HAND RANGE OF MOTION, STRENGTH, DEXTERITY, AND PAIN AS PREDICTORS OF HAND FUNCTIONAL PERFORMANCE

A THESIS

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To the Dean of the Graduate School:

I am submitting herewith a thesis written by Ann Elizabeth Burkard Mitchell entitled "Hand Range of Motion, Strength, Dexterity, and Pain as Predictors of Hand Functional Performance." I have examined this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in physical therapy.

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ABSTRACT

Hand Range of Motion, Strength, Dexterity,
and Pain as Predictors of Hand
Functional Performance

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Purposes of this study were to determine (a) thresholds for the resources of range of motion (ROM), strength, dexterity, and pain in specific functional task performance in persons with diseased or injured hands using Nonlinear Causal Resource Analysis; (b) resources limiting performance; and (c) whether changes in resources would predict changes in performance. Twenty-one subjects were measured for hand ROM, grip and pinch strength, dexterity, pain, and self-reported performance of meal preparation and feeding, toileting, and dressing and grooming. Data were used to model resources required for performance and predict levels of performance. Twelve subjects were retested on the same variables, and the model developed initially was tested. Thresholds of performance and limiting resources were identified, and levels of task performance were predicted. In conclusion, results of this study suggest that this model may help clinicians identify limiting resources and predict task performance in individual patients with varied hand dysfunctions.

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CHAPTER I

INTRODUCTION

The ability to move and use one's hand in a purposeful and meaningful way is dictated by several basic elements: sufficient range of motion (ROM), strength, motor control, and sensation, and the absence or degree of pain present. Disease and/or injury can produce physiological changes, or pathology, in these basic elements. Intervention to minimize the effect of pathology in the hand can take the form of medication, surgery, or therapy.

Therapeutic intervention in hand pathology typically begins with an evaluation. The evaluation is used to establish a clinical diagnosis from which initial status, baseline pathology, treatment planning, goals setting, and effects of intervention can be determined. In a recent survey of Certified Hand Therapist, 99% reported using standardized and non-standardized assessment tools with their patients (Muenzen et al., 2002). Measurements of impairments in the basic elements of ROM, strength, dexterity (motor control), and sensation, and the measurement of pain are usually included in an examination, as well as measurement of edema and functional limitations. Specifically, these elements are integral to the assessment of the hand: ROM because "loss of range of motion is associated in most cases with loss of function" (American Physical Therapy Association, 1997, p. 1208), strength, as measured by grip and pinch, because strength is considered a measure of hand function (Fess, 1992), and sensibility because it is a "prerequisite to normal hand function" (Aulicino, 1995, p. 70). Assessment of each of these elements helps clinicians identify impairment.

In the Nagi disablement scheme (Jette, 1994), pathology owing to injury or disease may lead to impairment. Impairment may or may not result in functional limitations. Functional limitations may produce disability. An individual may sustain a fracture to a phalanx without any apparent impairment, or the fracture may produce pain, edema, and loss of ROM with impairment. In the second example, the impairment may not limit function and therefore no disability occurs from the fracture. If the impairment does limit function, such as an inability to write, it will only produce a disability if the individual is limited in, or unable to perform, his or her usual activities. Therapists use the process of impairment identification (limited resources) and limited functional performance to develop a treatment plan and direct patient care.

Investigators have linked the previously mentioned "basic elements" to function, demonstrating a correlation between hand ROM, strength, motor control, sensation, and pain with functional tasks performed with the hands. Dellhag and Burckhardt (1995) studied ROM, grip strength, and pain as predictors of function in patients with rheumatoid arthritis (RA). These investigators used correlation and regression analysis to demonstrate that one half of the variance in hand function could be predicted. Vliet Vlieland, van der Wijk, Jolie, Zwinderman, and Hazes (1996) studied strength and ROM as well as deformity and stiffness in patients with RA with respect to function. Using a stepwise multiple regression analysis, strength, stiffness, and deformity explained 78% of the variance in a combined functional measure. In the clinical setting, therapists use knowledge of the correlation of "basic elements" to function in the development of a treatment plan. The development of a treatment plan would be enhanced if the therapist could identify which of the resources (basic elements) most limits the patients performance of a specific function and at what level a change in that resource will effect a change in the performance of the function. Identification of the limiting resource and knowledge of the amount of change that will effect performance would allow therapists to develop a treatment plan targeting those limited resources, establish goals with the changes in the limited resource needed to effect the desired performance, and potentially improve the effectiveness of treatment.

Ronlinelli et al. (1997) in a simulation of hand impairment studied strength and ROM as predictors of the degree of impact these elements would have on function. Impairment was simulated with a splint that partially immobilized the wrist and thumb. An impairment rating was determined by a computer system. The impairment rating was standardized according to the American Medical Association (AMA) guidelines (1993) and was derived from ROM and strength measurements. Function, measured by three separate tests, was altered. With correlation and regression analysis the researchers determined that the degree of impairment, a single impairment percentage, was not predictive of the degree of functional loss. The use of a single impairment rating to represent only 14 ROM measures and 8 strength measures weakened the conclusion that the degree of impairment was not predictive of the degree of functional loss. Ronlinelli et al. discussed attempts to examine the data with scatter plots in an attempt to find linear and nonlinear regressions, however, these results were not significant. Once again the impairment rating was used instead of the actual impairment measurements.

Nonlinear Causal Resource Analysis (NCRA) is a method of analysis that predicts performance of high level tasks (HLT) using the resources available (basic performance resources, BPR), and allows the determination of which of the BPRs is limiting performance (Kondraske, Johnston, Pearson, & Tarbox, 1997). NCRA is based on the General Systems Performance Theory (GSPT) and the Elemental Resource Model (ERM) (Kondraske, 1999). GSPT and the ERM, emphasizing cause and effect principles, are human performance modeling concepts developed by Kondraske (2000). Given the requirements for performance of a task, the ERM uses resource economic principles and the measurements of the basic elements required to perform the task to determine the performance thresholds of each element (Kondraske, 2000). One advantage of this approach is the focus on resources rather than deficits. NCRA may provide an alternative to correlation/regression analysis for investigating the basic elements (resources) of hand function and their determination of functional task performance.

