Hand Force Profiles of Women with Hand Osteoarthritis during Sealed Jar Opening

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Dedication

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This work is also dedicated to the population of women with hand osteoarthritis. I'm hopeful these women and the therapists treating them will benefit from the findings of this study.

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Chapter 1

Introduction

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Introduction

Activity limitation is defined by the World Health Organization[1] as "difficulties an individual may have in executing a task or action" (p.10). The prevalence of activity limitation, formally referred to as disability, is likely to increase due to the aging of the world population. An estimated 10% of the world population or 650 million persons are currently living with an activity limitation of some form. In countries with greater than 5000 in population, 74% of all individuals over the age of 65 have reported some form of "old age disability"[2]

According to the U.S. Census Bureau[1,3], in the year 2000, 12.7% of all persons living in the United States were 65 years or older and it is estimated that by 2030, 19.6% will be 65 or older. Liao et al.[4] (2001) report that among the non-institutionalized Americans 70+ years of age there has been a trend in increased ADL dependence from the mid 1980's to the mid 90's. The aging world population and its high incidence of activity limitations are predicted to tax our health care system financially and will likely result in increased healthcare workforce demand[5].

It has been documented that with aging, the incidence of chronic illness increases and with that so does the incidence of activity limitation[6]. One would anticipate that by preventing or remediating activity limitation, fewer placements would be needed for long-term care where individuals are dependent upon others at the most fundamental level (basic activities of daily living). Aging in place would lessen the financial burden of long term care expenses and perhaps offset the implications of the anticipated long-term care workforce shortage. Occupational therapists are equipped to prevent and remediate such activity limitation through their interventions. However, now more than ever, there is a need for evidence to equip these professionals with the knowledge and skills to effectively do so.

The occupational therapist must consider many factors when determining the cause of activity limitations[7] as many variables (i.e., age, gender, highest attained educational level, incidence of organ level impairment, physical limitations, cognitive decline, and depression) have been demonstrated to be correlated with or predictive of such[8,9]. Although activity performance is supported by multiple factor, the influence of physical limitations has and "will continue to play an important role in occupational therapy practice and research"[10].

Upper Extremity Variables Influencing Activity Limitations

Joint mobility. Jette, Branch, and Berlin[11] reported that impaired measures of hand joint ROM per an impairment rating scale developed by Jette and Branch[12] significantly predicted decline in self-reported ADL performance ($\beta = -0.01$, $p < 0.01$).

Pain. As one might expect, the presence of upper extremity pain also influences hand function and occupational performance. Droll et al.[13] studied N? and found that self-reported measures of pain after radiographically verified union of combined fractures of the radius and ulna (i.e., both-bone forearm fractures [BBFF]), explained 45% of DASH scores. Geertzen, Dijkstra, van Sonderen, Groothoff, ten Duis and Eisma[14] studied 65 subjects with diagnoses of Reflex Sympathetic Dystrophy and found that Visual Analogue Scale (VAS) measures of hand pain were highly correlated to scores of the Groningen Activity Restriction Scale: IADL subscale ($r = .71$, $p < 0.01$) and moderately correlated to ADL subscales ($r = .53$, $p < 0.01$).

Maximum proximal strength. Measures of proximal upper extremity strength have also been demonstrated to influence functional performance. McGee and Mathiowetz[15] found a moderate correlation ($r = 0.45$, $p=.05$) between Maximal Voluntary Contraction (MVC) shoulder abduction strength, measured by hand-held dynamometry, and the self-reported IADL performance, the Lawton IADL Scale of elderly women ($n = 30$) living in assistive living settings. The authors also questioned if proximal upper extremity strength impairment ratings were predictive of IADL participation and found that those with shoulder external rotation strength below normal limits (i.e., 2 standard deviations below normative values) more likely to be dependent in IADL ($\chi^2 = 4.0$, $p < 0.05$).

Maximum distal strength. Many researchers have studied the relationships between diminished grip/pinch strength and occupational performance or the predictive maximum voluntary contraction (MVC) measures of grip and pinch strength are of functional independence. In a cohort study, Giampaoli, Ferrucci, Cecchi, et. al[16] measured the MVC grip strength of 140 men aged 71-91 years without any reported deficits in occupational performance at baseline and then surveyed their occupational performance and grip strength again 4 years later. The results suggested that grip strength deficits were highly associated with reduced occupational performance in men 77 years or older ($r = .96$, CI = 95%), and the authors recommended that measures of grip strength be used as an inexpensive screening instrument to identify elderly persons likely to have activity limitations.

Similarly, Keller[17] found that among institutionalized older men, measures of grip strength had a moderate correlation ($r = .68$, $p<.05$) to observed performance of ADL via the Barthel Index. Visser et al.[18] found that women, acutely following a hip fracture, who had the greatest decline in MVC measures of grip strength, had a worse recovery of mobility than those who did not ($p = 0.04$). Sonn et al.[19] reported grip strength to be significantly greater ($p < 0.001$) in men and women who were independent in Instrumental Activities of Daily Living (IADL) performance at 70 years of age versus those who were dependent at 76 years. In a cross sectional study of 2190 community dwelling seniors, Judge, Schectman, and Cress (1996) reported that MVC hand grip strength accounted for up to 25% of the variance in self-reported IADL independence (r^2=.25, $p = 0.007$).

Upper Extremity Variables Influencing Hand Force Generation

It is apparent in the literature that upper extremity impairments can predict or are related to functional limits. Hand strength, although often simplistically quantified, if impaired is often a gross representation of other neuromusculoskeltal impairments. Recognizing the importance of hand strength in function, many researchers have explored how other physical components relate to or explain the variance of hand grip forces.

Sensation. One such component, upper extremity sensation, when impaired, has been shown to affect hand function detrimentally. Johansson and Westling[20] studied factors influencing the control of precision grip after hand sensory impairments were temporarily induced via local anesthesia. They reported that among those with the induced mechanoreceptor sensory impairment, applied grip force (i.e., forces exerted on an object to prevent slippage) latencies were greater across frictional conditions. Blennerhassett, Matyas, and Carey[21] found the same to be true of a clinical stroke population with sensory impairment. Their findings indicated that poorer friction discrimination was significantly associated with longer latencies of grip-lift measures ($r = .34$; $p = .03$) and impaired grip force regulation ($r = .34$; $p = .03$). Both research teams concluded that impaired friction discrimination ability contributes to altered timing and force adjustment during gripping and lifting-while-gripping tasks.

Similar trends were found among individuals living with cervical myelopathy, a disorder characterized by spinal cord compression and sensorimotor disturbances of the upper and lower limbs. Doita, Sakai, Harada, Nishida, Miyamoto, Kaneko, and Kurosaka[22] reported that subjects with moderate to severe loss in non-standardized measures of light touch sensation scored significantly lower on Kaneko and Muraki's Test of Hand Function[23] than did those with mild impairments or less ($p < 0.05$). The authors also reported that moderate to severely impaired non-standardized measures of upper extremity proprioceptive awareness were significantly associated with reduced precision grip ($p < 0.05$).

Range of motion. Impaired upper extremity range of motion (ROM) and joint status have also been studied as indicators of hand function and occupational performance. Hughes, Gibbs, Edelman, Singer, and Chang[24] reported that joint impairment scores (i.e., a non-standardized 3-point scale where one point is assigned for the presence each of the following variables: joint tenderness, deformity, and joint motion limitation) explained 59% ($R^2 = .59$) of the variance in MVC measures of grip strength among a diversely functional sample ($n = 541$) of persons over the age of 60.

Limited thumb circumduction ROM and ROM measures of the most limited finger proximal interphalengeal joint were found to moderately correlate with self-perceived performance of fine motor tasks as measured by a non-standardized 41-item survey of function (r = -0.63 and r = -0.61respectively) given 95 individuals with rheumatoid and osteoarthritis[25]. Measures of limited ROM proximal to the hand have also been reported to be related to upper extremity dysfunction. Droll, Perna, Potter, Harniman, Schemitsch, and McKee[13] found that in 30 subjects, who were an average of 5.4 years after surgical fixation of BBFF, available wrist flexion ROM was moderately correlated (r = .51, p = .004) with self-reported measures of hand limitation per the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire.

Pain. Ozkan, Keskin, Bodur, and Barça[26] reported that a sample of elderly persons living with hand osteoarthritis (n = 100) reported Visual Analog Scale pain ratings which significantly correlated (p = 0.001) with two standardized measures of hand function (i.e., Dreiser's Functional Index and the hand disability index of the Health Assessment Questionnaire) as well as grip strength, lateral pinch, and palmar pinch measures (p = 0.001).

Hand Force Changes among Older Adults

The aging hand has been studied in detail and many age-related declines in hand function are reported throughout the literature. The literature explores many dimensions of hand function across physiologic, organ, and physical levels.

Trends in older adult hand grip and pinch strength are well documented. Mathiowetz, Kashman, Volland, Weber, Dowe, and Rogers[27] reported that in a sample of adults (n = 638) aged 20 year and older, average MVC grip strength scores began to steadily decline between 55 and 59 years regardless of gender and reported that there were moderate negative correlations between age and right grip strength (r=-0.62), left grip strength (-0.64), and right 3-point pinch (-.51) (i.e., that advancing age was accompanied by lower average MVC grip strength). In a meta-analysis of the average grip strength measures of persons 75 years and older (n = 739), Bohannon, Bear-Lehman, Desrosiers, Massy-Westropp, and Mathiowetz[28] reported progressively weaker s MVC grip strength (Q = 29.715, p < 0.001) across 4 age groups (75-79, 80-84, 85-89, and 90-99).

Ranganathan, Siemionow, Sahgal and Yue[29] compared measures of grip strength, maximum pinch force (MPF), and ability to maintain a steady sub-maximal pinch force at three force levels (2.5 N, 4 N, and 8 N) between groups of well and independent young and old participants. When the groups were compared, younger subjects' grip force was, on average, 70% stronger (p < .001) than the older subjects; younger subjects' maximal pinch force was 74% higher (p < .05), and their ability to maintain steady submaximal pinch force in a precision pinch posture was also significantly greater (p < .05). The researchers concluded that aging had an adverse effect on hand function, including declines in hand and finger strength and ability to control submaximal pinch force so as to maintain a steady precision pinch posture. Likewise, Potvin, Synulko, Tourtellotte, Lemmon, and Potvin[30] studying 61 men of ages spanning 20-80 years, found that more than 50% of all age-related declines were related to steadiness of submaximal hand-forces, speed of movement, and ability to sense vibration.

Osteoarthritis and Hand Function

Various age-related conditions have been found to predispose older adults to hand impairment. Repetitive stress injuries are thought to be more common among the elderly because they utilize a greater percentage of their MVC grip strength during ADL and grip forces exceeding 15-20% of MVC grip strength may be linked these conditions[31,32].

Another example, the population of interest in this study, is arthritis. Symptomatic hand osteoarthritis affects 1 in 12 persons (2.9 million) in the United States and significantly increases with age (95% CI, 1.44-8.36) as reported by Dillon et al.[33]. Twenty-one million individuals living in the U.S. are estimated to have this form of arthritis which is most common in women over 55 years of age[34].

The previously referenced prevalence of arthritis among older women and the ever increasing prevalence of persons over the age of 65 warrants an exploration of how various types and locations of arthritic presentation will affect occupational performance and, in the interest of this study, how the presence of arthritis affects hand function.

Some scholarly work has shared this focus. Dominick et al [35] studied whether radiographically evident hand OA (n = 700) was associated with hand grip/pinch strength and found that the presence of OA in the 1st hand ray (i.e., thumb) to be most significantly correlated to reduced grip and pinch strength ($b = -11.08$, $p < 0.001$, and $b = -2.05$, $p < 0.001$ respectively). The authors also reported significant associations between hand joint OA severity, as indicated per Kellgren and Lawrence[36] grades, and hand grip and pinch strength ($b = -0.67$, $P < 0.001$ and $b = -0.16$, $p < 0.001$ respectively).

Bagis, Sahin, Yapici, Cimen, O.B., and Erdogan, C.[37] studied 100 post-menopausal women with hand osteoarthritis and 70 gender matched healthy controls. Eighty-six percent of the subjects with hand OA were suffering from pain and 57 % were found to have tenderness. Grip and pinch strength were significantly lower ($p<0.05$) and Dreiser's Functional Index[38] scores were significantly lower ($p<0.001$) when compared to the controls.

Several problematic manual tasks have been described throughout the arthritis literature however difficulty associated with opening jars has been pervasive. For example, jar-opening has been identified as being one of the top three[39]or four[40] most commonly reported problematic activities for women with hand osteoarthritis.

Task Specific Hand Forces

Much attention has been given to population and diagnosis specific incidence of hand grip/pinch strength impairments and how grip and pinch strength predict or relate to task performance performance[17,19,41]. However, to this date, few have attempted to establish task-specific grip and pinch force requirements.

Nalebuff and Philips[42] stated that, based on their clinical experience in rheumatology and hand rehabilitation, one needs to have 20 lbs of grip and 5-7 lbs of pinch strength to be independent in activities of daily living (ADL) however their assertions were made without any data to substantiate them.

Berns[43] instrumented containers with strain-gauges and reported that, for the normal population, the necessary torque to successfully manage a large jar to be 40 in-lbs. Imrhan and Loo[44] observed that non-disabled women, on average, applied 39 N of MVC grip force when twisting textured jar lids and that hand grip explained 41-67% of the torque generated.

Rice, Leonard, and Carter[45] examined the pinch and grip forces exerted on six common household containers among healthy college-aged participants, while Rahman, Thomas, and Rice[46] continued this work and studied functionally independent, well-elderly participants. Unfortunately, thresholds were not able to be determined given that, across both studies, grip/pinch measures were all within normal limits and the participants were all successful when accessing the six containers. Rahman, Thomas, and Rice[46] did, however, suggest that the elderly participants utilized a greater percentage of their MVC to access the containers. The authors questioned if sampling from a population of persons living with hand-grip or pinch impairments or clinical populations might yield data to explain how little grip or pinch strength is required to participate successfully in various daily occupations.

Aside from the limited amount of research done to explore this topic, there are issues with the nature and sensitivity of the methods used to gather relevant grip force data. Four methods of measuring the grip forces acting upon objects are reported in the literature. As previously discussed, Rice et. al[45]and Rahman et al.[46] instrumented 8 common household containers with force sensing resisters. Fowler and Nicol[47] quantified the forces acting on interphalengeal (IP) joints during simulated functional tasks (i.e., twisting a jar lid, twisting a water bottle cap, and turning a key). In their study, a force transducer was incorporated into the body of the aforementioned objects to quantify the pinch forces of one digit acting on the object and video motion analysis was used to collect kinematic data. With this information they were able to extrapolate data to determine the reactive forces acting on the distal and middle IP joints across the simulated tasks. Others have instrumented the hand with adherent FSR[48] or through wearing a FSR embedded glove[49].

These instruments, however, are all flawed in that they change the natural condition of the tasks being studied. The glove with FSR and skin adherent FSR would presumably alter one's sensory experience and resultantly skew grip-force modulation and precision skills. Conversely, instrumenting the objects with FSR would change the object properties making the task less representative of what it is that you're attempting to measure. Theses sensors are also likely to experience skin slip. Although the hand would be free from a muffled tactile experience, the artificial objects used in the simulated tasks presented by Fowler and Nicol[47] would more than likely not represent the dimensions and textures of an object in its natural form and therefore the results would appear to have poor face validity.

The type of force meters utilized in previous works may also have influence the results. Rice, Leonard, and Carter[45] and Rahman, Thomas, and Rice[46] reported their FSR to be incapable of reading forces not perpendicular to them and therefore forces not applied to the sensors at a 90 degree angle may have been omitted or skewed. Resultantly, the quantification of the required grip and pinch forces was over-simplified.

Aims of the Study

An aging population challenged by disabling conditions such as arthritis and subsequent activity limitations, a large body of literature supporting that grip strength influences function, and a well-documented prevalence of hand-grip impairments among older women with hand arthritis collectively warrant attention.

Specifically, there is the need to explore how much hand force is required of older women with arthritis to successfully complete commonly problematic manual tasks. This investigation should also involve determining which approaches are most ergonomic and successful. To this end, a scientific yet ecological exploration is needed which should include capturing the various hand grip forces acting upon the object of focus (i.e., non-normal forces) as well as other measures of hand function believed to influence success.

The chosen activity to be instrumented should be perceived as meaningful and a common a source of difficulty for women with hand arthritis.

1. Reliability and Validity of a Novel Instrument for the Quantification of Hand Forces during a Jar Opening Task (Chapter 2).

The first aim of the study is to investigate the accuracy, within session intra-tester repeatability, and ecological validity of a novel force-sensing jar instrument which is later used to address research aims 2-4. This novel instrument was developed to appear and feel true-to-form, and capture a comprehensive profile of hand forces acting upon a jar lid when opening a sealed jar. Moreover, this tool was developed in such a manner to address the previously described design and procedural issues. In chapter two, this aim is formulized and investigated.

The research hypotheses are as follows:

1) The instrument will have an acceptable accuracy of ~95%,
2) The instrument will yield high within session repeatability (i.e., ICC of $\geq$.6), and
3) Participants will report the task of opening a jar to be meaningful and the instrument to be similar to commonly encountered jars.

2. Differences in the hand force requirements of women with hand arthritis when opening jars with and without joint protection strategies (Chapter 3).

The second aim of this project is to examine if hand force profiles differ by 1) the hand turning the lid, 2) two grasp pattern types, and 3) the use of a non-skid material. The rehabilitative literature presumes that joint protection strategies such as the use of nonskid materials decrease the loading of arthritic joints[50]. Although, combined interventions of exercise, orthotic wear, and joint protection strategies have been successful in reducing pain, improving hand strength and improving self-reported activity levels[51,52], a basic science exploration of the effects of a single intervention, joint protection, on force requirements during commonly problematic tasks (i.e., jar opening) has not been performed. In chapter 4, the independent and combined influence of a joint protection strategy, the type of hand-hold, and the hand turning the lid will be scrutinized. The hand forces and associated workload across these factors will be considered so as to determine the most efficient approach to opening a sealed jar by those of the population of interest.

The associated research hypotheses are as follows:

1) There will be no significant effect of the hand turning (right vs. left) and hand force production,
2) The grasp pattern of the hand stabilizing the base of the jar will have no significant effect on the hand force production of the turning hand, and
3) The use of a nonskid material will require significantly less hand force than without during jar opening.

3. Hand Force Requirements and Factors Influencing Success of women with Symptomatic Hand Osteoarthritis during a Jar Opening Task (Chapter 4).

The third aim of this study is to explore how the hand force and work profiles of women with hand osteoarthritis who were successful in opening a sealed jar differ from those who were not. Trends in the peak maximal hand forces and associated work (i.e., total force/time) employed by those who did and did not successfully open a ‘sealed’ jar are evaluated in chapter 3. In addition, the use of MVC grip and pinch dynamometry values as a proxy for the instrument’s output is considered.

Moreover, this chapter investigates if several measures of hand function known to affect grip force production explain 1) the forces used when opening a sealed jar and 2) successful jar turning. These variables include arthritis location, self-reported disease impact, hand sensibility, hand mobility, pain, and hand anthropometrics. Because it is presumed that the process of opening a jar is multifactorial, this investigation expands upon the question of hand force requirements to determine if and how much other factors influence the ability to generate hand forces when opening a sealed jar as well as a successful turn. Occupational therapists must have a fundamental understanding of which factors best predict success as they often work to remediate performance limitations believed to be barriers to successful engagement. This exploration is intended to enlighten the occupational therapist practitioner.

The research hypotheses are as follows:

1) Hand force thresholds for successful 'sealed' jar opening for right and left hands will be clearly defined,
2) Work requirements for successful 'sealed' jar opening for right and left hands will be clearly defined,
3) MVC grip and pinch dynamometry thresholds for successful 'sealed' jar opening for right and left hands will be clearly defined,
4) Measures of thumb mobility will be a significantly positive predictor of force generation and success,
5) Measures of pain will be a significantly negative predictor of success and force generation,

6) The presence of thumb CMC OA will be a significantly negative predictor of success and force generation,
7) Self-perceived disease impact will be a significantly negative predictor of success and force generation, and
8) Hand Sensibility will be a significantly positive predictor of success and force generation.

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Chapter 2

Reliability and Validity of a Novel Instrument for the Quantification of Hand Forces During a Jar Opening Task

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Chapter 2 Table of Contents

Introduction

An estimated 27 million adults in the U.S. are currently living with osteoarthritis[1], a condition most commonly diagnosed in women who are 55 years of age or older[1]. Nearly 10% of our population is now affected by arthritis-related activity limitations and arthritis has been reported to be our nation's leading cause for disability for nearly two decades[2].

Symptomatic osteoarthritis (OA) of the hand affects 1 in 12 persons (2.9 million) in the United States and the ratio significantly increases with age [3]. Women aged 20 years or older experience an even higher prevalence than does the general population in that nearly 1 out of 11 (9.2%) are currently living with symptomatic and radiographically confirmed hand OA[4] and these numbers climb to 75% for women aged 60 to 70 years[3]. In a sample of 87 women living with hand OA, a total of 801 total activity limitations were described per the Canadian Occupational Performance Measure (COPM)[5 6] and the sample reported experiencing a moderate disruption in performing daily activities per the Australian/Canadian Osteoarthritis Hand Index (AUSCAN)[6 7] . Thus, with the aging of America, more individuals, particularly women, will likely be affected by hand OA and with such it's also likely that a higher prevalence of moderate activity limitation will follow.

OA in the hand typically presents at the distal interphalangeal joints (DIP), the proximal interphalangeal joints (PIP), and the first carpometacarpal (CMC) joints[8] and has a multifactorial etiology (i.e., genetics, gender, age, etc.)[9]. However, amidst the shades of 'etiological gray', there is much evidence to support that "biomechanical joint stress has a substantial etiologic role" in the development and progression of arthritis[9].

Because joint stress appears to be a consistent risk factor, it deserves focused attention. Similarly, the intervention approaches used to reduce biomechanical stressors deserve attention. These investigations can be made possible through instrumenting daily objects which require heavy manual handling with force sensing technology. To date, however, that has not yet been attempted with an arthritic population. The Osteoarthritis Research Society International (OARSI) has recommended that additional research is "needed to develop and test measures to evaluate changes in response to treatment in OA related…participation in valued activities"[9].

The purpose of this study is to investigate the psychometrics of a novel instrument which has been developed to study the forces used by women during a given daily activity and to determine if joint protection strategies alter these hand forces.

Review of Literature

Many symptoms accompany hand osteoarthritis including diminished grip strength. Dominick et al.[10] studied whether radiographically evident OA in specific digits (n = 700) was associated with a loss of hand grip/pinch strength, They found that the presence of OA in the 1st hand ray to be significantly predictive of reduced grip and pinch strength ($b = -11.08$, $p < 0.001$, and $b = -2.05$, $p < 0.001$ respectively). The authors also reported that hand joint OA severity, as indicated per Kellgren and Lawrence[11] grades, was significantly predictive of hand grip and pinch strength ($b = -0.67$, $P < 0.001$ and $b = -0.16$, $p < 0.001$ respectively).

Bagis, et al.[12] studied 100 post-menopausal women with hand osteoarthritis and 70 gender matched health controls. Eighty-six percent of the subjects with hand OA suffered from pain and 57 % reported joint tenderness. Grip and pinch strength were significantly lower ($p<0.05$) and hand function were significantly lower ($p<0.001$) when compared to the controls. Among women with hand OA, grip/pinch force and pain during grip force explains 55% ($p<0.0001$) of AUSCAN function score and 33% ($p<0.0001$) of COPM performance scores[6].

Activities most commonly reported to be difficult are those believed to require maximum gripping and twisting capabilities specifically, opening a jar, twisting a washcloth, and opening a prescription bottle[6 10].

Although hand strength is known to be associated with hand arthritis among women and is believed to explain much of the variance in women's ability to perform manual activities, none have quantified the hand force requirements of activities/occupations known to affect women with osteoarthritic hands. In fact, few have attempted to establish task-specific hand force requirements in normal or aging populations.

Nalebuff and Philips[13] stated that one needs to have 20 lbs of maximum grip strength and 5-7 lbs of maximum pinch strength to be independent in activities of daily living (ADL). However, their assertions were based on their clinical experience in rheumatology and hand rehabilitation, rather than specifically collected data.

Berns[14] instrumented containers with strain-gauges and reported that, for the normal population, the necessary torque to successfully manage a large jar to be 4.24 N*m. Imrhan and Loo (1988) observed that non-disabled women, on average, applied 39 N of maximum voluntary contraction (MVC) grip force when twisting textured jar lids and that hand grip explained 41-67% of the torque generated.

Rice, Leonard, and Carter[15] examined the pinch and grip forces exerted on six common household containers among well college-aged, while Rahman, Thomas, and Rice[16] continued this work and studied functionally independent, well elderly participants. Unfortunately, thresholds were not able to be determined given that, across both studies, grip/pinch measures were all within normal limits and the participants were all successful when accessing the six containers. Rahman, Thomas, and Rice[16] did, however, suggest that the elderly participants utilized a greater percentage of their MVC to access the containers. The authors questioned if sampling from a population of persons living with hand-grip or pinch impairments or clinical populations might yield data to explain how little grip or pinch strength is required to participate successfully in various daily occupations.

Aside from the limited volume of research done on this topic, there are issues with the nature and sensitivity of the methods used to gather relevant grip force data. Four methods of measuring the grip forces acting upon objects are reported in the literature. This includes placing the force sensing units on the interior of the device, on the exterior of the device, directly on the hand or within a force sensing glove.

As previously discussed, Rice et. Al.[15]and Rahman et al.[16] instrumented the surface of 8 common household containers with force sensing resisters. Fowler, and Nicol[17] quantified the forces acting on interphalengeal (IP) joints during simulated functional tasks (i.e., twisting a jar lid, twisting a water bottle cap, and turning a key). In their study, a force transducer was incorporated into the body of the aforementioned objects to quantify the pinch forces of one digit acting on the object and video motion analysis was used to collect kinematic data. With this information they were able to extrapolate data to determine the reactive forces acting on the distal and middle IP joints across the simulated tasks. Others have instrumented the hand with adherent force sensing resistors (FSR)[18] or with a FSR embedded glove[19].

These instruments, however, are all flawed in that they change the natural condition of the task being studied. An FSR glove, whether in or adhered to skin would presumably alter sensory experiences and resultantly skew grip-force modulation and precision skills. Conversely, instrumenting the objects with FSR would change the object properties making the task less representative of the real experience. These sensors are also likely to experience skin slippage. Although the hand would be free from a muffled tactile experience, the artificial objects used in the simulated tasks presented by Fowler and Nicol[17] no longer represent the dimensions and textures of an object in its natural form and therefore the results would appear to have impaired face validity.

The type of force sensor may also have influence the results. Rice, et al.[15] and Rahman et al.[16] reported that their FSR were incapable of reading forces that were non-perpendicular to them therefore forces not applied to the sensors at a 90 degree angle may have been omitted or skewed. Resultantly, the quantification of the required grip or pinch forces was over-simplified.

The void in the literature on hand force requirements as well as the absence of appropriately designed instrumentation have necessitated a novel approach to developing instruments which are true-to-form and do not alter the person-object interface. Although women with hand arthritis have reported three manual tasks to be most problematic[6], the task of opening a sealed jar was chosen to be instrumented for this study given that 1) jar opening has been reported to be the most commonly problematic activity and 2) household jars were suitable for housing the instrumentation required to quantify forces without substantially changing the properties of the object.

Given that the current study's tool was developed based on the qualities of a large-jar for the purpose of descriptively reporting within-person differences across several trials of jar opening efforts within a single session, the tool's face validity and intra-rater reliability must first be determined. After validity and reliability are established, the tool will be able to be used to 1) measure of hand force requirements for women with hand arthritis for the purposes of rehabilitation goal setting and informing industry on human factors as well as 2) measure the kinetics of joint protection approaches.

The aim of the present study is to investigate the tool's accuracy, within session intra-tester repeatability, and ecological validity, of the novel force-sensing jar instrument.

The research hypotheses are as follows:

1) The instrument will have an accuracy of ~95%,
2) The instrument will yield good to excellent within-session repeatability (i.e., ICC of $\geq .6$), and,
3) Participants will report the task of opening a jar to be meaningful and the instrument to be similar to commonly encountered jars.

Methods

Development and Bench Testing

The jar instrument was conceptualized by occupational therapy and biomedical engineering professionals and later designed and fabricated. The design of the jar's exterior was constructed to replicate, as best as possible, the look and feel of a large household jar with the lid of the jar being that of an actual peanut butter jar and the base (105 mm x 83 mm) being made from a plastic similar to the base of a peanut butter jar. The weight of the instrumented jar was 822.1 grams (29oz) slightly lighter than an unopened large-sized jar of peanut butter (907.2 g or 32 oz). Additionally, a generic product label was affixed to the jar's exterior to obscure the participant's view of the internal instrumentation and to better represent the true form of a jar (Figure 2.1).

Figure 2.1. Jar Instrument

The diameter of jar base and lid was 83 mm, the optimally accessible jar lid diameter across hand anthropometrics[20]. A lid height of 20 mm is a common height for lids of this diameter; however, lid height has non-significant effects on the ability to generate opening torque on a jar lid[21], so it would appear inconsequential to the design.

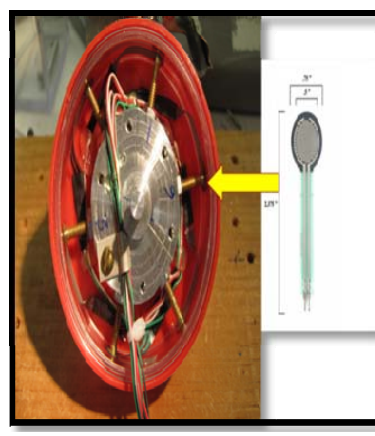
Figure 2.2. Force Sensing Resistor Placement

The jar was outfitted with 6 force sensing resistors (FSR) equally spaced radially around the lid (Figure 2.2). In addition to the FSRs, a load cell and torque limiter was centrally affixed to the lid (Figure 2.3).

Figure 2.3. Load Cell and Torque Limiter Setup

The AMTI FS6-100 six degree of freedom load cell, was chosen to measure the axial (Fz), tangential (Fy) and normal (Fx) forces acting upon the jar lid as well as torques about these axes. The force range/resolution of the load cell in the normal (x) and tangential (y) directions was ±185 / 0.090 N, and in the axial (z) direction ±445 / 0.362 N. The load cell's torque range/resolution was ±3.76 / 0.0018 N·m about the x and y axes and was ±4.70 / 0.0023 N·m about the z axis. The device is reported to have excellent repeatability and accuracy[21]. To record the handgrip forces acting upon the lid, the lid was equipped with the aforementioned FSRs. The 5 mm FSR has a maximum force capacity of 100 N and resolution of 0.024 N. When comparing the jar lid's FSR force output to known loads applied via precision 'F2' class weights to portions of the lid which corresponded with each FSR, the combined accuracy of the 6 FSRs was 94%. This is consistent with the 6% error reported by the manufacturer[19] and in the absence of an industry standard, was determined to be acceptable.

The torque limiter allowed the jar to open when torque equaled or exceeded 41.5 in-lbs or 4.24 N*m, when the jar lid would open freely for 45º and then stop. The aim was to provide a standard experience similar to opening a sealed jar that would be identical for all research participants. We followed the industry practice of sealing the lid with a torque equivalent to ½ the lid's diameter[22] when constructing the apparatus.

Reliability testing in an 'upper limb healthy' population

Participants. Following IRB approval (IRB# 0908M71484) and informed consent, a convenience sample of 29 women, participated in two trials of 'opening' the sealed jar with their preferred hand. Approximately thirty subjects were needed for sufficient statistical power (Beta = .20, alpha = .05) according to Walter, Eliasizw, and Donner's[23] proposed formula for determination of such. Consent and IRB approval forms can be found in appendix 2A.

Participants were eligible to participate if they were female, 18 years or older, and free of hand or wrist pain as well as any self-reported diagnoses which impacted the distal upper quadrant. Healthy subjects were the focus of this pilot phase in an effort to measure repeatability of the jar turning task in those less prone to injury prior to considering using it with a population at risk for exacerbation of upper limb symptomology. The average age of the participants was 24.5 (±5.8) years and 89.7% self-identified as being Caucasian, 6.9% Asian American, and 3.4% Native American. Three subjects reported being left hand dominant and the remaining 26 indicated their right hand was preferred.

Procedure. While in a standing position, all participants were instructed to keep both shoulders fully adducted and between 30 and 45 degrees of internal rotation; the elbow of the stabilizing hand between 60 and 90 degrees of elbow flexion with the forearm in neutral; and the elbow of the limb grasping jar lid placed in 90 degrees of elbow flexion with forearm in full pronation and hand with pads of all digits in contact with the lid in a power grasp pattern[24] (See Figure 2.4). Participants were given 30 seconds rest between 2 trials.

Figure 2.4. Standardized Position

Participants were instructed to maintain standardized glenohumeral, ulnohumeral joint positions as well as hand placements to control for any distal kinetic variance that might result from non-standardized posturing.

Figure 2.5. Experimental Setup.

Instrumentation. Force signals from the load cell were amplified via an AMTI MSA-6 amplifier (AMTI, Watertown, MA). An NI USB-6215 (National Instruments) data acquisition board was used to convert FSR and load cell analogue input into a digital output. A laptop with LabVIEWVersion 8.2 (National Instruments, Austin, TX) data acquisition software processed and transformed data. Matlab Version 7.9 software (Mathworks, Natick, MA) was used to compute peak forces and moments for the load cell output and peak forces for the 6 FSR. Figures 2.5 and 2.6 illustrate the experimental setup.

Statistical Analysis. SPSS version 22 (IBM) was used to sum FSR peak forces, calculate within and between subjects mean differences and standard deviations between trials 1 and 2, intraclass correlation coefficients (ICC), standard error of the measurement (SEM), and minimal detectable difference (MDC). Within session (intratester) repeatability of peak forces was determined through the use of a mixed model for fixed effects (type 3,1) ICC as recommended by Portney and Watkins[29]. Stability of the measure was determined through SEM. The SEM is calculated by taking the Pooled SD of the trials*(1-ICC)[25]. To determine the smallest amount of change in measurements that one can be 95% certain is not due to chance, the Minimal Detectable Change (MDC) was determined. The formula for calculating the MDC is as follows: $MDC = (1.96*\sqrt{2})*SEM$[25].

Figure 2.5. Data Acquisition Board (left) and Load Cell Amplifier (right).

Reliability in Women with Hand Osteoarthritis

Participants. Following IRB approval (IRB# 0908M71484) and informed consent, 31 women, 18 years or older, with hand osteoarthritis participated in two trials of ‘opening’ the sealed jar with both their right and left hands. Approximately thirty subjects were needed for sufficient statistical power (Beta = .20, alpha = .05) according to Walter, Eliasizw and Donner’s[23] proposed formula for determination of such. Participants were recruited through orthopedic, women's health, and hand therapy clinics, as well as community-based centers which served older adults. Consent and IRB approval forms are in Appendix 2B.

Participants were eligible for the study if they were female, over the age of 18, and 1) had radiographicially confirmed and symptoms of arthritis or 2) a combination of self-reported physician diagnosis and symptoms (i.e., achiness and stiffness) of hand OA. Although recruiting subjects through orthopedic and hand therapy clinics would likely always yield documented radiographic confirmation of hand arthritis, a homogenous sample of women with hand symptomology so severe that care was sought out, would not represent well the heterogeneous spectrum of disease impact and severity. Recruiting through community-based organizations and women's health clinics opened the door to participants who were likely less impacted by their hand symptomology. However, the desired radiographic confirmation of this was not accessible. Thus, the study included participants who both reported a physician rendered diagnosis of hand oseteoarthritis and who reported symptoms of hand osteoarthritis. This combination of criteria was chosen because Szoeke et al.[26] found that this combination yielded the highest sensitivity (70.5%) and specificity (68.0%) when compared to the gold standard of radiography. Recruits were excluded from participating if any one of the following were present:

- Movement disorder with upper limb manifestation (e.g., Parkinson's, stroke, head injury, intentional tremor)
- Amputations in the upper limb
- Any history of hand joint arthroplasty

- Trauma within last 6 months that had increased symptoms that were non-arthritic in origin
- diagnosis of concurrent hand/wrist conditions such as CTS or tendonitis
- Hand deformities that do not allow for grasp of instruments
- Strength testing is contraindicated due to medical co-morbidities

The average age of the participants was 63.7 (±13.9) years and 83.3% self-identified as being Caucasian, while the remaining 16.7% identified themselves as being African American. Twenty-eight subjects reported being right hand dominant, 2 were ambidextrous, and 1 was left hand-handed. Seventeen participants had radiographically confirmed hand arthritis in one or both of their hands whereas 14 reported having a physician diagnosis and demonstrated symptoms of arthritis (e.g., pain, stiffness).

Instrumentation. Using the previously mentioned experimental setup and standardized positioning when opening the jar, participants completed two trials of opening with each hand in a randomized fashion. Thirty second rest periods were again offered between trials. Beyond the jar turning, participants were asked to complete a questionnaire which, in addition to collecting demographic information, was used to help isolate the location of the arthritis when the diagnosis was self-reported (see Appendix 2C). Participants also completed the short version of the Arthritis Impact Measure 2 (AIMS2-SF)[27] to assist in the characterization of the impact of the conditions on the sample of interest. The AIMS2-SF (see Appendix 2D) is widely used and focuses on several domains of health and activity limitations. Moreover, an upper limb subscale allows the evaluator to isolate the effects of upper limb arthritis on health and activity. All subscales are reported on a 0-10 scale with ‘0’ being “good health” and ‘10’ being "poor". Likewise, a composite or "Total Health score is reported on a 40 point scale with '0' again being "good health" and 40 being "poor" [27]. The tool is reported to have good to excellent reliability and strong concurrent validity with the Health Assessment Questionnaire (HAQ)[28]. Statistical analyses were performed as previously described in the 'Upper Limb Healthy' methods.

Results

Reliability of instrument in women with 'healthy' upper limbs

Each participant completed two trials of jar turning while using their preferred hand; all succeeded in opening the jar on both trials. Mean within-person differences in force and torque output were not significantly different from zero and are given with the corresponding ICC, SEM and MDC in table 2.1. The mean difference of the force output between trials 1 and 2 ranged from 2.43 to 5.45 Newtons (N) and the mean difference for the torque outputs varied from .004 to .007 Newton-Meters, none of which were significantly different. The within session intra-rater ICC (3,1) values ranged from .60-.76 across all peak forces and torques. Standard Error of the Measurement values varied from .37-1.60 N as it pertained to the force output and between .01 and .001 Newton-Meters (N*m) for the torque output. The MDC values varied from 1.03 to 4.43 N across all force output whereas the MDC for all torque output ranged from .03 to .003 N*m.

Table 2.1. Pilot Data Within–Subjects Mean Differences, Interclass Correlation Coefficients, Standard Error of Measurement Values for Grip, Axial, Normal, and Tangential forces acting upon a Jar Lid (n=29 healthy participants, 29 sets of two jar turning trials).

Force	Mean Diff. (SD)	Pearson R (p value)	ICC (95%CI)	SEM	MDC
Grip	5.29 (4.00)	0.60(.001)	0.60 (.30-.79)	1.60	4.43
Normal Force (Fx)	2.53(1.70)	0.67(<.001)	0.65 (.38-.82)	0.58	1.60
Tangential (Fy)	4.89(3.61)	0.61(<.001)	0.61 (.32-.80)	1.41	3.91
Axial (Fz)	5.45(1.29)	0.71 (<.001)	0.71 (.47-.85)	0.37	1.03
Mx	0.007(.005)	0.75 (<.001)	0.75 (.53-.87)	0.01	0.03
My	0.004(.003)	0.77(<.001)	0.76 (.55-.88)	0.001	0.003
Mz	0.0005(<.001)	0.67 (<.001)	0.65 (.38-.82)	0.001	0.003

Note: Forces are reported in Newtons. Moments are reported in Newton-Meters. “Grip” force is the sum of the peak forces of the 6 FSR. ICC = Interclass Correlation Coefficient, SEM = Standard Error of Measurements, and MDC = Minimal Detectable Change. SEM = Pooled SD*(1-ICC); MDC = (1.96*√2)*SEM.

Reliability and validity testing in women with hand osteoarthritis

Reliability. The severity of arthritis symptoms appeared to be, on average, mild to moderate in nature (x=3.47, SD=2.24). Currently, however, there are no criteria for interpreting AIMS2-SF data as the authors only qualify that a subscale score of ‘0’ indicates “good health” while a score of “10” equates to “poor health”. Similarly, AIMS2-SF also revealed that participants had an average Total Health Score of 10.6/40 (SD=5.3) which, in

Table 2.2. Summary Statistics for Arthritis Impact Scale 2 – Short Form

	Mean	Standard Deviation
Physical Function	1.81	1.4
Symptoms	3.47	2.2
Affect	2.32	1.9
Upper Limb Disability	1.31	1.2
Total Health Score	10.6	5.3

Note: Total health score includes all areas of function, with scores ranging from zero (no effect on function) to 40 (severely affected). Physical function, Symptom, Affect, and Upper Limb disability subscales are interpreted similarly yet on a 0-10pt scale where ‘0’ is no effect and ‘10’ is severely affected.

the absence of interpretation criteria, might imply that overall perceived health was mildly impacted by the condition. Participants also reported mild disease impact in the physical, upper limb, social, and affective subscales. These findings are summarized in Table 2.2. Only 12 subjects (39% of the sample) had employment of some kind so the work subscore was not calculated nor included in the total health equation.

