods are used to assess hand dexterity, this work will focus on the PPT (Lafayette Instrument, Layfette, IN). The PPT was developed as a practical evaluation instrument to measure hand dexterity. The test has grown in use as a dexterity evaluation tool in clinical research because it uses tasks that reflect basic self-care, is simple for interviewers to administer and participants to complete and is reasonably priced. It has also been utilized as a tool for many different health disorders to measure outcomes. Evidence supports the PPT as a valid, reliable tool to assess hand dexterity and fine motor skills. Additionally, previous evidence suggests a correlation exists for hand dexterity and HGS (Ij, 2020).

Handgrip Strength as a Measurement of Muscular Strength

A recent study discovered how HGS can be an effective tool for predicting muscular strength (Vaidya & Nariya, 2021). Specifically, this cross-sectional study included 30 adults (n=10 males and n=20 females), which sought to determine if handgrip dynamometry was a predictor of muscular strength and endurance, and to examine the correlation between body mass index (BMI) and these handgrip tasks. The HGS test instructed participants to squeeze with maximal effort twice on each hand, and the sum of measures on either right or left hand was used. Muscular strength was measured through a series of tests such as the horizontal jump test (HJT) and vertical jump test (VJT). Additionally, aerobic power was measured to assess VO_2 max, whereby participants were instructed to run and walk as many laps as possible on a 400-meter track for 12 minutes. Post-vitals were measured immediately after aerobic testing. The findings of this investigation showed a positive correlation between HGS and HJT ($r=0.82$, $p<0.05$), VJT ($r=0.69$, $p<0.05$), and VO_2 max ($r=0.72$, $p<0.05$). However, HGS was negatively correlated with BMI ($r=-0.13$, $p<0.05$). As such, the findings from this investigation support the notion that HGS can be an effective tool for predicting muscular strength and endurance (Vaidya & Nariya, 2021).

Handgrip Strength and Age-Related Disability

As the older adult demographic continues growing, decreased muscular strength will be a crucial risk factor for functional limitations and disability (Rantanen, 1999). Measuring muscular strength as a predictor of muscular function is critically important for health surveillance during aging. In a 25-year prospective cohort study examining HGS for functional limitations and age-related disability (Rantanen, 1999), HGS measurements from 6,089 participants in a 25-year study were recorded between 1965 and 1970, and disability assessments (walking speed, chair stands) were conducted between 1991 and 1993.

The results of this investigation indicated that the mean HGS was 39.2±6.0 kg, slow walking speed was observed in 201 (6.2%), and 72 (2.2%) participants were unable to stand up from a chair without assistance. The study found supportive data that HGS was an excellent predictor of functional limitations (Rantanen, 1999). These findings also suggest that increased muscle strength in midlife may prevent age-related functional disability (Rantanen, 1999).

Handgrip Strength and Activities of Daily Living

Understanding the attributes that affect the health of older adults is crucial for maintaining their quality of life, independence, and longevity. Measures of strength capacity, including HGS, and basic self-care, such as ADLs, are markers of health during aging (Ukegbu et al., 2014). ADL tasks may include dressing, cooking, cleaning, bathing, brushing hair, brushing teeth, and feeding.

Ukegbu et al. (2014) utilized a cross-sectional design for evaluating the relationships between HGS and ADLs in 252 older adults (Ukegbu et al., 2014). HGS was assessed using a handgrip dynamometer, and ADLs were determined by adding the values for instrumental and physical ADLs (0–28; a higher score indicates greater functional capability). The results revealed that there was a positive correlation between HGS and ADL score ($r = 0.50$, $p < 0.001$). This study builds confidence in the notion that HGS and ADLs are connected.

Handgrip Strength, Hand Dexterity, and Fine Motor Skills

Although muscle strength decreases during aging, hand dexterity similarly declines. The hand is generally the most interactive and utilized component of the upper extremity. Several hand performances and talents are referred as having "hand dexterity" such as reaction time, hand preference, wrist flexion speed, finger tapping speed, aim, hand stability, and arm stability (Martin et al., 2015).

Martin et al., (2015) examined the associations of age, HGS, and dexterity in 107 persons aged 18 - 93 years from the Birmingham (UK) area. Assessments of hand dominance, HGS, and hand dexterity were measured. HGS was measured with the handgrip dynamometer and dexterity was measured using the Vienna Test System: Motor Performance Series Workboard. The results showed significant negative correlation between age and grip strength ($r = -0.42$, $p<0.001$). Additionally, there were correlations between age and each measure of the Motor Performance Series Workboard (steadiness: $r = 0.56$, $p<0.001$; line tracking: $r = 0.61$, $p<0.001$; aiming: $r = -0.46$, $p<0.001$, and: tapping: $r = 0.51$, $p<0.001$) and between strength and each dependent measure of the Motor Performance Series Workboard (steadiness: $r = -0.42$, $p<0.001$; line tracking: $r = -0.40$, $p<0.001$; aiming: $r = 0.57$, $p<0.001$, and: tapping: $r = 0.62$, $p<0.001$) (Martin et al., 2015). These findings provided evidence that increased age was related to decreased strength (Martin et al., 2015), and further, highlighting the relationships of age and hand dexterity, measures of steadiness, line-tracking, aiming, and tapping (Martin et al., 2015).

Significance of Handgrip Strength in Occupational Therapy

The main objective of occupational therapy (OT) is to increase a person's functional independence in fulfilling daily activities. Hand function plays a vital role in occupational performance and is a critical task in most occupational therapies (Poole, 2021). As we age, impairments in hand function increase, which ultimately limits daily task abilities.