Analysis of individual hand resources as predictors of function versus amalgamated impairment scores needs to be investigated. The use of NCRA may help to determine whether a limiting resource can be identified in the performance of a given task and whether there are thresholds within that resource (impairment) associated with varying levels of performance. If limiting resources and thresholds associated with given levels of task performance can be identified clinicians may have a better framework on which to develop treatment goals and plans.

Statement of the Problem

Correlation and regression studies support the conviction that hand ROM, strength, sensibility, motor control/dexterity, and pain affect hand function. How much of each of these basic elements is needed to function at a specific level and whether one or more of these basic elements has a greater influence on hand function during the performance of a given task is not well understood with respect to the hand. The clinician is left with the questions: "What is the limiting factor (resource)?" and "How much of the resource is enough to perform specific tasks?"

Purpose of Study

The purposes of this study were to (a) determine threshold values for ROM, strength, and dexterity, and levels of pain in specific functional task performance in people with diseased or injured hands using NCRA; (b) identify whether differing threshold values for each resource were detectable for varying levels of specific functional task performance; and (c) determine whether changes in ROM, strength, dexterity and/or pain would produce predictive changes in function when using the GPST model developed in the initial part of the study.

Research Questions

The research questions for this study were as follows:

Would threshold values be discernible for each measure of ROM, strength, dexterity, and pain in the hand with respect to the self-rated performance of the task of meal preparation and feeding?

Would threshold values be discernible for each measure of ROM, strength, dexterity, and pain in the hand with respect to the self-rated performance of the task of toileting?

Would threshold values be discernible for each measure of ROM, strength, dexterity, and pain in the hand with respect to the self-rated performance of the task of dressing and grooming?

Would the self-reported changes in the performance of meal preparation and feeding and the changes in the measures of ROM, strength, dexterity, and/or pain be consistent with the predictions derived from GSPT?

Would the self-reported changes in the performance of toileting and the changes in the measures of ROM, strength, dexterity, and/or pain be consistent with the predictions derived from GSPT?

Would the self-reported changes in the performance of dressing and grooming and the changes in the measures of ROM, strength, dexterity, and/or pain be consistent with the predictions derived from GSPT?

Definitions

The following words and terms were operationally defined for the purpose of this study:

1. Active Range of Motion (AROM) – the amount of movement a subject was able to produce at a joint, that is, the difference in the extremes of a joint's motion.

2. Extremes of Motion (EOM) - the beginning and the end point of a joint's

motion. The EOM was measured and recorded on each motion at each joint for the fingers and thumb. The finger motions and joints measured were: flexion and extension of the metacarpal phalangeal joints (MCP), proximal interphangeal joints (PIP), and distal interphangeal joints (DIP). The thumb motions and joints measured were: carpal metacarpal (CMC) palmar and radial abduction, metacarpal phangeal joint (MP) and interphangeal joint (IP) flexion and extension, and opposition. All measurements were reported in degrees with the exception of opposition, which was recorded in cm from the volar surface of the distal phalanx of the thumb to MC joint of the small finger.

3. Total Active Motion (TAM) – the sum of the flexion at the MCP, PIP, and DIP minus any extension deficits, reported in degrees for each of the eight fingers. The thumb's TAM was the sum of palmar and radial abduction, and MP and IP flexion minus any extension deficits. Thumb opposition was considered separately.

4. Grip strength – the magnitude of isometric force produced by the hand (thumb and fingers) as measured by a dynamometer in kilograms. The average of three efforts was used.

5. Pinch strength – the magnitude of force produced by the fingers in each of three pinching positions: palmar (also referred to as three-jaw chuck), tip (tip of the thumb to the tip of the index finger), and lateral (also referred to as key) as measured by a dynamometer in kilograms. The average of three efforts was used.

6. Dexterity – the ability of the hand to manipulate objects as measured by the Purdue Pegboard (Smith & Nephew, Inc., Germantown, WI). The scores (the number of parts successfully placed) were recorded for each of four sub tests (the right hand test, the

left hand test, both hands working together test, and the assembly test) and the total score, which was the sum of all four tests. Each test was administered in the time specified by the Purdue Pegboard procedures.

7. Pain – the subject's perception of an noxious stimulus as measured by a self-reported visual analog scale using a 10 centimeter line.

8. Functional task - activities performed in daily living, specifically:

Dressing and Grooming – putting on or taking off typical clothing items worn, including underclothing, shoes, socks, pants, shirts, skirts, and outer ware. Dressing and grooming also included bathing, hair care, shaving, and oral hygiene.

Toileting – removing necessary clothing, manipulating toilet tissue, cleaning one's self and redressing.

Food preparation and feeding – ability to prepare a usual meal and feed one's self.

9. Diseased and/or injured hand – one or both hands that are affected by pathology either owing to disease or injury.

10. Self-report of function – subject's own assessment of his/her performance of a selected task using a study-specific tool (see Appendix A) for the assessment of functional performance of three specific tasks measured using an ordinal scale of 1 to 10 (1 being unable to perform the activity and 10 being able to perform the activity at the same level as before the injury or problem).

11. Hand – the part of the body distal to the wrist, including the thumb and fingers.

12. Screening for shoulder, elbow, and wrist - a process to limit the potential of shoulder, elbow, and wrist impairments from impacting the study; specifically, subjects were required to be able to touch with each hand the back of the head, the opposite acromion, and the small of the back to be considered as potential subjects.

13. Impairment – "A loss or abnormality of anatomical, physiological, mental, or psychological structure or function" (American Physical Therapy Association, 2001, p. 688). For example, decreased ROM is an impairment.

14. Hand dominance – the hand an individual prefers to use in the performance of single-handed activities, usually the right or left hand, but in some cases may be either hand. Dominance was recorded as R (right), L (left), or B (bilateral or ambidextrous) on the intake assessment form.

15. Basic Performance Resource (BPR) – the lower level resources used to accomplish a higher level task. In this study BPRs will consist of strength, ROM, dexterity, and pain (more accurately the absence of pain is the resource).

16. Limiting resource – the BPR with the lowest predicted task performance level for an individual using the NCRA predictive model.