On average, participants had two digits affected by OA in both right and left hands (2.1±1.5 and 2.0±1.5 respectively). Ninety percent of participants had

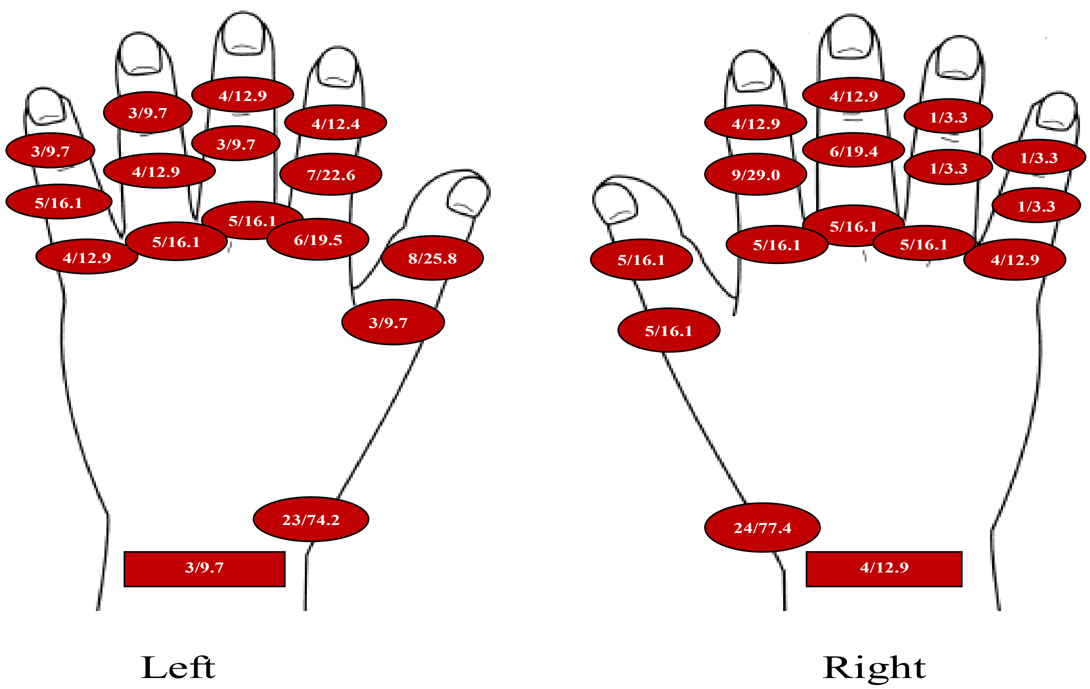

Figure 2.7. Distribution of joint involvement by hand.
Note: Text boxes describe the number of participants with osteoarthritis in the underlying joint (left number) and associated percentage (right) of the sample with involvement in that joint.

radiographically confirmed or self-reported thumb OA, 45% index finger, 42% long finger, 23% ring, and 29% in the small fingers of at least one hand. This varies from the distribution patterns described in the literature where index, middle, and small fingers are most often radiographically confirmed[33] but is expected given that the presence of 1st CMC OA, when compared to interphalengeal hand arthritis yields significantly worse hand function and symptomology (p<.01)[30]. A sample comprised heavily of women with 1st CMC arthritis would be expected given that 17 participants were recruited from orthopedic clinics where arthritis care is typically sought out only when symptomology and function warrant. See figure 2.7 and table 2.3 for the joint-specific distribution of affected arthritic joints by hand.

Table 2.3. Total Number and Percentages of Participants with Hand Arthritis, Bilateral Involvement, and single limb involvement by joint.

Digit/Joint	Participants with Joint Involvement	Participants with Bilateral Involvement	Participants with only right Involvement	Participants with only left Involvement
Wrist	5(16.2%)	2(6.5%)	2(6.5%)	1(3.2%)
Thumb				
CMC	26 (83.9%)	21(67.7%)	3 (9.7%)	2 (4.5%)
MP	5 (16.1%)	3(9.7%)	2(4.4%)	0 (0%)
IP	8 (25.8%)	5 (16.1%)	0 (0%)	3 (9.7%)
Index				
MCP	8 (25.8%)	3(9.7%)	2(6.5%)	3 (9.7%)
PIP	11(35.5%)	5 (16.1%)	4 (12.9%)	2(4.5%)
DIP	8(25.8%)	8 (25.8%)	0 (0%)	0 (0%)
Long				
MCP	6 (19.5%)	4 (12.9%)	1 (3.3%)	1(3.3%)
PIP	6 (19.4%)	3 (9.7%)	3 (9.7%)	0 (0%)
DIP	4 (12.9%)	4 (12.9%)	0(0%)	0(0%)
Ring				
MCP	6(19.5%)	4(12.9%)	1(3.3%)	1(3.3%)
PIP	4(12.9%)	1(3.3%)	0(0%)	3(9.7%)
DIP	3(9.7%)	1(3.3%)	0(0%)	2(6.5%)
Small				
MCP	5(16.1%)	3(9.7%)	1(3.3%)	1(3.3%)
PIP	5(16.1%)	1(3.3%)	0(0%)	4(12.9%)
DIP	4(12.9%)	0 (0%)	1(3.3%)	3(9.7%)

One participant was unable to successfully participate in the 4 trials of jar turning due to her arthritic symptoms. All others were able to fully participate in 4 trials (2 trials for both right and left hands). As in the healthy controls, mean within-person differences in force and torque output were not significantly different from zero (table 2.4). The mean difference of the force output between trials 1 and 2 ranged from 1.60 to 7.01 N and the mean difference for the torque outputs ranged from .008 to .06 N*m. Within session intra-rater ICC (ICC 3,1) values ranged from .68-.99 across all peak forces and torques. Standard Error of the Measurement values varied from .03-3.97 N as it pertained to the force output and between <.001 and .02 N*m for the torque output. The MDC values varied from .08 to 11.01 N across all force output whereas the MDC for all torque output ranged from .03 to <.003 N*m.

Table 2.4. Pilot Data Within-Subjects Mean Differences, Interclass Correlation Coefficients, Standard Error of Measurements Values for Grip, Axial, Normal, and Tangential forces acting upon a Jar Lid (n=31 participants with hand OA, 58 turns).

Force	**Mean Diff. (SD)**	**Pearson R (p)**	**ICC (95% CI)**	**SEM**	**MDC**
Grip	6.84 (9.28)	0.87(<.001)	0.87(.79-.93)	1.21	3.35
Normal Force (Fx)	7.01 (14.71)	0.65(<.001)	0.63 (.44-.77)	3.97	11.01
Tangential (Fy)	1.65 (2.99)	0.99(<.001)	0.99 (.98-.99)	0.03	0.08
Axial (Fz)	1.60 (2.95)	0.99 (<.001)	0.99 (.99-1.0)	0.03	0.08
Mx	0.008 (.025)	0.99(<.001)	0.99 (.99-1.0)	0.001	0.003
My	0.06 (.09)	0.76 (<.001)	0.76 (.62-.85)	0.02	0.06
Mz	0.04 (.08)	0.98 (<.001)	0.99 (.97-.99)	0.002	0.006

Note: Forces are reported in Newtons. Moments reported in Newton-Meters "Grip" force is the sum of the peak output of 6 FSR, ICC = interclass correlation coefficient, SEM = Standard Error of Measurements, and MDC = Minimal Detectable Change. SEM = Pooled SD*(1-ICC). MDC = (1.96*√2)*SEM.

Validity. All participants with hand OA were asked to complete a face validity survey after their experiences interacting with the jar instrument (see appendix 2E). The majority (87%, n=27) reported that attempting to 'open' the jar instrument was similar to their experiences at home and 87.5% (n=27) reported that a similar jar was used at least 2-3 times monthly if not more often (table 2.5).

Table 2.5. Self-Reported Frequency of opening jars similar to the instrument (n=31)

	never	**2-3x/ month**	**1x/week**	**2-3x/week**	**4-6x/week**	**1x/daily**
n/% Total	4/12.9	4/12.9	10/32.26	7/22.58	3/9.68	3/9. 68

Participants used a modified version of the Canadian Occupational Performance Measure (COPM)[35] to rate their perceived importance of opening jars and satisfaction in their ability to open a jar. Like in the COPM, participants scored the 'importance' and 'satisfaction' of the task on 10 point scales. Scores of '1' indicated that the task had little importance or that their performance provided little satisfaction whereas ratings of '10' indicated high importance/satisfaction. When asked to rate "how important it is for you to be able to open a jar", the mean rating was 8.7(SD = 2.5), and the mode was10. Conversely, when asked to "rate your satisfaction in your ability to open a jar" using a similar COPM-like 10 point scale, participants reported a median score of 5.6 (SD = 2.5) and mode of 7.

Discussion

In this study, the standardized procedures and instrumentation yielded good to excellent within session repeatability in a homogenous sample of young women with no known upper limb symptomology or dysfunction. Given that homogenous samples generally yield lower repeatability[29] and given that no adverse events occurred when testing women without known upper limb dysfunction, a decision to test women with hand arthritis was justified.

In the 'normal' sample, the repeatability of torque about the y-axis [M(y)] was most repeatable (ICC = .76) whereas grip force, force in the y-direction [F(y)] and torque about the z-axis [M(z)] were the least repeatable (ICC of .60, .61, and .65 respectively). Given that persons without hand arthritis appeared able to generate the pure torque necessary for opening the jar [M(z)] with ease and little between-subject variance (SD of .003 N*m), a lower ICC value was produced. This was likely because those with normal hand function are less likely to use inefficient turning patterns (i.e., generating torque about the y and x axes). Conversely, the lower ICC values for grip and F(y) are likely explained by the higher within-subject variance between trials 1 and 2. This larger variance is likely to be the result of the motor learning that occurred after the participant's first exposure to the jar.

The sample of participants with hand arthritis presented with what appeared to be moderate symptomology but only mild functional impact per the AIMS2-SF findings. The presence of at least moderate symptomology would have been expected given that the majority of participants (i.e., 17/31) came from clinical settings where care was being sought to address arthritis-related symptoms. Similarly, given that all participants were community dwelling, mobile, and actively engaged, the functional impact of their moderate symptoms, as measured by the AIMS2-SF, was understandably lower.

Repeatability. Good to excellent repeatability (ICC range of .63-.99) was found in the arthritic sample. The lowest ICC values were found for compression forces perpendicular to the jar [F(x)] and Torque about the y-axis [M(y)] (ICC = .65 and .76 respectively. These lower reliability scores were not surprising given the sample's strong representation of persons with 1^{st} CMC OA and the pain commonly experienced when compressing into the thenar region/using a lateral pinch, inconsistent application of forces perpendicular to the jar and 'jar lid-tipping' torques likely initiated by the thenar eminence.

When comparing the results of the normal and arthritic samples, those without known hand dysfunction had relatively lower ICC values. As noted earlier, lower ICC values were expected because they are a function of both within subject and between subject varience[29] and because 'normal' populations are generally more homogenous than clinical populations, The within subjects variances are reported in tables 2.1 and 2.4 in the form of standard deviations (SD) however the between subject values are not. When comparing the between subjects differences of trials 1 and 2 for those with and without arthritis, the SD of the 'between subjects' differences of those with arthritis was notably higher [e.g., 50.9 vs. 29.6 for grip force, 69.2 vs. 13.7 for F(x), and 0.49 vs. 0.02 for M(y)]. See Table 2.6 in the Appendix 2F for details. The clinical sample's lowest ICC value of 0.65, although still good, is likely explained by the large within subject variance between trials 1 and 2.

Overall, the good to excellent repeatability may be ascribed to well defined standardized processes and strong fidelity to these processes as well as to the fact that only one researcher administered the tool. The standardized positioning did constrain the proximal upper extremity to minimize the trial-to-trial variance so as to later investigate the effect of distal upper extremity positioning and joint protection interventions on hand force generation. Although this was done to enhance repeatability, the use of standardized upper limb postures added some artificiality to the experience of 'opening a jar'. This artificiality is likely reflected by the lack of 100% agreement that the experience was similar to daily encounters with a jar. Should the tool be considered for use as an outcome measure, inter-rater reliability and 'between-sessions' test-retest reliability will require further exploration. However, the good to excellent ICC values and lower SEM values noted for the clinical population demonstrate that the tool is appropriate for cross sectional descriptive or comparative studies where several within session measurements of hand forces and torques are quantified. When evaluating for differences within cross sectional studies of hand force requirements for persons with or without hand arthritis, a value of greater than the SEM of each measurement should be used to be certain that the difference is not as a result of measurement error. A more conservative estimate of true change, the 95% Minimal Detectible Change (MDC), could also be used to be used to have 95% certainty that change values greater than the MDC are not attributable to measurement error.

Validity. Also supporting the use of this tool and associated procedures in the population of interest are the face validity findings. On average, participants with hand arthritis reported that the task of jar-opening was highly important (Mean COPM Importance Score = 8.7) yet a source of dissatisfaction (COPM Mean Satisfaction Score = 5.6). This, along with the previous gap in the literature, helped to support the reasoning behind instrumenting a jar measure for use in this population. Moreover, 87% of participants reported that opening the instrumented jar was 'similar' or 'very similar' to their experiences at home. Thus, not only is jar opening an important task that is a common source of dissatisfaction for this sample but the novel tool and procedures were highly similar to their experiences at home. These findings support further exploration of hand force requirements in this population via the use of the tool and standardized procedures.

Limitations

The generalizability of the tool's repeatability to all women with hand osteoarthritis is limited by 1) the fact that the sample of women with hand arthritis reported only mild to moderate disease impact, 2) the homogeneity of the distribution of the hand arthritis and 3) the artificiality of aspects of the standardized upper limb positioning. Should the tool be used for persons with more severe arthritic symptoms or should different upper limb positioning be used, the tool's reliability in such applications would need to be re-established. In addition, the tool‘s test-retest reliability is unknown and, until such is investigated, any use as an outcome measure for longitudinal intervention studies will need to be interpreted with caution.

Although the tool has shown ecologic validity, the novelty of the tool's purpose does not permit for establishing concurrent or criterion validity as there are no similar tools for comparison.

Lastly, the design of the instrument does not capture the forces required of the hand that stabilizes the base of the jar. These forces can be presumed to be equal and opposite to the forces acting on the lid given that the role of the stabilizing hand is to counter the rotational forces being generated by the turning hand, but this is, as yet, unquantified within the literature and are not measured via this tool.

Conclusions

Opening a sealed jar is a meaningful and commonly problematic task for women with hand OA. This manual task presumably requires the ability to produce substantial hand forces and women with hand OA are known to have diminished hand force production capacity. Thus, it is critical to understand how much hand force is needed and what approaches to opening a jar can successfully lessen the forces required to complete this task. This information can inform therapists' goal-setting and joint protection interventions. Additionally, this human-factors data can be used to inform industry of the potentially-large loads placed on arthritic hands when breaking a seal.

The current study provides a novel and ecologically valid tool for the purpose of measuring the comprehensive hand force profiles of women with hand arthritis when opening a large sealed jar. The jar instrument has good to excellent within session repeatability and thus can be used to characterize repeated trials of hand force profiles in women with hand OA within a single session. Further research on 'between session' test-retest reliability and inter-rater reliability are required prior to considering this tool for use as an outcome measure in pre-post design studies.

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Chapter 3

Differences in the hand force requirements of women with hand arthritis when opening jars with and without joint protection strategies

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Introduction

Second only to the knee, the hand is a most prevalent host to symptomatic osteoarthritis[1]. Variables known to predispose a person to hand osteoarthritis (OA) or degenerative joint disease include genetics, trauma, joint laxity, imbalance of muscular strength, joint incongruences, gender, and advanced age[2] and those who most commonly experience symptoms of hand osteoarthritis (OA) are post-menopausal women over the age of sixty[3]. Symptoms of hand arthritis include stiffness, pain, and decreased strength[3]; all of which are believed to affect occupational performance, participation, quality of life, and overall satisfaction when performing daily activities[4].

As the population of women affected by arthritis grows so does the call for establishing the most effective forms and protocols of conservative hand arthritis management. Conservative treatments, including joint protection (JP) strategies, thermal modalities, orthotics, and exercise are widely used in occupational therapy practice to reduce arthritic symptoms and prevent progression[5]. The mechanisms or effectiveness of these interventions, however, remains largely understudied.

Recently, the European League against Rheumatism's (EULAR) task force on the management of hand osteoarthritis[4] acknowledged the necessity of further investigation and recommended studies that "determine the most appropriate form or combination of exercise for the different subsets of hand arthritis". The authors went on to state that the "avoidance of adverse mechanical factors" associated with joint protection training remains unproven.

This has been EULAR's position, because, although Stamm et al.[6] (2002) had demonstrated that a combined JP and hand strengthening intervention significantly improve hand strength ($p=.02$) and self-reported hand function ($p<.05$), the benefits of JP alone were unknown. New evidence[7] however, supports the independent effects of JP training. In this study, 33% of women with hand arthritis who were assigned to an occupational therapy 'joint protection only' intervention were positive "responders" as measured by the Australian/Canadian Hand Osteoarthritis Index[8,9] and per OARSI Criteria[10]. This response rate significantly differed from the 21% who had improved outcomes without JP training (p=0.03).

The previously described epidemiology, aforementioned EULAR mandate, and new evidence supporting the conservative JP intervention all warrant further exploration of OA conservative interventions, specifically JP. Although there is some modest evidence to support the clinical utility of JP, its face validity remains unquantified. The purposes of this study are to test the face validity of a commonly recommended joint protection strategy, the use of non-skid materials when opening sealed containers as well as to investigate if particular approaches to jar opening are more efficient than others.

Review of Literature

Pereira et al.[11] reported that 43.9% of adults 40 years and older are living with hand OA whereas Dahaghin et al.[12] report that 67% percent of women have radiographically confirmed OA in at least one joint of the hand by age 55. Others[13] have reported a ten-fold increase in the prevalence of hand OA between the third and fourth decades of women's' lives (1.3% to 13.5%) and a 41.1% prevalence rate in women aged 50-53.

It's well documented that persons with symptomatic hand OA often have difficulties with activities of daily living (ADLs) and instrumental activities of daily living (IADLs) due to pain and stiffness of their joints[5,14]. According to Kjeken et al.[3], the daily activities of jar turning, wringing out cloths, and opening bottles are often of most difficulty for women with hand OA.

The occupational therapist will select interventions which are 'conservative' in nature to enable engagement and social participation through 1) altering the mechanics of the occupation or the person engaging in the occupation to, in theory, reduce joint reactive forces, 2) remediate physical limitations in strength and hand mobility, 3) rest inflamed structures, and 4) minimize the experience of pain through physical agent modalities.

Conservative Interventions for Persons with Hand OA

The American College of Rheumatology (ACR) recommends that persons with hand OA visit occupational therapy to maximize joint health and function[15]. Occupational therapists provide a variety of conservative interventions for persons which are moderately supported by the literature[5,15,16]. These interventions may include use of orthotics, heat and cold modalities, exercise programs, and joint protection[16].

Exercise. Exercises that are low-impact in nature and do not cause pain or discomfort are used in treatment of hand OA[17]. Boustedt, Nordenskiold, and Lundgren[18] demonstrated that a combined intervention of exercise, splinting, and joint protection training had significantly less pain and stiffness a year post-intervention when compared to the control ($p < 0.012$). In addition, Rogers and Wilder[19] investigated the effects of a two-year isotonic grip strengthening program on radigraphically confirmed osteoarthritic hands. This three times weekly, non-descript regiment yielded significantly increased bilateral isometric ($p<.002$) and isotonic ($p<.0003$) grip strength and significantly decreased hand pain ($p<.006$).

Orthotics. Researchers have investigated the effects of splinting on time until 1st CMC joint replacement[20] and thumb pain during activities[21] and failed to report any significant findings. Others have compared the effects of various splint types[22,23] and reported that one make of a 1st CMC stabilization splint is more effective than another in terms of pain control and improved grasp but these results were not compared to another type of intervention or a non-intervention group.

Joint protection. According to Cordery[24], in theory, joint protection includes reducing the strain and stress on a joint as a way to prevent "progressive deterioration" by "redistributing the forces in activity proportionately to the strength and vulnerability of the parts of the joints involved" (p. 285). This includes avoiding stressing positions, using larger joints for tasks instead of affected joints, modifying the task or environment, engaging in activities that can be stopped if pain ensues, and responding to pain. Additionally, the use of assistive devices and rest are also considered joint-protective[24]. According to Beasley[17], reducing the force applied on joints through joint protection strategies can help protect the arthritic joints affected because the cartilage in hand joints with OA is weaker, it is less able to protect the bones of the joint from experiencing force from activity.

Joint protection, a standard occupational therapy practice, is "routinely employed in all patients with joints affected by arthritis" (p. 793)[18], and is moderately supported by the literature. Boustedt et al.[18] compared the effect of joint protection programming to that of a combined intervention of hand joint protection, splinting, and exercise on pain, hand strength, stiffness, and daily functioning. Those receiving joint protection alone reported significant improvements in pain during movement and a significant reduction of disability one week post-intervention ($p < 0.034$). However, the combined intervention group reported less pain at night and with movement, decreased stiffness, and a reduction in disability ($p < 0.012$, 0.012, 0.041, and 0.003, respectively), suggesting that joint protection in combination with these interventions may lead to more benefits for those with hand OA.

Stamm et al.[6], examined whether joint protection strategies combined with home exercises would impact grip strength and hand function in people with OA. The joint protection strategies used in the study include built-up writing utensils, nonskid materials, angled knives, book holders, and other devices based on individual participant's activity demands. At follow up, grip strength improved by 25% ($p < 0.0001$ in right hand, $p = 0.0005$ in left hand) and global hand function improved by 65% ($p < 0.05$) for the treatment group, concluding that instruction for joint protection and hand exercises completed at home are effective tools to use to increase grip strength and to promote hand function.

Thus, it can be inferred that joint protection interventions alone are useful when seeking to minimize pain during activity and improve daily function and when combined with orthoses and exercise, reduce pain at night, decrease joint stiffness, improve hand strength and hand function among individuals with OA of the hand.

Although, combined interventions of exercise, orthotic wear, and joint protection strategies have been successful in reducing pain, improving hand strength and improving self-reported activity levels[25,26] and the literature anecdotally presumes that joint protection strategies such as the use of nonskid materials decrease the loading of arthritic joints[27], a basic science exploration of the effects of a single intervention, joint protection, on force requirements during commonly problematic tasks (i.e., jar opening) has not been performed.

The aims of the present study were to examine if hand force profiles differ by 1) the hand turning the lid, 2) two grasp pattern types, and 3) the use of a non-skid material.

The research hypotheses were as follows:

1) The use of a nonskid material will require significantly less hand force than without during jar opening,
2) The approach to stabilizing the base of the jar will have a significant effect on the hand force production of the turning hand, and
3) There will be no significant effect of the hand turning: right vs. left and hand force production.

Methods

Design

A 2x2x2 experimental cross-sectional design was employed to investigate within-subjects differences in the hand force profiles, integral of hand forces, and hand generated torques during a jar-opening task across three factors: 1) grasp pattern used to twist the lid, 2) hand used to twist the lid, and 3) whether or not a nonskid material was used to twist the lid.

Participants

Following IRB approval and informed consent, thirty-one women, 18 years or older, with hand osteoarthritis participated in 16 trials of ‘opening’ the sealed jar across the above mentioned experimental factors. Participants were recruited through orthopedic, women’s health, and hand therapy clinics, as well as community-based centers which served older adults.

Participants were eligible for the study if they were female, over the age of 18, and 1) had radiographicially confirmed and symptoms of arthritis or 2) a combination of self-reported physician diagnosis and symptoms (i.e., achiness and stiffness) of hand OA. Although recruiting subjects through orthopedic and hand therapy clinics would likely always yield documented radiographic confirmation of hand arthritis, a homogenous sample of women with hand symptomology so severe that care was sought out, would not represent well the heterogeneous spectrum of disease impact and severity. Recruiting through community-based organizations and women's health clinics opened the door to participants who were likely less impacted by their hand symptomology however to do this, radiographic confirmation was not accessible. Thus, participants who both reported a physician rendered diagnosis of hand oseteoarthritis and reported symptoms of hand osteoarthritis were included in the study. These combined criteria were chosen because Szoeke et al.[28] found that this combination yields the highest sensitivity (70.5%) and specificity (68.0%)

Table 3.1. Baseline Characteristics of Sample.

Sample Size (n)	31
	% of n
Hand Dominance	
Right	90.3%
Left	6.5%
Ambidextrous	3.2%
Race	
Caucasian	83.3%
African American	16.7%
Diagnosis Confirmation	
Radiographic	54.8%
Self-reported diagnosis	45.2%
	X(SD)
Age (yrs)	63.70(13.9)
Years of Symptoms	9.02(6.8)
Years Since Diagnosis	8.17(6.0)
MVC Grip (Newtons)	
Right	232.15 (71.6)
Left	225.17 (60.5)
MVC Lateral Pinch (Newtons)	
Right	62.23 (16.0)
Left	56.76 (17.3)
MVC 3 Point Pinch (Newtons)	
Right	52.18 (16.9)
Left	50.53 (16.5)
AIMS2-SF	
Physical Function	1.81(1.4)
Symptoms	3.47 (2.2)
Affect	2.32 (1.9)
Upper Limb Disability	1.31 (1.2)
Total Health	10.62 (5.3)
Baseline Hand Pain (NRS)	0.90 (1.6)

when compared to the gold standard of radiography. Recruits were excluded from participating if any one of the following were present:

- Movement disorder with upper limb manifestation (e.g., Parkinson's, stroke, head injury, intentional tremor)
- Upper limb amputations
- Any history of hand joint arthroplasty
- Trauma within last 6 months that has increased symptoms that are non-arthritic in origin
- The diagnosis of hand/wrist conditions such as CTS or tendonitis
- Hand deformities that do not allow for grasp of instruments
- Strength testing is contraindicated due to medical co-morbidities

The average age of the participants was 63.7 (±13.9) years and 83.3% self-identified as being Caucasian, while the remaining 16.7% identified themselves as being African American. Twenty-eight subjects reported being right hand dominant, 2 reported being ambidextrous, and 1 reported being left handed. Laterality was determined based on self-report. Seventeen participants had radiographically confirmed hand arthritis in one or both of their hands whereas 14 reported having a physician diagnosis and symptoms of arthritis. On the average, participants had been symptomatic for 9.02 years (± 6.8) and had been living with confirmed hand arthritis for 8.17 years (±6.0). The distribution of hand osteoarthritis and the disease impact of the sample are described in detail in chapter 2. See table 3.1 for detailed information on the sample's characteristics.

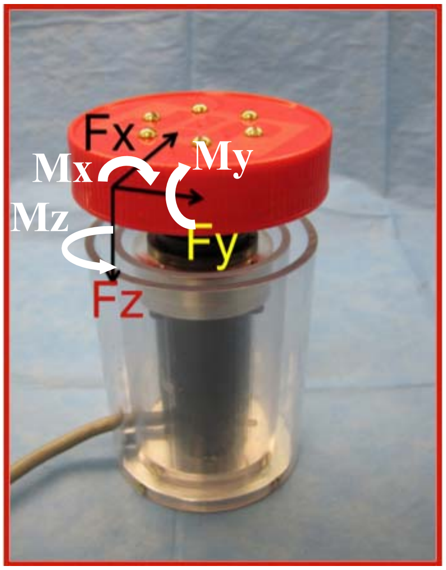
Instrumentation

Primary Outputs.

Jar instrument. Participants were asked to complete 16 trials at attempting to 'break the seal' of a force-sensing jar apparatus (figure 3.1) through counter-clockwise twists. The experimental setup, design of the device, and the device's psychometric properties are summarized in chapter 2. The force-sensing jar's lid was instrumented with 6 force sensing resistors as well as a 6-axis load cell which allowed for the jar to detect both grip forces (i.e., forces applied to jar lid through a power grasp in preparation for jar lid movement relative to the jar's base), gross compressive loads acting upon the jar's lid in each of the orthogonal axes (F(x), F(y), and F(z)), and lastly the moments (a.k.a., torque) applied to lid about these axes (M(x), M(y), and M(z)); see Figure 3.2.

Figure 3.1. Jar Instrument.

The three compressive loads can be described as 1) downward through the lid's axis of rotation (F(z)), 2) perpendicular to the side of the lid (F(x)), and 3) tangential to the lid (F(y)) (Figure 3.2). The moments about these orthogonal axes are 1) those which create a 'rocking' torque or the same type of torque one would use to pop the lid off of a canister of chips or tennis-balls (M(x) and M(y)) and 2) those which produce 'pure' rotational movement about the jar's axis of rotation (M(z)). During each jar opening simulation the torque required to turn the jar device was set to replicate the actual torque required to open a sealed jar with a 83mm diameter lid (4.24 M(z)) [29].



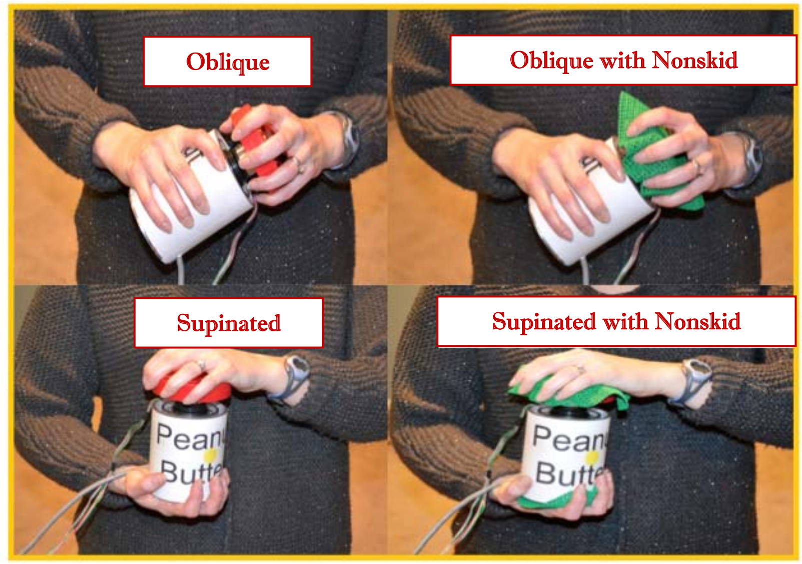


Figure 3.2: Jar Instrument-83 mm lid. **Figure 3.3: Four Grasp Patterns of the Left Hand.**

The jar turning simulations consisted of two trials of each of 16 combinations of three factors, each at two levels: 1) approach ('supinated' stabilizing hand vs. 'oblique' stabilizing hand), 2) hand gripping the lid (right vs. left), and 3) use or absence of a non-skid material. The two approaches to grasping a jar's lid and base were chosen as they have been described as being common methodologies[30]. An unrestrained approach (i.e., the absence of a supportive surface for the base of the jar such as a counter top) to opening the jar across all trials was chosen as the kinematics associated with use of a supportive surface have been proven to be less efficient ($p<.0001$) when compared to either of the aforementioned two unstrained approaches[30]. Although the kinematics of these two unrestrained approaches were not dissimilar ($p = 0.76$), the underlying differential kinetics have not been explored. It is for these reasons that these approaches were selected. Prior to testing, participants were randomly assigned to already composed sequences of the 8 combinations of twisting hand, grasp pattern, and non-skid material usage (see table 3.2).

Standardized procedures were utilized for each of the 16 jar turning simulations. Across conditions of hand twisting the lid and use/non-use of nonskid materials, participants were either asked to apply a 'supinated' approach (jar held vertically with the stabilizing forearm in full supination and associated palm in contact with bottom of the jar-base and the palmar surface of the turning hand grasping the lid through in a power grasp[31] or an 'oblique' approach (jar held obliquely with palmar surface of stabilizing hand on the jar-base's side and the palmar surface of the turning hand grasping the lid through in a power grasp) (Figure 3.3). Across all 8 possible conditions, participants performed two trials. Participants were randomly assigned to a predetermined sequence of the 8 conditions to control for the effect of order on pain and fatigue and were offered a 30 second rest period between trials. Primary outputs [Grip force, F(x), F(y), F(z), M(x), and M(z)] were recorded for a maximum period of 6 seconds during each trial.

Table 3.2. Factors and Levels of Experiment

Approach (2 levels)	***Hand (2 levels)***	***Nonskid (2 levels)***
Oblique	Right Hand Superior	Yes (2 trials)
		No (2 trials)
	Left Hand Superior	Yes (2 trials)
		No (2 trials)
Supinated	Right Hand Superior	Yes (2 trials)
		No (2 trials)
	Left Hand Superior	Yes (2 trials)
		No (2 trials)

Before each trial, participants were given standardized directions on how to complete the task. When a new approach was introduced, this was followed by a demonstration of the task and the opportunity for a trial run. While in a standing position, all participants were instructed to maintain standardized glenohumeral joint, elbow joint positions, and hand placements to control for any distal kinetic variance that might result from non-standardized posturing.

The standardized positioning for the approaches is as follows:

1) ‘Oblique’ standardized position (Figure 3.3):

- With the jar apparatus situated at midline, both shoulders were fully adducted and between 30 and 45 degrees of internal rotation;
- The elbow of the stabilizing hand between 60 and 90 degrees of elbow flexion with the forearm in approximately 45 degrees of pronation;
- The stabilizing hand was placed in on the side of the jar’s base in a location indicated by visual markers;
- The elbow of the limb turning the jar lid was placed in 90 degrees of elbow flexion with forearm in 45 degrees of pronation; and
- The turning hand was positioned with pads of all digits in contact with the lid with a power grasp.

2) ‘Supinated’ standardized position (Figure 3.3):

- With the jar apparatus situated at midline, both shoulders were fully adducted and between 30 and 45 degrees of internal rotation;
- The elbow of the stabilizing hand between 60 and 90 degrees of elbow flexion with the forearm in full supination;
- The elbow of the limb grasping jar lid placed in 90 degrees of elbow flexion with forearm in full pronation and hand with pads of all digits in contact with the lid with a power grasp; and
- Visual markers were again used to standardize the location and orientation of the hands.

Secondary Outputs.

Success. Following each attempt at opening the jar instrument, success (or lack thereof) in 'breaking the seal' was recorded.

Pain. The Numerical Rating Scale (NRS) was administered to assess participant's pain at baseline intensity, intensity after each trial of jar turning, and to determine the difference between baseline and post-trial intensity. The NRS, a 0-10 scale of pain intensity, was selected due to its common use in clinical practice as well as its high responsiveness to changes in pain intensity[32]. A rating of '0' on the NRS indicates no pain while a '10' indicates extremely strong or maximal pain experienced in their hand.

Disease Impact. To characterize the impact of arthritis on the sample, participants were also administered at baseline the short version of the Arthritis Impact Measure 2 (AIMS2-SF)[33] to assist in the characterization of the impact of arthritis on the sample of interest. The AIMS2-SF is widely used and focuses on several domains of health and activity limitations. Moreover, an upper limb subscale allows for the evaluator to better isolate the effects of upper limb arthritis on health and activity. The tool is reported to have good-excellent reliability and strong concurrent validity with the Health Assessment Questionnaire (HAQ)[34].

Hand Dynamometry. To characterize the generalized hand strength of the sample, maximal voluntary contraction (MVC) strength of the dominant and non-dominant hands was assessed through the use of the Jamar™ dynamometer. The Jamar has high accuracy, good test-retest reliability[35] and was the measurement device used to collect the adult normative grip and pinch strength data by Mathiowetz, et al.[36]. Three trials were administered per hand via the positioning and verbiage recommended by the American Society of Hand Therapists[36].

Bilateral hand measures of lateral and 3-point pinch were gathered via the B & L pinch meter™, which has high accuracy, good test-retest reliability, and excellent interrater reliability[35]and was the assessment tool used while collecting pinch strength data for the norms reported by Mathiowetz et al.[36]. Again, three trials were administered bilaterally via the positioning and verbiage recommended by the American Society of Hand Therapists[36]. All MVC measures were administered at the session's end so as to avoid exacerbating arthritic symptoms through maximal gripping and pinching prior to the administration of the primary outcome measure.

Statistical Analysis

Matlab®[37] Version 7.9 software was used to compute peak grip and compressive (i.e., F(x), F(y), F(z)) forces at the time of maximum torque about the lid's axis of rotation (i.e., M(z)), areas under the force-time curve (i.e., integral of force) for grip and compressive forces, and the peak moments (i.e., M(x), M(y), and M(z)) acting on the jar's lid. Descriptive statistics and within subjects comparisons (Student's *t*, Cochran's *Q,* and Wilcoxon Signed Rank) for baseline sample characteristics, hand force, integral of hand force, moments, success, and pain were performed through use of SPSS®[38] version 22. SAS®[39] version 9.4 (Proc Mixed) was used to estimate the effect of and interactions between the three experimental factors on pain, peak force, integral of force, and peak torque using a mixed-effects linear model with hands as repeated factor and subjects as random effect to incorporate the correlation between repeated measurements from each subject. Change scores of post-test NRS scores relative to baseline pain were also calculated through use of SPSS® ver. 22. Matlab and SAS code are presented in appendices 3B and 3C.

Results

Participants

One participant was unable to participate in 4 trials of turning due to her arthritic symptomology. All others were able to fully participate in all 16 trials. The AIMS2 average total health score of 10.62 (SD=5.28) indicated that overall perceived health was mildly impacted by the condition. Participants also reported mild disease impact in the physical, upper limb, social, and affective subscales. These findings are summarized in Table 3.1.

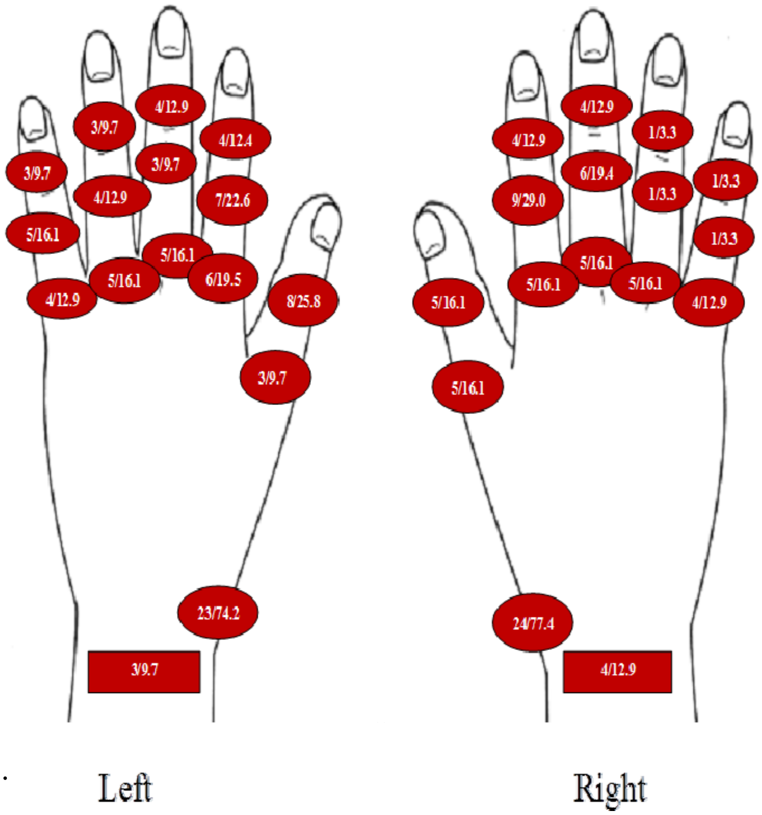


Figure 3.4. Distribution of joint involvement by hand.
Note: Text boxes describe the number of participants with osteoarthritis in the underlying joint (left number) and associated percentage (right) of the sample with involvement in that joint.

On the average, participants had two digits affected by OA in both right and left hands (2.1±1.5 and 2.0±1.5 respectively). Ninety percent of participants had radiographically confirmed or self-reported thumb OA, 45% index finger, 42% long finger, 23% ring, and 29% in the small fingers. This varies from the distribution patterns described in the literature where index, middle, and small fingers are most often radiographically confirmed[40] but is expected given that the presence of 1st CMC OA, when compared to interphalengeal hand arthritis yields significantly worse hand function and symptomology ($p<.01$)[41]. Given that 17 participants were recruited from orthopedic clinics where arthritis care is typically sought out only when symptomology and function warrant, having a sample comprised heavily of women with 1st CMC arthritis would be expected. A test of difference in distribution of joint involvement revealed that the distribution of right and left arthritic joints was nonsignificantly different ($p>.05$) across all joints with the exception of the small finger proximal interphalangeal (PIP) joint. In this instance, the left hands of the participants had significantly more small finger PIP joints impacted by OA than did the right ($z=2.00$, $p=0.5$). The total joint counts were also nonsignficantly different ($p>.05$) when comparing right and left hands. The distribution of arthritis is illustrated in figure 3.4 yet additional detail on the distribution can be found in chapter two.

Hand strength, as measured by the grip and pinch dynamometry was all determined to be within 1 SD of the normative values[36] for the average age of the participants with the exception of left 3-pt pinch which was determined to be 1.1 SD below the norm. Average measures of right and left grip and 3-point pinch strength were non-significantly different whereas left lateral pinch strength was significantly less than right [mean difference (MD)=5.45±11.0, $t=2.76$, $p=.01$].

Force Outcomes at Peak M(z)

Grip force.

The average within-condition grip force used when attempting to 'break the seal'(i.e, peak M(z)) of the instrumented jar ranges from 129.84(42.2) to 169.93 (58.6) newtons. The right (hand superior) supinated approach without nonskid material required the highest amount of peak grip force and was significantly greater than all combinations aside from right nonskid oblique and right nonskid supinated approaches. Contrary to this, the left nonskid oblique approach used the least amount of average grip force at peak M(z) and significantly differed (p<.05) from all right handed approaches however did not from the other left hand approaches (see table 3.3 and Figure 3.8).

There were clear and significant main effects on grip force of left (hand superior) vs right hand and of supinated vs oblique approach. On average the left hand used 134.00(6.1) newtons of grip force across all approaches and with or without nonskid materials which was significantly less than what was required (158.13±6.2) of the right hand (<.0001). This effect allowed for increased hand grip force with a supinated when compared to the oblique approach (MD=19.98±6.2, t =6.2, p=.01) as the average hand grip forces were 153.5(6.3) and 138.5±6.2 respectively. See table 3.7 for details on main effects of hand and approach on grip force.

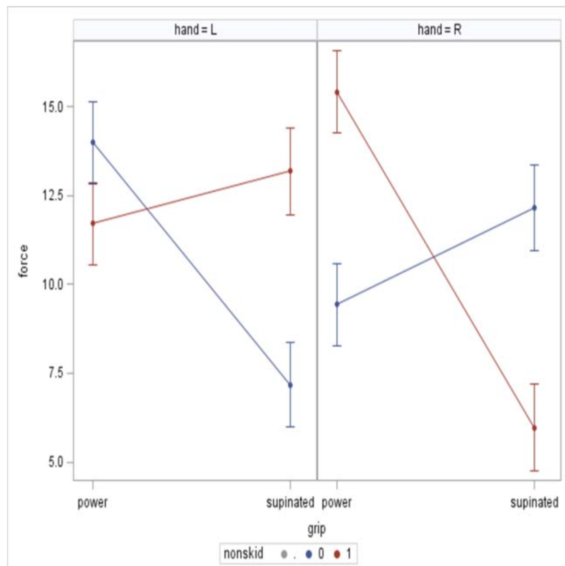


Figure 3.5. Effect of Hand, Approach, and Nonskid Material on F(x).

F(x).

Average within subjects compressive forces perpendicular to the jar-lid's side at the time of peak M(z) ranged from 5.92(4.5) to 15.43(11.2) Newtons. The least amount of F(x) at the time of maximal M(z) torque was used with a right nonskid supinated approach and, when compared to all others except the left supinated approach sans nonskid, used significantly less F(x)($p<.05$). The right nonskid oblique approach used the most and was significantly greater ($p<.05$) than all others with the exception of the left oblique approach sans nonskid material. See table 3.3 and figure 3.8 for additional details on descriptives and pairwise comparisons.