The existence of HGS and use in functional tasks was examined in a recent panel study. Specifically, Mahoney et al., (2015) examined the associations between HGS asymmetry and limitations in individual ADLs in 18,468 Americans in the Health and Retirement Study. ADL limitations were self-reported by the ability to complete the following tasks: 1) dressing 2) eating 3) transferring in-or-out of bed, 4) toileting, 5) bathing, and 6) walking across a small room. The highest recorded HGS values from the non-dominant and dominant hand were used to calculate HGS ratio: (nondominant HGS, kg)/dominant HGS, kg). Persons with >10% asymmetry between hands were considered as having asymmetric strength.

Of the participants included (N=18,468), 9,548 (51.7%) had any HGS asymmetry. Those with any HGS asymmetry had 1.21 (95% confidence interval [CI] = [1.01–1.46]) greater odds for a toileting limitation and 1.25 (CI = [1.03–1.52]) greater odds for a transferring limitation. Participants with dominant HGS asymmetry had 1.24 (CI = [1.01–1.53]) greater odds for a transferring limitation. Furthermore, those with nondominant HGS asymmetry had 1.39 (CI = [1.01–1.93]) and 1.44 (CI = [1.05–1.96]) greater odds for a bathing and toileting limitation, respectively. The results showed that HGS asymmetry was differentially associated with future limitations in specific ADLs, indicating that having a strength asymmetry may put aging Americans at more risk for some ADLs than for others. Using handgrip dynamometers for early detection of HGS asymmetry can support specific efforts in prevention and treatment to maintain fundamental self-care, which is important for OT.

Purdue Pegboard Test Measures

Dexterity, or the speed of coordinated movement, has long been considered an important aspect of hand function (Stein & Yerxa, 1990). Fine dexterity is characterized as an interdigital manipulative skill, whereby fine manipulative movements of objects held between the thumb and fingers occur (Super, 1949). When evaluating hand function during occupational tasks, functional hand dexterities are crucial. Declines in manual dexterity can be the result of injuries or morbidities, which in turn, leads to hand restrictions and limitations (Rule et al., 2021). Additionally, decreased dexterity in those with hand injuries can affect their self-care, occupational productivity, and daily leisure activities (Sigirtmac & Oksuz, 2021). Therefore, occupational therapists need to consider dexterity to monitor the healing process and surveil the results of the treatment interventions. The PPT is a great example of a tool used in clinical and research settings to measure fine dexterity and gross movements of the hands.

Purdue Pegboard Test Validity and Reliability in Adults

The PPT has evidence-based support validity and reliability. For example, a cross-sectional study examining hand dexterity from the criterion validity of the PPT was conducted in 101 persons with hand injuries compared to 162 non-injured participants. The Disabilities of Arm Shoulder and Hand Questionnaire Turkish version was used as the criterion measure (DASH-T). (Sigirtmac & Oksuz, 2021). The findings from this investigation revealed a positive correlation ($r = 0.282$, $p<0.05$) between the PPT and DASH-T subtests. The assembly subtest of the PPT had a cutoff of 24.5. For PPT subtests, the area under the curve (AUC) results ranged from good-to-exceptional (AUC: 0.82–0.92), and the PPT was considered valid for hand dexterity (Sigirtmac & Oksuz, 2021).

Purdue Pegboard Test in Adults with Health Conditions

In OT, tools that guide occupational therapists to evaluate assessments in the most efficient and effective way are critical to their work. Suggestions for OT interventions suggest the development and use of valid and reliable instruments is a priority for OT practice (Buddenberg & Davis, 2000). While the PPT has demonstrated validity for assessing hand dexterity, the test might also have utility for persons with disabilities and other health conditions such as those with carpal tunnel syndrome (CTS), Multiple Sclerosis (MS), and Parkinson’s Disease (PD).

The PPT is designed to assess fine motor hand function using three common objects, 1) Pegs, 2) Washers, and 3) Collars, to be inserted on the pegboard (Amirjani et al., 2010). Due to the assessment of fine motor skills of the PPT, it is important to assess any underlying conditions, such as CTS, that could arise from low test scores. CTS may lead to severe functional impairment because the median nerve supplies the majority of the sensory and motor innervation of the hand. For example, Amirjani et al, (2010) conducted a cross-sectional study examining the reliability and validity of the PPT in 190 adults with CTS relative to 122 healthy participants. The Levine Self-Assessment Questionnaire was used to assess the severity of CTS. Both the test-retest reliability and the PPT completion time were evaluated from each participant. Given that age may influence PPT performance, participants were placed into age groups: 1) young (20-39 years old), 2) middle-aged (40-59 years old), and 3) older adults, (≥60 years old).

This investigation found that the CTS participants were noticeably slower in the PPT's performance than the healthy controls. Young participants with CTS performed slower on all subsets of the PPT compared to the healthy participants ($p<0.001$). Middle-aged CTS participants showed a decline in all subsets ($p<0.01$), besides the assembly performance ($p= 0.10$). Older adults with CTS performed slower in all the subsets ($p<0.001$) compared to the healthy participants. In contrast to the young and middle-aged participants, older adults had significant correlations between all components of the PPT scores ($p<0.01$), besides assembly ($p<0.05$) and symptom severity of CTS, as defined by the Levine Self-Assessment Questionnaire. Additionally, the PPT showed high test-retest reliability among both healthy and CTS participants ($p< 0.001$). With an intraclass correlation coefficient of 0.97, this study supports the claim that the Purdue Peg-board Test has strong test-retest reliability for estimating functional impairment in CTS (Amirjani et al., 2010).