Assumptions

The assumptions made for this study were as follows:

1. Subjects performed to the best of their ability in each test.

2. Self-reported performance ratings were reliable and valid measures of the subject's functional abilities.

3. The subjects understand the self-reports and provided honest responses on all self-reports.

5. The shoulder, elbow, and wrist screen adequately detected and eliminated persons with shoulder, elbow, and wrist limitations with potential to impact the results of the study.

Limitations

The limitations of this study were as follows:

1. Both the functional performance self-report and the visual analog pain scale were subjective.

2. The geographic pool from which the subjects were recruited was similar.

3. The NCRA assumption of parametric data was violated by the scores obtained in the self-report of pain and functional performance.

Significance

Patients, clinicians, and third party payers can benefit from the answer to the questions of "how much of a resource is enough?" and "what is the limiting resource?" in task performance. Patients, armed with the knowledge of how much of a given "basic element" (resource) is necessary to perform a task they wish to perform, can be motivated to comply with specific interventions that they may otherwise perceive as not beneficial. Clinicians could more specifically develop and modify treatment plans if they had knowledge of which "basic elements" were limiting functional performance. Third party payers could be better informed as to the potential for functional improvement given a patient's "basic elements" limitations. The knowledge of how much of a basic element is needed and what element is the limiting factor in the performance of a task has the potential for patient motivation, clinical application, and justification of treatment.

CHAPTER II

LITERATURE REWIEW

The purposes of this study were to (a) determine threshold values for ROM, strength, and dexterity, and levels of pain in specific functional task performance in people with diseased or injured hands using NCRA; (b) identify whether differing threshold values for each resource were detectable for varying levels of specific functional task performance; and (c) determine whether changes in ROM, strength, dexterity and/or pain would produce predictive changes in function when using the GPST model developed in the initial part of the study. This literature review provides the reader with the following: (a) an overview of the hand and its function, (b) a justification of the measurements, instruments, and tools to be used for the assessment of ROM, strength, dexterity, pain, and function, and (c) a basic understanding of the NCRA.

The Hand and Its Function

The ability of a person's hand to perform countless actions is dictated by a marvelous interaction between its structures and the brain. The wrist, elbow, and shoulder function primarily to position the hand. The structures of the hand are an intricate balance of bone, ligament, muscle, tendon, nerve, vascular, and soft tissue components. The interaction of these structures gives the hand the ability to perform both simple and complex functions. The functions of the hand are frequently described as: grasp, prehension, and sensory receptor.

The structures of the hand enable it to change its shape and therefore perform a variety of functions. The vascular and integumentary components support the viability of the hand but will not be covered in this review. The bone, ligament, muscle, and nerve components are more closely linked to the active, purposeful function of the hand relevant to this study and will be reviewed.

The bones of the hand include 8 carpal, 5 metacarpal, 14 phalanges (2 for the thumb and 3 for each finger). The carpal bones provide the architectural base on which the other components work and are aligned in two rows providing a strong mobile base (Kapandji, 1982). The first metacarpal articulates with the trapezium carpal, which is a saddle-shaped joint. This joint allows the thumb its diverse motions, especially opposition. The second and third metacarpals articulate with the trapezoid and the capitate, respectively, and are relatively fixed in terms of mobility (Cailliet, 1982). The fourth and fifth metacarpals articulate with the hamate and are mobile. Each of the metacarpals articulate distally with the proximal end of the proximal phalanx, forming the metacarpal phalangeal joints (MCP for the four fingers and the MP for the thumb). The MCP and MP allow for active flexion, extension, abduction, and adduction. Some rotation is present, but only passively (Cailliet). The proximal phalanges articulate with the middle phalanges in the fingers forming the proximal interphalangeal joints (PIP) and the distal phalange in the thumb forming the interphangeal joint (IP). The middle phalanges articulate with the distal plalanges of the fingers forming the distal interphangeal joints (DIP). The IP, PIP, and the DIP joints are hinge joints allowing for flexion and extension. The movements of the bones and joints of the hand are dictated by the shape of the articular surfaces, ligaments, muscles, and neuromuscular connections.

The ligamentous connections in the hand range from simple to complex. Some ligaments have only connections between bones and primarily provide stability for those joints, such as the lunato-capitate or the scapho-trapezial ligaments. Other ligaments are parts of complex ligamentous systems, like the fibro-cartilaginous plate acting in the MCP joints. The major function of the fibro-cartilaginous plate in the MCP joints is to articulate with the metacarpal head in extension and limit bony impact during flexion (Kapandji, 1982), while having collateral and transverse ligament attachments for stability. Some ligaments in the hand act as pulleys preventing bow-stringing of tendons and directing their line of pull. It is common in the hand for many ligaments to act in concert with each other to stabilize the bones, direct the muscle action, and hold tendons in place (Kapandji).

Muscular control of the hand is provided by two groups of muscles, intrinsic and extrinsic muscles (having the origin within the hand and proximal to the hand, respectively). The muscles of primary interest in this study are those that effect the thumb and fingers. The thumb has nine muscles that control its actions extrinsically: (a) the abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, and flexor pollicis longus; and intrinsically: (b) the flexor pollicis brevis, opponens pollicis, abductor pollicis brevis, first anterior interosseus, and adductor pollicis. The thumb's extrinsic muscles have the combined action of grip strength and grip release while the intrinsics are primarily for precision and coordination (Kapandji, 1982). The extrinsic muscles of the fingers are the flexors and extensors of the fingers, i.e., the flexor digitorum superficialis, flexor digitorum profundus, extensor digitorum communis, extensor indicis, and extensor digiti minimi. The intrinsic muscles of the fingers are the four interosseous, four lumbricals, abductor digiti minimi, flexor digiti minimi, adductor digiti minimi, and opponens digiti minimi. The actions of these muscles and more importantly the interactions of these muscles with each other and the flexor and extensor ligamentous systems are complex and help to give the hand its great mobility and flexibility.

The median, radial, and ulnar nerves, which provide muscle innervation and sensation to the hand, orginate from the nerve roots, C_5-T_1. The ability of the hand to move, manipulate objects, and to provide information back to the central nervous system is governed by an intact nervous system. Pathology of peripheral nerves and subsequent impairment in the hand will not be investigated in this study.