A main effect of approach on F(x) was apparent as the supinated approach required less F(x) compressive forces than did the oblique approach (MD= 3.28+0.9, t= 3.65, p=.003). Beyond this, an interaction effect of hand, approach, and nonskid material on F(x) forces was present (Figure 3.5, Tables 3.7 and 3.8). For example, without nonskid material, the left supinated approach was half of that exerted during a right Supinated approach sans nonskid material (MD= -5.71±1.6, t=-3.64, 0.0003) whereas with nonskid material, F(x) exerted in the left supinated approach was twice that exerted in a right supinated approach (MD =6.83±1.9, t =3.58, p=0.0004). In the right hand, nonskid material increases F(x) during an oblique turn but decreases F(x) in a supinated turn; this is reversed for the left hand.

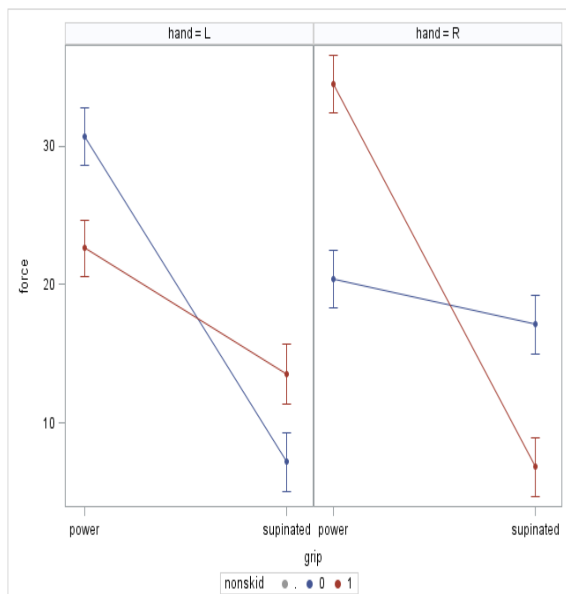


Figure 3.6. Effect of Hand, Approach, and Nonskid Material on F(y).

F(y).

The average compressive forces parallel to the side of the jar lid, or shear forces, at the time of peak M(z) ranged from 6.38(6.2) to 34.48(18.0) N*m. The least amount of

F(y) was used during the right nonskid supinated approach and was significantly less ($p<.05$) than all but the left supinated approach. The greatest average amount of F(y) at peak M(y) was produced by the right nonskid oblique approach and was significantly greater ($p<.05$) than all but the left oblique approach sans nonskid materials. Table 3.3 and figure 8 display these trends as well as pairwise comparisons.

The main effects of approach on F(y) were present as the supinated grasp requires less F(y) than does the Oblique (MD= 17.19$\pm$1.3=, t= 13.62, $p<.0001$). In addition to this, the effect of the hand turning the lid on F(y) was approaching significance and the left hand appeared to used less F(y) (MD = -2.14$\pm$1.2, -1.78, p=0.08). The GLM analysis also revealed interaction effect of hand, approach, and nonskid material on F(y). In fact, the same paradoxical effect was noted for F(y) as was present with F(x). For example, the left supinated approach without nonskid material was, on the average, more than half of that which was required during a right Supinated approach sans nonskid material (MD= -10.71$\pm$2.2, t=4.94, $p<.0001$) whereas an opposite, yet less significant, effect was noted when comparing the use of a right supinated approach with nonskid material to the left hand supinated approach with nonskid material (MD = 5.8669+2.6407, t=2.22, p=0.0268). The main and interaction effects of hand, approach and nonskid material on F(y) are described in more detail in tables 3.7 and 3.8 and are illustrated in figure 3.6.

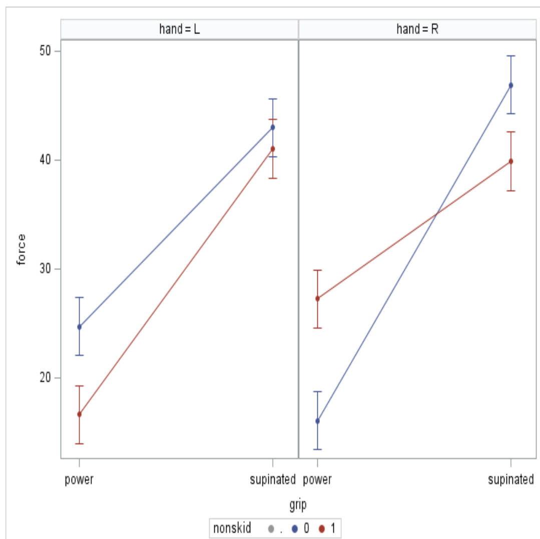


Figure 3.7. Effect of Hand, Approach, and Nonskid Material on F(z).

F(z).

The average compressive forces directed downwardly through the jar lid's axis of rotation [F(z)] at the time of peak M(z) ranged from 16.05(12.8) to 46.55(21.3) N*m. The least amount of F(z) was used during the right oblique approach and was significantly less ($p<.05$) than all but the left nonskid oblique approach. The greatest average amount of F(z) at peak M(y) was produced by the right supinated approach and was significantly greater ($p<.05$) than all but the left supinated approach sans nonskid material (see table 3.3 and Figure 3.8).

Per the general linear model analysis, the supinated grasp produced significantly more downward compressive forces into the jar's lid (MD=22.2506+1.4603, t=15.24,p<.0001). However, the interaction between the nonskid material and hand turning the lid resulted in the left hand supinated approach requiring the least amount of F(z) forces relative to the other combinations [$F(1,411)=7.73$, $p=0.0057$].

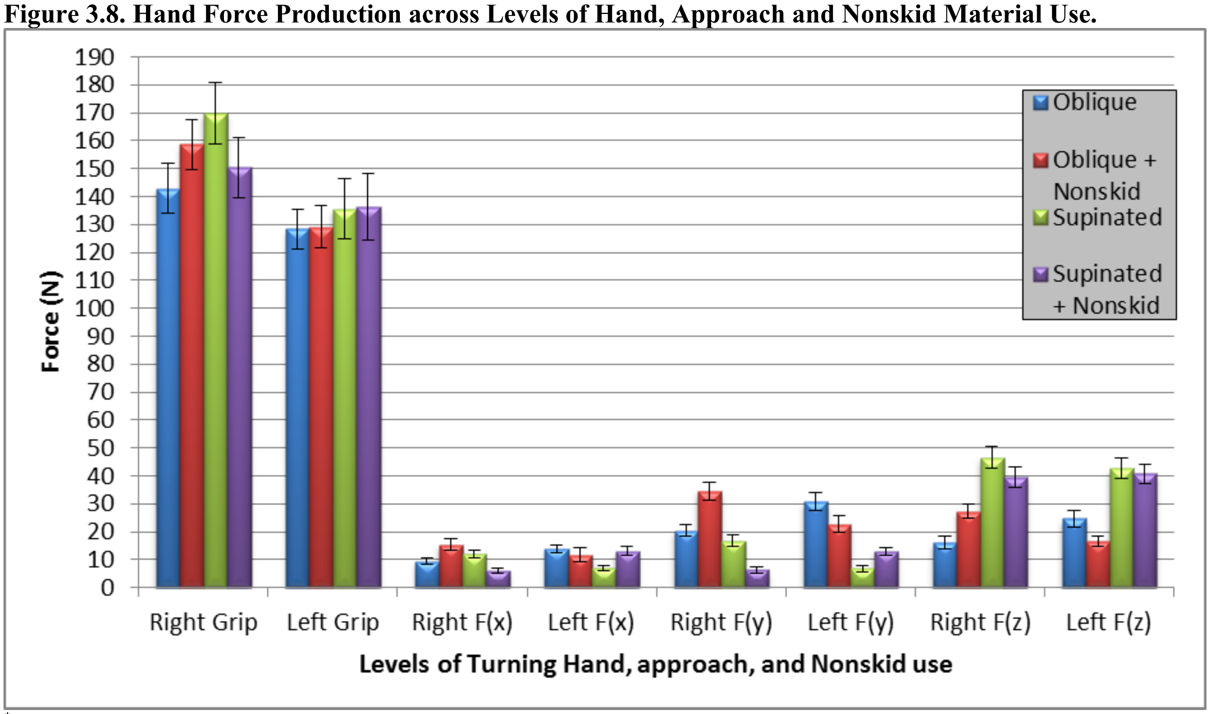
An interaction effect between hand, approach and nonskid material is also notable for F(z). For example, the right oblique approach with nonskid material required, on the average, significantly more F(z) than of that which was required during a left oblique approach with nonskid material (X Diff =11.2486+2.6094, t=4.31, p<.0001) whereas an opposite effect was noted when comparing the use of a right supinated approach with nonskid material to the left hand supinated approach with nonskid material (MD = -7.4732+2.8769, t=-2.60, p=0.0097). Tables 3.7 and 3.8 describe the main and interaction effects on F(x) in additional detail and Figure 3.7 illustrates such.

Table 3.3. Descriptives and Within Subjects Comparisons for Grip and Compensatory Forces across Four Approaches to Opening a Sealed 83mm Jar[*]

Approach +/- Nonskid	Hand Turning	N	Trials	Grip Force X(SD)	F(x) X(SD)	F(y) X(SD)	F(z) X(SD)
Oblique	Right	30	60	142.93(50.5)[af]	9.43(6.1)[ac]	20.42(12.1)[a]	16.05(12.8)[a]
	Left	31	62	128.54(39.7)[ac]	13.99(17.6)[b]	30.69(18.1)[b]	24.70(17.0)[b]
Oblique Nonskid	Right	30	60	158.60(49.7)[abg]	15.43(11.2)[b]	34.48(18.0)[b]	27.24(13.7)[b]
	Left	31	62	129.08(42.2)[ch]	11.71(9.1)[ab]	22.61(18.9)[a]	16.62(9.6)[a]
Supinated	Right	28	56	169.93(58.6)[bd]	12.10(7.9)[ab]	16.68(11.3)[ad]	46.55(21.3)[c]
	Left	29	58	135.62(56.8)[ace]	7.12(4.9)[cd]	6.76(6.4)[c]	42.61(19.2)[ce]
Supinated Nonskid	Right	27	54	150.34(56.5)[defgh]	5.92(4.5)[d]	6.38(6.2)[c]	39.60(19.3)[de]
	Left	27	54	136.20(63.4)[cf]	13.15(8.1)[b]	13.09(7.4)[d]	40.79(18.2)[de]

[*]Note: Force is reported in Newtons. All force values were recorded at the time of peak M(z) torque. Pairwise comparisons (within each force outcome) in mean forces across categories determined via Student's *t*. Means that do not share a letter were significantly different ($p<.05$); means sharing a letter were not.

Figure 3.8. Hand Force Production across Levels of Hand, Approach and Nonskid Material Use.



[*]**Note:** Mean forces ±SE are reported. Force is reported in newtons. Force values were recorded at the time of peak M(z) torque.

Integral of Force Outcomes

Integral of grip forces.

The average area under the force-time curve, or integral of grip force, ranged from 576.17(320.5) to 1072.62(341.4) newton*seconds. The highest average amount of integral of grip force was used during the right nonskid oblique approach and was significantly greater (p<.05) than all but the right oblique approach sans nonskid material. The smallest average integral of grip force was produced by the left nonskid supinated approach and was significantly less than all but the right nonskid supinated approach(p<.05). Table 3.4 and figure 3.13 present details on descriptives and pairwise comparisons.

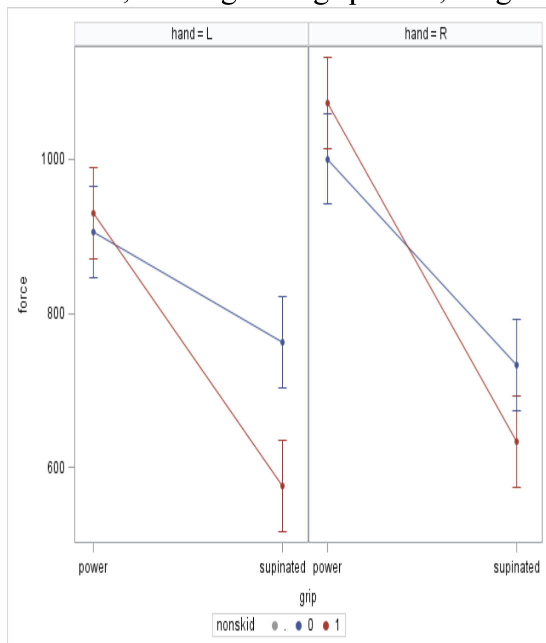


Figure 3.9. Interaction Effects of Approach and nonskid material on integral of grip force.

An interaction effect between approach and nonskid material influenced the integral of grip force utilized during the turning task (F(1,411)=8.70, p=0.003) and the combination of a supinated approach and nonskid material yielded the smallest average integral of grip force when compared to all other possible interactions (p<.05). See tables 8 for details on interaction effects on integral of grip force and figure 3.9 for the illustration of the significant interaction effect.

Integral of F(x).

The average area under the force-time curve, or integral of F(x), ranged from 15.36(10.5) to 44.83(36.1) newton*seconds. The highest average amount of F(x) integral was used during the left nonskid oblique approach and was significantly greater ($p<.05$) than all supinated approaches but non-significantly different from other oblique combinations. The smallest average amount of F(x) integral was produced by the right nonskid supinated approach and was significantly less than all but the left nonskid supinated and right supinated approaches ($p<.05$). See table 3.4 and figure 3.13 for descriptives and pairwise comparison details.

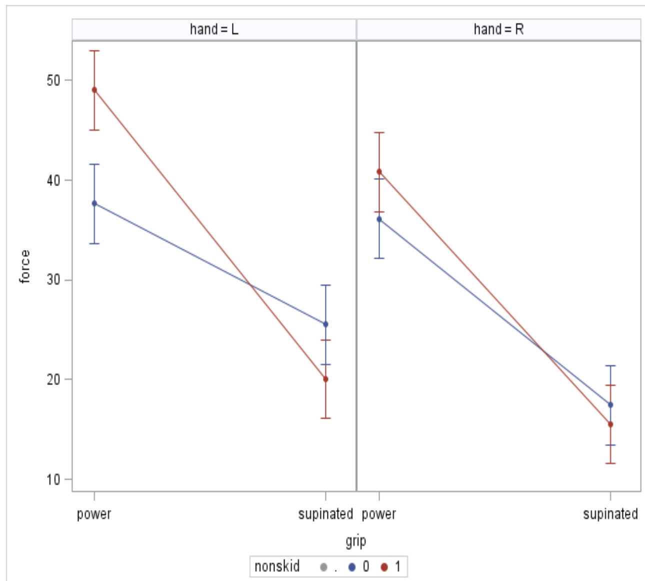


Figure 3.10. Interaction Effect of Approach and Nonskid Material on Integral of F(x).

Independent of one another, the turning hand and approach yielded significant effects on F(x) integral. In particular, the left hand generates more F(x) (MD =7.55$\pm$3.0, t=2.53, p=0.01) integral than does the right. Moreover, the supinated approach requires less F(x) (MD=14.80$\pm$3.1, t=4.84, p<.0001 and F(y) (MD=51.00$\pm$5.3, t=9.58, p<.0001) than does the oblique.

In addition to the independent significant effects of turning hand and approach, a near-significant interaction between approach and nonskid material exists. The supinated approach, regardless of nonskid material use, yielded significantly lower F(x) integral than either oblique approach however the oblique approach with nonskid material produces the greatest F(x) integral (F(1,411)=3.26, p=0.07). See tables 3.7 and 3.8 for details on main and interaction effects on F(x) and figure 3.10 for the illustration of the near-significant interaction effect.

Integral of F(y).

The average area under the force-time curve, or integral of F(y) force, ranged from 13.96(15.4) to 104.21(52.6) Newton*seconds. The highest average amount of F(y) integral was used during the left nonskid oblique approach and was significantly greater (p<.05) than all other combinations. The smallest average amount of F(y) integral was produced by the Right nonskid supinated approach and was significantly less than (p<.05) all but the left nonskid supinated and right supinated approaches. See table 3.4 and figure 3.13 for descriptives and pairwise comparison details.

Independently of other effects, the left hand generates more F(y) integral than does the right (MD=19.39±5.1, t=3.81, p=0.0002).

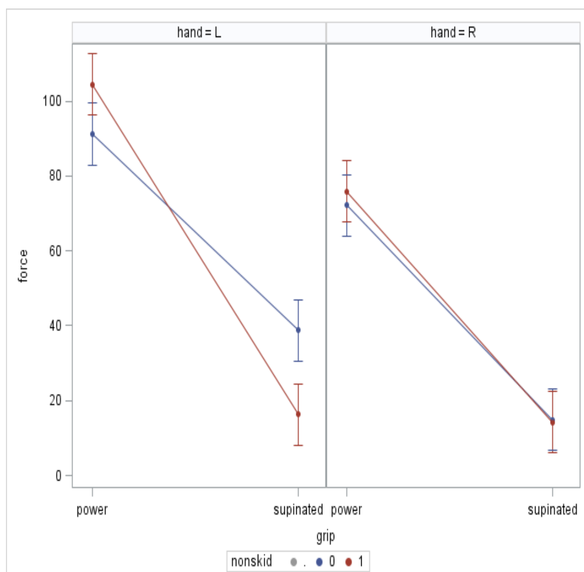


Figure 3.11. Interaction Effect of Approach and Nonskid Material on Integral of F(y).

Moreover, a significant interaction between approach and nonskid on F(y) exists in that the supinated grasp with or without nonskid material requires less F(y) integral than does either oblique approaches [F(1,411)=4.99, p=0.03].

Additionally, when nonskid material is used with an oblique approach, the right hand generates more F(y) integral than does the left and when it is absent generates less

F(y) integral than the left. Conversely, the absence of nonskid material when using a supinated approach increases F(y) integral in the right hand more so than in the left [F(1,411)= 4.63, p=0.03]. See tables 3.7 and 3.8 for details on main and interaction effects and figure 3.11 for the illustration of the interaction effect.

Integral of F(z).

The average area under the force-time curve, or integral of F(z), ranged from 51.49(43.9) to 110.15(98.7) Newton*seconds. The highest average amount of the integral of F(z) was used during the left supinated approach and was significantly greater (p<.05) than all other combinations with exception to the right supinated and left nonskid oblique approaches. The smallest average amount of F(z) integral was produced by the right oblique approach and was significantly less than all but the left nonskid supinated and right nonskid oblique approaches (p<.05). See table 3.4 and figure 3.13.

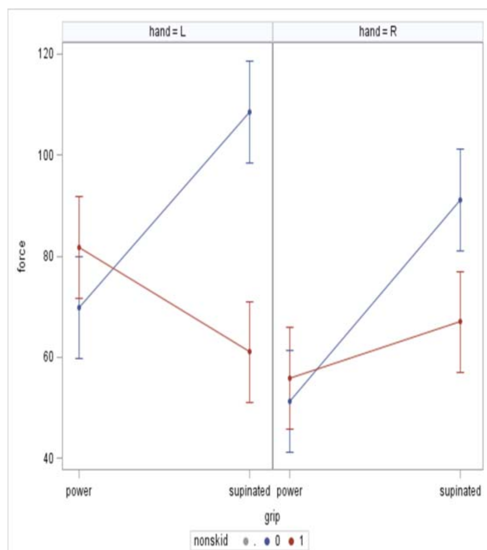


Figure 3.12. Interaction Effect of Approach and Nonskid Material on Integral of F(z).

Significant main effects of nonskid materials, hand, and approach on F(z) integral were noted. When using the nonskid material, participants used less integral of F(z) than without (MD=10.82+5.2,t=2.07, p=0.04). Additionally, the use of the left hand generated more F(z) force across time than did the right (MD=17.11±5.2, t=3.29p=0.001). Lastly, a supinated approach used more integral of F(z) than oblique (MD= 32.70±5.5,t=5.98, p<.0001).

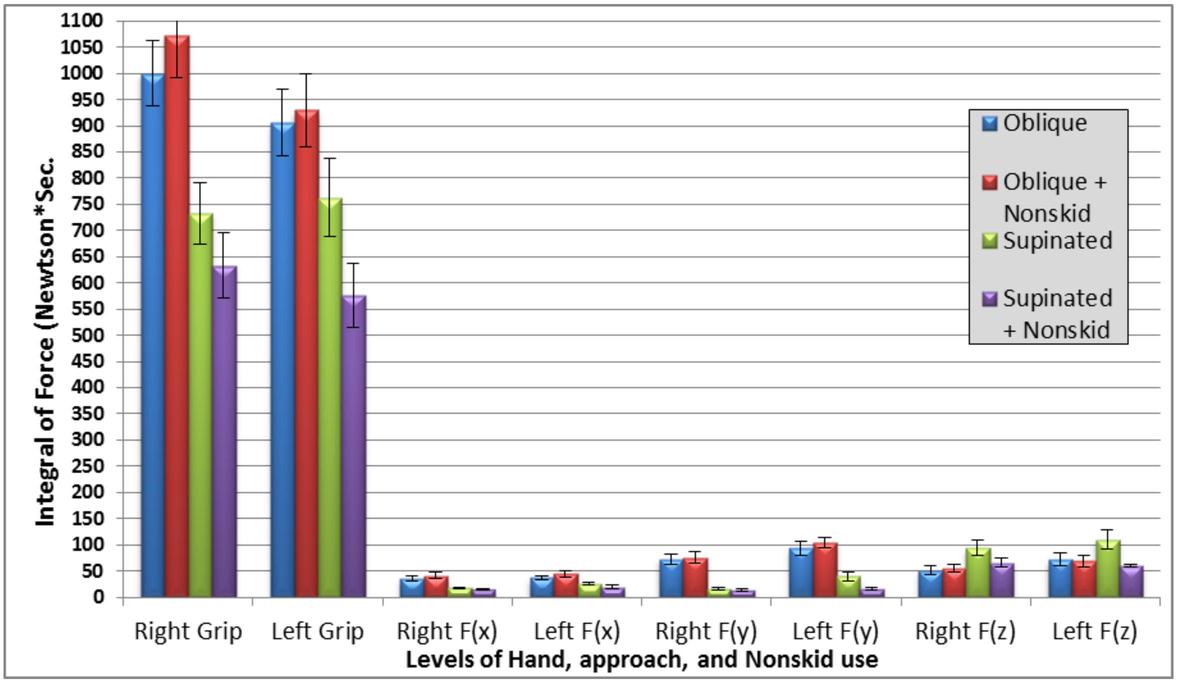
Aside from the main effects, interaction between approach and nonskid material usage were discovered. This is evidenced by the fact that the supinated approach without nonskid material generates more F(z) integral than does any other combination [F(1,411)= 8.70,p=0.003]. Beyond this, the analysis also revealed that hand, approach, and nonskid material interacted to produce combined effects on F(z) integral. Specifically, more F(z) integral is required when using an oblique approach with a nonskid material in the right hand than is with the left and similarly, less F(z) integral is needed when using an oblique approach without nonskid material with the right hand than with the left. See tables 3.7 and 3.8 for details on main and interaction effects and figure 3.12 for the illustration of the interaction effect.

Table 3.4. Descriptives and Within Subjects Comparisons of Integral of Force across Four Approaches to Opening a Sealed 83mm Jar*

				Integral of Grip Force	**Integral of F(x)**	**Integral of F(y)**	**Integral of F(z)**
Approach +/-Nonskid	**Hand Turning**	**n**	**Trials**	**X(SD)**	**X(SD)**	**X(SD)**	**X(SD)**
Oblique	Right	30	60	1000.19(341.4)[abd]	35.98(23.5)[a]	72.72(56.1)[a]	51.49(43.9)[a]
	Left	31	62	905.77(357.7)[ae]	37.20(25.2)[a]	93.47(78.3)[a]	71.64(63.0)[b]
Oblique Nonskid	Right	30	60	1072.62(446.8)[b]	41.32 (36.1)[a]	75.90(62.3)[a]	55.36(43.5)[a]
	Left	31	62	929.96(378.5)[ac]	44.83(33.9)[a]	104.21(52.6)[b]	69.04(53.8)[bd]
Supinated	Right	28	56	733.23(324.5)$_d$	17.86(10.3)[b]	16.00(11.9)[ce]	93.74(74.8)[bc]
	Left	29	58	762.79(420.6)[eg]	25.62(21.4)[ce]	39.76(46.9)[d]	110.15(98.7)[cd]
Supinated Nonskid	Right	27	54	633.16(345.7)[fg]	15.36(10.5)[bd]	13.96(15.4)[e]	65.76(44.3)[a]
	Left	27	54	576.17(320.5)[f]	19.53(22.0)[de]	16.06(12.2)[e]	59.76(57.2)[a]

*Note: Integral of force is reported in newton*second given that the distance associated with jar turning is uniformly fixed. Pairwise comparisons (within each force outcome) were calculated via t-test. Significantly different (p<.05) pairwise comparisons are denoted when individual superscript letters do not match. Matching superscript letters indicate non-significant differences.

Figure 3.13. Integral of Hand Forces across Levels of Turning Hand, Approach and Nonskid Material Use.



*<u>**Note:**</u> Mean integral of forces ±SE are reported. Integral of force is reported in Newton*seconds.

Moments

Peak M(x).

The average torque about the x-axis of the jar-lid [M(x)], ranged from 1.40(0.7) to 1.61(0.5) N*m. The highest average amount of M(x) was used during the left nonskid oblique approach and was significantly greater (p<.05) than all other combinations. The smallest average amount of M(x) was produced by the left supinated approach and was significantly less than all but the left nonskid supinated and right supinated approaches(p<.05). See table 3.5 and figure 3.15.

Per the general linear model analysis results, the main effects of approach and nonskid material had significant and near-significant effects on M(x) respectively. Specifically, the supinated approach required less M(x) than did the oblique (x diff =0.32+0.04, t= 7.78, p<.0001) and the use of nonskid material helped to produce greater

M(x) than without (MD=0.07+0.04, t=-1.70, p=0.09). See table 3.7 for details regarding the main effects.

Peak M(y).

The average torque about the y axis of the jar lid [M(y)], ranged from 0.75(0.4) to 1.27(0.4) N*m. The highest average amount of M(y) was used during the left nonskid oblique approach and was significantly greater than all other combinations with exception of the right nonskid oblique approach ($p<.05$). The smallest average amount of M(y) was produced by the left supinated approach and was significantly less than all but the left nonskid supinated and right oblique approaches ($p<.05$). See table 3.5 and figure 3.15 for additional information on descriptives and pairwise comparisons.

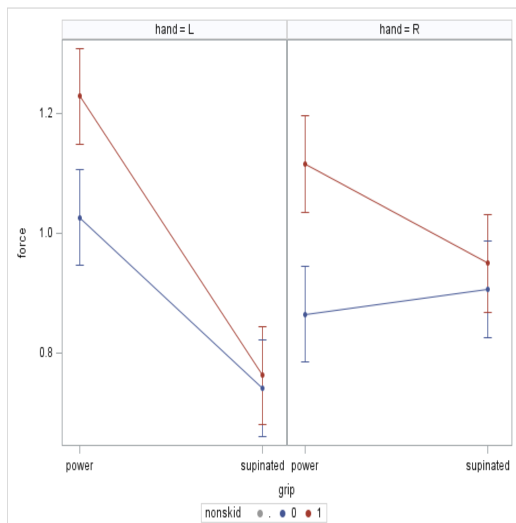


Figure 3.14. Interaction Effect of Hand, Approach, and Nonskid Material on M(y).

A significant interaction between hand and approach was revealed per the general linear model analysis. In particular, the left hand supinated approach produced the least amount of M(y) while the left hand oblique approach produced the most ($F(1,411)=13.83$, $p=0.0002$). Furthermore, a near-significant interaction effect of approach and nonskid material use were noted as the oblique approach with material generated the most M(y) and supinated approach without nonskid the least ($F(1,403)= 3.40$,$p=0.07$). See table 3.5 and figure 3.14.

Peak M(z).

The average torque about the z-axis of the jar lid [M(z)], ranged from 3.21(1.1) to 4.27(0.9) N*m. The highest average amount of M(z) was used during the left nonskid supinated approach and was significantly greater ($p<.05$) than all other combinations with exception of the right nonskid supinated approach. The smallest average amount of M(z) was produced by the Right oblique approach and was significantly less than ($p<.05$) all but the right nonskid oblique and left oblique approaches. See table 3.5 and figure 3.15.

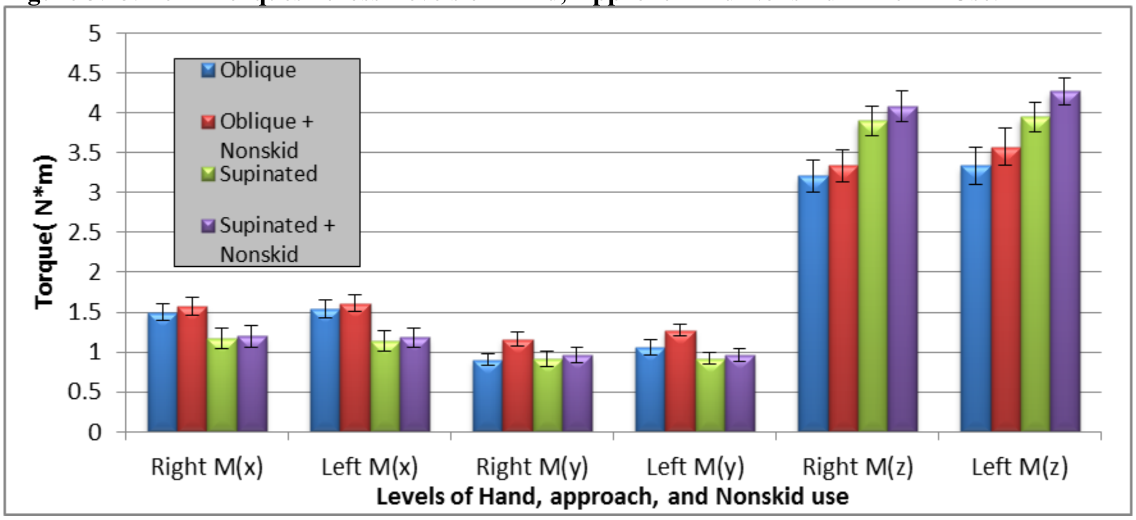
Three independent effects of hand, approach and nonskid material on M(z) were discovered: 1) the left hand produced more M(z) than did the right (MD=0.16+0.07, t=2.47, p=0.01), 2) the supinated approach produced more M(z) than did the oblique (MD= 0.70+0.07, t=10.07, p<.0001) and 3) the use of nonskid material generated more M(z) than without (MD= 0.23+0.07, t=3.53,p=0.0005). Figure 3.18, located in this chapter's Appendix 3A, illustrates the force-time and moment-time profiles of individual participants across each of the 8 possible patterns to jar opening.

Table 3.5. Descriptives and Within Subjects Comparisons of Torque across Four Approaches to Opening a Sealed 83mm Jar*

				M(x)	M(y)	M(z)
Approach +/-Nonskid	**Hand Turning**	**n**	**Trials**	**X(SD)**	**X(SD)**	**X(SD)**
Oblique	Right	30	60	1.50(0.6)[a]	0.90(0.4)[adg]	3.21(1.1)[a]
	Left	31	62	1.54(0.6)[ab]	1.06(0.5)[ab]	3.34(1.3)[ab]
Oblique Nonskid	Right	30	60	1.57(0.6)[b]	1.16(0.5)[bce]	3.34(1.1)[a]
	Left	31	62	1.61(0.5)[c]	1.27(0.4)[c]	3.57(1.1)[b]
Supinated	Right	28	56	1.17(0.7)[de]	0.92(0.5)[a]	3.90(1.1)[c]
	Left	29	58	1.14(0.7)[d]	0.75(0.4)[df]	3.95(1.0)[ce]
Supinated Nonskid	Right	27	54	1.20(0.7)[e]	0.96(0.5)[aeg]	4.08(1.0)[de]
	Left	27	54	1.18(0.6)[de]	0.77(0.4)[dfg]	4.27(0.9)[d]

*Note: Moments are reported in Newton-Meters. Pairwise comparisons (within torque meaures)were calculated via t-test. Significantly different ($p<.05$) pairwise comparisons are denoted when individual superscript letters do not match. Matching superscript letters indicate non-significant differences.

Figure 3.15. Peak Torques across Levels of Hand, Approach and Nonskid Material Use.*



***Note:** Mean torques ±SE are reported. Force is reported in Newton*meters

Success

Across the levels of all factors, Success rates range from 18.3% to 85.2% with the right hand oblique sans nonskid material having the least favorable success rate and the left hand supinated with nonskid material having the best($p<.05$). The analysis of distribution differences of binomial responses (i.e., success 'yes' versus 'no') demonstrated significantly more distributions of successful attempts among left nonskid supinated trials when compared to all other combinations ($36.0<Q>3.77$, $p<.05$). See table 3.6 for details.

Pain

Across the levels of all factors, the average pain intensity scores ranged from 2.21(2.2) to 3.42(2.5) with the highest intensity occurring after a left oblique approach with nonskid material whereas the least intense pain was experienced after a left supinated approach with nonskid material which was significantly less ($p<.05$) than all but the left supinated approach without nonskid material.

The largest average increase in pain from baseline was 2.74(2.6), however, was experienced when participants used a right hand oblique approach with nonskid material whereas the smallest average increase 1.33(2.5) in pain from baseline occurred with a left hand supinated grasp with nonskid material. This average change in pain was smaller than all (p<.05) but the left supinated approach sans nonskid material. See table 3.6 for additional details on descriptives and pairwise differences and figure 3.17 for the illustration of such.

Per the general linear model analysis, the approach to turning the lid significantly influenced pain intensity as pain NRS scores were highest with an oblique approach when compared to a supinated [F(1,411)= 25.98, p<.0001]. Similarly, the change in pain ratings from baseline was also significantly impacted by the main effect of approach as, yet again, change in pain from baseline was greatest with an oblique approach [F(1,411)=23.77, p<.0001].

The main effect of hand on change in pain intensity was also notable. Women of this sample experienced significantly larger increases in pain when using the right hand as opposed to the left [f(1,411)= 3.88, p=0.05]. Lastly, a near-significant interaction effect of nonskid material and approach on pain intensity was noted as the supinated approach with nonskid

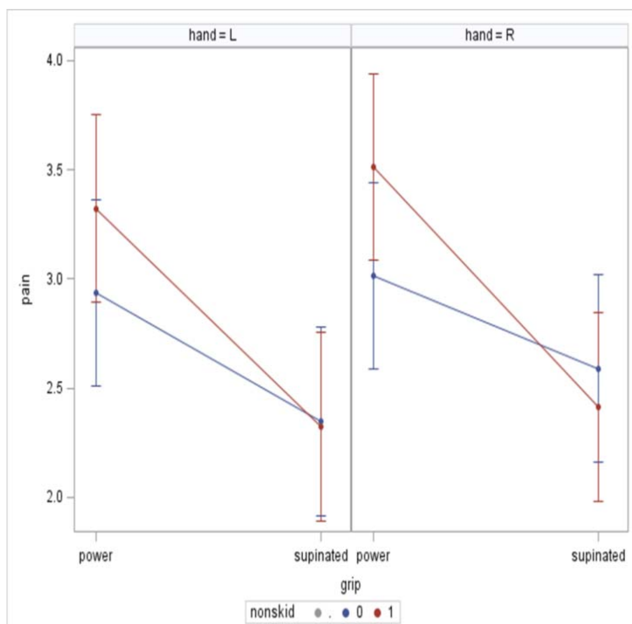


Figure 3.16. Interaction Effect of Approach and Nonskid Material on Pain Intensity.

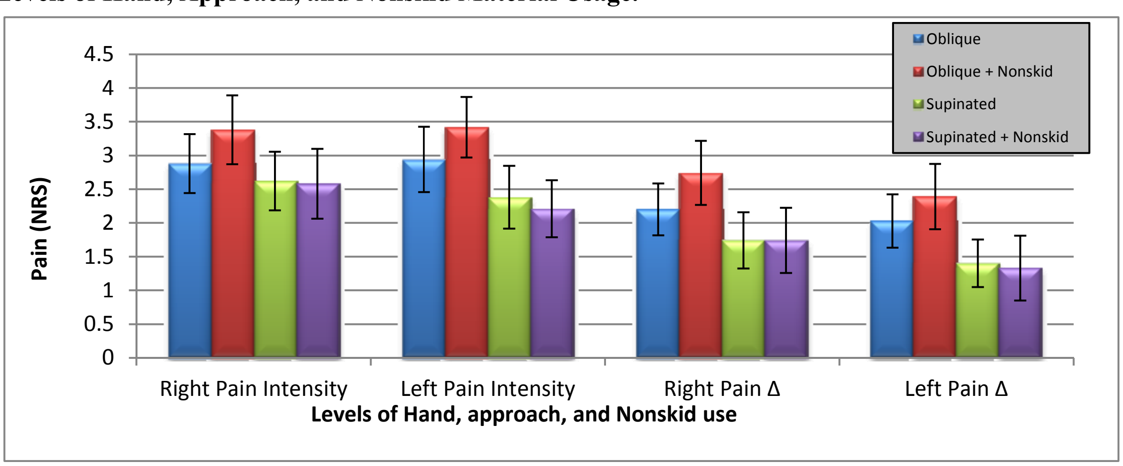
material yielded the lowest NRS scores and the oblique nonskid approach the greatest. Yet, quite surprisingly, the combination of a nonskid material and oblique approach yielded a pain rating significantly higher than any other combination (p<.05). See tables 3.7 and 3.8 for details on main and interaction effects on pain and figure 3.16 for the illustration of the near-significant interaction effect.

Table 3.6. Descriptives and Within Subjects Comparisons for Success in Opening and Pain across Four Approaches to Opening a Sealed 83mm Jar[*]

Approach +/- Nonskid	Hand Turning	n	Trials	Successes (% Total)	Pain Intensity X(SD)	Δ Pain X(SD)
Oblique	Right	30	60	11(18.3)[a]	2.88(2.4)[aef]	2.20(2.1)[ab]
	Left	31	62	19(30.6)[b]	2.94(2.7)[abcd]	2.03(2.2)[abd]
Oblique + Nonskid	Right	30	60	16(26.7)[ab]	3.38(2.8)[ce]	2.74(2.6)[b]
	Left	31	62	23(37.1)[bc]	3.42(2.5)[ac]	2.39(2.7)[bg]
Supinated	Right	28	56	28(50.0)[cd]	2.62(2.3)[d]	1.74(2.2)[cdg]
	Left	29	58	33(56.9)[de]	2.38(2.5)[dgh]	1.40(1.9)[ce]
Supinated + Nonskid	Right	27	54	39(72.2)[e]	2.58(2.7)[bfg]	1.74(2.5)[acd]
	Left	27	54	46(85.2)[f]	2.21(2.2)[h]	1.33(2.5)[e]

***Note:** Successes = number of trials where the jar lid 'seal' was broken. Reports of pain are not specific to a hand. Pain severity was reported after each trial via the Numerical Pain Rating Scale (NRS). Change in pain = (pain NRS score after each trial) – (baseline NRS score). Differences in success frequencies determined via Cochran's Q whereas differences in pain were determined via Student's *t*. Within columns, significantly different (p<.05) pairwise comparisons are denoted when individual superscript letters do not match. Matching superscript letters indicate non-significant differences.

Figure 3.17. Pain Intensity and Change in Pain Intensity from Baseline Across Levels of Hand, Approach, and Nonskid Material Usage.*



***Note:** Reports of pain are not specific to a hand. Pain severity was reported after each trial via the Numerical Pain Rating Scale (NRS). Change in pain = (pain NRS score after each trial) – (baseline NRS score).

Table 3.7. 'Main Effects' of Hand use, Grasp Pattern, and Nonskid Material use on Hand Pain, Forces, Hand Torques, and Integral of Force*			
	Main Effects		
Factor	**x̄ + SE**	**x̄ + SE**	**F [P(diff)]**
Hand	**Right**	**Left**	**Hand**
F(y)	15.42+1.8	23.83+1.8	0.08
Grip Force	158.13+6.2	134.0+ 6.1	<.0001
Fx Integral	26.4+1.5	33.95+2.5	0.01
Fz Integral	71.62+8.5	88.73+8.5	0.001
Grip Integral	781.0 + 29.2	710.4 + 28.9	0.009
M(z)	3.55+0.2	3.71+0.2	0.01
Δ Pain	2.10+0.3	1.79+0.3	0.05
Approach	**Oblique**	**Supinated**	**Approach**
F(x)	12.73+0.9	9.45+0.9	0.0003
F(y)	28.44+1.8	10.82+1.8	<.0001
F(z)	20.69+2.3	42.94+2.3	<.0001
Grip Force	138.5+6.2	153.5+6.3	0.01
F(x) Integral	37.57+2.6	22.77+2.6	<.0001
F(y) Integral	79.04+6.6	28.0+6.6	<.0001
M(x)	1.49+0.1	1.17+0.1	<.0001
M(z)	3.28+0.2	3.98+0.2	<.0001
Pain intensity	3.20+0.4	2.42+0.4	<.0001
Δ Pain	2.34+0.3	1.55+0.3	<.0001
NonSkid	**Yes**	**No**	**NonSkid**
M(x)	1.37+0.1	1.30+0.1	0.09
M(y)	1.03+0.1	0.90+0.1	0.003
M(z)	3.74+0.2	3.51+0.2	0.0005
F(z) Integral	34.1+4.1	27.8+2.5	0.04

***Note*: Reports of pain are not specific to a hand. Pain severity was reported after each trial via the Numerical Pain Rating Scale (NRS). Change in pain = (pain NRS score after each trial) – (baseline NRS score). Force Values are reported in newtons, Moments are reported in Newton-Meters, and integral of force is reported in Newton*Seconds given that the distance associated with jar turning is uniformly fixed.**

Table 3.8. General Linear Model (GLM) 'Interaction Effects of Approach, Hand Use, and Nonskid Material use on Hand Forces, Hand Torques, and Integral of Force

Interaction Effects									
Interaction	**x̄ ± SE**	**x̄ ± SE**	**x̄ ± SE**	**x̄ ± SE**					**P(diff)**
Hand*Approach	**Right Hand Oblique**	**Right Hand Supinated**	**Left Hand Oblique**	**Left Hand Supinated**					**Hand* Approach**
F(z)	16.12 ± 2.5^{b}	42.10 ± 2.4^{a}	25.54 ± 2.4^{c}	43.66 ± 2.5^{a}					0.005
M(y)	1.02+0.08^{c}	9.911+0.07^{c}	1.18+0.07^{a}	0.74+0.08^{b}					0.0002
Hand*Nonskid	**R + Nonskid**	**R - Nonskid**	**L + Nonskid**	**L - Nonskid**					**Hand* Nonskid**
F(z)	33.98±2.5^{b}	31.80±2.5^{b}	28.00±2.5^{a}	33.50±2.4^{b}					0.006
M(y)	1.12 ± 0.1^{a}	0.81 ± 0.1^{c}	0.95 ± 0.1^{b}	0.99 ± 0.1^{b}					0.0001
Approach*Nonskid	**Oblique + Nonskid**	**Oblique – Nonskid**	**Supinated + Nonskid**	**Supinated – Nonskid**					**Approach* Nonskid**
M(y)	1.21 ± 0.1^{a}	0.99 ± 0.1^{a}	0.85 ± 0.1^{b}	0.80 ± 0.1^{c}					0.07
F(x) Integral	42.46 ± 3.1^{b}	32.69 ± 3.4^{c}	22.26 ± 3.6^{a}	23.29 ± 3.0^{a}					0.07
F(y) Integral	86.29 ± 7.7^{b}	71.79 ± 7.3^{c}	23.92 ± 7.9^{a}	32.17 ± 7.2^{a}					0.03
F(z) Integral	67.30 ± 9.1^{ab}	60.34 ± 9.4^{a}	82.22 ± 9.7^{b}	110.83 ± 9.0^{c}					0.0007
Grip Force Integral	1003.34±54.0^{a}	929.48±56.5^{a}	675.94±58.3^{c}	810.89±53.2^{b}					0.003
Pain Intensity	3.42±0.4^{c}	2.97±0.4^{b}	2.37±0.4^{a}	2.47±0.4^{a}					0.07
Interaction	**x̄ ± SE**	**x̄ ± SE**	**x̄ ± SE**	**x̄ ± SE**	**x̄ ± SE**	**x̄ ± SE**	**x̄ ± SE**	**x̄ ± SE**	**P(diff)**
Hand*Approach* Nonskid	**Right Oblique + Nonskid**	**Right Oblique - Nonskid**	**Right Supinated + Nonskid**	**Right Supinated - Nonskid**	**Left Oblique + Nonskid**	**Left Oblique - Nonskid**	**Left Supinated + Nonskid**	**Left Supinated - Nonskid**	**Hand* Approach* Nonskid**
F(x)	16.20±1.4^{b}	9.20±1.5^{ac}	6.00±1.4^{c}	12.34±1.3^{ade}	11.23±1.3^{ae}	14.30±1.3^{bde}	12.83±1.6^{e}	6.64±1.3^{c}	<.0001
F(y)	34.71±2.3^{a}	23.16±2.5^{b}	6.89±2.3^{c}	17.16±2.2^{e}	23.31±2.2^{b}	30.85±2.2^{a}	12.75±2.6^{e}	6.46±2.2^{c}	<.0001
F(z)	26.58±2.8^{c}	16.70± 3.0^{d}	41.39±2.9^{a}	46.90±2.7^{b}	15.33±2.7^{d}	24.17±2.8^{c}	40.67±3.1^{a}	42.82±2.7^{ab}	<.0001
F(y) Integral	70.47 ± 8.9^{a}	66.09 ±9.9^{ab}	22.14 ± 9.1^{e}	17.68 ± 8.5^{e}	102.11 ±8.4^{f}	78.45 ± 8.7^{a}	24.50±10.3^{e}	46.65 ± 8.6^{b}	0.03

***Note**: Reports of pain are not specific to a hand. Pain severity was reported after each trial via the Numerical Pain Rating Scale (NRS). Change in pain = (pain NRS score after each trial) – (baseline NRS score). Force Values are reported in Newtons, Moments are reported in Newton-Meters, and Integral of Force is reported in Newton*seconds given that the distance associated with jar turning is uniformly fixed. Pairwise comparisons were calculated via t-test. Significantly different (p<.05) pairwise comparisons are denoted when individual superscript letters do not match. Matching superscript letters indicate non-significant differences.