Due to issues with upper-extremity motor performance that may compromise overall functional abilities, people with MS may be referred to an occupational therapist (Gallus & Mathiowetz, 2003). This demographic may benefit from using the PPT, a test that evaluates both upper extremity fine motor dexterity and gross motor coordination. Evaluation of the test-retest reliability of the PPT in persons with MS was performed with 25 participants from a community-based maintenance rehabilitation center. Participant ages ranged from 30-69 years ($\mu=55.3$ years) and received a diagnosis of MS in a range from 3-35 years (μ= 15.7 years). The participants were tested at baseline and retested 1 week later at the same time of day. Three consecutive trials of each of the PPT four subtests were collected from participants. For administration in a single trial, the test-retest reliability coefficients ranged from 0.85-0.90 ($p<0.05$), and for the total of three trials, the coefficients ranged from 0.92-0.96 ($p<0.05$) (Gallus & Mathiowetz, 2003). This study suggested that the PPT showed test-retest reliability in persons with MS.

PD can decrease manual dexterity and ultimately affect performance of daily self-care tasks, such as dressing, grooming, and eating (Proud et al., 2019). The ability to execute regular self-care activities might be hindered by decreased hand dexterity, and occupational therapists advise using a battery of tests, including the PPT, to assess manual dexterity in persons with PD (Proud et al., 2019).

Proud et al., (2019) performed a cross-sectional, observational study examining the test–retest and interrater reliability of PPT in people with PD. The study included 30 qualified candidates (age: 67.1±9.5 years) with PD who were recruited through specific PD outpatient programs and support groups. The PPT subtests demonstrated superior test-retest reliability (ICC=0.90; $p<0.05$), and the minimum detectable change scores showed that both techniques had acceptable measurement errors. These findings indicate that the PPT is a reliable measure of dexterity loss for individuals with PD (Proud et al., 2019).

Purdue Pegboard and Handgrip Strength

HGS and the PPT can both be utilized as a measure of hand function in adults, which may help to provide insights into HGS performance and related tasks. Liu et al., (2016) examined the associations between HGS, arm curl strength, and manual dexterity coordination in 84 older adults (age: 72.0±6.9 years). The results of this study found that older adults with better arm curl strength (β=-0.25, $p<0.01$) and manual dexterous coordination (β=-0.52, $p<0.01$) performed better on the time-based hand function test. In comparison, older adults with better HGS (β=0.40, $p<0.01$), arm curl strength (β=0.23, $p<0.05$), and manual dexterous coordination (β=0.23, $p< 0.05$) had better self-report of upper extremity function. These findings highlight how hand function relies on coordinated extrinsic and intrinsic muscles of the hand flexors and extensors to provide mobility, stability, and dexterity (Liu et al., 2016).

CHAPTER 3: METHODOLOGY

Participants

A cross-sectional design was utilized for this investigation. The North Dakota State University Institutional Review Board has approved all study protocols. To account for any missing data and adhere to the recommended minimum number of persons for 80% power in a single group cross-sectional design, the student investigator has recruited 30 participants (Wilson Van Voorhis & Morgan, 2007). The student investigator recruited with word-of-mouth, email list serves, and flyers. Persons interested in participating in this study contacted the student investigator to complete a pre-consent screening questionnaire.

To be eligible in this thesis study, participants must be at least 65 years, capable of traveling to North Dakota State University, able to squeeze an object with both hands without experiencing severe pain or limitations, not receiving treatment for cancer (other than minor skin cancer), not living with a neurological health condition (e.g., stroke), be able to read and speak English at an eighth grade level, and never have been diagnosed with Alzheimer's disease or severe dementia. Individuals that are determined eligible by completing the pre-consent screening questionnaire visited the Research 2 building at North Dakota State University for a single 60-minute study visit. Prior to any testing, persons were asked to refrain from activities that would strain hand function at least 24 hours prior to the visit and be advised to clip or cut fingernails short. All participants provided written informed consent before beginning study protocols.

Measures

Self-report Questionnaires

Demographic Characteristics: Participants completed a self-report questionnaire regarding their hand dominance, age, gender, race and ethnicity, marital status, educational achievement, employment and volunteering status, cigarette smoking status, alcohol consumption, self-rated health, independent living tasks, basic self-care tasks, and if a doctor had ever diagnosed them with the following health conditions: COVID-19, chronic lung disease, stroke, heart condition, psychiatric problems, and diabetes. Those with ≥2 reported morbidities were classified as having multimorbidity.

Cognitive Functioning: The well-validated Montreal Cognitive Assessment (MoCA) evaluated cognitive functioning. Participants completed the MoCA with a trained interviewer. Scores range from 0-30 with higher scores indicating greater cognitive functioning. Continuous scores were included, and participants with scores <26 were categorized as having a cognitive impairment.

Depressive Symptomology: The frequently utilized 9-item Patient Health Questionnaire examined depressive symptomology. Scores range from 0-27, with higher scores representing more depressive symptoms. Continuous scores were included in the analyses.

Anthropometrics

Standing height was measured to the nearest 0.5 centimeter (about 0.2 in) and body mass to the nearest 0.1 kilogram with the Seca 286 measuring station (Seca; Chino, CA). BMI was calculated and included in analyses as body mass in kilograms divided by height in meters squared.