The delicate balance of bone, ligament, muscle, and nerve interaction creates one of the most amazing components of the human body, the hand. The hand has two major functions: to manipulate objects and to act as a sensory organ for the central nervous system. Neither can be accomplished without the other. One must be able to move a stone around and between the fingers to cognitively appreciate its weight, texture, and shape, while at the same time one could not manipulate the stone without the feedback provided by the CNS. For the purpose of this study, the function of the hand was primarily viewed from its function as a manipulator, but its sensory functions were not discounted.

The function of the hand as a manipulator of objects is gained primarily through different forms of prehension. The terminology used to describe the different forms of prehension are varied, but there is commonality in the grouping used to categorize them: static, dynamic, and gravity-dependent grips. A grip can occur between any two or more parts of the hand and the naming of the parts involved in grip is where the terminology differs. Some differences in describing a specific grip relate to whether the tip of the digit used, or the pad of the digit, or the radial aspect of the joint. Terminology is even more difficult when a specific grip (especially seen in dynamic grips) may be the combination of several different forms. For example, using chop sticks requires the static grip of one stick while a dynamic grip is required for the other. Casanova and Grunert (1989) reported 334 distinct terms for forms of prehension, and Kapandji (1982) described 16 broad groupings for static and gravity-dependent grips. Kapandji stated that dynamic grips are innumerable. In this study, grip strength was tested using gross hand grip (thumb in opposition to the four fingers) and three pinch grips (key, tip to tip, and three-jaw chuck). Each of these grips is fully described in the methods section. The functional grips people use in their everyday lives was assessed with a self-report. The complexities involved in the structure and function of the hand are great, but consequently, a large amount of research exists, and there are excellent resources available for in-depth study.

Measurements, Instruments, and Tools of Hand Assessment

Many measurements, instruments, and tools exist for the evaluation of the hand. Most commonly used measurements are grip/pinch strength measures, ROM measures, manual muscle testing, sensation measures, volumetric displacement, dexterity tests, functional tests, and pain assessments. For the purposes of this study ROM, grip/pinch strength, pain, dexterity, and function were reviewed.

Range of Motion

Range of motion (ROM), perhaps more accurately called extremes of motion (EOM), is second only to grip/pinch strength in its frequency as a measurement for hand assessment (King & Walsh, 1990). ROM is defined as "the arc through which movement occurs at a joint or a series of joints" (APTA, 2001). In this study, ROM was used to describe the motion available at any given joint or series of joints.

The measurement of thumb and finger ROM is important in assessment of the articular, musculotendinous, and ligamentous integrity of the hand. In the early part of the 20th century the use of goniometers, very similar to ones used today, began in Paris to measure ROM and rehabilitation progress (Smith, 1982). In the ensuing years, disagreement has persisted over the instruments used to measure ROM, measurement positions, nomenclature, numerical values, measurement expression, measurement recording, and interpretation of the information (Moore, 1949).

Instruments used to measure ROM range from the examiner's eye in visual estimation to digital photography. The universal goniometer, a protractor with two arms, is most widely used to measure ROM in clinics and in research. The American Medical Association (AMA) (1993), the American Academy of Orthpaedic Surgeons (AAOS) (1965), and Gerhardt and Russe (1975) refer to using the goniometer in impairment guidelines, methods guidelines, and standards, respectively.

Joint-specific devices were common until the 1950s when Hellebrandt, Duvall, and Moore (1949) compared the universal goniometer with devices designed to measure specific joints and found the universal goniometer more dependable. Both Salter (1955) and Miller (1985) refer to radiography as the most precise and accurate method of assessing joint ROM. In the clinical setting however, the universal goniometer remains the instrument of choice for general measurement purposes.

More specifically, the instrument used to measure thumb and finger ROM is either a small universal goniometer or a dorsal finger goniometer. In 1958, Noer and Pratt introduced their design for a dorsal finger goniometer, which is similar to the universal goniometer with modifications in size and scale. Noer and Pratt's instrument addressed the need for a simple, compact goniometer to use with patients with hand dysfunction that can be operated by the examiner with one hand. Dorsal finger goniometers of today are only slightly modified from the original form.

Hamilton and Lachenbruch (1969) compared measurement of the finger joints using the universal, dorsal finger, and pendulum goniometers. The hand was placed in a device fabricated to immobilize the joints. The immobilization device was tested for its ability to immobilize the joints using multiple radiographs. The researchers found that the immobilization device was able to hold the fingers in reproducibly static positions. The study involved several testers measuring each joint with all three goniometers on four different days, thereby producing four measurements for each joint with each of the goniometers. The testers were blinded, and a proctor read each measurement. Analysis of variance was performed to detect differences among testers, among goniometers, and among the measurements made by each testers. The authors found a significant variation among testers, $\underline{F} = 8.24$ with a .01 level of significance, and concluded that repeated measures by different testers would probably not be reliable. The authors did not find a significant variation among the goniometers, $\underline{F} = .74$, and concluded that all three goniometers had the same degree of precision. There was little variance for any one tester's measurement, though no level of significance was expressed. The authors concluded that an individual tester is capable of accurate repeated measurements. The authors recommended that clinicians should feel comfortable in selecting the goniometer that best suits their patient population.

Bruton, Ellis, and Goddard (1999) compared the reliability of visual estimation to a dorsal finger goniometer with 40 testers using two joints in a normal immobilized hand. The hand was immobilized with a splint that was assumed to minimize position variation, though this was not confirmed. The testers consisted of 40 occupational and physical therapists (20 of each) with clinical experience ranging from less than 1 to more than 16 years. All testers were provided with a written goniometry measurement protocol using the dorsal technique, but were not given instructions for the visual estimation. The tester made one visual estimation and then three goniometric measurement for the two immobilized joints, which were read and recorded by a proctor in order to blind the tester. Appendix B contains the mean and standard deviation and range for these measurements. The authors reported inter-rater repeatability coefficients using analysis of variance and found inter-rater reliability high. They concluded that dorsal goniometric measurement is more reliable than visual estimation in the fingers.

In a concurrent study Ellis, Bruton, and Goddard (1997) examined wire tracings and goniometric measurements at the same time using the same immobilized subject's hand. They included an examination of inter- and intra-rater reliability. The authors reported, using the repeatability coefficients, considerably better intra-rater that inter-rater reliability.