Discussion

Nonskid Materials

The results of this study reveal that the use of nonskid material alone does enhance the torques acting upon the jar lid about two of the three axes of jar-lid rotation. Nonskid material's most notable main effect on torque was on M(z), the torque required to overcome a sealed jar torque requirement. Regardless of the hand and approach, the use of nonskid enhanced the ability to generate M(z) torque by roughly 6.1% and the mean M(z) torque of those using the nonskid material was only .5 newtons less than what was required to 'break the seal' of the instrumented jar. The main effects of nonskid material also enhanced M(x) and M(y) torques acting upon the jar lid the effect of nonskid material on M(x), in favor of the nonskid material, was approaching significance ($p=0.09$).

Additionally, the use of nonskid material assisted in creating more downward compression into the top of the lid across time [integral F(z)]. Being capable of sustaining this downward compressive load is likely needed to increase the frictional interaction between the palm of the hand and the superior surface of the lid prior to initiating turning as well as when the turning hand is grasping while attempting to break the seal. This is demonstrated on all of the sample force-time curves located in figure 3.18 in the chapter's appendix 3A as the F(z) force curve tended to precede the time curve of one sample FSR. Data from only one of the six FSR (i.e., grip force) was displayed in the diagram so as to minimize clutter but yet trends in grip force appear well represented by the lone FSR. The effect of non-skid material was not the only variable influencing hand force, hand force integral, and torque acting upon the lid.

Approach

Without consideration of other experimental factors, the supinated approach required less non-grip, or compressive, forces in two of the three orthogonal axes of the jar lid [i.e., F(x) and F(y)] than did the oblique approach yet, conversely, generated more F(z) force. The necessity to sustain F(x) and F(y) forces across time (i.e., integral of force) was also greatest with the oblique approach. As with the nonskid material, the enhanced generation of F(z) is likely improving the frictional interplay of the hands and jar-lid surface so as to enhance its capacity to generate grip forces without slippage. This hypothesized relationship appears to be supported by the larger grip forces inherent to the supinated grasp. Additionally, the greater average increases in pain and higher NRS ratings associated with the oblique approach are likely related to the generation of higher 'thenar-push' directed forces [F(x) and F(y)] as well as their integrals, integral F(x) and integral F(y). Moreover, the mean within-subjects change in NRS from baseline to after completing trials of all oblique approaches exceeded the clinically significant change of 2 units[42] whereas the mean within-subject changes per those using a supinated approach did not.

Hand

Although the sample was 90.3% right handed and the participants' right hand was, per dynamometry, as strong if not stronger than the left, the left hand helped to produce more F(y) force as well as F(x) and F(z) integral. Moreover, the left hand appeared to be better equipped to generate the type of torque primarily responsible for breaking a jars seal, [M(z)]. Because the distribution of hand arthritis was statistically indifferent across all right and left joints, save the small finger PIP, these results cannot be attributed to the right hand having a higher joint count.

Relatedly, an argument cannot be made that the left hand generated less grip force across all factors and levels because it was weaker than the right. This is not supported by the sample's baseline characteristics of having non-different average right and left hand MVC grip and 3-point pinch.

Pain intensity also did not appear to be impacted by the hand doing the turning. According to the generalized linear model analysis, the hand initiating the twist had no effect on pain ($p<0.32$). The hand turning the lid did, however, influence the pain experienced after a trial of jar-lid twisting when compared to baseline NRS ratings. Study participants who performed a left handed twist to the jar lid reported a smaller change relative to their baseline scores than did those twisting with their right hand ($MD=-0.31\pm0.16$, $p=.05$).

Combined effects of hand, approach and nonskid material

The left hand supinated approach with nonskid material resulted in 85.2% success rate, the lowest pain intensity and the least amount of change in pain from baseline. This is likely for a constellation of reasons. One of which is the independent and positive effects of nonskid material on pure [M(z)]. Off-axis [M(y)] torque, however, does not contribute to the act of opening a lid which rotates for removal and was controlled for through a left hand supinated approach.

A second is the main effect of nonskid material on the sustained ability to generate forces that enhance palm-lid contact [F(z)]. When combined with a supinated approach and left hand the interaction amongst the three resulted in an average F(z) force which was significantly greater than all oblique combinations and no different than other supinated approaches.

Third, although the supinated grasp does allow for greater grasp forces, the steep F(z) trajectories on the force time curves (Figure 3.18) appear to allow for a rapid attainment of peak grip forces and M(z), and thus the sustained effort, or integral of grip forces, is significantly lower during the supinated approach, particularly when using the left supinated approach with nonskid material.

An additional finding in favor of this approach's efficiency is the decreased need to sustain (i.e., integral) F(x) when using a supinated approach with nonskid material. The reduced F(x) integral may have been critical to 83.9% of the sample with 1st carpometacarpal OA because F(x) is likely generated through a thenar 'push' which would add overpressure to an area which is typically tender. This is exemplified by the significantly greater pain experienced by those using the approach which requires the most F(x) integral, the oblique with nonskid material approach.

Similarly, because the role of thumb in jar turning is two-fold: 1) providing a pushing force perpendicular to the side of the lid [i.e., F(x)] and 2) facilitating rotational movement through application of a force tangential to the lid[43] [i.e., F(y)], the main effect of approach on F(y) revealed that the supinated approach also unloads the thumb through reducing F(y). Moreover, the reductions in F(x) and F(y) noted in supinated approaches appear linked with the increases in F(z) attributable to nonskid material use and a supinated approach as well as increases in Integral F(z) attributable to the left hand. This is likely because the downward compressive forces [F(z)] used with a supinated grasp helps to facilitate movement in place of some F(x) and F(y) forces. In addition, the left hand's reduced grip force profile during jar turning likely diminishes the joint reactive forces of the digits involved in the turning task, particularly the thumb as it has been reported to constitute 50% of the grip force profile during jar twisting[43].

Lastly, for most participants with 1st CMC arthritis, the girth of the jar base stressed the stabilizing hand's thumb into maximal palmar abduction when using the oblique approach which qualitatively resulted in increased pain and difficulty maintaining the counterforce necessary to rotate the lid independent of the base. This is not reflected in the data but was a commonly reported theme throughout data collection.

The marriage of the left hand's reduced grip force requirements and compensatory F(z) force and M(z) torque enhancements; the torque and integral F(z) enhancing benefits of nonskid material; and the compensatory F(x) and F(y) 'force-sparing' and F(z) enhancing supinated approach, in the absence of any other recommendations, appears to be best approach to opening a sealed jar through one's own body power in an 'unrestrained' fashion.

Moreover, although the kinematics of the 'unrestrained' supinated and oblique approaches (sans nonskid material) have been demonstrated to be non-different[30], the kinetics, as per the aforementioned main and combined effects of approach and hand, are statistically dissimilar.

Although least painful, most efficient and most successful, the left supinated grasp with nonskid material approach still required about 30.6 (136.2 N) lbs. of grip force when attempting to open a jar sealed to common torque for 83 mm closures of 4.2 N*m. This amount equates to 60.4% of the participants' average left hand MVC grip strength. Because it is has suggested that the frequent utilization of forces exceeding 15-20% of

MVC strength may be linked to developing upper limb musculoskeletal disorders[44,45], persons with hand arthritis should supplement these task modification principles with other joint protection strategies such as breaking up work and using rest when baking or such where multiple sealed jars are to be opened. Even though jar opening is often a transient and isolated task and breaking the seal of a jar is even more so, the sustained loading of the hand within or across inefficient or multiple failed attempts, could have cumulative implications.

These findings also call to question the validity of the common assumption that 20 lbs. of MVC grip strength is enough to engage in daily activities[46]as many participants were unable to successfully ‘break the seal’ of the tool and, on the average had MVC grip strength values of 30 lbs. greater than such, and exerted between 30.6 (136.2 N) and 38.2 (169.9 N) lbs of grip force when attempting to ‘break the seal’ of the instrument.

Conclusions

The left hand supinated approach with nonskid material:

1) Resulted in the most successful attempts at ‘opening’ the jar;
2) Resulted in the least amount of pain intensity and change in pain from baseline;
3) Required less inefficient torques [M(x) and M(y)] than any oblique approach;
4) Produced more M(z) torque than all but the right supinated approach with nonskid material;
5) Required the least amount grip force across time;
6) Although not statistically different from other left hand approaches, required significantly lower grip force than all but one right hand approaches, right supinated with nonskid;

7) Required less frictional force tangential to the side of the lid [F(y)] across time than any oblique approach as well as the left supinated approach without nonskid material
8) Required less compressive force perpendicular to the side of the jar lid [F(x)] across time than any oblique approach
9) Generated more F(z) force and integral of F(z) than any oblique approach

These findings are generalizable to a population of women with mild to moderate hand osteoarthritis symptomology. However, given the high percentage of participants with base of thumb OA, these results might be more generalizable to this subset of the population. Therapists cannot simply make recommendations for women with hand arthritis to use nonskid material to open large sealed jars; the approach and hand used to open the jar must also be considered. Like any other intervention, it should be individualized however for the population represented by this study, regardless of hand dominance, and without the presumed influence of differences in MVC strength and joint-counts, the use of nonskid material, supinated approach, and left hand is recommended.

Limitations.

Pain scores by hand were not gathered after each trial and thus pain could not be isolated to hand twisting or the hand stabilizing. The participants in this study scored relatively low on the AIMS-2 Total Health Scale, indicating milder symptoms and effects on function. Further study is needed to determine if similar results would be present in a population with more severe hand arthritis. For the present study, radiographic staging was not available to determine arthritis severity however cohort studies have revealed that radiographic changes in hand arthritis do no often correspond with clinical symptmoglogy[47,48].

Much of the why this trifecta has pain reducing and success enhancing qualities remains unexplained through the present experiment. Confounding factors include the lack of understanding of the jar and person-level kinematics. It would be helpful to understand why the ulnar deviation moment of the left wrist is greater than the radial deviation of the right hand. Kinematics could likely help to explain such. For example, the increased success of the left turn with a supinated grasp may be because the ulnar wrist deviators were contributors to the compressive loads upon the lid and have a ulnar-volar directed moment (i.e., in the direction of F(z)). Additionally, the lack of a biomechanical analysis of the hand-jar base interface leaves some unanswered questions.

Lastly, the integral of force analysis, a measure of force and the length of exertion time, included those who were and were not successful and because those who were not successful commonly exerted forces for the full duration of the task, it is likely that the integral of force findings are closely tied to success.

Suggestions for future research.

- Quantify the hand force profiles and kinematics of the non-turning hand
- Evaluate the impact of hand sensibility, thumb mobility, wrist strength, and EMG activity of the upper limb on the kinetics of jar opening success
- Integrate 3D analysis of the upper limbs and jar to better understand the kinetics of the tasks as well as determine the joint reactive forces through inverse dynamics modeling

- Instrument other commonly problematic tasks to learn if applying joint protection principles to such is also beneficial
- Investigate the required hand force thresholds for successful jar opening
- Perform sub-analyses on the integral of forces across all approaches for those who were successful to control for the likely effect of success on hand force over time.

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Chapter 4

Hand Force Requirements and Factors Influencing Success of women with Symptomatic Hand Osteoarthritis during a Jar Opening Task

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Introduction

Our population is aging. It is widely understood that with advanced age the incidence for physical and physiological impairment as well as activity limitation increases[1]. Reduced grip strength, a broadly studied physical impairment, has been demonstrated to have significant relationships with and predictive of declines in functional performance among older adults[2-4]. This literature along with evidence that grip and pinch strength decline steadily after age 55[5,6] would seem suggest that hand grip strength is a variable worthy of attention when attempting to prevent or ameliorate activity limitation among older adults.

Arthritis is a highly prevalent condition among older adults, is known to negatively impact handgrip strength, and is the single most disabling condition in the United States[7]. A common site of arthritis is in the hand and one in twelve U.S. inhabitants (2.9 million), primarily composed of post-menopausal women, are estimated be living with a symptomatic form of the condition[8].

Much attention has been given to population and diagnosis specific incidence of hand grip/pinch strength impairments and how grip and pinch strength predict or relate to task performance. However, to this date, few have attempted to establish task-specific hand force requirements and the available literature is methodologically flawed, or anecdotal. Moreover, it is not specific to a growing population of persons, often women, who experience activity limitation, related to pain and reduced hand strength[8-11].

There is the need to explore the hand force requirements of a population of persons often challenged by the effects of reduced hand strength as they engage in those tasks, namely women with hand osteoarthritis. One manual task which is reported to be particularly troublesome to women with hand arthritis is jar-opening[9]. This study explores the force requirements of jar turning through an experimental yet naturalistic design and attempts to accurately capture the various hand grip forces acting at the site of the person-object interface. In addition, study aims to determine to what extent factors commonly believed to influence hand function explain the force profiles used by and success of women with hand arthritis when opening a sealed jar.

Review of Literature

Occupational Performance and Hand Osteoarthritis

The previously referenced prevalence of arthritis among women and the ever increasing prevalence of persons over the age of 65 warrants an exploration of how various types and locations of arthritic presentation will affect occupational performance, specifically hand function.

Kjeken, Dagfinrud, Slatkowsky-Christensen, Mowinckel, Uhlig, et al.[9] conducted a descriptive study on the self-reported daily experiences of persons with hand osteoarthritis and found personal care and household maintenance activities to be the greatest sources of occupational dysfunction (Mean Canadian Occupational Performance Measure 'performance score' = 5.23/10). The specific task of greatest difficulty was reported to be opening a jar (Australian/Canadian Osteoarthritis Hand Index Score = 1.80/4).

Symptomatic hand osteoarthritis has also been demonstrated to be predictive of self-reported difficulty with lifting 10 lbs. (OR 2.31; 95% CI 1.23-4.33), dressing [Odds Ratio(OR) 3.77; 95% CI 1.99-7.13], and eating (OR 3.44; 95% CI 1.76-6.73)[8]

Arthritis and Hand Strength

Dominick et al.[10] investigated the association of radiographically evident hand OA (n = 700) with hand grip/pinch strength and found that the presence of OA in the 1st hand ray to be a significant predictor of reduced grip and pinch strength ($b = -11.08$, $p < 0.001$, and $b = -2.05$, $p < 0.001$ respectively). The authors also reported significant associations between hand joint OA severity, as indicated per Kellgren and Lawrence (1957) grades, and hand grip and pinch strength ($b = -0.67$, $P < 0.001$ and $b = -0.16$, $p < 0.001$ respectively).

Similarly, maximal voluntary grip and pinch strength measures of post-menopausal woman with generalized hand osteoarthritis were significantly lower ($p<0.05$) when compared to age and gender matched healthy controls[11]. Individuals with erosive and nodule generalized arthritis have also been found to have significantly less grip strength ($p<0.03$) relative to those with hands unaffected by arthritis[12].

These trends in reduced MVC measures of grip and pinch strength among those living with hand arthritis, and the prevalence of these conditions among older women support the study’s focus with this sample in mind.

Required Grip/Pinch Forces for Occupational Performance

Nalebuff and Philips[15] stated that, based on their clinical experience in rheumatology and hand rehabilitation, one needs to have 20 lbs of grip and 5-7 lbs of pinch strength to be independent in activities of daily living (ADL) however their assertions were made without any data to substantiate them.

Berns[13]instrumented containers with strain-gauges and reported that, for the normal population, the necessary torque to successfully manage a large jar to be 40 in-lbs. Imrhan and Loo[14] observed that non-disabled women, on average, applied 39 N of MVC grip force when twisting textured jar lids and that hand grip explained 41-67% of the torque generated.

Rice, Leonard, and Carter[16] examined the pinch and grip forces exerted on six common household containers among well college-aged while Rahman, Thomas, and Rice [17]carried forth this work and studied functionally independent, well-elderly participants. Unfortunately, thresholds were not able to be determined given that, across both studies, grip/pinch measures were all within normal limits and the participants were all successful when accessing the six containers.

Rahman, et al.[17] did, however, suggest that the elderly participants utilized a greater percentage of their MVC to access the containers. The authors questioned if sampling from a population of persons living with hand-grip or pinch impairments or clinical populations might yield data to explain how little grip or pinch strength is required to participate successfully in various daily occupations.

Aside from the limited volume of research done to explore this topic, there are issues with the nature and sensitivity of the methods used to gather relevant grip force data. Four methods of measuring the grip forces acting upon objects are reported in the literature. As previously discussed, Rice et. al.[16] and Rahman et al[17] instrumented 8 common household containers with force sensing resisters. Fowler, and Nicol[18] quantified the forces acting on interphalengeal (IP) joints during simulated functional tasks (i.e., twisting a jar lid, twisting a water bottle cap, and turning a key). In their study, a force transducer was incorporated into the body of the aforementioned objects to quantify the pinch forces of one digit acting on the object and video motion analysis was used to collect kinematic data. With this information they were able to extrapolate data to determine the reactive forces acting on the distal and middle IP joints across the simulated tasks. Others have instrumented the hand with adherent FSR[19] or through wearing a FSR embedded glove[20].

These instruments, however, are all flawed in that they change the natural condition of the task being studied. The glove with FSR and skin adherent FSR would presumably alter one's sensory experience and resultantly skew grip-force modulation and precision skills. Conversely, instrumenting the objects with FSR would change the object properties making the task less representative of what it is that you're attempting to measure. Theses sensors are also likely to experience skin slip. Although the hand would be free from a muffled tactile experience, the artificial objects used in the simulated tasks presented by Fowler and Nicol[18] would more than likely not represent the dimensions and textures of an object in its natural form and therefore the results would appear to have poor face validity.

Lastly, because the grip forces used during dyanamic manual activities are only moderately correlated with distal upper limb electromyography[21], studying only the grip forces used during occupational performance is likely underestimating other externally applied forces (e.g., palm compression and shear forces).

Other factors believed to influence or predict grip force

It is apparent in the literature that upper extremity impairments can predict or are related to functional limitations. Hand strength, although often simplistically quantified, if impaired is often a gross representation of other neuromusculoskeltal impairments.

Thus, many have explored what other physical components relate to or explain the variance in the ability generate hand grip forces.

Sensation. One such component, upper extremity sensation, when impaired, has been shown to affect hand function detrimentally. Johansson and Westling[22] studied factors influencing the control of precision grip after hand sensory impairments were temporarily induced via local anesthesia. They reported that among those with the induced mechanoreceptor sensory impairment, applied grip force (i.e., forces exerted on an object to prevent slippage) latencies existed across frictional conditions. Their finding indicated that poorer friction discrimination was significantly associated with longer latencies of grip-lift measures ($r = .34$; $P = .03$) and altered grip force regulation ($r = .34$; $P = .03$). Both concluded that impaired friction discrimination ability contributes to altered timing and force adjustment during pinching and lifting tasks.

Similar trends were found among individuals of a different clinical population, those living with cervical myelopathy. Doita, Sakai, Harada, Nishida, Miyamoto, Kaneko, and Kurosaka[23] reported that those with moderate to severe loss in non-standardized measures of light touch sensation scored significantly lower than those with mild impairments or less ($p < 0.05$) on a standardized hand function test. The authors also reported that moderate to severely impaired non-standardized measures of upper extremity proprioceptive awareness were significantly associated with reduced precision grip ($p < 0.05$).

When comparing the proximal interphalangeal position (PIP) joint sense of persons with rheumatoid arthritis (RA) to age and gender matched controls, persons with RA demonstrated significantly less proprioceptive awareness that did the controls(p <

0.0005). The errors demonstrated by the participants with RA appeared to favor the flexed posture and the authors speculated that joint effusion may have disrupted afferent input from those proprioceptors which signal extended positions however the mechanism was not tested through histologic examination[24]. The authors related that similar trends also likely exist in the osteoarthritic hand given that decreased kinesthetic awareness in the osteoarthritic knee has also been documented[25].

The authors went on to speculate that this altered joint position sense may contribute to the flexion deformities experienced by persons with RA and when compared to health controls without the presence of hand deformity, the presence of such deformities have been reported to result in relative reductions of ($p<.05$) grip strength[26].

Lastly, those from the population of interest, women with hand arthritis, have been reported to use higher grip forces and have longer latency times when applying grip forces to varied loads when compared to age matched controls $F= 6.576$; $p = 0.020$ and ($F= 7.175$; $p = 0.015$) respectively[27].

Range of motion. Upper extremity range of motion (ROM) and joint impairment have been discussed in the arthritis literature as being indicators of hand function and occupational performance. Limited thumb circumduction ROM and ROM goniometric measures of the most limited proximal interphalangeal joint were found to be moderately correlated with self-perceived performance of fine motor tasks as measured by a non-standardized 41-item survey of function ($r = -0.63$ and $r = -0.61$ ($p<.05$) respectively) among 95 individuals with osteoarthritis[28].

Pain. Ozkan, Keskin, Bodur, and Barça[29] sampled from a population of elderly persons living with hand osteoarthritis ($n = 100$) and found Visual Analog Scale pain ratings to be significantly correlated ($p = 0.001$) with standardized measures of hand function (i.e., Dreiser's Functional Index and the hand disability index of the Health Assessment Questionnaire) as well as grip strength, lateral pinch, and palmar pinch measures ($p = 0.001$).

Likewise, Bagis, Sahin, Yapici, Cimen, and Erdogan[30] studied 100 post-menopausal women with hand osteoarthritis and found that 86 percent of the subjects with hand OA were suffering from pain and 57 percent were found to have point tenderness. Those subjects that reported pain were found to have significantly lower maximal voluntary pinch strength ($p<.05$) and standardized tests of hand function measures ($p<.001$) than those without.

Perceived effort. Although reports of effort, like pain measures, are not objective measures of hand function per se, they have been used in humans factors research to help quantify musculoskeletal strain due to proof that measures of grip force alone are only mildly to moderately ($r=0.18\text{-}0.47$, $p<.05$) correlated with electromyographic evidence of muscle strain during dynamic manual activities[21]. McGorry et al.[31] did, however, find that measures of dynamic grip forces are strongly related to perceived effort. In this study, healthy male laborers were asked to report their perceived effort per the Borg CR10 Scale[32] after each trial of handling force-sensing ratchets and screwdrivers. Average peak forces and integrated grip force (i.e., grip/time) during tool handling had good to high correlations with perceived effort ($r=0.77\text{-}0.91$, $p<.05$ and $r=0.81\text{-}90$,$p<.05$ respectively) and thus may also have validity when estimating the hand forces of persons with injured or arthritic hands.

Hand Anthropometrics. Hand length (i.e., the length of the hand from the radial styloid to the tip of the long finger)[33] has been reported to be highly correlated (r=0.80, p>0.01) to MVC grip strength[34] and is known to relate (r=.36, p<.01) to women's ability to generate maximal torque when turning a jar lid[35]. Thus, hand length is another physical components, which may impact the ability to generate hand grip forces.

The outcome of successful opening of the jar lid is dependent on one's ability to exceed to torque at which a jar lid is sealed by the manufactor[36]. Thus, the ability to generate torque about the imaginary axis of jar lid rotation in the direction opposite of the how the seal was created (i.e., counterclockwise) is the primary objective of the consumer.

As described by Edwards et al.[37], "The intrinsic muscles contract isometrically to make the whole hand immobilised and the extrinsic muscles can transmit a

strong force and torque across the wrist for opening the jar". The overarching aim of this study was to characterize the hand forces used to enable the generation of the necessary torque to open a sealed jar among persons from a population often troubled by this activity. Beyond this, the objective was to study if and how much the aforementioned factors influence the ability to generate these grip forces and torques by women with hand osteoarthritis.

Specific Aims and Study Hypotheses

The aims of this study were to:

1) Explore how the hand force profiles of women with hand osteoarthritis who were successful in opening a sealed jar differ from those who were not and

2) Determine if several measures of hand function known to affect grip force production explain 1) the forces used when opening a sealed jar and 2) successful jar turning. Occupational therapists must have a fundamental understanding of which factors best predict success as they often work to remediate performance limitations believed to be barriers to successful engagement. This exploration is intended to enlighten the occupational therapist practitioner.

The research hypotheses were as follows:

1) There will be a significantly greater hand forces for participants who are successful in opening a sealed jar than for those who were not,
2) The integral of force requirements for successful 'sealed' jar opening for right and left hands will be clearly defined,
3) MVC grip and pinch dynamometry differences will exist between those who were and were not successful opening 'sealed' jar with right and left hands,
4) Measures of thumb mobility will be a significantly positive predictor of hand force generation,
5) Measures of pain will be a significantly negative predictor of hand force generation,
6) The presence of thumb CMC OA will be a significantly negative predictor of hand force generation,
7) Self-perceived disease impact will be a significantly negative predictor of force generation, and
8) Hand Sensibility will be a significantly positive predictor of force generation.

Methods

Design

A 2x2x2 factorial crossover design, with factors turning hand, approach, and use of nonskid material, was employed to investigate hand force profiles used by women with hand osteoarthritis who were or were not successful in opening a jar as well as hand factors (i.e., MVC grip strength, hand length, 1st digit mobility, hand sensibility, pain, and perceived effort) which explain the hand forces acting upon a jar lid while opening a sealed jar.

Participants

Following IRB approval and informed consent, thirty-one women, 18 years or older, with hand osteoarthritis participated in 8 trials of 'opening' the sealed jar across the above mentioned experimental factors. Participants were recruited through orthopedic, women's health, and hand therapy clinics, as well as community-based centers which served older adults.

Participants were eligible for the study if they were female, over the age of 18, and 1) had radiographicially confirmed and symptoms of arthritis or 2) a combination of self-reported physician diagnosis and symptoms (i.e., achiness and stiffness) of hand OA. Although recruiting subjects through orthopedic and hand therapy clinics would likely always yield documented radiographic confirmation of hand arthritis, a homogenous sample of women with hand symptomology so severe that care was sought out, would not represent well the heterogeneous spectrum of disease impact and severity. Recruiting through community-based organizations and women's health clinics opened the door to participants who were likely less impacted by their hand symptomology however to do this, radiographic confirmation was not accessible. Thus, participants who both reported a physician rendered diagnosis of hand oseteoarthritis and reported symptoms of hand osteoarthritis were included in the study. These combined criteria were chosen because Szoeke et al.[38] found that this combination yields the highest sensitivity (70.5%) and specificity (68.0%) when compared to the gold standard of radiography. Recruits were excluded from participating if any one of the following were present:

- Movement disorder with upper limb manifestation (e.g., Parkinson's, stroke, head injury, intentional tremor)
- Upper limb amputations
- Any history of hand joint arthroplasty
- Trauma within last 6 months that has increased symptoms that are non-arthritic in origin
- The diagnosis of hand/wrist conditions such as CTS or tendonitis
- Hand deformities that do not allow for grasp of instruments
- Strength testing is contraindicated due to medical co-morbidities

The average age of the participants was 63.7 (±13.9) years and 83.3% self-identified as being Caucasian, while the remaining 16.7% identified themselves as being African American. Twenty-eight subjects reported being right hand dominant, 1 reported being ambidextrous, and 2 reported being left handed. Laterality was determined based on self-report. Seventeen participants had radiographically confirmed hand arthritis in one or both of their hands whereas 14 reported having a physician diagnosis and symptoms of arthritis. See table 4.1.

Procedure

Table 4.1. Sample Demographics	
Sample Size (n)	31
	% of n
Hand Dominance	
Right	90.3%
Left	6.5%
Ambidextrous	3.2%
Race	
Caucasian	83.3%
African American	16.7%
Diagnosis Confirmation	
Radiographic	54.8%
Self-reported MD	45.2%
	X(SD)
Age (yrs)	63.70(13.9)

At the onset of the data collection session, participants were asked to participate in assessments of disease impact, pain, hand sensation, hand mobility, and hand anthropometrics. Then participants engaged in 16 trials of attempting to twist the lid of a force-sensing jar instrument. As the research questions did not pertain to the use of nonskid material, this study and analyses focused on the eight trials where nonskid materials were not used. Immediately following each trial of jar turning, participants were asked to report pain intensity and perceived effort. During this period of approximately 30 seconds partcipants were instructed to disengage from gripping the jar tool and rest their hands prior to engaging in the subsequent trial. At the end of the session, participants were given several minutes to rest during a debriefing period. After which, maximal hand strength measurements were gathered via grip dynamometry.

Instrumentation

Primary Measure.

Jar instrument. Participants were asked to complete 8 trials of attempting to 'break the seal' of a force-sensing jar apparatus (figure 4.1) through counter-clockwise twists. The experimental setup, design of the device, and the device's psychometric properties are summarized in

Figure 4.1. Jar Instrument.

chapter 2. The force-sensing jar's lid was instrumented with 6 force sensing resistors as well as a 6-axis load cell which allowed for the jar to detect both grip forces, gross compressive loads acting upon the jar's lid in each of the orthogonal axes (F(x), F(y), and F(z)), and lastly the moments (a.k.a., torque) applied to lid about these axes (M(x), M(y), and M(z)).

The three compressive loads can be described as 1) downward through the lid's axis of rotation (F(z)), 2) perpendicular to the side of the lid (F(x)), and 3) tangential to the lid (F(y)) (Figure 2). The moments about these orthogonal axes are 1) those which create a 'rocking' torque or the same type of torque one would use to pop the lid off of a canister of chips or tennis-balls (M(x) and M(y)) and 2) those which produce 'pure' rotational movement about the jar's axis of rotation [M(z)] (See figure 2). During each jar opening simulation the torque required to turn the jar device was set to replicate the actual torque required to open a sealed jar with a 83mm diameter lid [4.24 M(z)] [39].

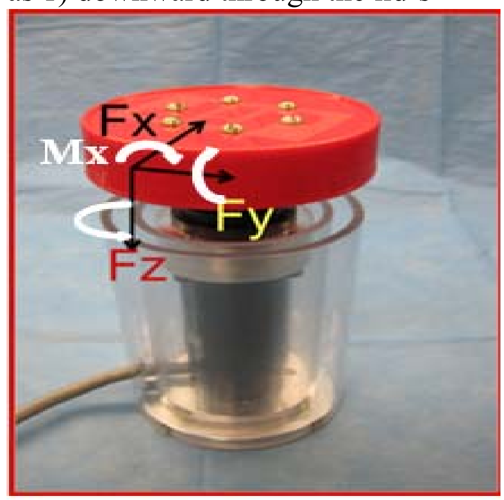

Figure 4.2: Jar Instrument-83 mm

The jar turning simulations consisted of two trials of two different factors, each possessing two levels: 1) the approach (supinated grasp vs. oblique grasp) and 2) the hand gripping the lid (right vs. left). Table 4.2 and Figure 4.3 illustrate the experimental design and approaches.

The two approaches to grasping a jar's lid and base were chosen as they have been described in the literature as being common methodologies[40] so as to determine if measures of hand function have unique effects on the force and success outcomes for differing approaches and turning hands. An ‘unrestrained’ approach (i.e., the absence of a supportive surface for the base of the jar such as a counter top) to opening the jar across all trials was chosen as the kinematics associated with use of a supportive surface have been proven to be the less efficient ($p<.0001$) when compared to either of the aforementioned two unrestrained approaches[40].

Secondary Measures.

Grip Dynamometry. Maximal Voluntary Contraction (MVC) grip force measurements of bilateral hands were assessed through the use of the Jamar dynamometer. The Jamar has high accuracy, good test-retest reliability[41] and was the measurement device used to collect the adult normative grip and pinch strength data by Mathiowetz, et al.[6]. The average of three trials was collected with the positioning and verbiage recommended by the American Society of Hand Therapists[6]. Measures of maximal pinch strength were not considered for analysis given that such would introduce redundancy due to the strong[42] associations($r=.55-.63$ for women, no p-value reported), between maximal grip and lateral/3 point pinch strength[6]

Table 4.2. Factors and Levels of Observations

Approach (2 levels)	**Turning Hand (2 levels)**
Oblique	Right Hand (2 trials)
	Left Hand (2 trials)
Supinated	Right Hand (2 trials)
	Left Hand (2 trials)

Perceived effort. The Borg CRI0 scale was administered in order to assess participants’ perception of effort following each trial of jar turning. Although the Borg Scale[32] has been used most widely to assess the subjective response of patients during graded exercise tests, a modified scale of perceived exertion, the CR10, has recently been used as a predictor of physical capacity[21, 21,31] . The Borg Scale is a general intensity category scale with numbers from 0 to 10 where 0 relates to no effort at all and 10 relates to extremely strong or almost maximal effort. The following standardized language was used to explain the scale to the study participants: "*using this scale, where 0 relates to no effort at all and 10 relates to extremely strong or almost maximal effort, how much hand effort did you use to open the jar?"*. See appendix 4A.

Pain. Instantaneous upper extremity pain intensity was assessed before and after each trial of jar turning through the use of the Numerical Rating Scale (NRS), a 0-10 numerical scale. The NRS has excellent test-retest reliability of for individuals with RA who were literate *(r* = 0.96) and for individuals who are illiterate (*r* = 0.95). The scale was chosen due to its validated use in arthritic populations[43] and because persons with chronic pain have preferred the NRS over other measures of pain intensity, including the pain VAS, due to its comprehensibility[44]. Lastly, the NPS has been used in many clinical trials for persons with OA and have produced evidence to support that a change of 2 units or 30% in the NPS is clinically meaningful[45]. During the data collection session, the following standardized instructions were given to all research participants: "*Rate your current arm pain on this 0 to 10 scale. Zero being no pain at all and 10 being pain so severe that it*

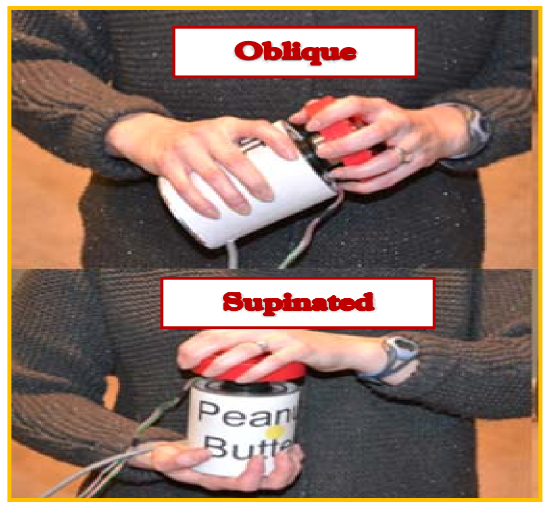

Figure 4.3: Two Approaches (for left hand)

would cause you to seek medical attention " while the scale was synchronously displayed (see appendix 4B).

Sensation. Light touch sensibility was evaluated through the use of a Semmes Weinstein Monofilaments mini kit[46]. This instrument has been demonstrated to be appropriate for the assessment of dysfunction in quickly adapting sensory fibers (e.g., those primarily involved with providing the cutaneous input needed to perform the desired tasks). These nylon monofilaments were applied to the hand in several predetermined locations per the standardized protocol[47]. Semmes-Weinstein Monofilaments have been well studied in normal and clinical populations and are reported to highly repeatable with little alteration in application forces[47] and according to Novak, Kelly, and Mackinnon[48] the test also possesses excellent inter-rater reliability (r = .965, CI = 95%).Given that only the volar aspect of each participants hand was in contact with the jar, sensation was only tested in the distal median and ulnar nerve distributions. A composite scoring system was then used to synthesize information (see Appendix 4C) and create composite scores that represent distal ulnar sensory thresholds, and distal median sensory thresholds.

Hand Mobility. As previously referenced, hand active range of motion assists in explaining the variance in MVC grip measures, is moderately correlated to self-reported performance of ADL among those with hand arthritis, and rheumatoid arthritis. It is for these reasons that this variable was considered when attempting to determine which assessments of hand function explain jar opening performance.

Active range of motion of bilateral thumbs was assessed through goniometry. Goniometry has long be been demonstrated to be a reliable form of assessing upper extremity joint range of motion[49,50]. A single measurement of flexion, extension, and hyperextension (when appropriate) of each digit's metacarpalphalangeal and interphalangeal joints (via a dorsal approach) was taken per participant.

Each thumb's AROM measurements was converted into a composite measurement described by Cambridge-Keeling[51] which is a summation of the total lag in extension and total available flexion as a percentage of the composite flexion normally available to that digit (total active motion or TAM). Through doing this instead of reporting a range of numbers per digit, the digit's total available active range of motion across all joints will be represented by one composite number. Because TAM measurements fail to take into consideration hyperextension deformities, hyperextension values were reported independent of TAM values. Only goniometric values of the thumb were included in this analysis given that the thumb has been reported to represent 40-50% of hand function[52] and other mean goniometric measures of wrist and forearm movement were, after analysis, within normal limits of the associated reference values.

Palmar abduction of the 1st carpometacarpal joint was assessed via the 'inter metacarpal distance' or 'IMD' (i.e., distance from the center of the 1st metacarpal head to the center of the 2nd metacarpal head)[53]. This approach to measuring 1st CMC abduction has excellent intratester reliability ICC= 0.95, 95% CI =0.95–0.99) and good inter-rater reliability (ICC=0.82, 95% CI= 0.79–0.96)[54]. An example of the data collection form is located in the appendix 4D.

Hand anthopometrics. Hand Length or the length of the right hand between the radial syloid and the tip of the long finger was measured through the use of a ribbon tape measurer. Each hand was placed on a table top with the middle finger placed in alignment the long axis the forearm[33]. This measurement was chosen because, in a study on the influence of personal and jar characteristics on consumers' ability to generate maximal torque when turning a jar lid , hand length was found to be highly correlated (r=0.80, p>0.01) to MVC grip strength[34].

Disease Impact. To characterize the impact of arthritis on the sample, participants were also administered the short version of the Arthritis Impact Measure 2 (AIMS2-SF)[55] to assist in the characterization of the impact of arthritis on the sample of interest. The AIMS2-SF is widely used and focuses on several domains of health and activity limitations. Moreover, an upper limb subscale allows for the evaluator to better isolate the effects of upper limb arthritis on health and activity. The tool is reported to have good-excellent reliability and strong concurrent validity with the Health Assessment Questionnaire (HAQ)[56].

Results

Data Management Statistical Analysis

Matlab® (Mathworks, Natick, MA) version 7.9 software was used to compute peak grip and compressive (i.e., F(x), F(y), F(z)) forces at the time of maximum torque about the lid's axis of rotation (i.e., M(z)), areas under the force-time curve (i.e., integral of grip force) for grip and compressive forces, and the peak moments (i.e., M(x), M(y), and M(z)) acting on the jar's lid. The resultant compressive force (i.e., the result of several forces acting in unison) of F(x), F(y), and F(z) was also computed through the use of Matlab and will thus forth be referred to as F(xyz).

Descriptive statistics, within-subjects comparisons (one-way ANOVA) for baseline sample characteristics, tests of correlation between dependent and explanatory variables (Pearson's r), multiple linear regression analyses analyses were performed through use of SPSS® (IBM, Armonk, NY) version 22. The tests of association and multiple linear regression analyses were used to:

1. Test associations between and estimate the effects of distal upper limb joint mobility, cutaneous hand sensation, hand length, perceived effort, pain, MVC grip strength, MVC pinch strength, the compressive forces acting on the jar lid at the time of peak M(z), and the grip forces acting on the lid at peak M(z) on the dependent variable, 'peak M(z)' for each combination of approach and turning hand (i.e., right oblique, left oblique, right supinated, left supinated) and;
2. Test associations between and estimate the effects of distal upper limb joint mobility, cutaneous hand sensation, hand length, perceived effort, pain, MVC grip strength, and MVC pinch strength on the dependent variable, 'grip forces acting on the lid at peak M(z)', for each combination of approach and turning hand (i.e., right oblique, left oblique, right supinated, left supinated).