Purdue Pegboard

Hand dexterity and fine motor skills of the hands were assessed with the PPT (Model 32020A; Lafayette Instrument, Layfette, IN). The participants were seated comfortably at a testing table with the PPT on the table in front of the participant. The testing board consists of a board with 4 cups across the top, and two vertical rows of 25 small holes down the center. The two outside cups contain 25 pins each; the cup to the immediate left contains 40 washers and the cup to the immediate right of the center contains 20 collars. The PPT were completed in the following order: 1) dominant hand, 2) non-dominant hand, 3) both hands, and 4) assembly.

The protocols followed by the PPT were based on the administration and scoring from The PPT Norms and Studies of Reliability and Validity study, (Tiffin & Asher, 1948). The trials were demonstrated and explained to participants by the student investigator. Scores of the PPT subtests were scored as a continuous variable. Higher subset scores associated in higher functioning tasks, as well as lower subset scores associated in lower functioning tasks.

Right Hand

Each participant was instructed to pick up one pin at a time with the right hand from the right-hand cup and place the pins in the right-hand row, starting with the top hole. The participants were allowed to put in three or four pins for practice before this part of the test. The practice pins were then removed. When the test began, the participant was allowed exactly 30 seconds to put in as many pins as possible with the right hand, taking the pins from the right-hand cup one at a time. The total number of pins placed in the right-hand column using the right hand in the allotted time was scored from 0-25, with higher scores indicating better performance, and the continuous score was included in analyses.

Left Hand

Participants were instructed to pick up one pin at a time with the left hand from the left-hand cup and place the pins in the left-hand row, starting with the top hole. The participant was allowed to put in three or four pins for practice before this part of the test began. The practice pins were removed again. When the test began, participants were allowed 30 seconds to put in as many pins as possible with the left hand, taking the pins from the left-hand cup one at a time. The total number of pins placed in the left-hand column using the left hand in the allotted time was scored from 0-25, with higher scores indicating better performance, and the continuous score was included in analyses.

Both Hands

This portion of the PPT required participants to use both hands together. The participants simultaneously took a pin from the right-hand cup with the right hand and a pin from the left-hand cup with the left hand, and simultaneously placed both pins in the two rows of holes, starting with the pair of holes farthest away from the participant. Practice in placing three or four pairs of pins was allowed before this test sequence was executed. After the practice and after all pins have been returned to their proper cups, participants had 30 seconds to place as many pairs of pins as possible, using both hands, each hand picking up and placing one pin at a time. The total number of pairs of pins placed in both columns using both hands in the allotted time was scored from 0-25, with higher scores indicating better performance, and the continuous score was included in analyses.

Right+Left+Both Hands

The sum of scores was generated from recorded performance from the right, left, and both hand assessments. These scores range from 0-75, with higher scores indicating better performance, and such continuous scores were included in the analyses.

Assembly

The assembly sequence assesses finger dexterity and consists of assembling the pins, collars, and washers. To confirm that the participants understood instructions, the student investigator provided directions and demonstrated. Participants were asked to pick up one pin from the right-hand cup with their right hand and place the pin in the top hole in the right-hand row, and then pick up a washer with their left hand. As soon as the pin has been placed, the washer was dropped over the pin. While the washer was being placed over the pin with the left hand, the right hand picked up a collar. While the collar was being dropped over the pin, the left hand picked up another washer and dropped it over the collar. This sequence completed the first 'assembly' consisting of a pin, a washer, a collar, and a washer. The score on the assembly test included the number of all parts assembled during the 60-second test period, fully completed or not completed. For example, if eight complete assemblies are made, the score is therefore 32. If eight assemblies are made but the eighth assembly is only half made, the score would be 30. Scores on the assembly sequence range from 0-100, with higher scores indicating better performance, and the continuous score was included in the analyses.

Handgrip Tasks

HGS testing was performed on Biopac electronic handgrip dynamometers (Biopac Systems; Goleta, CA). The Biopac dynamometer is a valid tool that enables force to be observed in real-time during a grip task. The protocols for each of our HGS assessments are based on HGS guidelines (Roberts et al., 2011). For all gripping tasks, participants sat comfortably with their forearms resting on a chair's arms, their wrists neutrally positioned just over the chair's arm, and their thumbs facing upward. Individuals that might be uncomfortable placing their arms on the chair can support themselves by resting their arms on another object. All HGS assessments were explained and demonstrated by the student investigator. Before the HGS examinations, participants were allowed to practice. The order of the hands first tested were block randomized. To account for the variety of grip force activities the participants completed, each HGS assessment involved three measurements on each hand, with a 60-second rest period between measures. The order of each gripping task was as follows: 1) maximal HGS, 2) submaximal force control, and 3) bilateral coordination.

Handgrip Strength

Participants squeezed the dynamometer with maximal effort, exhaled while squeezing, and then released the dynamometer. The highest recorded HGS on both hands were included in the analyses.

Submaximal Handgrip Strength Force Control

A 25% submaximal HGS value was calculated from the maximal HGS previously recorded for each hand. For this task, participants were asked to squeeze the dynamometer and maintain the 25% submaximal target grip force for 10 seconds. A computer screen displayed the grip force generated by each participant in real-time to help them gauge their grip force and maintain the 25% submaximal target. A coefficient of variation was calculated over the middle 8 seconds for each measurement (Clark et al., 2007). The lowest coefficient of variation on both hands was included in the analyses.