The use of the dorsal finger goniometry for the measurement of finger ROM is comparable to the universal goniometer and the pendulum goniometer and superior to visual estimation in terms of repeatability within the limitations of these two studies. In both studies, the fingers were immobilized, which is not a practical situation in the clinical setting. Investigators in both studies found measurements reported by the same tester more reliable (repeatable) than the same measurement made by different testers, regardless of the instrument used. Though research is inadequate to clearly establish one instrument for the measurement of finger and thumb ROM, the small finger goniometer had advantages for this study. The small finger goniometer is appropriate for the size of the joints to be measured, it can be operated with one hand, it is commonly available in clinics, and the tester is familiar with its use.

Over time, the method of application, positions from which the ROM measurements are taken, and the nomenclature used to describe ROM have varied. Smith (1982) described the state of confusion that existed after the development of the goniometer in terms of the lack of a standardized system of application and reporting. Smith discussed the development of the systems of joint measurement by Clark in 1920 and the method for measuring and recording joint functions by Cave and Robert in 1936. The Cave and Robert system subsequently became the basis for the AAOS system (1965). The AAOS system includes principles of the method, definitions, use of the goniometer and its limitations, the starting position for each motion, illustrations of the method for measurement, and normal ranges for each motion. This system has provided a standardization for joint ROM measurement that continues to the present.

In the measurement of finger ROM, the method of application, position of the joints, orientation of the goniometer, and nomenclature is gradually becoming standardized. In the AAOS (1965) system the examiner has three method options of apparent equal value: goniometric measurement, visual estimation, or composite motion. Composite motion is a measurement of the distance between the tip of the finger and the distal palmar crease.

Adams, Greene, and Topoozian (1992) in the ASHT's <u>Clinical Assessment and Recommendations</u> provide two basic methods of measuring finger ROM: goniometric and composite, with goniometric being preferred. The authors provided both written text and illustrations of each joint measurement including starting position, axis, and orientation of the goniometer. These recommendations are frequently used and cited in the methods sections of research requiring ROM measurements of the fingers and were the basis for the ROM measurements used in this study.

The ASHT (Adams et al., 1992) recommends dorsal placement of the goniometer for most joints. Hurt (1947) was one of the first to describe the dorsal placement of the goniometer for measuring finger ROM. The AAOS, AMA, and ASHT all advocate the use of dorsal placement except when deformity, scar, or other circumstance necessitate lateral placement.

Cambridge-Keeling (1995) recommended the practice of maximal flexion/extension of all three joints of a digit in order to measure active ROM and to better examine musculotendinous limitations. Cambridge-Keeling recommended isolated flexion/extension of a single joint with the adjacent joints in neutral to measure passive ROM in order to better examine joint structures. These are also the recommendations of the ASHT (1992). Though some clinical needs are better assessed with passive ROM (PROM), because this study examined ROM in relation to function, active ROM (AROM) was the more relevant measure and more accurately reflected the potential function performance. Therefore, the ASHT and Cambridge-Keeling recommendations were used.

Adams et al. (1992) discussed the progress made by the International Federation of Societies for Surgery of the Hand (IFSSH), building on the work by AAOS, in defining the terminology to describe the motions and their measurements. The ASHT (Adams et al.) has continued the process and provides a comprehensive explanation of terminology including the variances of active and passive ROM, isolated joint motion and total joint motion, and total active motion (TAM). TAM of a finger is the sum of MCP, PIP, and DIP flexion minus any extension deficits. The issue of total joint motion is discussed with a cautionary note that its use might mitigate subtle changes in an isolated joint and because it is a computation, its validity is questionable in certain situations. Total joint motion is frequently used in research to lessen the number of variables. In this study the results of both isolated joint AROM and TAM of the fingers were recorded. The method, positions, and nomenclature provided by the ASHT provide a standardized system that supports improved reliability and validity and was used in this study.

ROM has been expressed in many ways, from tracings to complex numbering systems. The goal of reporting or recording ROM measurements is to communicate. Miller (1985) provided a review of the three notation systems of which the 0-180° system is the most widely accepted. The author also explained different recording methods: charts, tables, sketches, graphs, and the sagittal-frontal-transverse-rotational (SFTR) system.

As previously mentioned, the 0-180° notation system recorded in chart form is most frequently used in reporting finger ROM. The identification of extensor lags, the inability to actively achieve full extension, and normally occurring hyperextension are the two most difficult aspects of finger ROM to document. In its principles section, the AAOS (1965) described extension as the opposite motion of flexion to the zero starting point (neutral). The AAOS guidelines state that if the motion is unnatural it is called hyperextension. This is where some of the conflict arises. Many consider hyperextension in the thumb and fingers natural, and therefore call it extension (Cantrell & Fisher, 1982). Some clinicians use a negative symbol to denote this hyperextension. The AAOS has not taken a definitive stand either way (Adams et al., 1992). The AMA (1993) and the ASHT (1992) use the term hyperextension to describe a motion that exceeds the zero starting position and express it with a positive symbol. Both groups recommend the use of the negative symbol to denote extensor lags and flexion contractures, a lack of extension to the zero starting position passively. Stanley and Tribuzi (1992) discussed this controversy and the gradual shift to the position of using positive symbols for hyperextension and negative for lack of full extension. This investigator followed the AMA and ASHT recommendation for recording.

Reliability in goniometric measurement of the thumb and fingers ROM requires the examination of the instrument, the tester, and the method. The validity of the goniometric measurement requires that it be both reliable and accurately measure the joint motion. The study of goniomertic reliability and validity as it pertains to the hand is inconsistent and has produced varied results. The following is a brief review of some of the more relevant studies.

The reliability of the dorsal finger goniometer as an instrument to measure ROM of the finger joints was examined using an alternate forms design in Hamilton and Lachenbruch's (1968) previously mentioned study. An analysis of variance between the three instruments (universal, dorsal finger, and pendulum goniometers) produced a non-significant $\underline{F}$ value. The assumption was made by the authors that each instrument method measured with the same degree of accuracy within the limits of the study. It is important to note that the joints measured were in a fixed position.