A forward stepwise entry approach was performed with model entry criteria of $p<.10$. SAS® (SAS Inc., Cary, NC) version 9.4 (Proc Mixed) was used to estimate the effect of and interactions between the two experimental factors (i.e., hands and approach) on peak force, mechanical power, and peak torque using a mixed-effects linear model with hands as repeated factor and subjects as random effect to incorporate the correlation between repeated measurements from each subject. Moreover, the SAS "Proc Mixed" function was also used to:

1. estimate the effects of distal upper limb joint mobility, hand sensation, hand length, approach, perceived effort, pain, MVC grip strength, MVC pinch strength, the compressive forces acting on the jar lid at the time of peak M(z), and the grip forces acting on the lid at peak M(z) on peak M(z) using a mixed-effects linear model with subjects as random effects while controlling for the effects of hand.
2. estimate the effects of distal upper limb joint mobility, hand sensation, hand length, approach, perceived effort, pain, MVC grip strength, and MVC pinch strength on the grip forces acting on the lid at peak M(z) using a mixed-effects linear model with subjects as random effects while controlling for the effects of hand.

The SAS Proc GenMod function was used to estimate the effects of distal upper limb joint mobility, hand sensation, hand length, approach, perceived effort, pain, MVC grip strength, MVC pinch strength, the compressive forces acting on the jar lid at the time of peak M(z), and the grip forces acting on success while controlling for the effects of hand. Change scores of post-test NRS scores relative to baseline pain (ΔPain),TAM scores, and tertiles for jar-turning percent success (i.e., 1st= success rates of turning jar≤33.33%, 2^{nd}=success rates>33.33 to ≤66.66%, 3^{rd} tertile=success rates >66.66%) of several demographics factors and hand function measures were also calculated through use of SPSS® ver. 22. Percent success = # successes/Total Trials and in all but one subject's case, the formula's denominator was 8. Appendix 4F contains the SAS codes used for the analysis.

Participants

One participant was unable to participate in 4 trials of turning due to her arthritic symptomology. All others were able to fully participate in all 8 trials. On average, participants had been symptomatic for 9.02 years (± 6.8) and had been living with confirmed hand arthritis for 8.17 years (± 6.1). The AIMS2 SF average total health score of 10.62 (SD=5.28) indicated that overall perceived health was mildly impacted by the condition. Participants also reported mild disease impact in the physical, upper limb, social, and affective subscales. See table 4.3.

On average, participants had two digits affected by OA in both right and left hands (2.1±1.5 and 2.0±1.5 respectively). A test of difference in distribution of joint involvement revealed that the distribution of right and left arthritic joints was non-significantly different (p>.05) across all joints with the exception of the small finger proximal interphalangeal (PIP) joint. In this instance, the left hands of the participants had significantly more small finger PIP joints impacted by OA than did the right (z=2.00,

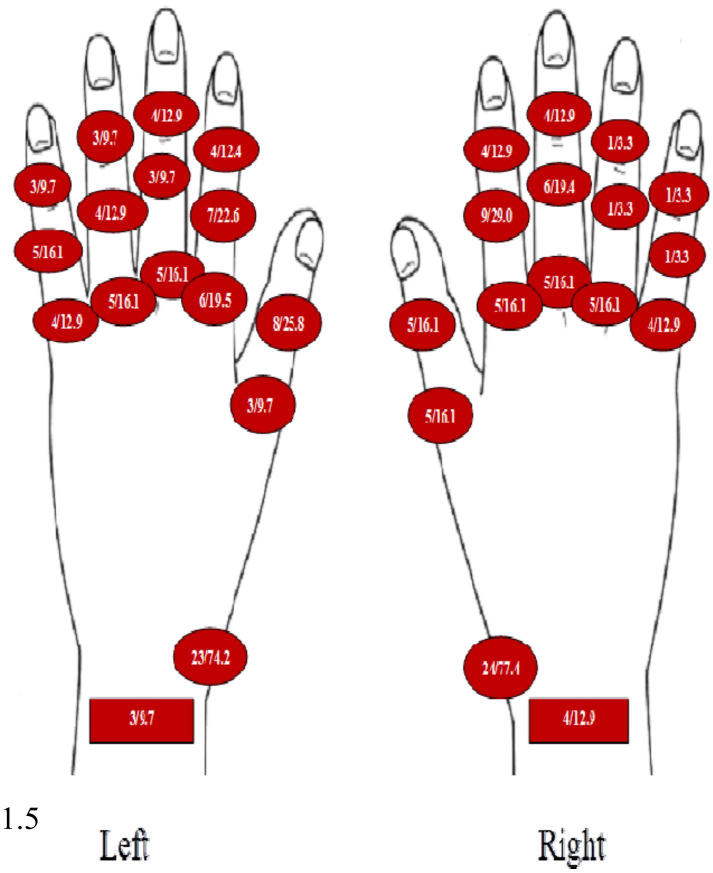

Figure 4.4. Distribution of joint involvement by hand.
Note: Text boxes describe the number of participants with osteoarthritis in the underlying joint (left number) and associated percentage (right) of the sample with involvement in that joint.

p=0.5). The total joint counts were also non-significantly different (p>.05) when comparing right and left hands. The distribution of arthritis is illustrated in figure 4 yet additional detail on the distribution can be found in chapter 2. The distribution of hand osteoarthritis and the disease impact of the sample are described in detail in chapter 2.

The average baseline NRS pain intensity rating was slightly less than 1.0 ($\bar{x}$ =0.90, SD=1.62) which, when compared to baseline characteristics of females with hand arthritis of a hand arthritis RCT[57]($\bar{x}$=5.0, SD=0.9), is relatively low. Semmes Weinstein Monofilament Composite scores in the median distribution of the right and left hands revealed that, on average, participants were experiencing some disruption of cutaneous sensory experiences ($\bar{x}$=27.03, SD=3.03 and $\bar{x}$=26.71, SD=2.85) in the radial-volar aspect of their hands. Differences between the right and left hands were non-significantly different. A similar trend was noted for the ulnar distribution ($\bar{x}$=13.39, SD=1.54 and $\bar{x}$=13.39, SD=1.52) with again non-significant differences between hands.

The TAM goniometric measures for the right and left thumbs were, on average, 16-22 degrees less than what has been reported to be normal[58]. Although this was not quantified, this is likely explained by Swan-neck and Boutonniere deformities which are commonly experienced by persons with thumb osteoarthritis [59]. The mean thumb TAM value for the right hand was significantly greater than the left (t=7.17, MD=2.06, p=.04). Total hyperextension measures for the right and left thumbs (HE-D1) averaged from 19.26(13.06) to 23.26(15.05) degrees respectively which varies slightly from what is reported to be the typical 15 degrees of interphalangeal joint hyperextension[15]. The average hypermobility of the left thumb was greater than the right and closely approached a statistically significant difference (3.8, t=1.91,p=.06).

The thumb palmar abduction IMD values averaged from 5.40(.74) to 5.52(.82) centimeters (cm) for right and left hands respectively and, although normative values have been documented, these values are approximately 10 millimeters(mm) less than what was reported by de Kraker et al.[54] in their reliability study. Here again, the left hand appeared to have more mobility as the webspace was 1.37mm wider on the left than on the right (2.08, p=.04).

Right and left hand lengths averaged from 19.24(1.26) to 19.40(.96) cm respectively which was about 1.5cm longer than was reported in an 1983 anthropometric study of 100 women between the ages of 62 and 90 years[35]. Right and left hand lengths were non-significantly dissimilar.

Maximum Voluntary grip strength (MVGrip), as measured by the grip dynamometry was determined to be within 1 SD of normative values[6] for the average age of the participants. Average measures of right and left grip were non-significantly different.

Table 4.3. Summary Statistics, Tertiles of Percent Success, and Comparisons (ANOVA) of Baseline Sample Characteristics (n=31) †

		Total (n =31)	1st Tertile (n=13)	2nd Tertile (n=11)	3rd Tertile (n=7)
Disease Duration	**Years since onset***	9.02 (6.78)	**14.22(7.10)**	**6.70(4.99)**	**5.15(3.54)**
	Years since diagnosed*	8.17 (6.05)	**12.44(8.14)**	**4.62(3.95)**	**6.29(2.93)**
Disease Impact	**AIMS2 Physical Subscale***	**1.81(1.35)**	**2.69(1.66)**	**1.80(1.39)**	**0.99(0.65)**
	AIMS2 Symptom Subscale Score	3.47 (2.24)	4.69(2.13)	3.33(2.78)	2.62(1.83)
	AIMS2 Upper Limb Subscale	1.31 (1.17)	1.94(1.53)	1.50(1.01)	0.68(0.79)
	AIMS2 Total Health Scale Score	10.62 (5.28)	13.31(4.44)	10.59(6.99)	7.91(3.53)
Total Digits with OA	Right[a]	2.10(1.49)	1.89(1.17)	2.00(1.41)	1.86(1.07)
	Left[a]	2.03(1.54)	1.78(0.83)	1.80(1.23)	2.00(1.83)
Pain	Baseline NRS Pain Intensity Rating	0.90(1.62)	2.00(2.29)	0.80(1.32)	0.29(0.76)
Sensation	Median-R[a]	27.03(3.03)	28.22(2.33)	26.40(2.50)	26.14(4.63)
	Median-L[a]	26.71(2.85)	27.56(2.79)	25.70(2.45)	27.43(3.55)
	Ulnar-R[a]	13.39(1.54)	13.56(1.33)	13.10(1.79)	13.71(1.80)
	Ulnar-L[a]	13.39(1.52)	14.00(1.58)	12.90(1.45)	13.29(1.80)
Upper Limb Mobility	TAM-D1-R[a]	116.13(32.48)	117.11(30.64)	116.20(18.80)	102.29(16.06)
	TAM-D1-L[b]	108.74(19.79)	113.56(24.20)	103.70(16.46)	104.86(20.91)
	HE-D1-R[a]	19.26 (13.06)	22.44(18.24)	19.00(11.58)	16.86(9.94)
	HE-D1-L[a]	23.26(15.05)	28.78(18.33)	26.10(12.58)	16.86(13.38)
	PA-R[a]	5.40(0.74)	5.73(0.61)	5.21(0.92)	5.46(0.74)
	PA-L[b]	5.52(0.82)	5.65(0.86)	5.40(0.94)	5.79(0.64)
Anthropometry	HL-R[a]	19.24(1.26)	19.34(1.02)	19.75(0.90)	18.71(1.44)
	HL-L[a]	19.40(0.96)	19.60(0.96)	19.83(0.67)	18.59(0.87)
MVC Hand Strength	MVGrip-R[a]	232.15(71.75)	221.25(82.16)	241.67(86.38)	225.57(44.22)
	MVGrip-L[a]	225.16(60.58)	214.671(73.84)	240.20(64.23)	219.25(31.23)

†1st tertile= success rates of turning jar≤33.33%, 2nd tertile=success rates>33 to -≤66.66%, 3rd tertile=success rates >66.66%; Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; R=right hand, L=left hand.; pain scores are not specific to one hand;* denotes differences between tertiles at p<01; superscript letters, when different, indicate differences at p<.05 between hands for a given variable.

Success

Across the tertile categories for percent success participant's baseline hand function characteristics were non-significantly different save two variables: 'Years since onset', and 'Years since diagnosed' ($F(30)=7.08$, $p=.003$; $F(30)=5.86$, $p=.007$). Table 4.3

illustrates how those with the highest percent success trended towards carrying symptoms for the shortest period and were more recently diagnosed. The average scores for the AIMS2-SF 'Physical Subscale' across the three tertiles approached statistical difference (F(30)=2.34,p=.11)in that persons with lower (i.e., higher functioning) scores were finding proportionally more successful than those with higher scores. These trends, although statistically non-significant, were observed in the remaining AIMS2-SF subscales as well as the Total Health Score. Only one other non-significantly different trend emerged in that those with less hypermobility trended towards being more successful. Beyond this, there were no apparent trends or statistically significant in baseline pain, total digits with OA, sensation, TAM, and MVC grip strength.

Hand Forces Across both the supinated and oblique approaches and across both turning hands, a successful trial generated more combined compressive and grip forces than those who were not(MD=21.72,t=7.36, p=.007) (table 4.4). Participants who were successful generated an average combined grip and compressive load into the jar of 197.08±7.9 N (44.31 lbs.) whereas participants who were not generated 175.37±8.3 n (39.42 lbs.) (table 4.4). Average torques acting upon the jar lid [(M(x), M(y), and M(z)] were also significantly larger among those who were successful than not (MD=.14, t=7.59,p=.006; MD=.44,t=28.06,p<.0001; MD=1.24,t=438.1,p<.0001 respectively; see Figure 4.6). This was not surprising, particularly for M(z), given that ~4.24 N*m must be exceeded to disengage the jar instrument's torque limiter in order to simulate the experience of breaking the seal. Table 4.4 presents this data and figures 4.6, 4.7, and 4.8 illustrate these differences.

What was surprising, however, was that participants who were successful used less grip force across time (i.e., Integral of Grip Force) when the factors of approach and turning hand were controlled for (MD=105.55, t=2.35,p=.02).

As described in chapter 3, the approach, turning hand, and their interaction all influence the forces acting upon the jar lid. For this reason, force comparisons have been made within each condition of each factor (i.e., right hand oblique, left hand oblique, right hand supinated, and left hand supinated). Grip forces were non-significantly different across all conditions however differences with the left hand oblique and supinated grasps approached significance at p=.06 and p=.09 respectively (table 4.4). Individuals who were successful in opening the jar through right oblique, left oblique and left supinated approaches used, on average, between 144.19±10.70 and 149.54±9.36 N however those who used a right supinated approach and were successful used a higher grip force of 179.12±11.20 N.

The resultant compression force, F(xyz), of those who were successful was significantly greater in most all approaches (p<.01) with exception of the left supinated approach. Individuals who were successful with right oblique, right supinated, and left oblique approaches used 34.61±5.00, 49.54±3.50, and 55.61±4.10 N respectively (table 4.4). Those who were successful through supporting the base of the jar with a supinated right hand and twisting with the left hand used the highest average F(xyz) (55.95±3.50) however the amount did not significantly differ from the mean compressive force of 49.44±3.90 N used by those who failed to break the seal. Further analysis revealed that, when the resultant force was deconstructed into its component parts and regardless of the approach taken, only F(y) was significantly different amongst those who were and were not successful (MD=4.49, t=8.87,p=.003).

The combination of grip forces and F(xyz) forces were significantly larger among those who were successful when using a left hand twist for either an oblique(MD=44.37,t=2.50,p=.01) or supinated (MD=37.21,t=2.10,p=.04) approach however were not significantly different for either condition of the right hand (table 4.4).

The integral of grip force was only significantly different between successful and unsuccessful groups for the supinated level of the approach factor. Those who successfully used the supinated approach required significantly less force across time (N-s) than did their non-successful counter parts (MD=122.97,t=2.31,p=.04). The approach which required the largest amount of sustained force was the right oblique approach (980.53±81.50) whereas the left supinated approach required the least (684.40±58.21) (table 4.4).

As expected, persons who were successful generated significantly more M(z) than their counterparts (MD>1.13, t>7.68,p<.0001). Across all conditions of each factor, turning hand and approach, those who were successful, on average, used from 4.31±0.18 to 4.43±0.14 N*m. Only those who successfully used a right supinated approach required significantly more M(x) torque (MD=0.25, t=2.31,p=.02) and, on average, used 1.32±0.11 N*m compared the1.07±0.12 N*m used by those who were unsuccessful.

Participants who were successful also used significantly greater M(y) when using a right supinated (MD=.29, t=2.47 (.01) and left oblique approach (MD=.74,t=6.03, p<.0001). Those who were successful while using the right supinated approach required

1.05$\pm$.09 N*m while those who were successful in using the left power approach used 1.56$\pm$.11 N*m.

Per the generalized linear model logistic regression analysis (SAS Gen Mod) (table 4.5, appendix 4E), Grip Force (B=.0016, P=.0003), the integral of grip force (B=-.00062,p=.0008), and the approach taken(B=-1.6302,p<.0001) were significant predictors of success. F(xyz), although later described as being a significant predictor of M(z), was a non-significant predictor (B= -0.0011, p=0.8764) as was the hand doing the turning (B=.3749,p=.2034) and interaction of hand*approach(B =-.7439,p=.2076). The resultant of F(xyz) was also broken down into its component parts, F(x), F(y), and F(z) to test if the one particular force component contributed to the model but the results were non-significant. Independent of the effect of the approach taken, for every one newton increase in grip force increased and every one unit decrease of the integral of grip force (N-s), the odds of success improved by .2% and .1%. Those who used a supinated approach were 80.42% more likely to be successful in twisting the lid. In the appendix, table 4.5 presents the model and figure 4.8 (appendix 4E) illustrates the relative effects of the hand forces on success.

Table 4.4. Comparisons (t-tests) of mean forces between successful and unsuccessful attempts by grasp pattern.*					
Hand	**Approach**	**Force/Torque**	**Success-Yes**	**Success-No**	
Right			**x̄ ± SE**	**x̄ ± SE**	p(diff)
	Oblique	Grip Force	149.54±9.36	136.19±17.3	.48
		Integral of Grip Force	980.53±81.50	1061.01±55.70	.32
		F(xyz)	**34.61±5.00**	**28.68±3.30**	**.002**
		Grip Force + F(xyz)	177.33±19.00	176.34±10.8	.96
		M(x)	1.60±0.14	1.45±0.10	.20
		M(y)	0.96±0.13	0.88+0.08	.58
		M(z)	**4.31±0.18**	**2.91±0.14**	**<.0001**
	Supinated	Grip Force	179.12±11.2	166.30±12.56	.42
		Integral of Grip Force	679.46±60.97	803.16±70.40	.10
		F(xyz)	**49.54±3.50**	**38.99±3.80**	**.01**
		Grip force +F(xyz)	**228.57±12.7**	**205.15+14.10**	.18
		M(x)	**1.32±0.11**	**1.07±0.12**	**.02**
		M(y)	**1.05±0.09**	**0.76±0.10**	**.01**
		M(z)	**4.43±0.14**	**3.30±0.15**	**<.0001**
Left					
	Oblique	Grip Force	144.19±10.70	113.46+13.40	.06
		Integral of Grip Force	864.15±70.05	959.96±57.89	.18
		F(xyz)	**55.61±4.10**	**39.10±3.30**	**<.0001**
		Grip force +F(xyz)	**203.62±15.60**	**159.25±11.3**	**.01**
		M(x)	1.66±0.12	1.49±0.10	.11
		M(y)	**1.56±0.11**	**0.82±0.80**	**<.0001**
		M(z)	**4.49±0.16**	**2.82±0.14**	**<.0001**
	Supinated	Grip Force	147.85±14.00	120.22±9.86	.09
		Integral of Grip Force	684.40±58.21	806.63±79.89	.13
		F(xyz)	55.95±3.50	49.44±3.90	.09
		Grip force +F(xyz)	**200.07±12.20**	**162.86±14.90**	**.04**
		M(x)	1.19±0.11	1.10±0.12	.43
		M(y)	0.79±0.09	0,71±0.10	.53
		M(z)	**4.36±0.14**	**3.40±0.15**	**<.0001**
Combined					
	Oblique	Grip Force	142.02±11.70	134.88±7.50	.60
		Integral Grip Force	922.34±62.95	1010.48±50.30	0.1222
		F(xyz)	**48.18±3.70**	**32.94±3.00**	**<.0001**
		Grip force +F(xyz)	190.48±13.10	167.79±9.00	.10
		M(x)	**1.63±0.12**	**1.47±0.09**	**.05**
		M(y)	**1.25±0.09**	**0.85±0.06**	**<.0001**
		M(z)	**4.40±0.13**	**2.86±0.13**	**<.0001**
	Supinated	**Grip Force**	**161.66±8.40**	**139.88±9.20**	**.06**
		Integral Grip Force	**681.93±52.25**	**804.90±62.54**	**.04**
		F(xyz)	51.49±3.20	46.53±3.30	.10
		Grip force +F(xyz)	**214.32±9.90**	**184.01±11.4**	**.02**
		M(x)	**1.25±0.10**	**1.09±0.10**	**.04**
		M(y)	**0.92±0.07**	**0.74±0.08**	**.04**
		M(z)	**4.39±0.13**	**3.35±0.14**	**<.0001**
All					
		Grip Force	149.18±6.22	136.93±6.52	.09
		Integral Grip Force	**802.14±51.35**	**907.69±50.49**	**.02**
		F(xyz)	**47.82±2.80**	**38.58±2.80**	**.0001**
		F(y)	**21.66±1.8**	**17.17±11.81**	**.003**
		Grip force +F(xyz)	**197.08±7.90**	**175.37±8.30**	**.007**
		M(x)	**1.45±0.09**	**1.31±0.09**	**.006**
		M(y)	**1.27±0.06**	**0.83±0.06**	**<.0001**
		M(z)	**4.38±0.13**	**3.14±0.13**	**<.0001**

***Note:** F(xyz) is the resultant of compressive forces acting on the jar's lid in the three orthogonal axes of X,Y,and Z; M(x) = torque about the x orthogonal axis, M(y) = torque about the Y axis, and M(z) = torque about the z axis; forces are reported in newtons; torques reported in newton-meters; Intregral of Grip Force reported in newton-seconds.

Hand function. As previously described, several measures of hand function were selected to predict success during jar opening for each of the commonly used approaches to jar turning (i.e., right oblique, left oblique, right supinated, left supinated). This was done because, as illustrated in chapter 3, the turning hand, approach, and the combination of the two had effects on the forces and torques acting upon the jar lid. For the previously described reasons, associations between pain after each trial of turning (Pain), change in pain from baseline to after each trial (Δ pain), light touch sensibility of the right median, left median, right ulnar, and left ulnar distributions (Median-R, Median-L, Ulnar-R, Ulnar-L), total active motion of the right and left thumbs (TAM-D1-R, TAM-D1-L), hyperextension of the right and left thumbs (HE-D1-R, HE-D1-L), right and left thumb palmar abduction IMD (PA-R, PA-L), right and left hand length (HL-R, HL-L), PE, and MVC grip strength of both hands (MVGrip-R, MVGrip-L) on success were considered.

Per the generalized linear model logistic regression analysis (SAS Gen Mod)(see Table 4.6, appendix 4E), TAM-D1 ($B=-0.0524, p=.0005$), HE-D1($B=-0.0875, p=.0001$), ΔPain ($B= -0.2353$, $p=.0045$), PE ($B=-.66, p<.0001$), MVGrip ($B=0.0506, p=.0209$), and approach ($B=-1.4407, p=.0052$) were all predictors of being able to break the jar lid's 'seal'. Independent of approach, for every decrease of one degree in TAM-D1, HE-D1, ΔPain, and PE and every one newton increase in MVGrip, the odds of success increased by 5.1%,8.4%,21%, 48%, and 5.2% respectively. Lastly, In this model the interaction effect of hand and approach was nearing significance ($B=-24.9562, p=.0768$). See Figure 4.7 in the appendix 4E for an illustration of the relative effects of these variables on successful jar lid opening.

Grip Forces at Peak M(z)

As the literature suggests and as the prior analysis on the predictive qualities of hand force on successful jar opening suggests, a deeper exploration of the impact of hand function variables which influence grip force is justified. For the previously described reasons, the predictive qualities of pain after each trial of turning (Pain), change in pain from baseline to after each trial (Δ pain), light touch sensibility of the right median, left median, right ulnar, and left ulnar distributions (Median-R, Median-L, Ulnar-R, Ulnar-L), total active motion of the right and left thumbs (TAM-D1-R, TAM-D1-L), hyperextension of the right and left thumbs (HE-D1-R, HE-D1-L), right and left thumb palmar abduction IMD (PA-R, PA-L), right and left hand length (HL-R, HL-L), PE, and MVC grip strength of both hands (MVGrip-R, MVGrip-L) with peak M(z) were explored.

Right hand oblique approach. Grip force during right hand oblique trials had a moderate significant negative relationship with Δpain ($p<.01$) a moderate significant positive relationship with TAM-D1-R ($p<.01$), a small significant positive relationship with HL-L ($p<.05$), and a small negative relationship with pain intensity ($p<.05$) (Table 4.7, appendix 4E).

Multiple regression analysis was used to test if the several hand function characteristics significantly predicted grip forces while using a right hand oblique approach. The results of the regression (Table 8, appendix 4E) indicated that Ulnar-L(ß=7.861,p=.05), TAM-D1-R(ß=.589,p=.012), PA-L(ß=-15.328,p=.047), HL-L(ß=15.689,p=.011), and ΔPain(ß =-4.954,p=.03) predictor variables explained 35.1% of the variance of Grip force (Adjusted R^2=.351, $F(5,55)=6.946$, $p<.0001$). While controlling for the effects of the other predictors, a one unit increase in Ulnar-L and H-L, and a one unit decrease in ΔPain significantly predicted a one newton increase in right grip forces when using an oblique approach. See table 4.8 in the appendix 4E for details.

Left hand oblique approach. Grip force during left hand oblique trials had small significant ($p<.05$) relationships with HE-D1-R. See table 4.9 in appendix 4E for Pearson's r values specific to the left hand oblique approach. The results of the regression analysis (Table 4.10, appendix 4E) indicated Median-R(ß=-11.022,p=.002), Ulnar-L(ß =26.281,p=.001),HE-D1-R(ß =-1.301,p=.024),HE-D1-L(ß=1.870,p=.001), PA-L(ß=17.253,p=.050), MVGrip-R(ß =-1.596,p=.003) and ΔPain (ß =6.382,p=.039) predictors explained 60.0% of the variance in Grip forces used during a left oblique approach (Adjusted R^2=.600, F(7,53)=4.228, p=.001).While controlling for the effects of the other predictors, a one unit decrease in Median-R, HE-D1-R, and MVGrip as well as a one unit increase in Ulnar-L, PA-L, and ΔPain significantly predicted a one unit (i.e., N) increase in Grip force used with a left supinated approach.

Right hand supinated approach. Grip force during right hand supinated trials had small significant ($p<.05$) relationships with MVGrip-L and TAM-D1-R (Table 4.11, appendix 4E). The results of the regression analysis indicated Ulnar-R(ß =18.165,p=.012),Ulnar-L(ß =-29.952.968,p=.007),TAM-D1-R(ß=2.409,p<.0001),HE-D1-R(ß =1.958,p<.0001),TAM-D1-L(ß=-1.230,p=.020),PA-R(ß=-45.917,p=.010), HL-L(ß=30.994,p=.019), MVGrip-R(ß =1.801,p=.034), MVGrip-L (ß =-5.126,p<.0001) and ΔPain(ß =-8.950,p=.007) predictors explained 34.6% of the variance (Adjusted R^2=.346, F(14,51)=9.88, p<.0001). Several predictors not included in the model, yet were approaching significance included Median-L(ß =8.8084, p=.070), PA-L(ß =-

25.104,p=.091), PE(ß=-3.873,p=.144). While controlling for the contributions of the other predictors to the model, a one unit increase in Ulnar-R, TAM-D1-R, HL-L, and MVGrip-R significantly predicted a one N increase in grip force whereas a one unit decrease in Ulnar-L, HE-D1-R, TAM-DA_L, PA-R, HL-R, MVGrip-L, and ΔPain significantly predicts an increase of one newton of grip force when using a supinated approach (Table 4.12, appendix 4E).

Left hand supinated approach. No hand function variables were significantly associated with the peak grip force during a left hand supinated approach however Ulnar-L, HL-L, and Δpain were all approaching significance (p=.06, .06, and .09 respectively). See table 4.8 in appendix 4E for Pearson's r values specific to the left hand supinated approach. The results of the regression analysis (Table 14, appendix 4E) indicated PA-R(ß=-58.120,p=.002), PA-L(ß =49.771,p<.004),HL-R(ß=-24.255,p=.043), and ΔPain(ß =14.270,p=.003) predictors explained 30.4% of the variance (Adjusted R^2=.304, F(9,55)=3.671, p<.0001). Several predictors were approaching significance including HL-L (p=.056), TAM-D1-L (p=.062), MVGrip-R(p=.085), and Ulnar-L (p=.108). When controlling for the effects of the other predictors, a unit increase in PA-L, and ΔPain and a one unit decrease in PA-R, and HL-R significantly predicted a one newton increase in grip force while using a left supinated approach.

Across all approaches. To consider the effect of these hand function variables have on grip force used during jar opening tasks without consideration to an approach a general linear model (GLM) multiple linear regression (SAS Proc Mixed) analysis was performed. The analysis (Table 4.15, appendix 4E) revealed that, independent of the approach taken, TAM-D1 (*B=.5826,p=.016)* and ΔPain (*B*=-43257, p=.0453) were significant predictors of the ability to generate grip force for either of the two approached taken by the study participants. The hand doing the twisting, as reported in chapter 3, remains a significant predictor of grip force generation in that, when the left hand is used to twist a jar lid by women who meet the study's demographics profile, the left hand is predicted to exert 33.5205 newtons fewer than the right(p=.001).

When comparing the separate regression models for each of the approaches, some trends were noted. See figure 4.9 (appendix 4E) for the illustration of these trends. Hyperextensibility of the stabilizing hand's thumb often predicted less grip force by the turning hand in right and left oblique approaches whereas, in the left oblique and right supinated approaches hyperextensibility of the turning hand's thumb predicted increased grip.

As Δpain increased, grip force decreased in the right hand regardless of approach, whereas when pain increased in left hand, regardless of approach, grip force increased.

In approaches where sensation was a significant predictor, the trend was that increased sensation resulted in increased grip force. The exception to this was observed when the right stabilizing hand with reduced sensibility in the median distribution predicted increased grip force by the left turning hand during an oblique approach (ß=-11.022,p=.002) for a when the left stabilizing hand with reduced sensation in the ulnar distribution predicted increased grip force in the right turning hand during a supinated approach(ß=-29.952,p=.007).

In all but the left oblique approach MvGrip-R was a positive predictor of Grip force however, in the case of MVGrip for the stabilizing hands during left oblique (ß=-

1.596,p=.003) and right supinated approaches (ß=-5.126,p<.0001), increased MVGrip predicted the use of less grip force by the turning hand.

Integral of Grip Force

Although grip force during jar opening was predictive of success, another earlier described measure of grip force, particularly its efficiency, the 'Integral of Grip Force' was also found to be a significant negative predictor of success. For this reason, an exploration of the influence of hand function on the integral of grip force was undertaken.

Right hand oblique approach. The integral of grip force during right hand oblique trials (Table 4.7, appendix 4E) had a small negative and significant (p=.05) relationship with Ulnar-L and a significantly moderate and positive relationship with PE (p<.01).

Multiple regression analysis was used to test if the several hand function characteristics significantly predicted the integral of grip forces while using a right hand oblique approach. The results of the regression (Table 4.16, appendix 4E) indicated that Median-R(ß=-57.342,p=.033), Median-L (ß =-66.163, p=.004), Ulnar-L(ß=192.924,p=.001), TAM-D1-R(ß=-3.991,p<.0001),HE-D1-R(ß=-9.843,p=.011), HL-R(ß=134.488,p=.011), HL-L(ß=-162.513,p=.006), Pain(ß=47.039,p=.006) and PE(ß =114.553,p<.001) predictor variables explained 52.1% of the variance of integral of grip force (Adjusted R^2=.521, F(11,55)=6.440, p<.0001). While controlling for the effects of the other predictors, a one unit increase in Ulnar-R, Hl-R, Pain and PE and a one unit decrease in Median-R, Median-L,TAM-D1-R,HE-D1-R, and HL-L significantly predicted a one newton-seconds increase in the integral of right grip forces when using an oblique approach.

Left hand oblique approach. The integral of grip force during right hand supinated trials had a small positive and significant (p=.05) relationship with Ulnar-L (See table 4.10, appendix 4E).Multiple regression analysis was used to test if the several hand function characteristics significantly predicted the integral of grip force while using a left hand oblique approach. The results of the regression (Table 4.17) indicated that Median-L (ß =-86.213, <.0001), Ulnar-L(ß=141.540,p<.0001),TAM-D1-R(ß =3.362,p=.030) and TAM-D1-L(ß =-5.062,p=.008) predictor variables explained 30.3% of the variance of Grip force across time (Adjusted R^2=.303, F(9,57)=3.749, p=.001). It should be noted that several predictors not included in the model were approaching significance, specifically PA-L(ß =78.505, p=.08), Median-R(ß =31.384, p=.103), ΔPain (ß =22.398p=.117), and PE(ß =25.484,=.06). While controlling for the effects of the other predictors, a one unit increase in Ulnar-L and TAM-D1-R and a one unit decrease in Median-L,TAM-D1-L significantly predicted a one newton-seconds increase in the integral of right grip forces when using an oblique approach.

Right hand supinated approach. The integral of grip force during left hand oblique trials (Table 4.11, appendix 4E) had a moderate positive and significant (p=.05) relationship with TAM-D1-L and a small positive relationship with PE (p<.05).

Multiple regression analysis was used to test if the several hand function characteristics significantly predicted the integral of grip force while using a right hand supinated approach. The results of the regression (Table 4.18, appendix 4E) indicated that Median-L (ß =-37.967, p=.041),TAM-D1-L(ß =5.792,p=.017) , HE-L(ß =-6.673,p=008), PE(ß =33.825,p=.002) predictor variables explained 32.5% of the variance of Grip force across time (Adjusted R^2=.325, F(5,52)=3.781, p<.0001). It should be noted that several predictors not included in the model were approaching significance and those include TAM-D1-R (ß =3.018, p=.085), PA-R(ß =91.124, p=.094), HL-R(ß =50.560,p=.100) and HE-R(ß =3.234,=.126). While controlling for the effects of the other predictors, a one unit increase in TAM-D1-L and PE, and a one unit decrease in Median-L, and HE-D1-L significantly predicted a one newton-seconds increase in the integral of right grip forces when using an oblique approach.

Left hand supinated approach. During left hand supinated trials, several factors were noted to be significantly related to the integral of grip force (Table 4.13, appendix 4E). This includes moderate positive relationships with HL-R (p<.01), HL-L (p<.01), PE (p<.01), Pain (p<.05), and ΔPain (p<.01). The multiple regression analysis revealed that 8 of the hand function variables were predictive of how much grip force was used across time (Table 4.19). These explanatory variables included Median-R(ß=41.477,p=.011), Ulnar-R (ß=63.229,p=.033), Median-L (ß=-79.883,p<.0001), TAM-D1-R(ß=5.206,p=.004), TAM-D1-L,(ß=-4.060, p=.049), PA-L(ß=32.969, p=.005), Pain (ß=32.969, p=.011), and PE (ß=25.238,p=.015) and the combined effects of these measures explained 34.9% of the variance (Adjusted R^2=.349, F(8,55)=4.688, p<.0001) in the hand grip forces acting on the jar when using this approach

Across all approaches. The GLM regression analysis (Table 4.20, appendix 4E) revealed that, regardless of the approach taken, PE (*B=23.4715, p=.0012)* was the only significant predictor of how much force over time was used when attempting to ‘break the seal’ of the jar instrument. When women like those of who were studied attempt to open a jar, for every one unit increase in the Borg CR10, a woman with hand osteoarthritis is predicted to use 23.417 newton-seconds of grip force while opening jars sealed to large sealed jars through one of these two commonly used approaches.

Figure 4.10 (appendix 4E) illustrates the positive, negative and absent effects of the hand function measures on the integral of grip force across the four difference approaches. The effects of left ulnar sensibility and left median sensibility on generating grip force across time were the largest and were biased towards the oblique approaches. Likewise, regardless of the approach or hand turning, when left median sensibility increased the integral of grip force decreased.

The length of one's hand seemed to only apply to the right oblique approach, as the left stabilizing hand's length increased, the amount of force used across time decreased however as the turning hand's length increased, so did its application of grip force across time. Again, only related to the oblique approach was that as the turning thumbs' TAM increased, the grip force/time decreased. Not surprisingly, as force/time increased so did pain for at least two of the approaches, right oblique and left supinated, and as force/time increased, so did PE for all but the left oblique approach.

Peak M(z)

As previously described, the process of opening a sealed jar-lid is primarily comprised of a grip-loading phase followed by the torque generation phase. Success in opening a sealed jar is inherently linked to having the capacity to overcome the torque requirements of the sealed jar. During the earlier exploration of how hand forces and hand function tests explain success in jar opening, the factor of torque was removed from the analysis because it is a dependent and not an explanatory variable. To build off the understanding that grip forces and the integral of grip forces (grip force/time) explain success and that success is inherently due to generating torque, the predictive qualities of hand grip and compressive forces on Peak M(z) was investigated. Similar to the exploration of how hand function explains grip forces during jar opening, the predictive qualities of the same explanatory factors were again tested but were regressed on peak M(z).

Hand Forces.

For each individual approach, relationships between grip force at peak M(z), the integral of grip force, and F(xyz) with Peak M(z) were tested. Grip forces were moderately positively correlated ($r=.381 p<.01$) with M(z) for the right oblique approach (Table 4.7, appendix 4E) and were strongly correlated for the right supinated approach($r=.607, p<.01$)(Table 4.11, appendix 4E). However they were non-significantly related to the two left hand approaches (Tables 4.9 & 4.13, appendix 4E). The integral of grip force was strongly negatively associated ($r=-.524, p<.01$) with M(z) during a right supinated approach (Table 4.11) and moderately negatively associated with M(z) during right oblique ($r=-.413, p<.01$) (Table 7) and left ($r=-.455, p<.01$) supinated approaches (Table 4.13). Moderately positive associations ($p<.01$) existed between M(z) and F(xyz) for all approaches with the highest associations occurring during the right supinated approach ($r=.455$) (Table 4.11, appendix 4E) and the lowest occurring with the right oblique ($r=.392$)(Table 4.7, appendix 4E).

Per the GLM multiple linear regression analysis, while controlling for the effect of approach (Table 21, appendix 4E), Grip Force ($B=.01894, p <.0001$), F(y)($B=.00992, p=.0044$), were both positive predictors of M(z) whereas the integral of grip ($B =-.00065, p<.0001$) and the approach taken ($B =-6481<.0001$) were both negative predictors of M(z). Because F(xyz) was not in itself a predictor, the components of F(xyz) (i.e., F(x), F(y), and F(z)) were introduced into the model in its stead. Of the three, only F(y) predicted torque output. The interaction between the hand turning and the approach taken was trending towards being a negative predictor (B =-.2569,p=.0978). When women like those studied attempt to open a jar, for every newton of grip force used, an increase of .01894 N*m of peak M(z) could be expected, for every N of F(y) used, an increase of .009920 N*m in peak M(z) could be expected and for every newton-seconds of grip force used across time, a woman with hand osteoarthritis is predicted to generate .00065 less N*m of peak M(z).

Figure 4.11 (appendix 4E) illustrates the positive, negative and absent effects of the hand force on M(z) independent of the approach used to attempt' breaking' the seal.

Hand function.

Right oblique. For the right oblique approach measures of hand function were moderately associated with M(z)(Table 4.7, appendix 4E) including Median-R(r=.432,p<.01), Ulnar-L(r=-.364,p<.01), and PE(r=-.341,p<.01) whereas HE-L (r=-.238,p<.05) and HL-L(r=.279,p<.05) had smaller but significant relationships with M(z). Nine measures of hand function (Table 4.22, appendix 4E) collectively explained 41% of the variance in peak M(z) (Adjusted R^2=.410, F(9,55)=4.981, p<.0001). These factors included Median-R(ß=-.167,p=.02), Ulnar-R(ß=.230,p=.050), Median-L(ß=.248,p=.014), Ulnar-L(ß=-.657,p<.001),PA-R(ß=-.733,p=.017), PA-L(ß=.879,p=.01), MVGrip-R(V=.047,p=.003), MVGrip-L(ß=-.041,p=.028) and ΔPain (ß=.114,p=.050).

Left oblique approach. All significantly related measures of hand function were moderated associated with peak M(z). These include: Median-R(r=-.384,p<.01), Ulnar-

L(r=-.347,p<.01), HE-L(r=-.417,p<.01), PE (r=-.512,p<.01) and HL-L (r=-.301, p<.01). See table 9 in appendix 4E. Seven measures of hand function explained 50.1% of the variance in peak M(z) when using a left oblique approach (Adjusted R^2=.501, F(7,57)=4.060, p<.0001). These factors (Table 23, appendix 4E) included TAM-D1-R(ß=.020), HE-D1-R(ß=.028,p=.011), TAM-D1-L(ß=-.028,p=.001), HE-D1-L(ß=-.050,p<.0001), MVGrip-R(ß=.020,p=.050), ΔPain (ß=.114,p=.038), and PE(ß=-.249,p<.0001) .

Right supinated approach. Only three factors were significantly correlated with peak M(z) for a right supinated approach, TAM-L(r=-.366, p<.01), PA-R(r=-.254, p<.05), and PE (r= -.429, p<.01). See table 4.11 in appendix 4E. Three measures of hand function (Table 4.24, Appendix 4E) explained 45.3% of the variability in peak M(z) while using a right supinated approach (Adjusted R^2=.453, F(3,51)=11.571, p<.0001). These factors included Ulnar-R(ß=-.158,p=.050), TAM-D1-L (ß=-.032,p<.0001), and PE(ß=-.200,p<.0001).

Left supinated approach. Right median nerve sensibility (Median-R) (r=-.235, p<.05), TAM-D1-L (r=-.324, p<.01), PA-R (r=-.315,p<.01), and PE(r=-.477,p<.01) were all significant negative correlates to peak M(z) (Table 4.13, appendix 4E). Two variables were significant predictors of peak M(z) (Table 4.25, appendix 4E). These included TAM-D1-L(ß=-.017,p=.005) and PE(ß=-.142, p<.0001).

Across all approaches. Figure 4.12 (appendix 4E) illustrates the positive, negative and absent effects of the hand function measures on peak M(z) across the four different approaches. This illustration of standardized regression coefficients illustrates the relative effects of each hand function measure so as to allow for comparisons across approaches. This figure illustrates several trends. First, for the oblique approaches, as PA increased for the stabilizing hand, increased torque output was predicted. The opposite appeared to be true for the oblique approach in that as the webpace increased for the turning hand, less torque was used. Second, it can be noted that increased MVGrip-R was predictive of torque in all but the left supinated approach whereas the left was only predictive with regards to the right oblique approach. Third, increased pain from baseline was only predictive of higher torques when using the oblique approach. Fourth**,** lower PE was predictive of higher torques in all but the right oblique approach which was, as mentioned in chapter 3, the least successful approach and most painful of the 4 approaches. Fifth, there were relatively fewer measures of hand function in both of the supinated approaches than were in the oblique approach models.

The GLM regression analysis (Table 4.26, appendix 4E) revealed that, regardless of the approach taken, HE-D1 (ß=-*.01587*, p=.0013) and perceived effort (ß=.-.08935,p=.0002) were significant predictors of how much peak torque was used while attempting to twist the lid of the jar instrument. When women like those of who were studied attempt to open a jar, for every one unit increase in a degree of composite thumb hyperextension, a .01587 N*m decrease in peak torque generation can be expected. Similarly, for every one unit increase in the Borg CR10, a woman with hand osteoarthritis is predicted to use newton-seconds of grip force while opening jars sealed to large sealed jars through one of these two commonly used approaches.