Handgrip Bilateral Coordination

Participants were asked to complete maximal HGS, with a handgrip dynamometer in each hand, at the same time. For each trial, the recorded HGS values on each hand were used to calculate bilateral HGS coordination ratio (higher HGS (kilograms) / lower HGS (kilograms)). The ability to produce equal amounts of force in a symmetric, in phase task suggests higher bilateral coordination (Woytowicz et al., 2016). Thus, the bilateral HGS coordination ratio closest to 1.0 was included in the analyses.

Neuromuscular Steadiness

To measure neuromuscular HGS stability during all HGS tests, an ActiGraph GT3X-BT triaxial accelerometer (ActiGraph; Pensacola, FL) was fastened to the top of the dynamometer. The accelerometer was initialized at 60 Hz using ActiLife software (ActiGraph), and data processing was used. Every HGS measurement's precise start and finish times (in seconds) was noted and matched with the time stamps from the Biopac handgrip dynamometer. Data was kept in epochs of one second. Every HGS evaluation included in the analyses was its average vector magnitude calculated. The average of the mean values included was used for analyses.

Statistical Analysis

All analyses were performed with SAS 9.4 software (SAS Institute; Cary, NC). Descriptive information was presented as mean±standard deviation for continuous variables and frequency (percentage) for categorical. Individual Pearson correlations was executed to examine the relationships of the right and left 1) maximal strength, 2) sub-maximal control, 3) bilateral coordination, and 4) neuromuscular steadiness measures on the corresponding 1) right, and 2) left PPT performance scores, respectively. The highest performing HGS values on each hand was then calculated as an asymmetry ratio ((*highest performing HGS (kg) / next highest* *performing HGS (kg)*) for strength, sub-maximal control, bilateral coordination, and neuromuscular steadiness) so that all ratios are ≥1.0. Thereafter, Pearson correlations assessed each individual handgrip task asymmetry ratios with the PPT scores for "both hands". Then, the highest performing values from each handgrip task was included in individual Pearson correlation analyses with PPT scores from "Right+Left+Both" and "Assembly". Absolute correlation coefficients were used to elucidate the strength of the relationships: <0.10 is negligible, 0.10-0.39 is weak, 0.40-0.69 is moderate, and ≥0.70 is strong (Schober & Schwarte, 2018). As supplementary analyses, we performed the same Pearson correlation analyses stratified by cognitive impairment status, multimorbidity status, and gender. An alpha level of 0.05 will be used for all analyses.

CHAPTER 4: RESULTS

The descriptive characteristics of the participations are in Table 1. Overall, participants were aged 72.4±5.3 years and were mostly female (70.0%). Table 2 presents the results for the Pearson correlation coefficients for the handgrip and pegboard measures by hand of completion. A non-statistically significant weak negative correlation existed for sub-maximal control and PPT scores for the right (r=-0.22; p=0.09) and left hands (r=-0.30; p=0.09). The correlation coefficients for the relationships between the handgrip ratios and PPT scores are shown in Table 3. A weak and non-statistically significant positive correlation existed between strength asymmetry and PPT scores from both hands (r=0.35; p=0.05). Table 4 displays the correlation coefficients for the relationships between the best performing handgrip tasks and PPT scores. Best sub-maximal control values had a non-statistically weak negative correlation with Left+Right+Both (r=-0.28; p=0.13) and assembly PPT scores (r=-0.10; p=0.61).

Appendix 1 shows the correlation coefficients for the relationships between the handgrip tasks and PPT scores by hand of completion for gender, multimorbidity status, and cognitive impairment status. A non-statistically significant moderate negative correlation existed for participants with multimorbidity on the right (r=-0.47; p=0.10) and left hands (r=-0.48; p=0.09) regarding sub-maximal control and PPT scores. Appendix 2 lists the correlation coefficients for the relationships between the handgrip task ratios and PPT scores by gender, multimorbidity status, and cognitive impairment status. A non-statistically significant moderate negative correlation was revealed for strength asymmetry ratio for men (r=-0.49; p=0.17), while a non-statistically weak positive correlation was found in women (r=0.30; p=0.17). The correlation coefficients for the relationships between the best performing handgrip tasks and PPT scores by gender, multimorbidity status, and cognitive impairment status are in Appendix 3. A non-statistically significant moderate negative correlation was revealed between sub-maximal control and Left+Right+Both PPT scores (r=-0.44; p=0.13) in participants with multimorbidity, but the magnitude of the correlation declined in participants without multimorbidity (r=-0.22; p=0.37).

Table 1. Descriptive Characteristics of the Participants.

	n=30
Female (n (%))	21 (70.0)
Age (years)	72.4±5.3
Non-Hispanic (n (%))	30 (100.0)
White (n (%))	30 (100.0)
Marital Status (n (%))	
Single	6 (20.0)
Married	13 (43.3)
Widowed	8 (26.7)
Other	3 (10.0)
Educational Achievement (n (%))	
High School Graduate or Equivalent	2 (6.7)
Some College or Vocational Training	9 (30.0)
Completed Associates Degree	2 (6.7)
Completed Bachelor’s Degree	13 (43.3)
Completed Graduate Degree	4 (13.3)
Employment Status (n (%))	
Full-time	2 (6.7)
Part-time	3 (10.0)
Retired	25 (83.3)
Current Cigarette Smoker (n (%))	2 (6.7)
Previous Cigarette Smoker (n (%))	10 (33.3)
Weekly Frequency of Alcohol Consumption (n (%)	
None	7 (2.3)
<1/week	12 (40.0)
1-2/week	6 (20.0)
3-4/week	2 (6.7)
≥5/week	3 (10.0)
Self-Rated Health (n (%))	
Excellent	5 (16.7)
Very Good	18 (60.0)
Good	7 (23.3)

Table 1. Descriptive Characteristics of the Participants (continued).