The method of application is another key issue in the reliability of finger goniometry. Hamilton and Lachenbruch (1968) required each tester to conform to very specific measurement techniques. Though not addressed, the intratester reliability may owe some of its strength to the uniformity of the methods applied. Previously mentioned research by Bruton et al. (1999) also addressed the method of application. All testers were provided with a written protocol for the dorsal goniometric measurement of the fingers and no instruction for the visual estimation. As previously mentioned the goniometric measurements produced much lower standard deviations and ranges when compared to visual estimations (see Appendix B). Bruton et al. explained that the difference in standardization may have contributed to the disparity in measurements between the two methods.

Groth, VanDeven, Phillips, and Ehretsman (2001) investigated interrater reliability and concurrent validity in goniometry of the proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints. Validity will be discussed later. The authors used a single patient with hand pathology and 39 testers, who were physical or occupational therapists. On the morning prior to the initial measurements the patient's involved hand was x-rayed and a "gold standard" for each of the eight joint motions was established. Each tester measured AROM of the index and long fingers' PIPs and DIPs on the involved hand (all fingers fully extended or fully flexed while individual joint measurements are taken). Each tester measured with the dorsal and lateral placement techniques. They were not blinded to the measurements. Interrater reliability was high for both dorsal and lateral placements, ICC(2,1), .99 and .86 respectively. In other studies of goniometric reliability, intratester reliability is usually higher than intertester and the discussion of standardization of method is usually presented as the single greatest contributor to improved reliability (Boone et al., 1978; Ekstrand, Wiktorsson, Öberg, & Gillquist, 1982; Fish & Wingate, 1985; Hellebrandt et al., 1949; Mayerson & Milano, 1984; Moore, 1949; Rothstein, Miller, & Roettger, 1983).

Standardization of method and inter- and intratester variances are only two of the many factors that can influence reliability of measures of hand ROM. Other factors include: the confined space from which measurements are taken, the complex muscle and tendon system, short axial segments, edema, scars, joint deformity, wounds, extreme sensitivity (Hamilton & Lachenbruch, 1969), time of day, time during treatment session, encouragement by clinicians (Stanley &Tribuzi 1992), observer bias (Brand & Hollister (1999), measurement error, individual variations in patients, and tester variations (Fish & Wingate, 1985). This investigator attempted to minimize these factors through strict method guidelines and the use of only one tester.

Validity of the measurement of finger ROM using the dorsal finger goniometer has not been supported. In a repeated measures single case design study of goniometry, Groth et al. (2001) investigated interrater reliability and concurrent validity. They compared the one time measurement of each of the eight motions, with both the dorsal and lateral methods, to a radiographic "gold standard" for each of the eight joint motions. Paired-difference t-tests were used to determine concurrent validity between lateral and/or dorsal placement and radiographic findings. Six testers were randomly chosen and their 16 measurements were used for the paired-difference t-test with the radiographic measurements. Of the 16 measurements, significant differences occurred in 14 of the measurements at the 0.05 alpha level. The goniometric measurements were significantly different from the radiographic measurements 87% of the time for these six testers. Concurrent validity was not demonstrated, but it was noted that the positions for the clinical measurement and the radiographic measurements were different. This difference in position, identified by the authors as a limitation of the study, could be the reason for the failure to demonstrate concurrent validity. Concurrent validity of finger ROM using a dorsal finger goniometer requires further research.

In summary, the measurement of ROM of the fingers is not as simple as it may appear. The dorsal finger goniometer and the measurement method recommended by the ASHT were used in this study. AROM was measured versus PROM because ROM was compared with function. The ASHT and AMA recommendations for reporting and recording measurements were used.

<u>Grip and Pinch Strength</u>

In King and Walsh's (1990) survey of hand therapists, grip and pinch strength evaluations were used by 100% of all respondents. Strength of the hand is an essential elements of hand function, and its assessment has been widely examined. Grip and pinch strength are used to give the examiner a measurement of the integrated strength of the hand as opposed to manual muscle test which give an isolated measurement of an individual muscle or muscle group. In their study of the determinants of hand function in rheumatoid patients, Vliet Vlieland et al. (1996) found that pinch and grip strength were highly correlated to hand function, with pinch accounting for 54% of the functional variance. Macey and Kelly (1993) and Swanson, Swanson, and Göran-Hagert (1995) reported that a grip strength of approximately 4 kg of force is needed for performance of 90% of ADL and that 1 kg of pinch force is enough for most simple activities. This information was reported by both groups of authors without reference as to its origin.

Historically, grip and pinch have been measured in a variety of ways with often confusing results. In 1957, the California Medical Association (Kirkpatrick, 1957) evaluated the instruments commonly used at the time and issued their recommendations, which assisted in the standardization of instrumentation used for grip strength assessment. In 1978, the American Society for Surgery of the Hand (ASSH) provided recommendations as to procedures used for the assessment of grip strength. The American Society of Hand Therapists (ASHT) made further procedural recommendations in 1981 and again in 1985 (Fess, 1992). Grip and pinch strength measurement has evolved to become a widely used and accepted component of the assessment of the hand.

Many different instruments are currently available to measure grip and pinch strength, ranging from the testers using their own hands to gauge the force to complex computerized devices. The Jamar® dynamometer (Jamar® Hydraulic Hand Dynamometer, Sammons Preston, Boling Brook, IL) was first recommended for measuring grip strength by the California Medical Association (Kirkpatrick, 1957) and has since been endorsed by the ASSH and ASHT for assessing grip strength. Many authors favor the use sphygmomanometer with the cuff rolled into a 5 cm cylinder inflated to 20-50 mm Hg for grip strength assessment when the hand is too weak to use the Jamar dynamometer (Clawson, Souter, Carthum, & Hymen, 1971; Spiegel, Paulus, Ward, Spiegel, Leake, & Kane, 1987; Swanson et al., 1995).

Recommendations for measuring pinch strength are less uniform than those for measuring grip strength. Swanson et al. (1995) favored the use of an electronic pinch meter based on the strain-gauge principle. Aulicino (1995) recommended the use of a pinch gauge using a hydraulic system similar the Jamar dynomemeter. ASSH and ASHT do not provide a specific recommendation.