Discussion

This study examined the forces used by women with hand osteoarthritis while engaging in a commonly problematic task, jar opening. The study explored the force profiles of participants who were and were not successful to determine if these force profiles differ so as to identify, with some approximation, how much force is needed to be successful. An additional aim of the study was to investigate how well the forces acting upon the jar lid predicted success and the torques used to open a jar lid across 2 commonly used approaches and for both right and left handed lid-twisting. Lastly, this study aimed to answer if and how much particular measurements of hand function predict successful jar opening, the grip forces used, the grip forces used across time, and the torque used to open the lid.

The study provided evidence to support that women with hand arthritis who open large diameter sealed jars, are using high grip loads and must generate high torques when attempting to open lids. Women who were successful, regardless of the grasp pattern, on average, were using 149.2 newtons (33.5 lbs.) of grip force at the time of opening, used a sustained grasp equating to 802.1 newton-seconds (180.3 lb.-seconds) for the duration of the task (i.e., 133.7 newtons per second if carried out for 6 seconds), 47.8 newtons (10.7 lbs.) of compressive forces at peak M(z), and 4.4 Newton-meters (3.2 ft. lbs.) of peak M(z).

Based on a conservative average of the thumb forces used when twisting a non-sealed jar apparatus[60], the thumb is estimated to exert about 41% of the grip forces used during a jar opening task. Given this, and that Cooney and Chao's[61] 1977 work illustrated that for every 9.8 newtons exerted during a lateral pinch, between 91.50 and 131.41 newtons were acting upon cadaveric 1st carpometacarpal (CMC) joint, an estimate of the forces acting upon the 1st CMC joint by study participants who were successful in opening a sealed jar would roughly be between 568 and 816 newtons. These rough estimates do not factor in the role that joint degradation/subluxation play in altering the loads acting on the joint surface[62].

The average successful grip forces were lowest when using a left-handed turn whereas the average successful F(xyz) forces were highest among those using a supinated approach. After deconstructing F(xyz) into its component parts, only F(y) was predictive of peak M(z) generation and was significantly larger among those who were successful. This relationship is logical given that F(y) forces are 'pushes' generated by the palm which run tangential to the side of the jar lid Across the right and left oblique approaches, there were non-significant differences in grip forces used by those who were and were not successful whereas in the supinated turns these differences were approaching significance ($p=.06$). Although the logistic regression analysis reveal that the ability to generate grip forces significantly predicted success without consideration of an approach, in the case of those using an oblique approach its quite likely that the majority of the participants were capable of generating sufficient hand grip forces with the turning hand yet were unable to sufficiently offer a counter force by the stabilizing hand.

This assumption is supported by the negative predictive value of a smaller webpace and a hyperextensible stabilizing thumb on peak M(z) during right and left oblique approaches. This trend is almost complete unique to this approach with the exception of the left supinated approach where decreased PA of the right stabilizing hand also predicted less torque output. This is also validated by the positive effects of increased left median sensibility and grip on the right turning hand when using the oblique approach. Some of these trends specific to the right oblique approach were also observed when evaluating the response variable, hand force integral. As the left stabilizing hand's median and ulnar sensibility and hand length increased, power, a function of time, decreased during a right oblique approach. Some additional evidence which may illuminate the decreased capacity to stabilize the base of the jar is that women from this sample used higher integral of grip forces, an indicator of efficiency, while using oblique approaches.

One uncertainty about the stabilizing hand, however, is to what extent it influenced the participant's ability to provide the necessary counterforces. This uncertainty rests in the fact that the Pain NRS was used to rate non-hand specific pain after a turning trial. However, given that increased pain was only predictive of increasing M(z) for either hand using the oblique approach and that the only significant hand-related postural change, forearm posture aside, which would place the sample's predominantly arthritic 1st CMC into a position of increased pain while using the oblique approach would the posture of extreme palmar abduction. This is also supported by the findings presented in chapter 3 on how the right oblique approach produced higher ΔPain than the right supinated ($p<.05$) and the left oblique greater than the left supinated ($p<.05$).
In short, because grip force didn't vary greatly across those who weren't and were successful it's likely because there was little variance in the maximal capacities of the sample. For this reason, the abilities of the non-turning hand may have had a greater influence. Even in a kinematic study of persons without known hand impairments, trends were reported which support that the jar lid in the oblique approach is potentially more prone to over-rotation by the turning hand when compared to the supinated approach[40]

Another factor to consider is that although this study has illustrated that grip force is predictive of success and torque as well as marginal significance ($p=.09$) to support that, on average, women with hand OA need to use 149.18±6.322 newtons of grip force to successfully open a jar across all approaches, these loads might be higher than is required. It could be that differences between the successful and non-successful groups is more dependent upon the stabilizing hand's ability to offer a counterforce given that evidence supports that only between 56% (±2.4%); 51%(±5.8%) of the kinematics of the jar turn are explained by the turning hand.[40]

Likewise, as referenced earlier, there is also evidence to support that during dynamic grip and lifting tasks, women with hand osteoarthritis use higher grip forces and display difficulties modulating how grips are applied when resistance is applied to a dynamic task[63]. These authors reported non-significant differences in cutaneous sensibility when compared to age matched controls. However, they speculated that grip-force modulation may result from proprioceptive changes occurring at the joint level due to degenerative processes. This theory is also supported by the belief that joint laxity, an OA correlate, is presumably related to denervation of ligamentous proprioceptors[64].

Either of these possibilities is supported by the fact that, in this study, the participants who were least successful were those who were applying higher grip forces for a sustained period. Although, across a few of the regression models, the integral of grip force is predicted, to some extent, by cutaneous sensibility, hand joint proprioceptive awareness was not assessed or entered into these models. Likewise, although hand function measures of the non-turning hand were studied, the force contributions or kinematics of the stabilizing hand were not quantified

Grip dynamometry scores (MVGrip) were predictive of success in that, regardless of approach, the odds for being successful increased by 15% with every 1 lb (4.4 N) increase in MVG grip strength. However, when the effect on grip force was considered by approach, it was more commonly tied to the stabilizing hand (e.g., MVGrip-R as a negative predictor for left oblique grip forces and MVGrip-L as a negative predictor for right supinated grip forces).

The effect of MVGrip on torque was also present but both turning hand MVGrip and non? turning hand MVGrip alike were predictive of peak M(z) (e.g., MVGrip-R positive predictor and MVCGrip-L a negative predictor for the right oblique approach, MVGrip-R positive predictor for left oblique, and MVGrip-R as a positive predictor of right supinated peak M(z)). This should illustrate to the rehabilitation therapist that the strength of the non-twisting, and perhaps non-affected hand, must be considered in an effort to reduce strain on it during bimanual tasks. These predictions, however, do not offer guidelines for the therapist to follow when looking to increase MVC grip strength to a level which facilitates success. Per the results, these hand function models explain between 30.4 to 60% of the variance in the grip forces used during for several commonly used approaches. These models are multifactorial however enhancing MVC grip strength of both hands, especially for the oblique approaches, may help to enhance ability to generate the grip force and torque needed to open a large diameter jar. What can be stated with much certainty is that the previous assertion that 20 lbs of grip strength[15] for persons with rheumatologic conditions is sufficient for daily activities does not apply to the multidimensional task of opening a sealed jar. The grip forces used by even those unsuccessful in jar opening well exceed such numbers as do the mean MVC grip strength scores of those in the first ‘success’ tertile.

Other factors for the rehabilitation therapist to consider would be the sensibility of the turning as well as the stabilizing hand especially for the client who prefers to use an oblique approach. Also specific to the oblique approach would be the effect of hand length. Although hand length is not something which can be remediated by the therapist, if slippage by the stabilizing hand is notable during an oblique approach, it may be because the length of the client's stabilizing hand is too short and another approach should be considered to offload some of the forces used by the turning hand.

While controlling for the effect of approach on grip forces, an improvement of 1 degree in TAM of the thumb would predict an increase of .58±.24 newtons. If a loss of motion is correctable, an increase of roughly 8 degrees would predict the ability to generate another 4.66 newtons (1.05 lbs,) of grip force when turning a jar lid. Because thumb hyperextension deformities are common to those with1st CMC osteoarthritis[62] and goniometric measures of such, per this study's findings predict an increase of .09 newton-meters of peak M(z) torque with reduction of 1 degree of total thumb hyperextension.

Additionally, one degree reduction in thumb hyperextension predicts a 8.4% increased likelihood of success. Thus, the therapist with a client with hand arthritis who has identified opening sealed jars as a targeted outcome should identify if thumb hyperextension is present and, if so, work to address it through best practice interventions such as hyperextension-blocking orthoses and dynamic stabilization exercises[67]. As referenced earlier, depending on the approach, thumb palmar abduction IMD of the turning and stabilizing thumbs may also be predictive of the ability to generate grip forces and M(z). If either 1st webspace postures in an adducted manner and a goal is to successfully open larger diameter sealed jars, addressing the webpace through corrective and preventative interventions would be justified.

Pain and/or ΔPain are both strong positive and or negative predictors of the grip forces, integrated grip forces, and toques used. Although specific to the task of opening a sealed jar, a client can be educated that, while opening a sealed jar, pain is predictive of 'real' increased loads and that evidence demonstrates such loads cause high forces on the joint[61]. The therapist would then work with the client to identify alternative approaches such as the supinated approach described within this study, and use pain as the predictor of the outcome of protecting the arthritic joint(s) during sealed jar opening. Per these findings, the difference between baseline and end-of-task NRS measures (Δpain) appears to be the best predictor of success, grip force, and M(z) whereas the pain intensity score (i.e., 'Pain') best predicts sustained grip force (i.e., the 'integral of grip force').

Relative to most other hand function predictors, perceived effort (PE) is a stronger negative predictor of M(z), positive predictor of the integral of grip force, and negative predictor of success. It does not, however appear to be a good predictor of instantaneous measures of grip forces at peak M(z) during a jar turning task. The Borg CR10 measure is often used in workplace assessment and human factors research[31] and appears to have a place in predicting responsiveness to joint protection interventions in rehabilitation and community-based contexts.

Lastly, per these findings and those presented in chapter 3, it is recommended to consider the approach used by the client when looking to predict responsiveness to a therapeutic intervention. The supinated approach best predicts success and per the findings presented in chapter 3, when the left hand in combination with nonskid materials are use, the success rate and pain is lowest. The client's preferences and any constraints prohibiting her from performing the supinated approach must also be considered along with any of the predictive hand factors described within these findings.

These findings have the potential to benefit consumers of large diameter sealed jars because the high hand grip, compressive forces, and sustained hand grip profiles which are intrinsic might inform manufactures that design and practice standards require alteration especially given the aging of the population and prevalence of hand osteoarthritis. This is because prior investigators have reported the torques and hand grip forces used by those with healthy hands but with non-sealed jars and not on a population of women with arthritic hands[14,18,20]. Additionally, other designs did mimic some design qualities of commonly used jars but not to the depth that was taken when designing this instrument and thus, the findings may have more generalizability to the marketplace as well as to the population of women with hand arthritis.

Limitations

Because opening a jar is a bimanual task, pain scores were not specific to one particular hand and thus pain could not be isolated to hand twisting or the hand stabilizing the lid. The participants in this study had lower AIMS-2 Total Health Scale scores, indicating milder symptoms and effects on function. Further study is needed to determine if similar results would be present in a population with more severe hand arthritis. These findings as well as the findings presented in chapter 3 support the use a left hand supinated approach for women of the sampled population. However, it is not certain whether or not this is a function of more advanced disease staging in the right hand. The distribution of joint involvement and most all measures of hand function were homogeneous save palmar abduction (greater in left), HE-D1 (also greater in left) and TAM-D1 (greater in right). For the present study, radiographic staging was not available to determine arthritis severity however cohort studies have revealed that radiographic changes in hand arthritis do no often correspond with clinical symptmoglogy[65,66].

Much of the unexplained variance of these findings is likely intrinsic to the stabilizing hand as the lack of a biomechanical analysis of the hand-jar base interface leaves some unanswered questions. Additionally, the torque generating capacity of the wrist deviators was not measured and may have helped to more comprehensively explain these findings.

Suggestions for future research

- Quantify the hand force profiles and kinematics of the non-turning hand
- Evaluate the impact of wrist strength, hand-specific pain, hand joint proprioceptive awareness, and EMG activity of the upper limb on the kinetics of jar opening success
- Integrate 3D analysis of the upper limbs and jar to better understand the kinetics of the tasks as well as determine the joint reactive forces through inverse dynamics modeling
- Instrument other commonly problematic tasks to learn if applying joint protection principles to such is also beneficial
- Future studies might include a comparison to age-matched controls

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Chapter 5

General Discussion

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Discussion

Arthritis has been reported to be our nation's leading cause for disability[1] and symptomatic hand osteoarthritis (OA) affects an estimated 2.9 million U.S. residents[2]. One out of 11 women aged 20 years or older[3] and 1 out of 4 women aged 60 to 70 years[2] are currently living with symptomatic and radiographically confirmed hand OA. Women with hand OA report a moderate disruption in performing daily activities[4] and, as the U.S. population ages, more women will likely be affected by hand OA and with such a higher prevalence of activity limitation will likely follow.

There is much evidence to support that "biomechanical joint stress has a substantial etiologic role" in the development and progression of arthritis[5.] Thus, intervention approaches used to reduce biomechanical stressors deserve attention. Authorities on hand osteoarthritis state that additional research is required to develop and test measures which can evaluate responsiveness to interventions and the ability to particpate[5]. Developing techniques to measure the biomechanics of manual daily activities performed by women with hand OA and how rehabilitative interventions change these mechanics would support this agenda. This can be made possible through instrumenting the person-object interface during commonly problematic tasks with force sensing technology. Prior to this study, this has not yet been attempted with an arthritic population.

In the absence of ecologically valid tools to measure forces occurring during daily activities, a new tool was developed. The task of opening a sealed jar was chosen to be instrumented for this study given that jar opening has been reported to be one of three most commonly problematic activities for women with hand OA[4] and because the act of opening a large 'sealed' jar instrument by women with hand OA had not yet been studied. The tool was developed and bench tested to answer the following research questions:

1. What are the intra-rater reliability and ecological validity of a novel instrument for the quantification of hand forces during a jar opening task (chapter 2)?
2. What are the differences in the hand force requirements of women with hand arthritis when opening jars with and without joint protection strategies (chapter 3)?
3. What are the overarching hand force requirements of women with hand arthritis during a jar opening task (chapter 4)?
4. What are the factors influencing hand force production and successful opening of a sealed jar in a population of women with symptomatic hand osteoarthritis (chapter 4)?

A jar was constructed to measure grip forces in the jar lid along with compressive forces into the jar lid along the X, Y, and Z orthogonal axes (i.e., F(x), F(y), and F(z)) as well as torques about these axes (i.e., M(x),M(y), and M(z). In chapter two, the psychometrics of this novel instrument are reported. Pilot testing on a population of 29 participants with healthy hands revealed mean grip force differences between to trials of $\leq$5.45 Newtons (N) and torque mean differences of $\leq$ .007 Newton-Meters (ns) and within session intra-rater reliability ICC (3,1) between .60 and .76 across all peak forces and torques. Good intra-rater reliability and the absence of adverse events justified carrying forth the same testing among the population of interest, women with hand arthritis. Good to excellent within-session repeatability for all measures of forces and torques (ICC range of .63-.99) was found among a cohort of 31 women with radiographically confirmed or self-reported MD diagnosis of hand osteoarthritis. Given the good to excellent repeatability, the findings that 87% of participants reported opening the instrumented jar to be ‘similar’ or ‘very similar’ to their experiences, and that participants reported jar opening to be a highly meaningful task (mean COPM[5] Importance scale score of 8.7/10), moving forward with the investigation of research questions 2, 3, and 4 was justified.

In chapter 3, the investigation focused on the forces and torques occurring at the hand-jar lid interface across combinations of three factors, the hand turning the lid (right vs. left), the ‘approach’ to jar orientation (oblique vs. supinated), and whether or not a nonskid material was used by the turning hand. The objectives of this phase of the project were to 1) determine if one of two commonly used approaches to opening a jar required less grip force and 2) to determine if the addition of a nonskid material to the task changed the mechanics in a favorable way. Thirty-one women ranging from with radiographically confirmed or self-reported MD diagnosis of hand osteoarthritis participated. Participants were recruited from a blend of clinical and community based settings, were primarily right hand dominant (90.3%), were, on average, about 64 years old (χ=63.7,SD=13.9), and reported moderate arthritis impact (AIMS2-SF[6] Total Health Score χ = 10.62/40). Participants completed 2 trials for each combination of factors and for most, this resulted in 16 total trials at attempting to ‘break the seal’ of the jar instrument.

The analysis revealed that success (i.e., a successful rotation of the jar’s lid) varied from 18.3% to 82.6 with the ‘right hand oblique’ approach being the least successful and the 'left hand supinated with nonskid material' approach the most. The left supinated approach with nonskid material also resulted in the lowest pain intensity, the least amount of change in pain from baseline, and the lowest perceived effort. The success, reduced perceived effort, and lower pain is likely for a constellation of reasons. These include 1) the reduced grip forces used by the left hand, 2) the positive effects of nonskid material on the ability to generate pure lid-turning torque (i.e., M(z)), 3) the main effect of nonskid material on the sustained ability to generate forces that enhance palm-lid contact [F(z)] , 4) the quick attainment of F(z) appears to allow for a rapid attainment of peak grip forces, M(z), and reduced sustained grip force, 5) the decreased need to sustain compression forces generated by the thenar eminence (i.e., F(x)) when using a supinated approach with nonskid material and 6) reducing the shear or tangential forces generated by the thumb (i.e., F(y)).

In chapter 4, this study investigated further the factors which explain success and the ability to generate hand forces among the previously described sample of participants with hand OA. This included exploring 1) which hand-generated forces predicted success and peak M(z) as well as 2) what commonly used measures of hand function predict success, peak grip forces at the time of peak M(z), and peak M(z). This phase of the project considered how these factors differed by combinations of approach (i.e., oblique and supinated) and the turning hand but did not incorporate the data from the trials where nonskid materials were used. The study explored the force profiles of participants who were and were not successful to determine if these force profiles differ so as to identify, with some approximation, how much force is needed to be successful.

Hand forces. The study provided evidence to support that women with hand arthritis who open large diameter sealed jars are, on average, using high grip loads of about 149.2 newtons (33.5 lbs.) of grip force at the time of opening, used a sustained grasp equating to 802.1 newton-seconds (180.3 lb.-seconds) for the duration of the task, 47.8 newtons (10.7 lbs.) of compressive forces at peak M(z), and 4.4 Newton-meters (3.2 ft. lbs.) of peak M(z). The average successful grip forces were lowest when using a left-handed turn whereas the average successful F(xyz) (i.e., the resultant force of F(x), F(y), and F(z)) forces were highest among those using a supinated approach. F(y) was predictive of peak M(z) generation and was significantly larger among those who were successful. Grip forces significantly and positively predicted success and peak M(z) without consideration of the approach.

Hand function. Reduced palmar abduction ROM (i.e., asmaller webspace) and a hyperextensible stabilizing thumb negatively predicted the turning hand's capacity to generate peak M(z) during right and left oblique approaches. Similarly, as left median sensibility increased, the grip force used by the right turning hand when using the oblique approach decreased, and when using a right oblique approach, as median and ulnar sensibility of the left stabilizing hand increased, the integral of force, a function of time, decreased illustrating improved efficiency.

Regardless of the approach, grip dynamometry scores were predictive of success and for every 1 lb (4.4 N) increase in MVC grip strength the likelihood of success increased by .15%. In addition, right MVC grip strength was negative predictor of left oblique grip forces and left MVC grip strength was a negative predictor for right supinated grip forces. This is likely because as the stabilizing hand became weaker, the turning hand needed to exert more gripping force due to the insufficient counterforce. Moreover, in several approaches, right and left oblique and right supinated, MVC grip strength of the turning and non-turning hand were predictive of peak M(z). An even better predictor of success, however, was perceived effort (PE) as for every one unit decline in a Borg CR10 score, the odds of success improve by 93.5%. Beyond success, PE is a positive predictor of grip force across time (i.e., integral) and a negative predictor of peak M(z). In addition to assessing PE, pain and/or a change in pain from baseline (i.e., ΔPain) are both strong positive and or negative predictors of the grip forces, integrated grip forces, and torques used and resultantly could certainly be considered as measures of joint protection outcomes.

Given that grip force didn't vary greatly across those who weren't and were successful, the capacity of and pain localized to the non-turning hand may have been of some influence. The stabilizing hand's ability to offer a counterforce and hand-specific pain assessments may have explained some of the unexplained variance in the regression models for grip force and peak M(z). Unfortunately, the pain of the non-turning hand was not quantified due to the pain scale being used in a non-specific manner.

Likewise, the non-significantly different grip forces between successful and non-successful might be explained by a disruption of grip-force modulation resulting from proprioceptive changes occurring at the joint level due to degredation[7]. This altered proprioception could result in a larger safety margin (i.e., larger difference between the exerted forces and those required to prevent finger slippage) when turning. Furthermore, evidence does support that, during a right hand counterclockwise turn of a lid-like object, thumb grip forces are greater ($p<.001$) and the margin of error of thumb grip forces are greater ($p<.01$) than a right clockwise turn (i.e., equivalent to a left counterclockwise turn)10[8]. Thus, the higher than necessary grip forces used for a right hand counterclockwise turn by healthy hands may be even higher than is needed as a result of joint sensory receptor changes.

All of these possibilities are supported by the fact that, in this study, the participants who were least successful were those who were applying higher grip forces for a sustained period. Although, across a few of the regression models, the integral of grip force is predicted, to some extent, by cutaneous sensibility, hand joint proprioceptive awareness was not assessed or entered into these models.

Clinical implications

Approach. This study supports that the use of a left hand supinated approach with nonskid materials will result in the greatest success, lowest pain, lowest PE, lowest grip force requirements, lowest integral of grip force, the lowest F(y), and with the exception of the left supinated grasp without nonskid material, has the lowest non-efficient torques (i.e., M(x) and M(y)). This approach adheres to and validates the joint protection principles of reducing high and prolonged exposures to grip forces[9].

Grip strength. The previous assertion that 20 lbs of grip strength[10] for persons with rheumatologic conditions is sufficient for daily activities is not supported by this study. The grip forces used by even those unsuccessful in jar opening well exceed such numbers as do the mean MVC grip strength scores of those in the first ‘success’ tertile. The results do, however, illustrate to the rehabilitation therapist that the strength of the non-twisting, and perhaps non-affected hand, must be considered in an effort to reduce strain on it during bimanual tasks. These predictions, however, do not offer guidelines for the therapist to follow when looking to increase MVC grip strength to a level which facilitates success. Per these findings, there is no specific turning hand grip strength that will guarantee successful opening of a large diameter jar however, 20 lbs of grip strength is clearly not adequate enough.

Sensibility. The study also gives credence to the consideration of assessing sensibility of the turning as well as the stabilizing hand especially for the client who prefers to use an oblique approach. Recognizing that sensory changes in the turning hand does, in fact, predict increased grip force exertion by the turning hand in the left oblique and right supinated approaches, it may wise for the evaluating therapist to consider recommending a left supinated approach with or without nonskid material when sensory changes of the non-turning hand are present.

Joint Mobility. For every 1 degree increase in total active motion (TAM) of the thumb, an increase of .58±.24 newtons of grip force force. So, if TAM is lacking and amendable to remediation, helping to increase joint mobility should predict the ability to exert more grip force when jar opening. Additionally, should a client with 1st carpometacarpal OA have thumb hyperextension deformities, a therapist can predict an increase of .09 newton-meters of peak M(z) torque with reduction of every 1 degree of total thumb hyperextension. Likewise, a one degree reduction in thumb hyperextension predicts an 8.4% increased likelihood of success with jar turning across without regard to the approach. If thumb hyperextension is present and jar opening is a problem, addressing hypermobility through dynamic stablization[11](i.e., strengthening of muscles which stabilizing the joint) non-obtrusive orthoses, stretching of a tight adductor pollicis, and stretching of a shortened extensor pollicis longus. Additionally, depending on the approach to jar opening, thumb palmar abduction inter metacarpal distance (IMD) of the turning and stabilizing thumbs may also be predictive of the ability to generate grip forces and M(z) Thus, if either 1st webspace postures in an adducted manner and a goal is to successfully open larger diameter sealed jars, addressing the webpace through corrective and preventative interventions may be useful. Examples of such might include serial static orthoses, stretching of the adductor pollicis, and strengthening of the antagonistic muscles (e.g., abductor pollicis longus, abductor pollicis brevis, and extensor pollicis brevis).

Pain. A client should be educated that, while opening a sealed jar, pain is predictive of 'real' heightened forces which can result in increased loads on the joint[7]. To address reducing pain or preventing the onset of pain, the therapist should work collaboratively with the client to consider using a joint protection strategy (i.e., left hand supinated turn), and use pain as an indicator of successful reduction in hand forces during sealed jar opening. Per these findings, the difference between baseline and end-of-task NRS measures (Δpain) appears to be the best predictor of success, grip force, and M(z) whereas the pain intensity score (i.e., 'Pain') best predicts sustained grip force (i.e., the 'integral of grip force').

Perceived effort. As mentioned earlier the Borg CR10 appears to predict well success, the integral of grip force, and peak M(z). This measure would seem to have a place in predicting responsiveness to joint protection interventions in rehabilitation and community-based contexts.

Lastly, this information can inform therapists' goal-setting and joint protection interventions. There is now some basic science evidence to predict real change instead of relying on unsubstantiated theory. Additionally, this human-factors data can be used to inform industry of the potentially-large loads placed on arthritic hands when breaking a seal.

Future directions

The current study describes a novel and ecologically valid tool that has been used for the purpose of measuring the comprehensive hand force profiles of women with hand arthritis when opening a large sealed jar. The jar instrument has good to excellent within session repeatability and thus can be used to characterize repeated trials of hand force profiles in women with hand OA within a single session. Further research on 'between session' test-retest reliability and inter-rater reliability are required prior to considering this tool for use as an outcome measure in pre-post design studies. Additional directions for future study include:

- Quantifying the hand force profiles and kinematics of the non-turning hand;
- Evaluating the impact of wrist strength, hand-specific pain, hand joint proprioceptive awareness, and EMG activity of the upper limb on the kinetics of jar opening success;
- Integrating 3D analysis of the upper limbs and jar to better understand the kinetics of the tasks as well as determine the joint reactive forces through inverse dynamics modeling;
- Comparing these results to age-matched controls; and

- Instrumenting other commonly problematic tasks to learn if applying joint protection principles to such is also beneficial.

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Appendix

Appendix 2A.

University of Minnesota

Twin Cities Campus
Human Research Protection Program
Office of the Vice President for Research

September 15, 2009

Virgil G Mathiowetz
Allied Health - OT, Ctr #8368
MMC 368 Mayo
420 Delaware
Minneapolis, MN 55455

RE: "Required Hand Grip Forces for Successful Manual Task Performance among Older Women with Hand Arthritis"
IRB Code Number: 0908M71484

Dear Dr. Mathiowetz

The Institutional Review Board (IRB) received your response to its stipulations. Since this information satisfies the federal criteria for approval at 45CFR46.111 and the requirements set by the IRB, final approval for the project is noted in our files. Upon receipt of this letter, you may begin your research.

IRB approval of this study includes the consent form dated September 11, 2009 and recruitment materials received September 11, 2009.

The HIPAA Authorization dated September 11, 2009has been approved.

The IRB would like to stress that subjects who go through the consent process are considered enrolled participants and are counted toward the total number of subjects, even if they have no further participation in the study. Please keep this in mind when calculating the number of subjects you request. This study is currently approved for 250 subjects. If you desire an increase in the number of approved subjects, you will need to make a formal request to the IRB.

For your records and for grant certification purposes, the approval date for the referenced project is September 3, 2009 and the Assurance of Compliance number is FWA00000312 (Fairview Health Systems Research FWA00000325, Gillette Children's Specialty Healthcare FWA00004003). Research projects are subject to continuing review and renewal; approval will expire one year from that date. You will receive a report form two months before the expiration date. If you would like us to send certification of approval to a funding agency, please tell us the name and address of your contact person at the agency.

As Principal Investigator of this project, you are required by federal regulations to:
*Inform the IRB of any proposed changes in your research that will affect human subjects, changes should not be initiated until written IRB approval is received.

Driven to Discover℠

Page 1

Appendix 2B.

Consent Form

Required Hand Grip Forces for Successful Manual Task Performance
among Healthy Adults

You are invited to be in a research study to determine the repeatability of new devices designed to measure the amount of hand strength adults use when opening a jar. You were selected as a potential participant because you are 18 years of age or older, have reported that you do not have hand or wrist arthritis, and have not had any persistent hand pain, weakness, or sensation changes within the past year.

We ask that you read this form and ask any questions you may have before agreeing to be in the study.

Principle Investigators

Corey McGee, PhD(c), OTR/L, CHT, and Virgil Mathiowetz, PhD, OTR/L, FAOTA of the University of Minnesota's Program in Occupational Therapy and Bradley Nelson, MD of
TRIA Orthopaedic Center

It is funded by, in part, by the Minnesota Medical Foundation

Study Purposes

The purposes of the study are to:

(1) Determine how consistent the equipment used to measure your hand strength during jar opening is when tested more than one time

(2) Determine how well your hand strength measurements during these activities relate to measures of your maximum hand grip and pinch strength

This information will help to validate the use of this equipment in further research aiming to measure how much strength a person such as yourself will need to successfully complete these tasks.

Study Procedures

If you agree to be in this study, we will ask you to do the following things:

(1) Allow us to measure your grip and pinch strength. This is done by having you grip a device 3 times as hard as you can and then perform one type of pinch using a separate device 3 times as hard as you can.

(2) Participate in brief interview involving questions about your life history, medical history and current functional capabilities.

(3) Participate in a simulated daily activity involving use of your hands (e.g., 6 trials of turning a key in a door lock mechanism per hand) to determine how much grip force you use to do them.

Risks of Study Participation

The study has the following risks:

(1) You might experience some hand fatigue or muscle aches for 2-3 days following the testing as a result of the repetitive nature of the tasks involved.

(2) You will be asked to give some information that you may feel to be of a personal nature.

(3) You will be asked to offer up 15-20 minutes of your time.

(4) At times, it may be necessary for the researchers to physically touch your hands or sides to ensure that you are in the correct positions. This, to some, may be uncomfortable.

We will attempt to limit the amount of fatigue your hands and arms may feel by offering you frequent rest breaks. This may also reduce the amount of ‘exercise soreness’ you may have in your hands and forearms after testing. If you are physically uncomfortable or uncomfortable with the nature of the questions or occasional touch, you are free to withdraw from participation at any time.

Benefits of Study Participation

You will not directly benefit from participating in this study. Although you will not directly benefit from this study, should these devices be validated through the results of this study, they have the potential to inform therapists as to how much hand strength is needed to turn a key in a door lock mechanism.

Study Costs/Compensation

You will not directly benefit from participating in this study. Although you will not directly benefit from this study, should these devices be validated through the results of this study, they have the potential to inform therapist as to how much hand strength is needed to turn a key in a door lock mechanism. If you agree to participate, you will receive a $5.00 gift card.

Research Related Injury

In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be billed in the ordinary manner to you or your insurance company. If you think that you have suffered a research related injury, let the study researchers know right away.

Confidentiality

The records of this study will be kept private. The only people that will view your data are the study staff and a review committee that is responsible for protecting your rights. In any publications or presentations, we will not include any information that will make it possible to identify you as a subject. To these extents, confidentiality is not absolute.

Protected Health Information (PHI)

Your PHI created or received for the purposes of this study is protected under the federal regulation known as HIPAA. Refer to the attached HIPAA authorization for details concerning the use of this information.

Voluntary Nature of the Study

Participation in this study is voluntary. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Alternatives to Study Participation: If you do not want to participate in this study, you do not have to.

Contacts and Questions

The researcher conducting this study is Corey McGee. The following graduate students will also be assisting with data collection: Jamie McGaha. You may ask any questions you have now, or if you have questions later, **you are encouraged to** contact Corey at 952-607-6387.

If you have any questions or concerns regarding the study and would like to talk to someone other than the researcher(s), you are encouraged to contact the Fairview Research Helpline at telephone number 612-672-7692 or toll free at 866-508-6961. You may also contact this office in writing or in person at University of Minnesota Medical Center, Fairview-Riverside Campus, 2200 Riverside Avenue, Minneapolis, MN 55454.

You will be given a copy of this form to keep for your records.

Statement of Consent

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature of Subject___________________________________Date_________________

Signature of
Investigator ____Date_________________

Consent Form

Required Hand Grip Forces for Successful Manual Task Performance among Women with Hand Arthritis

You are invited to be in a research study on how much hand grip force is needed by Women 18 years of age or older to do successfully open a sealed jar lid. You were selected as a potential participant because you are a woman, 18 years of age or older, and have hand arthritis.

We ask that you read this form and ask any questions you may have before agreeing to be in the study.

Principal Investigator

This study is being conducted by*:*
Corey McGee, PhD(c), OTR/L, CHT, and Virgil Mathiowetz, PhD, OTR/L, FAOTA of the University of Minnesota's Program in Occupational Therapy and Bradley Nelson, MD of TRIA Orthopaedic Center.

It is funded by, in part, by the Minnesota Medical Foundation and the University of Minnesota's Program in Occupational Therapy.

Study Purpose

The purposes of the study are to:
(1) Find out how little grip/pinch force people like yourself need to open a sealed jar.
(2) To learn if different ways of doing these items require less force than others.
(3) Find out if other things about people like yourself influence the forces you use when doing these tasks.

This information may be useful to therapists in estimating if our clients' grip strength needs strengthening to complete these tasks. It may also be helpful in determining which ways of doing these tasks are most efficient.

Study Procedures

If you agree to be in this study, we will ask you to do the following things:
(1) Allow us to measure your grip and pinch strength. This is done by having you grip 3 times as hard as you can and then perform one type of pinch 3 times as hard as you can.
(2)Participate in brief interview involving questions about your life history, medical history and current functional capabilitities.
(3) Participate in a simulated jar opening activities which involve use of your hands (e.g., 6 trials of twisting a jar lid per hand) to determine how much grip force you use to do them.

(4) Have your dominant hand sensation tested to determine how sensitive you are to touch
(5) Have your hand size measured to determine how hand size influences these forces used during daily activities.
(6) Sign a form that will permit the Physician managing your hand arthritis to confirm your diagnosis.

Risks of Study Participation

The study has the following risks:
(1) You might experience some hand fatigue or muscle aches for 2-3 days following the testing as a result of the repetitive nature of the tasks involved.
(2) You will be asked to give some information that you may feel to be of a personal nature.
(3) You will be asked to offer up to 45 minutes when participating.
(4) At times, it may be necessary for the researchers to physically touch your hands or sides to ensure that you are in the correct positions. This, to some, may be uncomfortable.

We will attempt to limit the amount of fatigue your hands and arms may feel by offering you frequent rest breaks. This may also reduce the amount of 'exercise soreness' you may have in your hands and forearms after testing. If you are physically uncomfortable or uncomfortable with the nature of the questions or occasional touch, you are free to withdraw from participation at any time.

Benefits of Study Participation

You will not directly benefit from participating in this study. Although you will not directly benefit from this study, it is possible that people like yourself who are undergoing hand or occupational therapy might benefit from the results of the study.

Study Costs/Compensation

There are no costs to you for participation. Should you choose to participate; a $10.00 gasoline card and a non-skid jar opener will be provided.

Research-Related Injury

In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be billed in the ordinary manner to you or your insurance company. If you think that you have suffered a research related injury, let the study researchers know right away.

Confidentiality

The records of this study will be kept private. The only people that will view your data are the study staff and a review committee that is responsible for protecting your rights.

In any publications or presentations, we will not include any information that will make it possible to identify you as a subject. To these extents, confidentiality is not absolute.

Protected Health Information (PHI)

Your PHI created or received for the purposes of this study is protected under the federal regulation known as HIPAA. Refer to the attached HIPAA authorization for details concerning the use of this information.

Voluntary Nature of the Study

Participation in this study is voluntary. Your decision whether or not to participate in this study will not affect your current or future relations with the Minnesota Arthritis Foundation or the clinical care institution through which we contacted you. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Alternatives to Study Participation: If you do not want to participate in this study, you do not have to.

Contacts and Questions

The researchers conducting this study are Corey McGee, Virgil Mathiowetz and Dr. Bradley Nelson. The following graduate students will also be assisting with data collection: Nina Affeldt, Sarah Braski, Michelle Kloke, Kim Stokke,and Katie Thomason. You may ask any questions you have now, or if you have questions later, **you are encouraged to** Corey at 952-607-6387.

If you have any questions or concerns regarding the study and would like to talk to someone other than the researcher(s), you are encouraged to contact the Fairview Research Helpline at telephone number 612-672-7692 or toll free at 866-508-6961. You may also contact this office in writing or in person at University of Minnesota Medical Center, Fairview-Riverside Campus, 2200 Riverside Avenue, Minneapolis, MN 55454.

You will be given a copy of this form to keep for your records.

Statement of Consent

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature of Subject____
Date_________________

Signature of Investigator____________________________________
Date_________________

Appendix 2C.

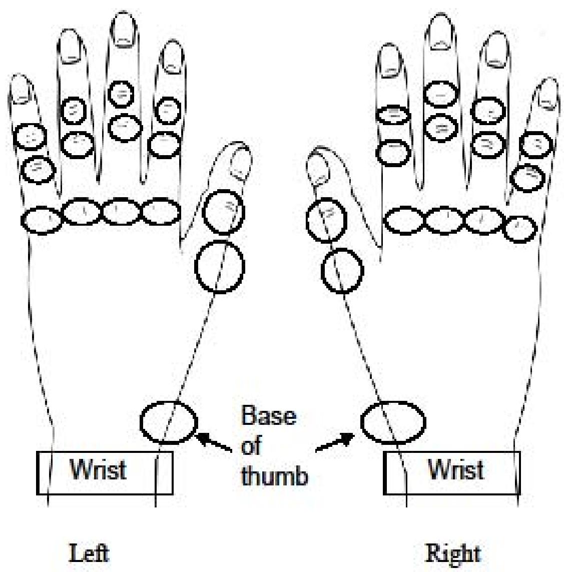
Version date: 5-20-13 1

DEMOGRAPHIC FORM

Required Hand Grip Forces for Successful Manual Task Performance among Women with Hand Arthritis

As part of our study, we need to collect some basic background information on each person who might be a participant. Please answer the questions on the next three pages of this form to the best of your ability. When you are finished, please return the entire form to one of the research staff. Thank you.

	For office use only
Are you: (Check one) _________ Male (1) ________ Female (2)	ID #______ Sex_______
What is your age? Age_______	Age_______
What is your racial/ethnic group? (Check one) ____________White (1) ____________Hispanic (2) ____________African-American (3) ____________American Indian or Alaskan Native (4) ____________Native Hawaiian (5) ____________Pacific Islander (6) ____________Asian Indian (7) ____________Asian (8) ____________Other (9) ____________I'd rather not say (99)	Ethnic_____
Which hand do you prefer using most (dominance)? ___________Right (1) ___________Left (2) ___________Ambidextrous (no preference) (3)	HandD___
What hand do you prefer twisting a jar lid with? (Check one) ___________Right (1) ___________Left (2) ___________Ambidextrous (no preference) (3)	
What type of Arthritis do you have? (Check one) ____________Osteoarthritis (1) ____________Rheumatoid Arthritis (2) ____________Unknown (3) ____________Other(4): Please specify_____________________	TypeA___
Where is your arthritis Located? (Place an "x" inside the circles or squares below)	



For office use only
1=yes, 2=no

Rthu____
RIF ____
RLF____
RRF____
RSF____
RWr____
RUn____
Other:
____

Lthu____
LIF ____
LLF____
LRF____
LSF____
LWr____
LUn____
Other:
____

What year did your symptoms first start?_____________ YrSx______

What year were you first diagnosed with Arthritis?___________ YrDx______

How many years of schooling did you complete? (Check one) Edu_______

___________ 12 years or less (1)
___________ 12- 15 years (2)
___________ more than 15 years (3)

What is your employment status? (Check one) Employ____

___________Full time (40 hours or more per week) (1)
___________Part time (20 to 39 hours per week) (2)
___________Part time (1 to 19 hours per week) (3)
___________Unemployed (unable to find work) (4)
___________Unemployed (chose not to work) (5)
___________Unemployed (unable to work - disability) (6)
___________Retired (7)

How many people are in your household? ______________

What is your HOUSEHOLD income per year? (Check one)	**For office use only**
___________Less than $5,000/year (1)	Hsehld_____
___________$5,001 to $10,000/year (2)	Income____
___________$10,001 to $20,000/year (3)	
___________$20,001 to $30,000/year (4)	
___________$30,001 to $40,000/year (5)	
___________$40,001 to $50,000/year (6)	
___________$50,001 to $75,000/year (7)	
___________$75,001 to $100,000/year (8)	
___________$100,001 to $150,000/year (9)	
___________$Greater than $150,000/year (10)	

Appendix 2D.

AIMS-2 SF
ARTHRITIS IMPACT MEASUREMENT
SCALES 2 Short Form

INSTRUCTIONS : Please answer the following questions about your health.
Most questions ask about your health during the past 4 weeks.
There are no right or wrong answers to the questions and most can be answered with a simple check (✓).
Please answer every question.

DURING THE PAST 4 WEEKS ...	**All days**	**Most days**	**Some days**	**Fews days**	**No days**
1. How often were you physically able to drive a car or use public transportation?	❑	❑	❑	❑	❑
2. How often were you in a bed or chair for most or all of the days ?	❑	❑	❑	❑	❑
3. Did you have trouble doing vigorous activities such as running, lifting heavy objects, or participating in strenuous sports ?	❑	❑	❑	❑	❑
4. Did you have trouble either walking several blocks or climbing a few flights of stairs ?	❑	❑	❑	❑	❑
5. Were you unable to walk unless assisted by another person of by a cane, crutches, or walker ?	❑	❑	❑	❑	❑
6. Could you easily write with a pen or pencil ?	❑	❑	❑	❑	❑
7. Could you easily button a shirt or blouse ?	❑	❑	❑	❑	❑
8. Could you easily turn a key in a lock ?	❑	❑	❑	❑	❑
9. Could you easily comb or brush your hair ?	❑	❑	❑	❑	❑
10. Could you easily reach shelves that were above your head ?	❑	❑	❑	❑	❑
11. Did you need help to get dressed ?	❑	❑	❑	❑	❑
12. Did you need help to get in or out of bed ?	❑	❑	❑	❑	❑

AIMS2 SF 1.3 - Quality of Life Group in Rheumatology, France 1995. Arthritis & Rheumatism 1997; 40: 1267-74
Adaptation from AIMS2 - R. Meenan - Boston, Ms

DURING THE PAST 4 WEEKS	All days	Most days	Some days	Few days	No days
13. How often did you have severe pain from you arthritis ?	❑	❑	❑	❑	❑
14. How often did your morning stiffness last more than one hour from the time you woke up ?	❑	❑	❑	❑	❑
15. How often did your pain make it difficult for you to sleep ?	❑	❑	❑	❑	❑
	Always	**Very often**	**Some times**	**Almost never**	**Never**
16. How often have you felt tense of high strung ?	❑	❑	❑	❑	❑
17. How often have you been bothered by nervousness or your nerves ?	❑	❑	❑	❑	❑
18. How often have you been in low or very low spirits ?	❑	❑	❑	❑	❑
19. How often have you enjoyed the things you do ?	❑	❑	❑	❑	❑
20. How often did you feel a burden to others ?	❑	❑	❑	❑	❑
	All days	**Most days**	**Some days**	**Few days**	**No days**
21. How often did you get together with friends or relatives ?	❑	❑	❑	❑	❑
22. How often were your on the telephone with close friends or relatives ?	❑	❑	❑	❑	❑
23. How often did you go to a meeting of a church, club, team or other group ?	❑	❑	❑	❑	❑
24. Did you feel that your family or friends were sensitive to your personal needs ?	❑	❑	❑	❑	❑
If you are unemployed, disabled or retired, END of questionnaire.	**All days**	**Most days**	**Some days**	**Few days**	**No days**
25. How often were you unable to do any paid work, house work or school work ?	❑	❑	❑	❑	❑
26. On the days that you did work, how often did you have to work a shorter day ?	❑	❑	❑	❑	❑

AIMS2 SF 1.3 - Quality of Life Group in Rheumatology, France 1995. Arthritis & Rheumatism 1997; 40: 1267-74
Adaptation from AIMS2 - R. Meenan - Boston, Ms

Appendix 2E.