Right Hand Dominant (n (%))	27 (90.0)
Nightly Hours of Sleep	6.9±0.8
Morbid Conditions	1.5±1.2
Instrumental Activities of Daily Living	0.1±0.3
Age (years)	72.4±5.3
Persons residing in Household	1.3±0.4
Depressive Symptoms	1.3±1.9
Montreal Cognitive Assessment Score	26.1±2.5
Cognitive Impairment (n (%))	11 (36.7)
Height (cm)	164.1±8.6
Body Mass (kg)	84.2±19.3
Body Mass Index (kg/m^2)	31.1±6.1
Right Hand Height (cm)	18.4±1.1
Left Hand Height (cm)	18.7±1.1
Right Hand Width (cm)	18.6±1.7
Left Hand Width (cm)	18.7±1.9
Strength Capacity	16.2±5.5
Sub-maximal Control	5.2±3.1
Bilateral Coordination Ratio	1.1±0.1
Neuromuscular Steadiness	2.8±5.0
Purdue Pegboard on Right Hand	11.4±2.2
Purdue Pegboard on Left Hand	9.9±2.1
Purdue Pegboard on Both Hand	8.5±2.5
Purdue Pegboard Right+Left+Both Hands	29.9±6.2
Purdue Pegboard Assembly	22.0±5.1

Table 2. Correlation Coefficients for the Relationships Between the Handgrip Task Ratios and Purdue Pegboard Scores.

	Both Hands Pegboard Score
Strength Asymmetry Ratio	r=0.35; p=0.05
Submaximal Asymmetry Ratio	r=-0.01; p=0.94
Bilateral Asymmetry Ratio	r=0.13; p=0.48
Steadiness Asymmetry Ratio	r=0.06; p=0.74

Table 3. Correlation Coefficients for the Relationships Between the Best Performing Handgrip Tasks and Purdue Pegboard Scores.

	Left+Right+Both Pegboard Score	**Assembly Pegboard Score**
Maximal Strength	r=0.02; p=0.88	r=0.08; p=0.66
Submaximal Control	r=-0.28; p=0.13	r=-0.10; p=0.61
Bilateral Asymmetry Ratio	r=0.06; p=0.71	r=0.07; p=0.68

CHAPTER 5: DISCUSSION

The principal findings from this thesis study suggest that while there were no statistically significant correlations between the handgrip measures and PPT performance, a consistent trend emerged. Specifically, sub-maximal control showed a negative (but insignificant) correlation with PPT scores, such that as sub-maximal control worsened, PPT performance similarly deteriorated. The trends were consistent across gender, multimorbidity status, and cognitive impairment status, and were likely influenced by power. These findings suggest that the ability to squeeze a handgrip dynamometer at a pre-specified sub-maximal force and time could be linked to the dexterity focused tasks involved in PPT. Accordingly, the neural systems that mediate the control of the coordinated muscle contractions involved in a sub-maximal grip task may serve as a more sensitive indicator for neuromuscular declines than maximal HGS alone, which could have implications for OT testing and screening for neurodegenerative diseases.

Sub-maximal control testing may help an occupational therapist employ motor control therapies as a strategy to improve performance. The process of fine-tuning movement involves several brain regions (Byars et al., 2023), and any area of the brain can be damaged, which can drive several types of functional deficiencies. When persons repeat functional task components, their brains rewire to rebuild new connections, a process known as neuroplasticity (Byars et al., 2023). Occupational therapist can create a task-specific training intervention that aids in drawing the principles of neuroplasticity when a person exhibits a sub-maximal control impairment. This enables an occupational therapist to execute task-based motor control interventions, which enhances functional performance by rewiring and repairing a person's brain-body connections when they become damaged (Byars et al., 2023). As such, sub-maximal control testing can aid an occupational therapist in finding deficiencies in motor control to then implement helpful interventions.

Close relationships have been found between hand control and cognitive function (Scherder et al., 2008). The inability to carry-out basic self-care tasks including eating, dressing, and bathing is linked with a progressive deterioration in hand motor skills, which may have an impact on quality of life and independent living (Scherder et al., 2008). Those with low hand motor skills could be at greater odds for residing in assisted living facilities (Scherder et al., 2008). Neurodegenerative diseases may be significantly predicted by hand motor function, particularly sub-maximal control. The parallel functional and structural control of cognitive and motor processes by the human brain can explain the intimate and widespread links between age-related reductions in maximal grip strength and symptoms of cognitive impairment (Carson, 2018).

Hand motor function, especially HGS, is an important predictor of functional disability in older adults (Gale et al., 2006). A study by Bray et al. (2012) provided evidence that prolonged performance of a high cognitively functioning task is associated with a decline in maximal voluntary muscular force generation in a handgrip squeezing task over time. Specifically, participants assessed their level of physical exhaustion, self-reported mental exertion, and completed a 4-second maximum voluntary contraction handgrip squeeze after the first minute and every three minutes thereafter. With a linear decrease in maximum voluntary contraction force output with time in the cognitively depleted condition and no change for controls, the findings revealed a significant interaction (Bray et al., 2012). The results of reported mental exertion showed a higher increase over time in the cognitive depletion condition as compared to controls (Bray et al., 2012). Accordingly, the findings from Bray et al. (2012) support the notion that cognitive taxing tasks reduces central nervous system resources that control the self-regulation of physically demanding tasks involving maximal voluntary effort.