In most current studies (Cederlund, Isacsson, & Lundborg, 1999; Hanten et al., 1999; King & Berryhill 1988; Shechtman, 2001a; Taylor & Shechtman, 2000) the ASHT recommendations are cited as the procedures used for grip strength testing. These recommendations include calibration of instrument, patient position (body, shoulder, elbow, and wrist), therapist supporting the weight of the dynamometer, verbal instructions, grip setting if only testing at one position, and three trials with the mean as the score. ASHT does not provide recommendations for pinch strength testing positioning though its grip strength positioning recommendations are cited as the basis for positioning (Woody & Mathiowetz, 1988). MacDermid, Evenhuis, and Louzon (2001) referenced this lack of standardization and gave specific recommendations of positioning (even including the fingers) for testing of key and tripod pinch strength testing, also using the ASHT grip strength position as the basis.

Reliability and validity of grip and pinch strength measurements have been studied by numerous authors (see Appendix C). MacDermid et al. (2001) studied the inter-instrument reliability of pinch strength with 40 volunteer subjects (20 with and 20 without hand pathology). They measured key and tripod pinch with three different pinch gauges: (a) the B & L model PG-30 (B & L Engineering, Sante Fe Springs, CA), (b) the Jtech (JTech Medical Industries, Heber City, UT), and (c) the NK (NK Biotechnical Engineering Company, Minneapolis, MN). The ASHT guidelines for grip strength positioning for the shoulder and elbow were used. The testers were novice therapists with little experience with the gauges. Testers were instructed in the test protocol. The test consisted of three trials, either alternated between hands or with a 15-second rest between each trial, depending on the device used. The mean of the three trials was used for analysis. Interclass correlation coefficients (ICC (2,1)) and their associated 95% confidence intervals (95% CI) were high for the whole group, the hand pathology subgroup, and the asymptomatic subgroup (ICC (2,1) = .81 – .98 and the 95% CI = .66-.89 – .96-.99). The authors concluded that the results indicated no instrument bias and that any of the three devices provided scores similar to the others.

A number of factors have been reported that may influence grip and pinch strength: substitution, calibration of instruments, protocols (specifically: verbal instructions, positioning, pace of testing, alternating hands, rest periods), fatigue, handedness, time of day, age, nutritional status, pain, sensory loss, and subject effort. Several studies have specifically addressed the issue of subject effort with procedures aimed at detecting less than maximal effort (Swanson et al., 1995; Aulicino, 1995; Taylor & Shechtman 2000; Shechtman 2001b). Reliability of the measurements obtained using the Jamar hand dynamometer and a hydraulic pinch gauge have been demonstrated when a strict protocol is followed.

In summary, grip and pinch strength measurements are the most frequently used measurement in the assessment of the hand. Strength testing provides a measurement of the integration of the different systems of the hand. The use of the Jamar hand dynamometer for the measurement of grip strength is reported to produce reliable results. The use of a hydraulic pinch gauge has also produced reliable results. Both of the devices and the ASHT recommendations were used in this study.

Pain

The need to assess pain in patients with hand dysfunction arises from the knowledge that pain can affect function (Noland, 1993). Pain can indicate an underlying pathology, and its assessment can be used to select an intervention and/or monitor the effectiveness of an intervention (Carter, 1987). The International Association for the Study of Pain (Merskey & Bogduk, 1994) defined pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage . . . always subjective" (p. 210). Cailliet (1993) cited Mersky's 1994 definition of pain as a sensory experience influenced by many factors. It is not only the factors that influence pain but its subjective nature that make pain so difficult to assess. The attempt to make pain assessment objective and measurable has been pursued for years.

The measurement of pain in patients with hand dysfunction has taken on many forms. Some assessment tool are disease specific, such as the Arthritis Impact Measurement Scales, others are generic, such as the Visual Analog Scale. Other assessment tools are a single device such as a pain diagram while others are an amalgamation of several tools like the McGill Pain Questionnaire which includes a: selection of descriptive words, rating scale, body diagramming, and questionnaire. In general, pain assessments are broadly categorized by behavioral observations, subjective descriptions, subjective rating, diagrams, cross matching, psychological tests, autonomic tests, or a combination of these. Macey and Kelly (1993) suggested that when measuring pain for an outcome measure, that acute pain may be usefully measured by VAS, but chronic pain may require both objective (volumetric, ROM) and subjective (rating scale, questionnaire, interview, and diagram) assessment. Subjective rating is the most widely used. A representation of different subjective rating pain measurement tools used in the recent past for the assessment of hand pain is presented in Appendix D.

Subjective rating scales are commonly used clinically because they are quick to administer, require minimal instruction to the patient, are easy for the patient to understand, and are easy to score. Subjective rating scales are usually presented in verbal or written form, and may be numeric (1-10 or 1-100, where the patient is asked to rate the pain with 1 and 10 or 100 being the extremes of pain), graphic (a line on which the patient marks a point to represent the level of their pain, either end of the line is usually identified as the extremes of pain), or categorizing (a brief description of different levels or types of pain which have a corresponding value, such as no pain-0, intermittent mild pain-1, intermittent moderate pain-2, constant mild pain-3, and so on) in nature. Chapman et al. (1985) in a review of pain measurement reported that of these subjective rating scales the two main types of scales are the VAS (graphic) and category scaling, of which the VAS is preferred clinically. The VAS, borrowed from psychology in the early 1900s, has developed into two basic types, horizontal and vertical lines with descriptors at both ends. Limitations of the VAS include its unidimensional perspective of pain, response biases, and the treatment of the scores as interval or ratio level data (Chapman et al., 1985).

In order to obtain a measurement of pain for this study, the visual analog scale method (VAS) was chosen. Though the subjects for this study were diverse in their pathology, most of the studies reviewed had homogenous subject populations with respect to their pathology. Davidoff, Morey, Amann, and Stamps (1988) investigated the evaluation of pain as an outcome measure in 17 subjects with definite or probable reflex sympathetic dystrophy syndrome. The subjects' mean age was 35.6 years; SD=8.0, and the mean for symptom duration was 11.8 months; SD= 4.8. There were 5 men and 12 women. Nine subjects had upper extremity (UE) involvement and 8 had lower extremity (LE) involvement. After a comprehensive interview and physical exam, two subjective pain assessments were administered: the McGill Pain Questionnaire (MPQ) and a visual analog scale (VAS). Each subject was then evaluated for joint pain with palpation, limb volume, skin temperature, and UE and LE active range of motion (AROM). Each of these assessment were repeated at 2-week intervals for 8 weeks during which time each subject received treatment. Treatment was identified as exercise with or without oral corticosteroids or regional sympathetic blockade.