Participant #:_______ Date:_____________

Required Hand Grip Forces for Successful Manual Task Performance Survey

Directions: Please read the following questions or statements below. Circle the response that most closely resembles your answer. You may leave comments in the spaces provided if you wish. Please ask for clarification if you need help.

1. How **frequently** do you use a *jar* like the one in the study? (Circle one)

Never   Once per week   Daily   Other:___________

If never, how is/are your jar(s) different? ____

____

2. How **similar** was opening a jar in this exercise to *opening a jar* at your residence? (Circle the number that applies)

1	2	3	4	5
Not at all Similar		Somewhat Similar		Very Similar

3. Was opening the jar in this study in any way uncomfortable or awkward? (Circle one)

Yes   No

If Yes, Please explain:____

____

4. Using the below scale, rate how **important** is it for you to be able to *open a jar*:

1	2	3	4	5	6	7	8	9	10
not important at all									extremely important

5. Using the below scale, rate your **ability** to *open a jar*:

1	2	3	4	5	6	7	8	9	10
not able to do it at all									able to do it very well

Participant #:________ Date:______________

6. Please rate your **satisfaction** with your ability to *open a jar:*

1	2	3	4	5	6	7	8	9	10
not satisfied at all									extremely well

7. How **frequently** do you use *equipment* that helps you open jars? (Circle one)

Never   Once per week   Daily   Other:____________

8. If equipment is used, please describe here:____

Comments:____

Appendix 2F.

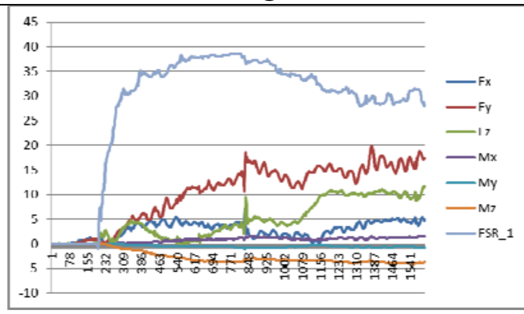
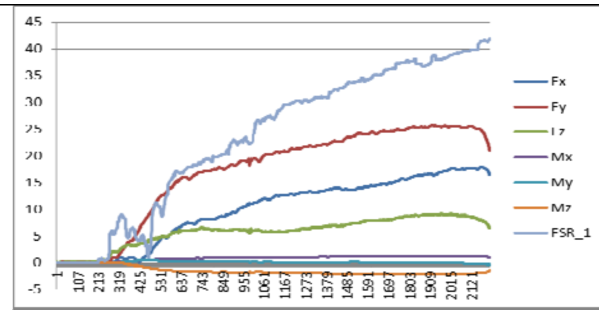
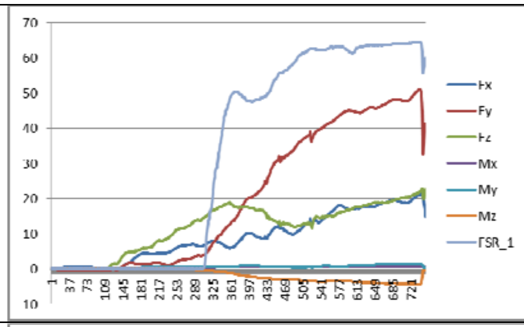
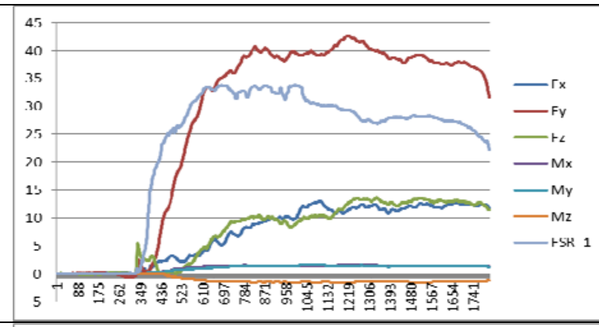
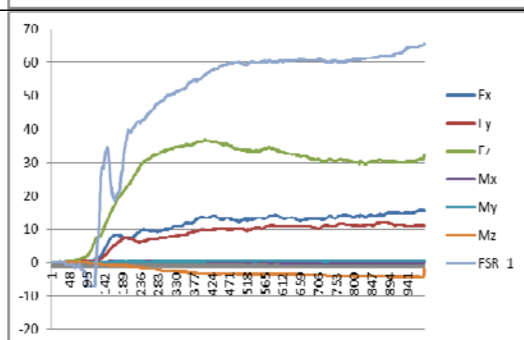
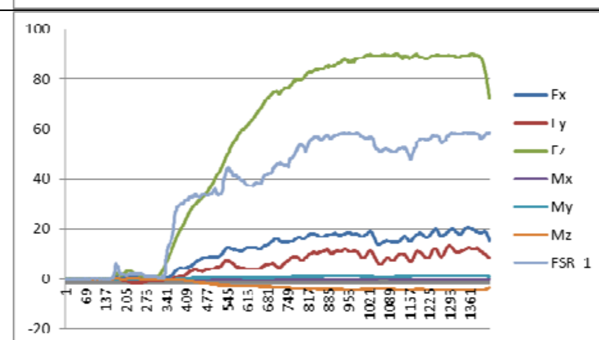
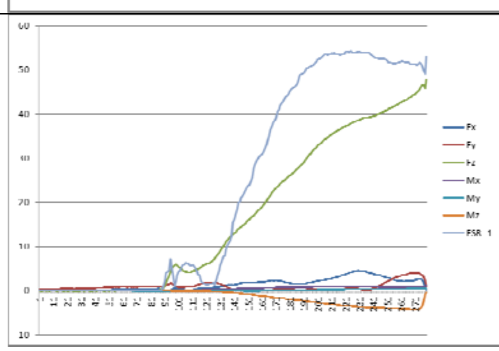
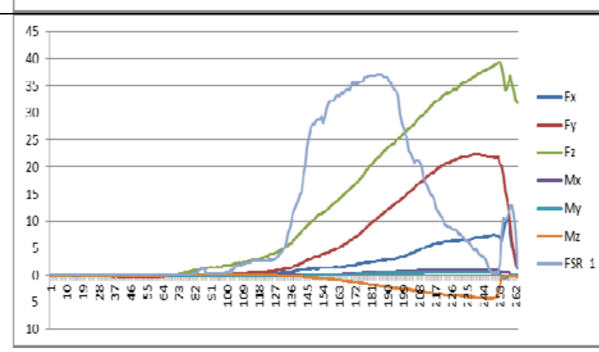
Table 2.6. Pilot Data for Between–Subjects Mean Differences for Grip, Axial, Normal, and Tangential forces acting upon a Jar Lid (29 healthy participants, 29 sets of two jar turning trials; 31 participants with hand OA, 58 turns).

Force	**Healthy Mean Diff. (SD) n=29**	**Arthritis Mean Diff. (SD) n=31**
Grip	3.73(29.6)	7.09(51.0)
Normal Force (Fx)	0.24(13.7)	21.7(69.2)
Tangential (Fy)	3.95(27.0)	4.62(14.6)
Axial (Fz)	9.47 (36.0)	0.44(15.0)
Mx	0.002(0.04)	0.02(0.12)
My	0.001(0.02)	0.044(0.50)
Mz	0.001(0.003)	0.040(0.37)

Note: Forces are reported in Newtons. Moments reported in Newton-Meters "Grip" force is the sum of the peak output of 6 FSR.

Appendix 3A.

Figure 3.18. Integral of Force (Force-Time) and Moment-Time Curves Across all Combinations of Hand, Approach, and Nonskid Material Use.*

	Right	Left
Oblique		
Oblique with Nonskid		
Supinated		
Supinated with Nonskid		

***Note:** Every 10 units on the horizontal axis equivalent to .02 seconds. Units on the vertical axis are Newton-meters for Moments and Newtons for force.

Appendix 3B. Matlab code.

```
%%%% Script for Analyzing Force Sensing Jar Data %%%%

clear all
clc
% Read files JarSubject001.txt through JarSubject009.txt
% fileout = input('Enter Output File Name: ', 's');
output_filename = input('Enter Name for Output File: ', 's'); %this will be the output
name
output_filename = strcat(output_filename, '.csv');
filein = input('Enter Input File Name: ', 's');
r1 = input('Enter Number of First File to Read: ');
r2 = input('Enter Number of Last File to Read: ');

trials = input('Enter Number of Trials to Read: '); %the number of trials will determine if
there is an A, B, or C number of trials
%if there is only A and B (trials = 2)
%if there is an A, B, and C (trials = 3)

if trials == 2
    subset = ['A', 'B'];
elseif trials == 3
    subset = ['A', 'B', 'C'];
end

row_counter = 1;

for k = r1:r2;
    for h = 1:trials

  Filename = [filein num2str(k) subset(h)];
  D = importdata(Filename, '\t', 24);
  D = D.data;
  Fx = D(:, 2);
  Fy = D(:, 4);
  Fz = D(:, 6);
%   Mx = D(:, 8);
%   My = D(:, 10);
  Mz = D(:, 12);
%   Fx_unconverted = D(:, 2);
%   Fy_unconverted = D(:, 4);
%   Fz_unconverted = D(:, 6);
%   Mx_unconverted = D(:, 8);
%   My_unconverted = D(:, 10);
%   Mz_unconverted = D(:, 12);
```

```
%   Fx=Fx_unconverted*4.44822162;
%   Fy=Fy_unconverted*4.44822162;
%   Fz=Fz_unconverted*4.44822162;
%   Mx=Mx_unconverted/8.85074579;
%   My=My_unconverted/8.85074579;
%   Mz=Mz_unconverted/8.85074579;

  F1 = D(:, 14);
  F2 = D(:, 16);
  F3 = D(:, 18);
  F4 = D(:, 20);
  F5 = D(:, 22);
  F6 = D(:, 24);

  %FxP = max(Fx);
  %FyP = max(Fy);
  %FzP = max(Fz);
  %MxP = max(Mx);
  %MyP = max(My);
  %MzP = max(Mz);

  %Fx_min = min(Fx);
  %Fy_min = min(Fy);
  %Fz_min = min(Fz);
  %Mx_min = min(Mx);
  %My_min = min(My);
  %Mz_min = min(Mz);

  %FxN=abs(Fx_min);
  %FyN=abs(Fy_min);
  %FzN=abs(Fz_min);
  %MxN=abs(Mx_min);
  %MyN=abs(My_min);
  %MzN=abs(Mz_min);

  %if FxP>FxN
   %   Fx_max=FxP;
  %elseif FxN>FxP
    %  Fx_max=FxN;
  %end

   %if FyP>FyN
    %  Fy_max=FyP;
  %elseif FyN>FyP
   %   Fy_max=FyN;
   %end
```

```
   %if FzP>FzN
    % Fz_max=FzP;
 %elseif FxN>FzP
  %   Fz_max=FzN;
   %end

   %if MxP>MxN
    % Mx_max=MxP;
 %elseif MxN>MxP
  %   Mx_max=MxN;
% end

 % if MyP>MyN
  %   My_max=MyP;
 %elseif MyN>MyP
  %   My_max=MyN;
  %end

   %if MzP>MzN
    % Mz_max=MzP;
 %elseif MzN>MzP
  %   Mz_max=MzN;
   %end

%Average of first 10 points
Fx_Average=mean(Fx(2:11));
Fy_Average=mean(Fy(2:11));
Fz_Average=mean(Fz(2:11));

Mz_Average=mean(Mz(2:11));

FS1_Average=mean(F1(2:11));
FS2_Average=mean(F2(2:11));
FS3_Average=mean(F3(2:11));
FS4_Average=mean(F4(2:11));
FS5_Average=mean(F5(2:11));
FS6_Average=mean(F6(2:11));

%Zero data
Fx = Fx-Fx_Average;
Fy = Fy-Fy_Average;
Fz = Fz-Fz_Average;

Mz = Mz-Mz_Average;
```

```
FSR1=F1-FS1_Average;
FSR2=F2-FS2_Average;
FSR3=F3-FS3_Average;
FSR4=F4-FS4_Average;
FSR5=F5-FS5_Average;
FSR6=F6-FS6_Average;

%Find peak and index of lid FSR data
[peak1,index1]=max(FSR1);
[peak2,index2]=max(FSR2);
[peak3,index3]=max(FSR3);
[peak4,index4]=max(FSR4);
[peak5,index5]=max(FSR5);
[peak6,index6]=max(FSR6);

[peak11,index11]=min(FSR1);
[peak22,index22]=min(FSR2);
[peak33,index33]=min(FSR3);
[peak44,index44]=min(FSR4);
[peak55,index55]=min(FSR5);
[peak66,index66]=min(FSR6);

p11=abs(peak11);
p22=abs(peak22);
p33=abs(peak33);
p44=abs(peak44);
p55=abs(peak55);
p66=abs(peak66);


peaks=[peak1, peak2, peak3, peak4, peak5, peak6, p11, p22, p33, p44, p55, p66];
[max_peak,max_index]=max(peaks);

if max_index==1
index=index1;
    elseif max_index==2
    index=index2;
    elseif max_index==3
    index=index3;
    elseif max_index==4
    index=index4;
    elseif max_index==5
    index=index5;
    elseif max_index==6
    index=index6;
    elseif max_index==7
```

```
        index=index11;
        elseif max_index==8
        index=index22;
        elseif max_index==9
        index=index33;
        elseif max_index==10
        index=index44;
        elseif max_index==11
        index=index55;
         elseif max_index==12
        index=index66;
end

F1P=FSR1(index);
F2P=FSR2(index);
F3P=FSR3(index);
F4P=FSR4(index);
F5P=FSR5(index);
F6P=FSR6(index);

[Mz_Peak Mz_Peak_index] = max(abs(Mz));

F1Mz=FSR1(Mz_Peak_index);
F2Mz=FSR2(Mz_Peak_index);
F3Mz=FSR3(Mz_Peak_index);
F4Mz=FSR4(Mz_Peak_index);
F5Mz=FSR5(Mz_Peak_index);
F6Mz=FSR6(Mz_Peak_index);
FxMz=Fx(Mz_Peak_index);
FyMz=Fy(Mz_Peak_index);
FzMz=Fz(Mz_Peak_index);

F_Magnitude = sqrt(FxMz*FxMz+FyMz*FyMz+FzMz*FzMz);

% find onset of force
SDNum = 10;
EndPoint = 50;
Fx_Thresh = SDNum*std(Fx(1:EndPoint));
Fy_Thresh = SDNum*std(Fy(1:EndPoint));
Fz_Thresh = SDNum*std(Fz(1:EndPoint));

FSR1_Thresh=SDNum*std(FSR1(1:EndPoint));
FSR2_Thresh=SDNum*std(FSR2(1:EndPoint));
FSR3_Thresh=SDNum*std(FSR3(1:EndPoint));
FSR4_Thresh=SDNum*std(FSR4(1:EndPoint));
FSR5_Thresh=SDNum*std(FSR5(1:EndPoint));
```

```
FSR6_Thresh=SDNum*std(FSR6(1:EndPoint));

OnsetFx = 0;
for i = 1:1:length(Fx)
   if Fx(i)>=Fx_Thresh
      OnsetFx = i;
      break
   else
      OnsetFx = 1;
   end
end
OnsetFx = OnsetFx/500;

OnsetFy = 0;
for i = 1:1:length(Fy)
   if Fy(i)>=Fy_Thresh
      OnsetFy = i;
      break
   else
      OnsetFy = 1;
   end
end
OnsetFy = OnsetFy/500;

OnsetFz = 0;
for i = 1:1:length(Fz)
   if Fz(i)>=Fz_Thresh
      OnsetFz = i;
      break
   else
      OnsetFz = 1;
   end
end
OnsetFz = OnsetFz/500;

OnsetFSR1 = 0;
for i = 1:1:length(FSR1)
   if FSR1(i)>=FSR1_Thresh
      OnsetFSR1 = i;
      break
   else
      OnsetFSR1 = 1;
   end
end
OnsetFSR1 = OnsetFSR1/500;
```

```
OnsetFSR2 = 0;
for i = 1:1:length(FSR2)
   if FSR2(i)>=FSR2_Thresh
      OnsetFSR2 = i;
      break
   else
      OnsetFSR2 = 1;
   end
end
OnsetFSR2 = OnsetFSR2/500;

OnsetFSR3 = 0;
for i = 1:1:length(FSR3)
   if FSR3(i)>=FSR3_Thresh
      OnsetFSR3 = i;
      break
   else
      OnsetFSR3 = 1;
   end
end
OnsetFSR3 = OnsetFSR3/500;

OnsetFSR4 = 0;
for i = 1:1:length(FSR4)
   if FSR4(i)>=FSR4_Thresh
      OnsetFSR4 = i;
      break
   else
      OnsetFSR4 = 1;
   end
end
OnsetFSR4 = OnsetFSR4/500;

OnsetFSR5 = 0;
for i = 1:1:length(FSR5)
   if FSR5(i)>=FSR5_Thresh
      OnsetFSR5 = i;
      break
   else
      OnsetFSR5 = 1;
   end
end
OnsetFSR5 = OnsetFSR5/500;

OnsetFSR6 = 0;
for i = 1:1:length(FSR6)
```

```
    if FSR6(i)>=FSR6_Thresh
        OnsetFSR6 = i;
        break
    else
        OnsetFSR6 = 1;
    end
end
OnsetFSR6 = OnsetFSR6/500;

% calculate area under the curve

FxArea = trapz(abs(Fx))/500;
FyArea = trapz(abs(Fy))/500;
FzArea = trapz(abs(Fz))/500;

FSR1Area=trapz(abs(FSR1))/500;
FSR2Area=trapz(abs(FSR2))/500;
FSR3Area=trapz(abs(FSR3))/500;
FSR4Area=trapz(abs(FSR4))/500;
FSR5Area=trapz(abs(FSR5))/500;
FSR6Area=trapz(abs(FSR6))/500;

%% plot F_Magnitude vector

p0(1) = 0;
p0(2) = 0;
p0(3) = 0;
p1(1) = FxMz;
p1(2) = FyMz;
p1(3) = FzMz;

x0 = p0(1);
y0 = p0(2);
z0 = p0(3);
x1 = p1(1);
y1 = p1(2);
z1 = p1(3);

plot3([x0;x1],[y0;y1],[z0;z1],'linewidth',2,'color',[(155-h)/255,(155-k)/255,1]);
% xlim([0 100]);
% ylim([0 100]);
% zlim([0 100]);

p = p1-p0;
alpha = 0.1;
beta = 0.1;
```

```
hu = [x1-alpha*(p(1)+beta*(p(2)+eps)); x1; x1-alpha*(p(1)-beta*(p(2)+eps))];
hv = [y1-alpha*(p(2)-beta*(p(1)+eps)); y1; y1-alpha*(p(2)+beta*(p(1)+eps))];
hw = [z1-alpha*p(3);z1;z1-alpha*p(3)];

hold on
plot3(hu(:),hv(:),hw(:),'linewidth',2,'color',[(155-h)/255,(155-k)/255,1]);
grid on
xlabel('FxMz /N')
ylabel('FyMz /N')
zlabel('FzMz /N')

  %%%% Write data to spreadsheet %%%%%
  %%%% before running this script, make a file of the output name in the
  %%%% current folder %%%%%
       results(row_counter, :) = {k, h, F1P, F2P, F3P, F4P, F5P,
F6P,OnsetFx,OnsetFy,OnsetFz,OnsetFSR1,OnsetFSR2,OnsetFSR3,OnsetFSR4,OnsetFS
R5,OnsetFSR6,FxArea,FyArea,FzArea,FSR1Area,FSR2Area,FSR3Area,FSR4Area,FSR
5Area,FSR6Area,F1Mz,F2Mz,F3Mz,F4Mz,F5Mz,F6Mz,FxMz, FyMz,
FzMz,F_Magnitude};
       row_counter = row_counter + 1; %counts the number of rows so results are placed
properly
    end
%, Fx_max, Fy_max, Mx_max, My_max, Mz_max

end
csvwrite(output_filename, results, 1, 0);
```

Appendix 3C. SAS Code.

```
Options ls=80 nodate pageno=1 nofmterr mergenoby=error;
 options formchar="|----|+|---+=|-/\<>*";

  * mcgee01.sas   26 Nov 2013;

 * temp.mcgee = imported Jardata3.xls = Jardata2 with recoded labels;

 proc sort data=temp.mcgee_long;
   by ID grip nonskid  hand trial ;

/* proc glm data=temp.mcgee_long;*/
/*   class trial hand grip nonskid ID;*/
/*   model force =  hand| grip| nonskid @ 3;*/
/*   lsmeans hand*grip*nonskid / stderr;*/


 proc mixed data=temp.mcgee_long;
   class trial hand grip nonskid ID;
   model force =  hand| grip| nonskid @ 3;
   repeated trial / subject= ID(hand*grip*nonskid) ;*r rcorr;
   random intercept / subject = ID ;* vcorr;
   lsmeans hand hand*grip*nonskid ;
   ODS output  LSmeans = means;

 run;
 data A;
   set means;
   force = estimate;
   lower=estimate - stderr;
   upper=estimate + stderr;
   drop estimate effect df probt tvalue;

 proc print data=A; run;

 proc sort data=A; by hand;

 proc SGpanel data=A ;  * makes interaction plot of response means by visit;
   panelby hand;
   scatter x=grip y=force / group=nonskid yerrorlower=lower yerrorupper=upper
                              markerattrs=(symbol=CircleFilled);
   series x=grip y=force / group=nonskid;

 run;
```

```
proc mixed data=temp.mcgee_long;
  class trial hand grip nonskid ID;
  model pain =  hand| grip| nonskid @ 3;
  repeated trial / subject= ID(hand*grip*nonskid) ;*r rcorr;
  random intercept / subject = ID  ;* vcorr;
  lsmeans grip hand*grip*nonskid ;
  ODS output  LSmeans = means;

run;
data A;
  set means;
  pain = estimate;
  lower=estimate - stderr;
  upper=estimate + stderr;
  drop estimate effect df probt tvalue;

proc print data=A; run;

proc sort data=A; by hand;

proc SGpanel data=A ;  * makes interaction plot of response means by visit;
  panelby hand;
  scatter x=grip y=pain / group=nonskid yerrorlower=lower yerrorupper=upper
                          markerattrs=(symbol=CircleFilled);
  series x=grip y=pain / group=nonskid;

run;

proc mixed data=temp.mcgee_long;
  class trial hand grip nonskid ID;
  model perceived =  hand| grip| nonskid @ 3;
  repeated trial / subject= ID(hand*grip*nonskid);*r rcorr;
  random intercept / subject = ID ;* vcorr;
  lsmeans hand grip nonskid hand*grip*nonskid ;
  ODS output  LSmeans = means;

run;
data A;
  set means;
  perceived = estimate;
  lower=estimate - stderr;
  upper=estimate + stderr;
  drop estimate effect df probt tvalue;

proc print data=A; run;
```

```
 proc sort data=A; by hand;

 proc SGpanel data=A ;  * makes interaction plot of response means by visit;
   panelby hand;
   scatter x=grip y=perceived / group=nonskid yerrorlower=lower yerrorupper=upper
                              markerattrs=(symbol=CircleFilled);
   series x=grip y=perceived / group=nonskid;

 run;

run; quit;/*

 proc contents data=temp.mcgee;

 run;

 data temp.mcgee_long;
   set temp.mcgee;
   length grip $9. ;

   force = grip_l_p_1;
   pain = pain_l_p_1;
   perceived = perc_l_p_1;
   trial=1;
   hand="L";
   grip="power";
   nonskid=0;
   output;
   force = grip_l_p_2;
   pain = pain_l_p_2;
   perceived = perc_l_p_2;
   trial=2;
   hand="L";
   grip="power";
   nonskid=0;
   output;
   force = grip_r_p_1;
   pain = pain_r_p_1;
   perceived = perc_r_p_1;
   trial=1;
   hand="R";
   grip="power";
   nonskid=0;
   output;
   force = grip_r_p_2;
```

```
  pain = pain_r_p_2;
  perceived = perc_r_p_2;
  trial=2;
  hand="R";
  grip="power";
  nonskid=0;
  output;
*******************;
  force = grip_l_s_1;
  pain = pain_l_s_1;
  perceived = perc_l_s_1;
  trial=1;
  hand="L";
  grip="supinated";
  nonskid=0;
  output;
  force = grip_l_s_2;
  pain = pain_l_s_2;
  perceived = perc_l_s_2;
  trial=2;
  hand="L";
  grip="supinated";
  nonskid=0;
  output;
  force = grip_r_s_1;
  pain = pain_r_s_1;
  perceived = perc_r_s_1;
  trial=1;
  hand="R";
  grip="supinated";
  nonskid=0;
  output;
  force = grip_r_s_2;
  pain = pain_r_s_2;
  perceived = perc_r_s_2;
  trial=2;
  hand="R";
  grip="supinated";
  nonskid=0;
  output;
*******************;
*******************;

  force = grip_l_p_ns_1;
  pain = pain_l_p_ns_1;
  perceived = perc_l_p_ns_1;
```

```
  trial=1;
  hand="L";
  grip="power";
  nonskid=1;
  output;
  force = grip_l_p_ns_2;
  pain = pain_l_p_ns_2;
  perceived = perc_l_p_ns_2;
  trial=2;
  hand="L";
  grip="power";
  nonskid=1;
  output;
  force = grip_r_p_ns_1;
  pain = pain_r_p_ns_1;
  perceived = perc_r_p_ns_1;
  trial=1;
  hand="R";
  grip="power";
  nonskid=1;
  output;
  force = grip_r_p_ns_2;
  pain = pain_r_p_ns_2;
  perceived = perc_r_p_ns_2;
  trial=2;
  hand="R";
  grip="power";
  nonskid=1;
  output;
*******************;
  force = grip_l_s_ns_1;
  pain = pain_l_s_ns_1;
  perceived = perc_l_s_ns_1;
  trial=1;
  hand="L";
  grip="supinated";
  nonskid=1;
  output;
  force = grip_l_s_ns_2;
  pain = pain_l_s_ns_2;
  perceived = perc_l_s_ns_2;
  trial=2;
  hand="L";
  grip="supinated";
  nonskid=1;
  output;
```

```
  force = grip_r_s_ns_1;
  pain = pain_r_s_ns_1;
  perceived = perc_r_s_ns_1;
  trial=1;
  hand="R";
  grip="supinated";
  nonskid=1;
  output;
  force = grip_r_s_ns_2;
  pain = pain_r_s_ns_2;
  perceived = perc_r_s_ns_2;
  trial=2;
  hand="R";
  grip="supinated";
  nonskid=1;
  output;
********************;
 keep ID force pain perceived trial hand grip nonskid;
 proc print;
run;
```

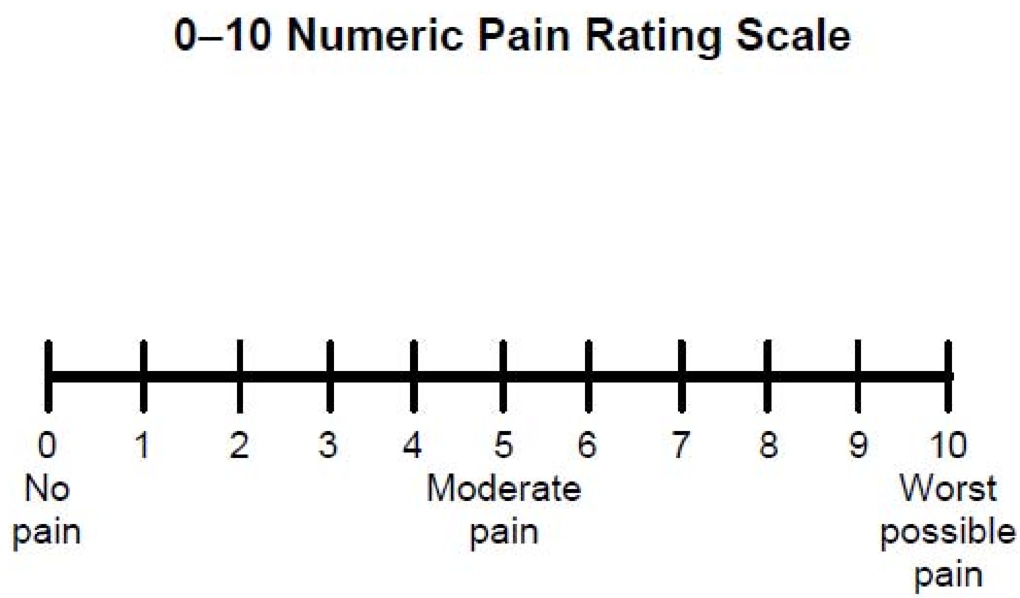
Appendix 4A. Borg CR-10 scales of perceived exertion.

Using this scale, where 0 relates to no effort at all and 10 relates to extremely strong or almost maximal effort, how much hand effort did you use to open the jar?

1
0 - nothing at all
.5 - extremely weak
1 - very weak (just noticeable)
2 - weak (light)
3 - moderate
4
5 - strong
6
7 - very strong
8
9
10 - extremely strong (almost max)

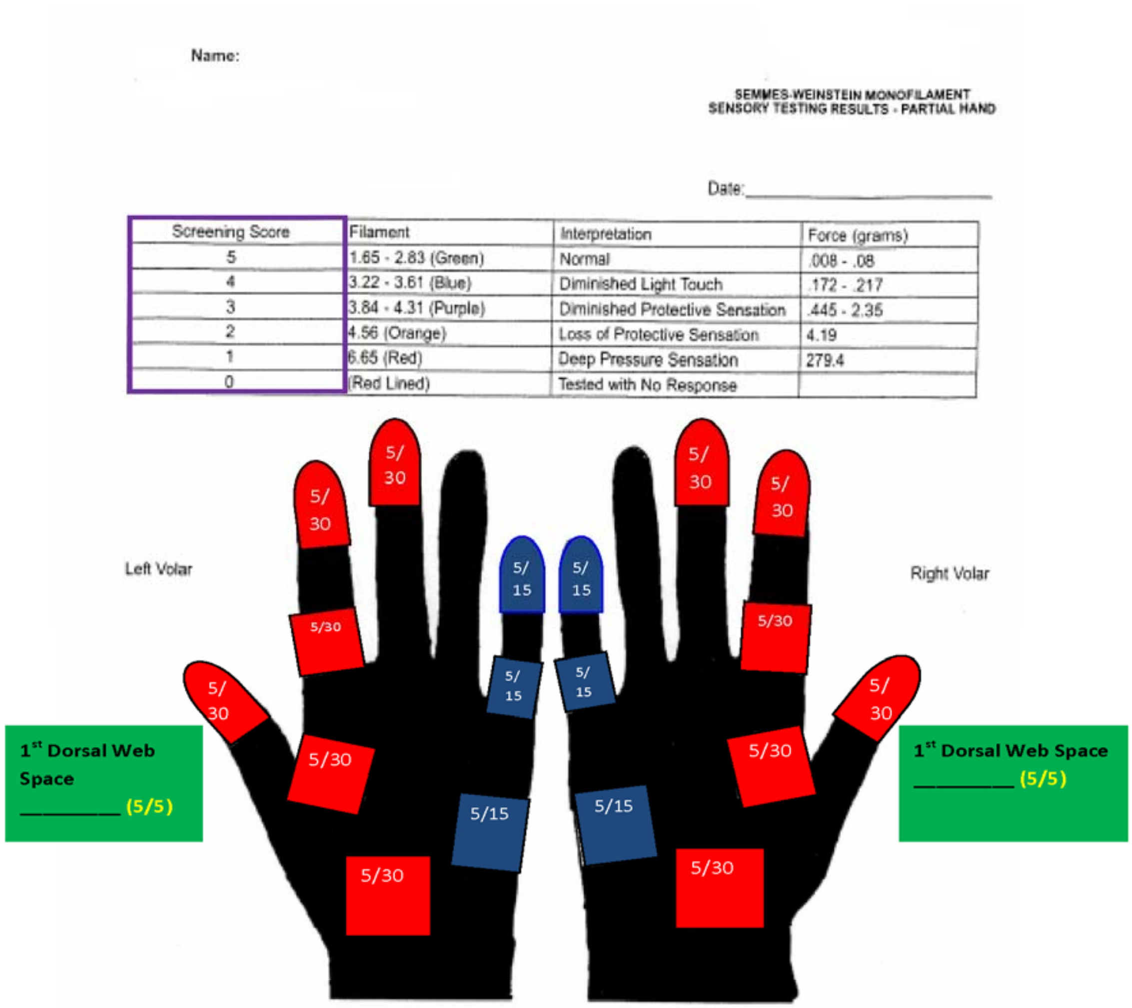
Adapted from:
Borg G. Psychophysical bases of perceived exertion. Med. Sci. Sports Ex. 14(5):377-381, 1982.

Appendix 4B. Numerical Pain Rating Scale.



0–10 Numeric Pain Rating Scale: From McCaffery M, Pasero C. Pain: Clinical Manual, St. Louis, 1999, P. 16. Copyrighted by Mosby, Inc. Reprinted with permission.

Appendix 4C. Sensory Testing Form.



Name:

SEMMES-WEINSTEIN MONOFILAMENT
SENSORY TESTING RESULTS - PARTIAL HAND

Date:____________________

Screening Score	Filament	Interpretation	Force (grams)
5	1.65 - 2.83 (Green)	Normal	.008 - .08
4	3.22 - 3.61 (Blue)	Diminished Light Touch	.172 - .217
3	3.84 - 4.31 (Purple)	Diminished Protective Sensation	.445 - 2.35
2	4.56 (Orange)	Loss of Protective Sensation	4.19
1	6.65 (Red)	Deep Pressure Sensation	279.4
0	(Red Lined)	Tested with No Response	

Score	Normal	Left	Right
Volar Median	30	/30	/30
Volar Ulnar	15	/15	/15
Radial Dorsal1st web space	5	/5	/5
Whole	50	/50	/50

Appendix 4D. Hand Mobility.

Joint		RUE AROM				
Digits		1st	2nd	3rd	4th	5th
MP	Ext.	-8	0	0	0	0
	Flex	55	84	88	88	88
PIP	Ext.		0	0	0	0
	Flex		99	98	106	94
DIP	Ext.	12	0	0	0	0
	Flex.	55	42	68	51	61
Composite		114	225	254	245	243
TAM		81.4	80.4	90.7	87.5	86.8

Joint		LUE AROM				
Digits		1st	2nd	3rd	4th	5th
MP	Ext.	-8	0	0	0	0
	Flex	57	84	90	82	83
PIP	Ext.		0	0	0	0
	Flex		91	90	89	92
DIP	Ext.	14	0	0	0	0
	Flex.	79	62	78	55	50
Composite		142	237	258	226	225
TAM		101	84.6	92.1	80.7	80.4

Note: TAM= (Total flexion)+(extension lag)/norm. x 100
where norm.(normal composite flexion) = 2-5 digits:280 deg.,
1st digit: 140 deg.

AROM

Wrist	
Ext.	70
Flex.	82
UD	40
RD	16
Forearm	
Sup.	87
Pro.	87

AROM

Wrist	
Ext.	66
Flex.	62
UD	30
RD	16
Forearm	
Sup.	84
Pro.	88

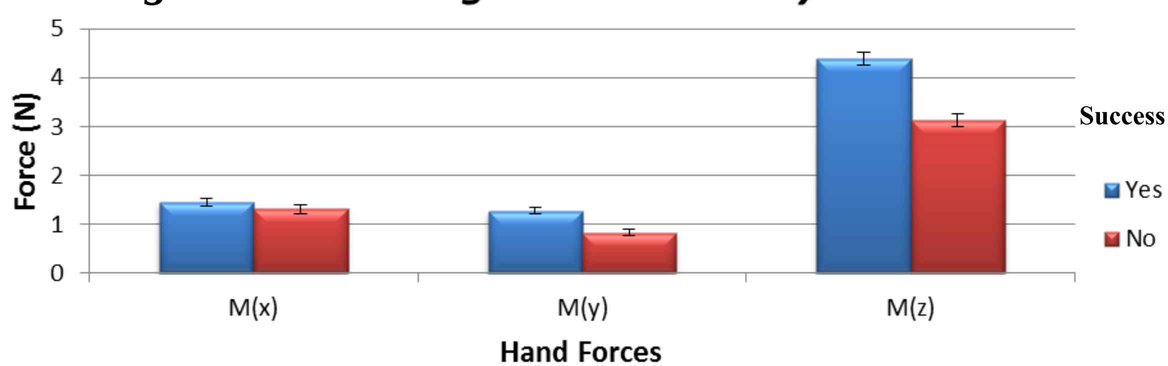
Appendix 4E. Additional Tables and Figures.

Table 4.5. Summary of Logistic Regression Analysis for 'Hand Force' Variables Predicting Success for Jar Turning while controlling for the effects of approach (n=228 trials)[a]

Predictor	*B*	*SE B*	Sig.	Exp(*B*)
(Constant)	2.0723	.6578	.0016	7.943
Grip Force	.0016	.0004	.0003	1.002
Integral of Grip Force	-.00062	.000182	.0008	.999
F(xyz)	-.0011	.0068	0.8764	.999
Hand turning lid (Left=1)	.3749	.2948	.2034	1.454
Approach (Oblique=1)	-1.6302	.3280	<.0001	.1958
Hand*Approach (Left Oblique=1)	-.7439	.7305	.3085	.2076

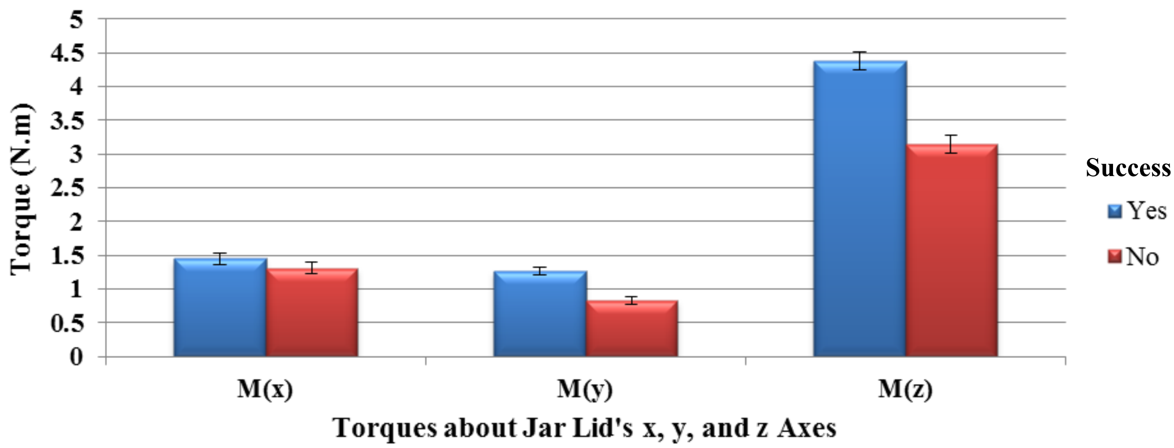
[a]Grip Force = finger squeezing forces acting on the jar lid at peak M(z), Integral of Grip Force= area under the grip force time curve; F(xyz) is the resultant of compressive forces acting on the jar's lid in the three orthogonal axes of x,y,and z; M(z) = torque about the z axis; forces are reported in newtons; torques reported in newton-meters; Intregral of Grip Force reported in newton-seconds. Model: *Success=2.0723+.0016*(GripForce)-.00062*(Integral of Grip Force)-.0011[*F(xyz)]-1.6302*(Approach).*

Figure 4.5. Average Hand Forces by Success[a]



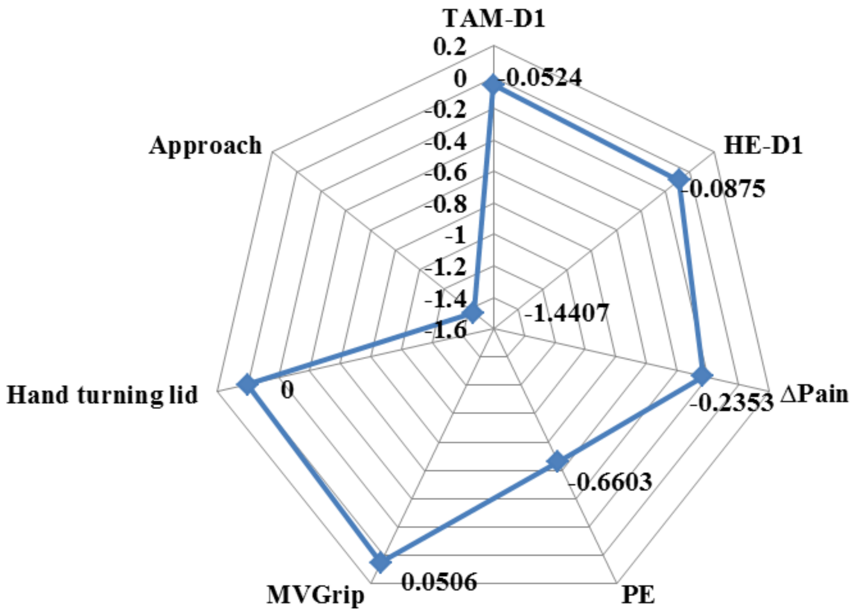
[a]Grip Force = finger squeezing forces acting on the jar lid at peak M(z); F(xyz) is the resultant of compressive forces acting on the jar's lid in the three orthogonal axes of 'x','y',and'z'; M(z) = torque about the z axis; forces are reported in newtons; torques reported in newton-meters;

Figure 4.6. *Average Torques by Success*[a]



[a] M(x) and M(y) are torque which rotate about the ‘x’ and ‘y’ axes of the jar lid and create a ‘rocking’ torque or the same type of torque one would use to pop the lid off of a canister of chips or tennis-balls; M(z) torques produce ‘pure’ rotational movement about the jar lid’s axis of rotation, the ‘z’ axis.