The PPT is frequently used to assess manual dexterity and predict cognitive deterioration (Hinkle & Pontone, 2021). According to Hinkle and Pontone (2021), PPT impairment was a predictor of decreased psychomotor processing speed in PD patients. PPT performance was further associated with the cognitive test Symbol Digit Modalities, and with changes in ADLs using The Unified Parkinson Disease Rating Scale. Even after controlling for objective measures of motor impairment, PPT performance continued to predict an increase in ADL limitations (Hinkle & Pontone, 2021).

This thesis study showed that a signal exists between sub-maximal control and PPT performance. The signal remained consistent regardless of sex, multimorbidity status, and cognitive impairment status, but was particularly pronounced when multimorbidity present. For example, muscle contraction quality can be limited in persons with diabetes, and the presence of diabetes represents a clustering of chronic cardiometabolic conditions such as hypertension, dyslipidemia, high blood inflammation (e.g., c-reactive protein), and obesity (Wyatt & Ferrance, 2006). COVID-19 may also influence musculoskeletal function and fine motor skills (Pescaru et al., 2022). Exercise interventions represent a single referral option which is useful for a broad range of morbidities for helping to restore muscle function in persons with multimorbidity (Di Raimondo et al., 2016).

The thesis study has limitations. Although a sample size of 30 participants could be considered adequate for a pilot-level investigation such as this thesis study, a larger sample size may have helped yield statistically significant findings. The sample was also fully non-Hispanic white, which limits generalizability. Completing the self-reported PHQ-9 (depressive symptoms) in the presence of an interviewer may have influenced response bias. Some participants may have had fingernails that limited PPT testing; however, all participants completed the PPT task.

The findings from this thesis study suggest that sub-maximal control was consistently linked with PPT performance. The findings from this thesis study suggest that sub-maximal control was consistently linked with PPT performance, albeit the correlations were statistically insignificant, but likely driven by sample size. Moreover, the strength of the correlation between sub-maximal control and PPT performance was pronounced when multimorbidity was present. These findings suggest that the sub-maximal control grip task could be a feasible and sensitive marker for dexterity and fine motor skill testing. Such findings may have implications for OT assessments and referral to intervention for restoring function, which in turn, may help our rapidly growing older adult population in the United States maintain quality of life and extend autonomous living.

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APPENDIX A: SUPPLEMENTARY TABLES

Table A1. Correlation Coefficients for the Relationships Between the Handgrip Tasks and Purdue Pegboard Scores by Hand of Completion for gender, multimorbidity status, and cognitive impairment status.

	Pegboard Score[†]
Men	
Right Hand	
Maximal Handgrip Strength	r=0.01; p=0.96
Submaximal Control	r=-0.12; p=0.75
Neuromuscular Steadiness	r=-0.42; p=0.25
Left Hand	
Maximal Handgrip Strength	r=0.43; p=0.24
Submaximal Control	r=-0.60; p=0.08
Neuromuscular Steadiness	r=-0.07; p=0.84
Women	
Right Hand	
Maximal Handgrip Strength	r=-0.05; p=0.82
Submaximal Control	r=-0.41; p=0.06
Neuromuscular Steadiness	r=0.42; p=0.05
Left Hand	
Maximal Handgrip Strength	r=0.14; p=0.51
Submaximal Control	r=-0.36; p=0.10
Neuromuscular Steadiness	r=0.53; p=0.01
Multimorbidity	
Right Hand	
Maximal Handgrip Strength	r=-0.07; p=0.81
Submaximal Control	r=-0.47; p=0.10
Neuromuscular Steadiness	r=-0.27; p=0.36
Left Hand	
Maximal Handgrip Strength	r=0.20; p=0.50
Submaximal Control	r=-0.48; p=0.09
Neuromuscular Steadiness	r=0.01; p=0.99
No Multimorbidity	
Right Hand	
Maximal Handgrip Strength	r=0.27; p=0.28
Submaximal Control	r=-0.12; p=0.61
Neuromuscular Steadiness	r=0.35; p=0.16
Left Hand	
Maximal Handgrip Strength	r=0.01; p=0.97
Submaximal Control	r=-0.09; p=0.72
Neuromuscular Steadiness	r=0.68; p<0.01

Table A1. Correlation Coefficients for the Relationships Between the Handgrip Tasks and Purdue Pegboard Scores by Hand of Completion for gender, multimorbidity status, and cognitive impairment status (continued).

Cognitive Impairment	
Right Hand	
Maximal Handgrip Strength	r=-0.36; p=0.26
Submaximal Control	r=-0.28; p=0.40
Neuromuscular Steadiness	r=0.36; p=0.27
Left Hand	
Maximal Handgrip Strength	r=-0.10; p=0.75
Submaximal Control	r=-0.14; p=0.66
Neuromuscular Steadiness	r=0.53; p=0.09
No Cognitive Impairment	
Right Hand	
Maximal Handgrip Strength	r=-0.06; p=0.79
Submaximal Control	r=-0.22; p=0.35
Neuromuscular Steadiness	r=-0.24; p=0.31
Left Hand	
Maximal Handgrip Strength	r=0.07; p=0.78
Submaximal Control	r=-0.34; p=0.14
Neuromuscular Steadiness	r=0.08; p=0.73

[†]Corresponds with the hand in which the grip task was performed.