Figure 4.7. Spider Plot of Logistic Regression Coefficients for Hand Function Predictors of Successful Jar Opening[a]



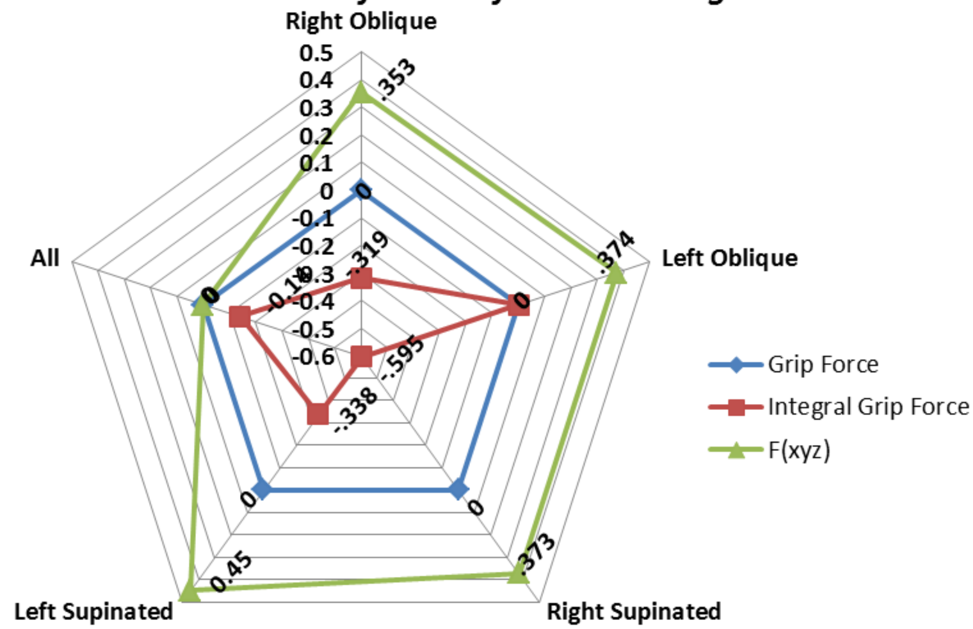
[a]TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; Approach = oblique vs. supinated approach towards jar opening with oblique approach as reference value Hand turning lid: right vs. left hand with left as reference value.

Table 4.6. Summary of Logistic Regression Analysis for 'Hand Function' Variables Predicting Success for Jar Turning for while controlling for the effects of approach (n=244 trials)[a]

Predictor	*B*	*SE B*	Sig.	Exp(*B*)
(Constant)	10.6553	1.8506	<.0001	42416.8089
TAM-D1	-0.0524	0.0151	0.0005	0.9489
HE-D1	-0.0875	0.0226	0.0001	0.9162
ΔPain	-0.2353	0.1379	0.0045	0.7903
PE	-0.6603	0.1187	<.0001	1.9354
MVGrip	0.0506	0.0219	0.0209	1.0519
Hand turning lid (Left=1)	0.6988	0.4452	0.1165	2.0114
Approach (Oblique=1)	-1.4407	0.5086	0.0052	0.2368
Hand*Approach (Left Oblique=1)	-24.9562	14.0213	.0768	-.4120

[a]TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale. *Model: Success=10.6553-.0524*(TAM-D1)-.0875*(HE-D1)-.2353*(ΔPain)-.6603*(PE)+.0506*(MVGrip)-1.4407*(Approach).*

Figure 4.8. ***Spider Plot of Logistic Regression Coefficients for Hand Force Predictors of Successful Jar Twisting***[a]



[a]Grip Force = finger squeezing forces acting on the jar lid at peak M(z); Integral of Grip Force= area under the grip force time curve; F(xyz) is the resultant of compressive forces acting on the jar's lid in the three orthogonal axes of x,y,and z; M(z) = torque about the z axis; forces are reported in newtons; torques reported in newton-meters; Intregral of Grip Force reported in newton-seconds.

Table 4.7. Relationships between Dependent and Explanatory Variables for Trials (n=58) of the Right Hand Oblique Approach[a].

	Grip Force	Integral Grip	F(xyz)	M(z)	Median-R	Ulnar-R	Median-L	Ulnar-L	TAM-D1-R	HE-D1-R	TAM-D1-L	HE-D1-L	PA-R	PA-L	HL-R	HL-L	MVGrip-R	*MVGrip-L*	PE	Pain	ΔPain
Grip Force	1	**.314***	**.240***	**.381****	-.011	-.006	-.024	.151	**.423****	-.184	.203	.071	.002	-.102	.162	**.261***	.184	.087	-.010	**-.257***	**-.402****
Integral Grip	**.314***	1	**.359****	**-.413****	-.042	.147	-.010	**-.205***	-.014	-.091	-.060	-.040	-.166	-.140	.086	.020	.098	.039	**.176***	.139	.081
F(xyz)	**.240***	**.359****	1	**.392****	-.205	**-.232***	**-.256***	**-.264***	-.039	.094	-.131	**-.357****	**-.337****	-.118	**-.310****	**-.266***	-.195	**-.265***	-.071	.124	-.013
M(z)	**-.381****	**-.413****	**.392****	1	**.432****	-.155	-.123	-.364**	.070	-.181	-.048	**-.238***	-.007	.090	-.127	**-.279***	.022	.027	**-.341****	.048	.156

[a]Grip Force=Jar Lid Grip forces at peak M(z) and are reported in newtons, Integral Grip is the area under the Grip force-time curve and are reported in newton-seconds, M(z) is the peak torque acting on the lid about the vertical axis of the jar and is reported in newton-meters; F(xyz) is the resultant of F(x), F(y), and F(z) forces acting on the jar lid at Peak M(z) and is reported in newtons, Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; PE= Perceived Effort as measured by the Borg CR10 scale; Pain = pain intensity per numerical rating scale following a trial of jarlid twisting; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; R=right hand, L=left hand. Pain scores are not specific to one hand as opening a jar is a bimanual task but are specific to the approach.;*= 05, **=.01.

***Table 4.8. Summary of Multiple Regression Analysis for Variables Predicting Grip Force* at Peak M(z) for Jar Turning for Right Hand Oblique Trials (n=58 trials)[a]**

Predictor	*B*	*SE B*	Standardized *B*	Sig.
(Constant)	-244.551	121.672		.050
Ulnar-L	7.492	3.840	.226	.051
TAM-D1-R	.589	.227	.292	.012
PA-L	-15.328	7.535	-.250	.047
HL-L	15.689	5.925	.301	.011
ΔPain	-8.047	2.564	-.362	.003

R^2=.410, Adjusted R^2=.351

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; ΔPain= change in pain score from baseline to following a trial of jar lid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; R=right hand, L=left hand; Model: Grip Force = -*244.551+7.492*(Ulnar-L)+.589*(TAM-D1-R) -15.328*(PA-L)+ 15.689*(HL-L) -8.047*(ΔPain)*.

Table 4.9. Relationships between Dependent and Explanatory Variables for Trials (n=58) of the Left Hand Oblique Approach[a].

	Grip Force	Integral Grip	F(xyz)	M(z)	Median-R	Ulnar-R	Median-L	Ulnar-L	TAM -D1-R	HE-D1-R	TAM-D1-L	HE-D1-L	PA-R	PA-L	HL-R	HL-L	MVGrip-R	MVGrip-L	PE	Pain	ΔPain
Grip Force	1	.207	.193	.140	-.136	.035	.056	.125	.074	-.040	-.013	**.249***	.087	.104	.017	.058	-.024	-.028	.038	-.114	-.021
Integral Grip	.207	1	**.242***	-.171	.145	.124	-.067	**.256***	.074	.101	-.048	.090	-.186	.079	.202	.128	.116	.001	-.081	-.168	.028
F(xyz)	**.193**	**.242***	1	**.394****	**-.343****	-.152	**-.299***	**-.222***	.043	.148	.012	-.076	-.178	.007	-.108	-.191	-.087	-.095	**-.278***	.104	-.013
M(z)	.140	-.171	**.394****	1	**-.389****	-.180	-.122	**-.347****	.083	-.102	-.110	**-.417****	-.091	.028	-.177	**-.301****	-.003	.093	**-.512 ****	.056	.032

[a]Grip Force=Jar Lid Grip forces at peak M(z) and are reported in newtons, Integral Grip is the area under the Grip force-time curve and are reported in newton-seconds, M(z) is the peak torque acting on the lid about the vertical axis of the jar and is reported in newton-meters; F(xyz) is the resultant of F(x), F(y), and F(z) forces acting on the jar lid at Peak M(z) and is reported in newtons, Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; PE= Perceived Effort as measured by the Borg CR10 scale; Pain = pain intensity per numerical rating scale following a trial of jarlid twisting; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; R=right hand, L=left hand. Pain scores are not specific to one hand as opening a jar is a bimanual task but are specific to the approach.;*= 05, **=.01.

Table 4.10. Summary of Multiple Regression Analysis for Variables Predicting Grip Force at Peak M(z) for Jar Turning for Left Hand Oblique Trials (n=60 trials)[a]

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	40.198	71.895		.579
Median-R	-11.022	3.418	-.564	.002
Ulnar-L	26.281	7.505	.675	.001
HE-D1-R	-1.301	.558	-.297	.024
HE-D1-L	1.870	.517	.486	.001
PA-L	17.253	9.154	.238	.050
MVGrip-R	-1.596	.518	-.422	.003
ΔPain	6.382	3.009	.272	.039
R^2=.710, Adjusted R^2=.600				

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; ΔPain= change in pain score from baseline to following a trial of jar lid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; R=right hand, L=left hand. Model: Grip Force = 40.198-11.022*(Median-R)+ 26.281*(Ulnar-L)-1.301 *(HE-D1-R)+1.870*(HE-D1-L)+ 17.253*(PA-L)+ 6.382*(ΔPain).

Table 4.11. Relationships between Dependent and Explanatory Variables for Trials (n=58) of the Right Hand Supinated Approach[a].

	Grip Force	Integral Grip	M(z)	F(xyz)	Median-R	Ulnar-R	Median-L	Ulnar-L	TAM-D1-R	HE-D1-R	TAM-D1-L	HE-D1-L	PA-R	PA-L	HL-R	HL-L	MVGrip-R	MVGrip-L	PE	Pain	ΔPain
Grip Force	1	.153	**.607****	.135	.032	-.044	.016	-.098	**.290***	.096	.114	.067	.064	-.098	-.059	-.042	-.125	-.249*	.011	.003	-.096
Integral Grip	.153	1	**-.524****	.172	.102	-.118	-.017	-.023	.176	.161	**.309***	-.040	.169	.025	.088	.195	.058	.042	.296*	-.068	.042
F(xyz)	.135	.172	**.455****	1	**-.225***	**-.251***	**-.276***	**-.342****	-.009	-.133	-.127	-.025	-.022	.142	.135	.071	-.058	.011	-.202	.321*	.408**
M(z)	**.607****	**-.524****	1	**.455****	-.196	-.135	-.177	-.216	-.088	-.099	**-.366****	-.008	-.254*	-.023	.112	-.082	-.028	-.061	-.429**	.154	-.063

[a]Grip Force=Jar Lid Grip forces at peak M(z) and are reported in newtons, Integral Grip is the area under the Grip force-time curve and are reported in newton-seconds, M(z) is the peak torque acting on the lid about the vertical axis of the jar and is reported in newton-meters; F(xyz) is the resultant of F(x), F(y), and F(z) forces acting on the jar lid at Peak M(z) and is reported in newtons, Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; PE= Perceived Effort as measured by the Borg CR10 scale; Pain = pain intensity per numerical rating scale following a trial of jarlid twisting; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; R=right hand, L=left hand. Pain scores are not specific to one hand as opening a jar is a bimanual task but are specific to the approach.;*= 05, **=.01.

Table 4.12. Summary of Multiple Regression Analysis for Variables Predicting Grip Force at Peak M(z) for Jar Turning for Right Hand Supinated Trials (n=54 trials)[a]

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	-224.517	143.366		.126
Ulnar-R	18.165	6.881	.457	.012
Ulnar-L	-29.952	10.442	-.759	.007
TAM-D1-R	2.409	.384	.932	<.0001
HE-D1-R	1.958	.492	.425	<.0001
TAM-D1-L	-1.230	.507	-.390	.020
PA-R	45.917	16.845	.566	.010
HL-L	30.994	12.647	.441	.019
MVGrip-R	1.801	.820	.469	.034
MVGrip-L	-5.126	.859	-1.141	<.0001
ΔPain	-8.590	2.981	-.308	.007

R^2=.382,Adjusted R^2=.346

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; ΔPain= change in pain score from baseline to following a trial of jar lid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; R=right hand, L=left hand.; Model: *Grip Force= -224.517+18.165*(Ulnar-R)+ 8.084*(Median-L) -29.952*(Ulnar-L)+2.409 *(TAM-D1-R)+1.958*(HE-D1-R)-4.573*(TAM-D1-L)+8.393*(HE-D1-L) -1.230* (TAM-D1-L) +45.917 *9(PA-R) -19.339*(HL-R)+ 30.994*(HL-L)+ 1.801*(MVGrip-R)- -5.126*(MVGrip-L) -8.590*(ΔPain) -3.873 *(PE).*

Table 4.13. Relationships between Dependent and Explanatory Variables for Trials (n=58) of the Left Hand Supinated Approach[a].

	Grip Force	Integral Grip	M(z)	F(xyz)	Median-R	Ulnar-R	Median-L	Ulnar-L	TAM -D1-R	HE-D1-R	TAM-D1-L	HE-D1-L	PA-R	PA-L	HL-R	HL-L	MVGrip-R	MVGrip-L	PE	Pain	ΔPain
Grip Force	1	.207	.263	.107	.142	.058	.059	.212	.115	.117	-.078	.039	-.100	.142	.123	.214	.145	.087	.021	-.029	.183
Integral Grip	.207	1	**-.455****	.172	.177	-.033	-.133	-.020	.078	.147	-.037	.201	-.009	.023	**.315****	**.316****	-.049	-.088	**.346****	**.332***	**.369****
F(xyz)	.107	.172	**.430****	1	-.042	**-.228***	-.181	**-.257***	-.041	.062	-.167	-.106	-.144	.052	.123	.196	-.226	-.102	-.024	-.107	**.305***
M(z)	.263	**-.455****	1	**.430****	**-.235***	-.042	-.163	-.211	-.033	-.005	**-.324****	-.032	**-.315****	-.159	-.062	-.164	-.036	.019	**-.447****	-.153	-.037

[a]Grip Force=Jar Lid Grip forces at peak M(z) and are reported in newtons, Integral Grip is the area under the Grip force-time curve and are reported in newton-seconds, M(z) is the peak torque acting on the lid about the vertical axis of the jar and is reported in newton-meters; F(xyz) is the resultant of F(x), F(y), and F(z) forces acting on the jar lid at Peak M(z) and is reported in newtons, Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; PE= Perceived Effort as measured by the Borg CR10 scale; Pain = pain intensity per numerical rating scale following a trial of jarlid twisting; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; R=right hand, L=left hand. Pain scores are not specific to one hand as opening a jar is a bimanual task but are specific to the approach.;*= 05, **=.01.

Table 4.14. Summary of Multiple Regression Analysis for Variables Predicting Grip Force at Peak M(z) for Jar Turning for Left Hand Supinated Trials (n=56 trials)[a]

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	-68.979	177.628		.700
PA-R	-58.120	17.853	-.679	.002
PA-L	49.771	16.560	.622	.004
HL-R	24.255	11.669	.413	.043
ΔPain	14.270	4.620	.415	.003
R^2=.418,Adjusted R^2=.304				

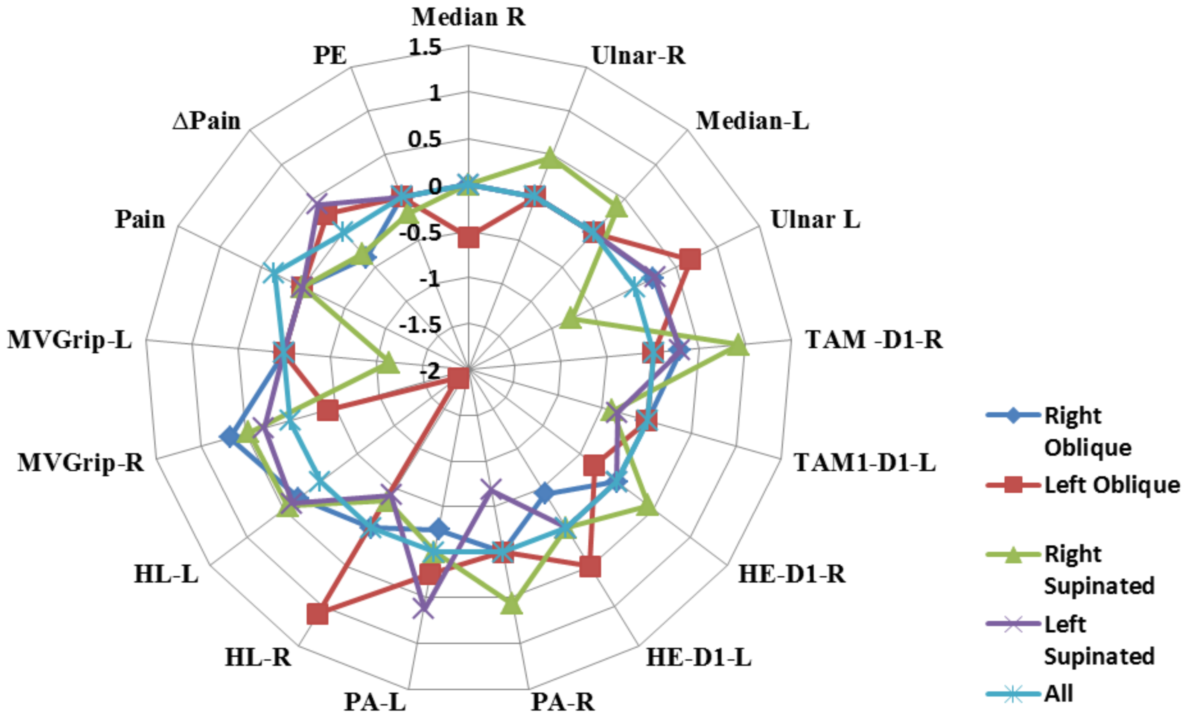
[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; ΔPain= change in pain score from baseline to following a trial of jar lid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand, R=right hand, L=left hand. *Model = Grip Force = -68.979-58.120*(PA-R)+ 49.771*(PA-L) +24.255*(HL-R)+ 28.468*(HL-L) 1.174*(MVGrip-R)+ 14.270*(ΔPain).*

Table 4.15. Summary of Multiple Regression Analysis for 'Hand Function' Variables Predicting Grip Force at Peak M(z) **During Jar Turning While Controlling for the Effects of Turning Approach (n=228 trials)**[a]

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	78.3691	28.3746	-1.2343	.0102
ΔPain	-4.3257	2.1459	-.1547	.0453
TAM-D1	.5826	.2395	.009619	.0160
Hand turning lid (Left=reference)	33.5205	10.0612	.06658	.0010
Approach (Oblique=reference)	-4.0326	10.0435	.5534	.6885

[a]TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; ΔPain= change in pain score from baseline to following a trial of jar lid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand. *Grip Force = 78.3691+0.5826*(TAM-D1) -4.3257*(ΔPain)+ 33.5205*(Hand).*

Figure 4.9. Spider Plot of Standardized Regression Coefficients for 5 Models for Hand Function Predictors of Grip Force at Peak M(z)[a]



[a]TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; Approach = oblique vs. supinated approach towards jar opening with oblique approach as reference value Hand turning lid: right vs. left hand with left as reference value.

***Table 4.16. Summary of Multiple Regression Analysis for Variables Predicting Integral of Grip Force* in Jar Turning for 'Right Hand Oblique' Trials (n=58 trials)[a]**

Predictor	*B*	*SE B*	Standardized *B*	Sig.
(Constant)	1500.053	680.482		.033
Median-R	-57.342	18.639	-.608	.033
Median-L	-66.163	17.696	-.617	.004
Ulnar-L	192.924	33.217	1.014	.001
TAM-D1-R	-3.991	1.508	-.344	<.0001
HE-D1-R	-9.843	2.460	-.474	.011
HL-R	134.488	46.488	.597	<.0001
HL-L	-162.513	56.507	-.542	.006
Pain	47.039	12.361	.410	.006
PE	113.553	17.900	.882	<.0001

R^2=.617, Adjusted R^2 =.521

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; Pain = pain intensity per numerical rating scale following a trial of jarlid twisting; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; R=right hand, L=left hand. Pain scores are not specific to one hand. Model: *Integral Grip Force = 1500.053-57.342*(Median-R) -66.163*(Median-L)+ 192.924*(Ulnar-L) - 3.991*(TAM-D1-R) -9.843*(HE-D1-R)+134.488*(HL-R) -162.513*(HL-L)+ 47.039*(Pain)+ 113.553*(PE).*

***Table 4.17. Summary of Multiple Regression Analysis for Variables Predicting Grip Force Integral* in Jar Turning for 'Left Hand Oblique' Trials (n=60 trials)[a]**

	B	***SE B***	**Standardized *B***	**Sig.**
(Constant)	256.121	372.275		.495
Median-L	-86.213	19.955	-.934	<.0001
Ulnar-L	141.540	34.581	.831	<.0001
TAM-D1-R	3.362	1.581	.312	.039
TAM-D1-L	-5.062	1.816	-.400	.008

R^2=.413, Adjusted R^2 =.303

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; Pain = pain intensity per numerical rating scale following a trial of jar lid twisting; ΔPain= change in pain score from baseline to following a trial of jar lid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; PE = Perceived effort of a trial at jar lid twisting per the Borg CR10 Scale; R=right hand, L=left hand. Pain scores are not specific to one hand. R=right hand, L=left hand; Model: *Integral Grip Force = 256.1214-86.213*(Median-L)+141.540*(Ulnar-L)+3.362*(TAM-D1-R)-5.062*(TAM-D1-L).*

Table 4.18. Summary of Multiple Regression Analysis for Variables Predicting 'Integral Grip Force' during Jar Turning for 'Right Hand Supinated' Trials (n=54 trials)[a]

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	-1230.641	652.509		.066
Median-L	-37.967	18.045	-.474	.041
TAM-D1-L	5.792	2.326	.328	.017
HE-L	-6.673	2.402	-.437	.008
PE	33.825	10.013	.428	.002

R^2=.442, Adjusted R^2 =.325

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; R=right hand, L=left hand. Model: *Integral Grip Force =-1230.641 +23.798*(Median-R) -37.967*(Median-L)+ 5.792*(TAM-D1-L)- 6.673(HE-L)+33.825*(PE).*

Table 4.19. Summary of Multiple Regression Analysis for Variables 'Integral Grip Force' during Jar Turning for 'Left Hand Supinated' Trials (n=56 trials)[a]

Predictor	*B*	*SE B*	Standardized *B*	Sig.
(Constant)	-289.491	391.392		.463
Median-R	41.477	15.746	.480	.011
Ulnar-R	63.229	28.841	.367	.033
Median-L	-79.883	19.373	-.859	.000
TAM-D1-R	5.206	1.695	.457	.004
TAM-D1-L	-4.060	2.005	-.296	.049
PA-L	141.028	47.530	.428	.005
Pain	32.969	12.509	.303	.011
PE	25.238	10.002	.322	.015
R^2=.444, Adjusted R^2 =.349				

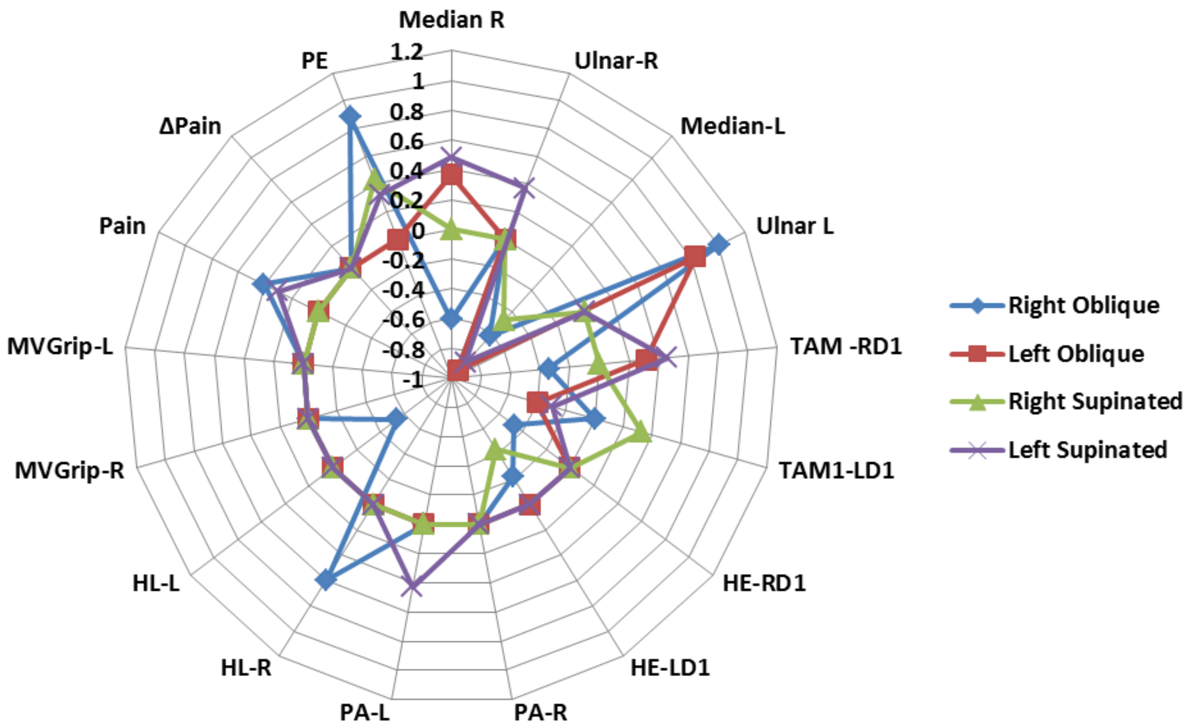
[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; R=right hand, L=left hand. Model: *Integral Grip Force = -289.491+41.477*(Median-R)+63.229(Ulnar-R)-79.883(Median-L)+5.206*(TAM-D1-R)-4.060*(TAM-D1-L)+141.028*(PA-L)+32.969*(Pain)+25.238*(PE).*

***Table 4.20. Summary of Multiple Regression Analysis for 'Hand Function' Variables Predicting Integral of Grip Force* During Jar Turning while controlling for the effects of approach (n=228 trials)[a]**

Predictor	*B*	*SE B*	Standardized *B*	Sig.
(Constant)	593.58	59.9067	0.04725	<.001
PE	23.4715	7.1136	0.2679	0.0012
Hand (Left=1)	-22.2209	42.9034	.596	0.3765
Approach (Oblique=1)	40.0367	45.1690	-.1593	0.3656

[a]PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale. Model: *Integral Grip Force = 593.58+23.4715(PE).*

Figure 4.10. Spider Plot of Standardized Regression Coefficients for 5 Models for Hand Function Predictors of Integral of Grip Force[a]



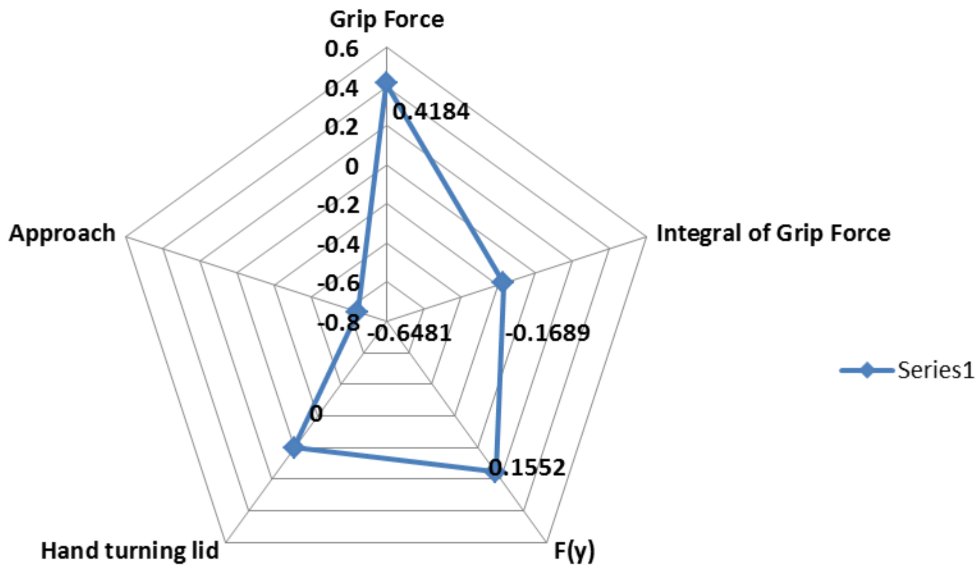
[a]TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; Approach = oblique vs. supinated approach towards jar opening with oblique approach as reference value Hand turning lid: right vs. left hand with left as reference value.

Table 4.21. Summary of Multiple Regression Analysis for 'Hand Force' Variables Predicting M(z) in Jar Turning while controlling for the effects of approach (n=228 trials)a

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	3.7542	.2368		<.0001
Grip Force	.01894	.04251	.4184	<.0001
Integral of Grip Force	-.00065	.000161	-.1689	<.0001
F(y)	.009920	.003440	.1552	.0044
Hand turning lid (Left=reference)	.06330	.1057	.1532	.4113
Approach (Oblique=reference)	-.6481	.1160	-.6174	<.0001
Hand*Approach	-.2569	.1544	-.2569	.0978

[a]Grip Force = finger squeezing forces acting on the jar lid at peak M(z), Integral of Grip Force= area under the grip force time curve; F(xyz) is the resultant of compressive forces acting on the jar's lid in the three orthogonal axes of x,y,and z; M(z) = torque about the z axis; forces are reported in newtons; torques reported in newton-meters; Integral of Grip Force reported in newton-seconds. *Regression model: Mz=*3.7542+.01894**(Grip Force)*-.00065**(Integral Grip Force)* +.009920**[F(y)]-.6481*(Approach).*

Figure 4.11. Spider Plot of Standardized Regression Coefficients for Hand Force Predictors of Peak M(z)[a]



[a]Grip Force = finger squeezing forces acting on the jar lid at peak M(z); Integral of Grip Force= area under the grip force time curve; F(xyz) is the resultant of compressive forces acting on the jar's lid in the three orthogonal axes of x,y,and z; M(z) = torque about the z axis; forces are reported in newtons; torques reported in newton-meters; Intregral of Grip Force reported in newton-seconds.

Table 4.22. Summary of Multiple Regression Analysis for Variables Predicting M(z) **in Jar Turning for 'Right Hand Oblique' Trials (n=58 trials)[a]**

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	9.791	2.745		.001
Median-R	-.167	.069	-.459	.020
Ulnar-R	.230	.115	.333	.050
Median-L	.248	.097	.600	.014
Ulnar-L	-.657	.165	-.894	.000
PA-R	-.733	.296	-.513	.017
PA-L	.879	.251	.646	.001
MVGrip-R	.047	.015	.675	.003
MVGrip-L	-.041	.018	-.499	.028
ΔPain	.114	.059	.231	.050
R^2=.525, Adjusted R^2=.410				

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; R=right hand, L=left hand. Pain scores are not specific to one hand. Model: *M(z)= 9.791-.167*(Median-R)+ .230*(Ulnar-R)+ .248*(Median-L)-.657*(Ulnar-L) -.733*(PA-R)+ .879*(PA-L)+.047(MVGrip-R)-.041*(MVGrip-L)+.114*(Pain).*

***Table 4.23. Summary of Multiple Regression Analysis for Variables Predicting M(z)* in Jar Turning for 'Left Hand Oblique' Trials (n=60 trials)[a]**

Predictor	*B*	*SE B*	Standardized *B*	Sig.
(Constant)	5.382	.831		.000
TAM-D1-R	.020	.007	.363	.006
HE-D1-R	.028	.011	.289	.011
TAM-D1-L	-.028	.008	-.428	.001
HE-D1-L	-.050	.010	-.575	.000
MVGrip-R	.020	.010	.232	.050
ΔPain	.114	.053	.217	.038
PE	-.249	.049	-.531	.000

R^2=.568, Adjusted R^2=.501

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; R=right hand, L=left hand. Model: *M(z)= 5.382+.020*(TAM-D1-R)+ .028*(HE-D1-R) -.028*(TAM-D1-L) -.050*(HE-D1-L)+ .020*(MVGrip-R -.114*(ΔPain) -.249*(PE).*

***Table 4.24. Summary of Multiple Regression Analysis for Variables Predicting M(z)* in Jar Turning for 'Right Hand Supinated' Trials (n=54 trials)[a]**

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	10.055	1.140		<.0001
Ulnar-R	-.158	.083	-.228	.053
TAM-D1-L	-.032	.006	-.586	.000
MVGrip-R	.014	.009	.214	.098
PE	-.200	.040	-.549	.000

R^2=.496, Adjusted R^2=.453

[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; R=right hand, L=left hand; Model: *M(z)= 10.055-.158*(Ulnar-R) -.032*(TAM-D1-L)+.014*(MVGrip-R)-.200*(PE).*

***Table 4.25. Summary of Multiple Regression Analysis for Variables Predicting M(z)* in Jar Turning for 'Left Hand Supinated' Trials (n=56 trials)[a]**

Predictor	***B***	***SE B***	**Standardized *B***	**Sig.**
(Constant)	8.052	.911		<.0001
TAM-D1-L	-.017	.006	-.338	.005
PE	-.142	.033	-.482	<.0001

R^2=.382, Adjusted R^2=.346

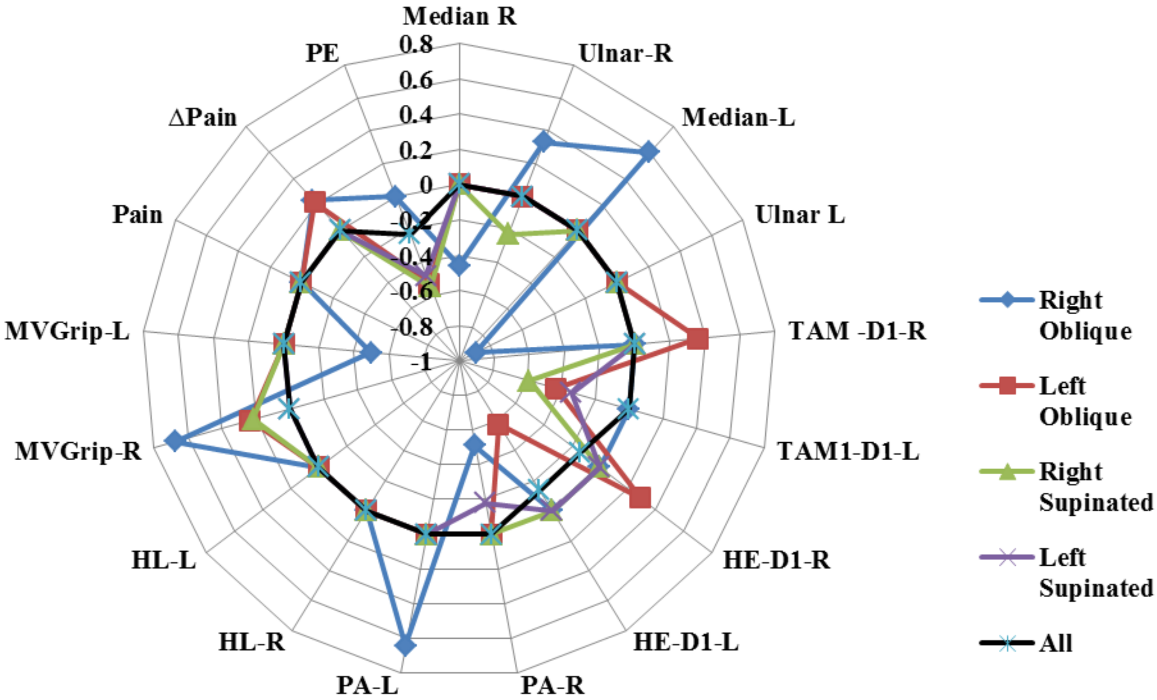
[a] TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; R=right hand, L=left hand; Model: *M(z)= 8.052-.017*(TAM-D1-L) -.142*(PE).*

***Table 4.26. Summary of Multiple Regression Analysis for 'Hand Function' Variables Predicting M(z)* in Jar Turning while controlling for the effects of approach (n=228 trials)[a]**

Predictor	*B*	*SE B*	Standardized *B*	Sig.
(Constant)	5.6126	.4896		<.0001
HE-D1	-.01587	.004853	-.01376	.0013
PE	-.08935	.02320	-.2304	.0002
Hand turning lid (Left=1)	.093	.1137	.1542	.4113
Approach (Oblique=1)	-.5815	.1199	.05182	<.0001
Hand*Approach	.05523	.1539	.04787	.7200

[a]TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PE = Perceived effort of a trial at jar lid twisting per the Borg CR10 Scale. Model: M(z)= 5.6126-.00672*(TAM-D1)-0.01587*(HE-D1)-0.08935*(PE)-.5815*(Approach).

Figure 4.12. Spider Plot of Standardized Regression Coefficients for 5 Models for Hand Function Predictors of M(z)[a]



[a]Median/Ulnar Values= composite scores of Semmes Weinstein Monofilament ratings across sites which are specific to cutaneous innervation patterns of median and ulnar nerves; TAM-D1=total active motion (composite flexion-composite extension lags) of the thumb and are reported in degrees; HE-D1 = hyperextension values of the thumb and are a composite of each digit's measurements (degrees) which exceed a neutral (0 degrees) extended position; PA = Palmar abduction of the thumb inter metacarpal distance and is reported in cm; HL= Hand Length and is reported in centimeters; MVGrip = is the average of three trials of maximal voluntary grip strength measurements per dynamometry and is reported in newtons; PE = Perceived effort of a trial at jarlid twisting per the Borg CR10 Scale; ΔPain= change in pain score from baseline to following a trial of jarlid twisting as measured by the numerical rating scale; Pain scores are not specific to one hand; R=right hand, L=left hand.

Appendix 4F. SAS Codes.

```
options ls=80 nodate pageno=1 nofmterr mergenoby=error;
 options formchar="|----|+|---+=|-/\<>*";

  * mcgee040.sas   8 July 2014  WThomas;

 data hand_characteristics0;
   infile "Z:\Students\McGee, Corey\Data, code\Hand characteristics.csv"
      DSD dlm="," firstobs=2 missover lrecl=500;
   input ID RUDW RRDW LUDW LRDW MedianR UlnarR MedianL UlnarL RTAM1
RHE1 LTAM1 LHE1 Rext Rflex Rsup Rpro Lext Lflex Lsup Lpro RPA LPA RHL LHL
GripR GripL
         thrptpR thrptpL LatPR LatPL;

 * proc contents  data=hand_characteristics;

 data jar.hand_characteristics;
   set  hand_characteristics0;
   hand = "R";
   UDW = RUDW;
   RDW = RRDW;
   median = MedianR;
   ulnar = UlnarR;
   tam1 = RTAM1;
   HE1 = RHE1;
   ext = Rext;
   flex = Rflex;
   sup = Rsup;
   pro = Rpro;
   PA = RPA;
   HL = RHL;
   Grip_strength = GripR;
   thrptp = thrptpR;
   LatP = LatPR;
   output;
   hand = "L";
   UDW = LUDW;
   LDW = LRDW;
   median = MedianL;
   ulnar = UlnarL;
   tam1 = LTAM1;
   HE1 = LHE1;
   ext = Lext;
```

```
  flex = Lflex;
  sup = Lsup;
  pro = Lpro;
  PA = LPA;
  HL = LHL;
  Grip_strength = GripL;
  thrptp = thrptpL;
  LatP = LatPL;
  output;
  keep id hand UDW  LDW  median ulnar tam1 HE1  ext  flex sup  pro  PA HL
Grip_strength thrptp;

 *proc sort  dat LatPa=hand_characteristics0;

 proc sort data = jar.hand_characteristics;
   by id hand;
 proc sort data = jar.corrected_long;
   by id hand;

 data jar.long_with_hand_char;
   merge jar.corrected_long jar.hand_characteristics;
   by id hand;
   if (id = .) then delete;

 proc genmod data=Jar.long_with_hand_char descending;
  class grip nonskid ID ;
  model success =  UDW  LDW  median ulnar tam1 HE1  ext  flex sup  pro  PA HL
Grip_strength thrptp
      grip nonskid / type3 dist = bin link = logit aggregate Pscale LRCI ;
  repeated subject=ID /  type=CS ;

* proc export data = Jar.long_with_hand_char
 outfile = "Z:\Students\McGee, Corey\Data, code\long_with_hand_char.csv"
 DBMS=CSV replace;


 run; quit;/*

-----------------------------------------------------------------------------
* mcgee050.sas   21 July 2014  WThomas;

 * Standardized coefficients:
   Binary predictors (class variables) - no adjustment
   Continuous predictors - multiply by standard deviation of predictor values
```

```
     or use proc stdize to standardize continuous variables, then run genmod or mixed
again
        with standardized variables;

 proc genmod data=jar.mcgee42 descending;
   where nonskid=0;
   where ID NE . ;
   class trial hand grip ID;
   model success =  hand| grip @ 2 / type3 dist = bin link = logit aggregate Pscale LRCI ;
 * this model contains only binary variables, so the reg coefficients = standardized reg
coef;
   repeated subject=ID / subcluster=trial  type=CS;* corrb covb;
   lsmeans hand grip  / ilink CL;

  run;

 proc mixed data= jar.mcgee42;
   where nonskid=0;
   class trial hand grip ID;
   model force = pain_change perceived hand| grip @ 2/solution ;
 * in this model, we standardize pain_change and  perceived, retaining restriction of
WHERE statement;
   random intercept / subject = ID ;

 * (1) multiply by standard deviation of predictor values;

 proc means stddev n data= jar.mcgee42;
   where nonskid=0;
   var pain_change perceived;

 * multiplication
  > -3.0604 * 2.1735111 =  -6.651813
  > -0.7097 * 2.9746689 =  -2.111123
   gives same results as below;


  * (2) multiply by standard deviation of predictor values;

 proc stdize  data= jar.mcgee42  out=jar.std_mcgee42;
   where nonskid=0;
   var pain_change perceived;

 proc mixed data= jar.std_mcgee42; * use standardized data, which has same variable
names;
```

```
  where nonskid=0;
  class trial hand grip ID;
  model force = pain_change perceived hand| grip @ 2 /solution ;
 * in this model, we standardize pain_change and  perceived, retaining restriction of
WHERE statement;
  random intercept / subject = ID ;

 run; quit;
```