Table A2. Correlation Coefficients for the Relationships Between the Handgrip Task Ratios and Purdue Pegboard Scores by gender, multimorbidity status, and cognitive impairment status.

	Both Hands Pegboard Score
Men	
Strength Asymmetry Ratio	r=-0.49; p=0.17
Submaximal Asymmetry Ratio	r=-0.43; p=0.24
Bilateral Asymmetry Ratio	r=0.07; p=0.84
Steadiness Asymmetry Ratio	r=-0.28; p=0.46
Women	
Strength Asymmetry Ratio	r=0.30; p=0.17
Submaximal Asymmetry Ratio	r=-0.01; p=0.96
Bilateral Asymmetry Ratio	r=0.15; p=0.50
Steadiness Asymmetry Ratio	r=0.05; p=0.79
Multimorbidity	
Strength Asymmetry Ratio	r=0.60; p=0.03
Submaximal Asymmetry Ratio	r=0.27; p=0.36
Bilateral Asymmetry Ratio	r=0.18; p=0.54
Steadiness Asymmetry Ratio	r=0.30; p=0.30
No Multimorbidity	
Strength Asymmetry Ratio	r=0.17; p=0.50
Submaximal Asymmetry Ratio	r=-0.18; p=0.48
Bilateral Asymmetry Ratio	r=0.01; p=0.94
Steadiness Asymmetry Ratio	r=-0.01; p=0.95
Cognitive Impairment	
Strength Asymmetry Ratio	r=-0.39; p=0.22
Submaximal Asymmetry Ratio	r=0.05; p=0.86
Bilateral Asymmetry Ratio	r=-0.11; p=0.73
Steadiness Asymmetry Ratio	r=0.01; p=0.95
No Cognitive Impairment	
Strength Asymmetry Ratio	r=0.60; p<0.01
Submaximal Asymmetry Ratio	r=-0.06; p=0.08
Bilateral Asymmetry Ratio	r=0.24; p=0.31
Steadiness Asymmetry Ratio	r=0.20; p=0.40

Table A3. Correlation Coefficients for the Relationships Between the Best Performing Handgrip Tasks and Purdue Pegboard Scores by gender, multimorbidity status, and cognitive impairment status.

	Left+Right+Both Pegboard Score	**Assembly Pegboard Score**
Men		
Maximal Strength	r=0.49; p=0.17	r=0.45; p=0.22
Submaximal Control	r=-0.66; p=0.05	r=-0.36; p=0.33
Bilateral Asymmetry Ratio	r=0.08; p=0.82	r=0.06; p=0.86
Women		
Maximal Strength	r=0.14; p=0.52	r=0.29; p=0.19
Submaximal Control	r=-0.38; p=0.08	r=-0.19; p=0.40
Bilateral Asymmetry Ratio	r=0.07; p=0.73	r=0.09; p=0.67
Multimorbidity		
Maximal Strength	r=0.13; p=0.65	r=0.13; p=0.65
Submaximal Control	r=-0.44; p=0.13	r=-0.15; p=0.61
Bilateral Asymmetry Ratio	r=0.13; p=-0.66	r=-0.10; p=-0.72
No Multimorbidity		
Maximal Strength	r=0.01; p=0.95	r=0.07; p=0.77
Submaximal Control	r=-0.22; p=0.37	r=-0.07; p=0.78
Bilateral Asymmetry Ratio	r=-0.08; p=0.74	r=0.17; p=0.49
Cognitive Impairment		
Maximal Strength	r=-0.21; p=0.52	r=-0.16; p=0.62
Submaximal Control	r=-0.35; p=0.27	r=-0.22; p=0.05
Bilateral Asymmetry Ratio	r=-0.07; p=0.82	r=0.25; p=0.44
No Cognitive Impairment		
Maximal Strength	r=0.15; p=0.53	r=0.12; p=0.60
Submaximal Control	r=-0.26; p=0.27	r=-0.05; p=0.81
Bilateral Asymmetry Ratio	r=0.14; p=0.54	r=0.01; p=0.98

APPENDIX B: IRB APPROVAL LETTER

NDSU NORTH DAKOTA STATE UNIVERSITY

10/13/2023

Dr. Ryan McGrath
Health, Nutrition & Exercise

IRB Approval of Protocol #IRB0004891 , "Relationships Between Electronic Handgrip Dynamometer-Derived Muscle Function and Purdue Performance"

Co-investigator(s) and research team:

- Ryan McGrath
- Samantha Leigh Fitzsimmons
- Yeong S Rhee
- Bryan Christensen
- Megan C Orr

Approval Date: 10/13/2023
Expiration Date: 10/12/2024
Research site(s): Research 2 Room 214D, Room 216A, Room 212, Room 204, or Room 102T.
Funding Agency:
Review Type: Full Board, meeting date – 10/13/2023 12:00 PM - Memorial Union, Peace Garden Room

Risk Level: Minimal

The protocol application and all included documentation for the above-referenced project have been reviewed and approved via the procedures of the North Dakota State University Institutional Review Board.

Additional approval is required:

- Prior to implementation of any proposed changes to the protocol.
- For continuation of the project beyond the approval period.

A report is required for:

- Any research-related injuries, adverse events, or other unanticipated problems involving risks to participants or others within 72 hours of known occurrence.
- Any planned or unplanned deviations from the approved protocol.
- Any significant new findings that may affect risks to participants.
- Closure of the project.

Thank you for cooperating with NDSU IRB procedures, and best wishes for a successful study.

NDSU has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

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