Davidoff et al. (1988) reported that the VAS had significant correlation with limb volume, active range of motion, and joint pain. Specifically, squared correlation coefficients from linear regression analysis of pain and function before and during treatment produced these results: VAS with limb volume (r^2=.160, p<0.0005), VAS with

UE and LE AROM (r^2=.167, $p<0.05$ and r^2=.508, $p=0.0001$, respectively), and VAS with joint pain (r^2=.341, $p<0.0001$). Subscales of the MPQ correlated with joint pain and LE AROM. The authors concluded that the VAS demonstrated statistically significant correlation to limb volume, AROM, and joint pain in subjects with probable reflex sympathetic dystrophy syndrome.

In a different study of another homogenous population, Dellhag and Burckhardt (1995) studied 52 patients (35 women and 19 men) with rheumatoid arthritis (RA) to determine predictors of hand function. The subjects' mean age was 53 years (ranging from 29-69) and disease duration was a mean of 7.7 years (ranging from 6-10). Measurements cconsisted of ROM, self-estimated hand function, grip strength, Sollerman Grip Function Test (a test of 20 tasks that are timed and scored based on the use of the correct grip pattern), pain on resisted motion, pain on non-resisted motion, stiffness, and a self-administered Swedish version of both the Health Assessment Questionnaire (HAQ), and the Arthritis Impact Measurement Scales (three sub scales of ability). It is not clear whether all of these measurement were obtained in a single session or in several sessions over a period of time. Dellhag and Burckhardt reported that finger ROM deficits, thumb ROM deficits, grip strength, pain on resisted motion, pain on non-resisted motion, and stiffness were significantly correlated with the outcome measurements (specifically, actual and estimated hand function). The reported Pearson correlation for pain on resisted motion and non-resisted motion with actual and estimated hand function demonstrated a fair zero-order correlation: $r = -.43$ ($p<0.01$) for pain on resisted motion to actual hand function, r = -.41 ($p<0.01$) for pain on resisted motion to estimated hand function, r = -.45 ($p<0.001$) for pain on non-resisted motion to actual hand function, and r = -.43 ($p<0.01$) for pain on non-resisted motion to estimated hand function. Further, the authors reported multiple regression analysis of several of the variables, but pain was not included because of its lack of independence from the other variables. With the multiple regression analysis of the selected variables, the authors were able to predict only one-half of the variance in function.

Portney and Watkins (2000) discussed the difficulty of validating the measurement of pain and emphasized the need to define the construct, pain, in terms of what is to be evaluated. For the purpose of this study, the VAS rating of the presence and intensity of pain, should be adequate to reflect the effect of pain on function in the hand. Both Vliet Vlieland et al. (1996) and Davidoff et al. (1988) demonstrated a moderate and robust correlation between pain, as measured by the VAS, and function.

In summary, though there are many tools available to measure hand pain, the VAS met the needs of this investigator. The VAS is concise, frequently used in studies relating to the hands, easily understood by patients, and most importantly had potential of predictability for function in the hands.

Dexterity

Dexterity of the hands is the ability to integrate and coordinate strength, active motion, and sensation for a task. It is subdivided into manual and finger dexterity. Apfel and Carranza (1992) differentiated manual dexterity, the use of the hands and arms, from finger dexterity, the use of only the fingers. In reality most all of the tests used to measure dexterity require some involvement of the wrist, forearm, elbow, and/or shoulder. In the evaluation of dexterity of the hand, manual or finger dexterity, the goal is to obtain information on the speed, accuracy, and quality of the hand(s) in performing a task. Many tests are a combination of dexterity and function and because the purpose of this study was to examine dexterity and function separately, only those tests that examine dexterity alone were considered in this review.

Many tests have been developed in individual clinics to assess a specific patient population. However, most of these test lack standardization and have not been studied in terms of reliability or validity. Several tests that have been standardized and studied are applicable to the needs of this investigator. These test are the Purdue Pegboard Test, Stromberg Dexterity Test, Moberg Picking Up Test, Minnesota Rate of Manipulation, O'Connor Finger Dexterity Test, Box and Block Test, The Nine Hole Peg Board test, The Rosenbusch Test of Finger Dexterity, and The Nineteen Item Pick Up Test. Excluded from this list are tests that require the use of a tool, for example, the Crawford Small Parts Test and the Bennett Hand Tool Dexterity Test, both require the use of screw drivers and/or tweezers. Of the nine tests considered above, only the Purdue Pegboard Test and the Minnesota Rate of Manipulation have been subjected to both test-retest reliability studies and concurrent validity studies (Apfel & Carranza, 1992).

The Purdue Pegboard (PP) test is comprised of a rectangular base that has two columns of holes vertically down its center, four recessed cups at the top, and metal pegs, washers, and collars. During an examination the board is placed vertically in front of the patient and the tester gives the patient the instructions for the test to be performed. There are five different tests that can be administered: right hand, left hand, both hands, right, left and both hands, and assembly. The scoring is based on the time to complete the test and time is limited to a maximum of 7.5 minutes (Totten & Flinn-Wagner, 1992).

The Minnesota Rate of Manipulation Test (MRMT) is comprised of a rectangular base that has holes in it to accommodate a disk. The disks are red on one side and black on the other. During an examination the board is placed in front of the patient and the tester gives the patient one of five different sets of instructions, according to which of the five different tests will be administered: placing the disc, turning the disc, removing the disc, one-handed turning and placing, and two-handed turning and placing. The scoring is based on the time to complete the test and it is unlimited (Totten & Flinn-Wagner, 1992). The Purdue Pegboard test and the MRMT are similar in many aspects. The major distinguishing features are the size of the items manipulated and the possibility of using more than one item to manipulate (the Purdue Pegboard test gives the tester the option of using just the pegs, or using pegs, washers, and collars). The Purdue Pegboard test is used to evaluate finer coordination than the MRMT (Fess, 1995), and therefore, provided a stronger measure of dexterity for this study.

The Purdue Pegboard was designed to test unilateral, bilateral, and fingertip dexterity to assist in the selection of employees in industrial jobs with dexterity requirements (Tiffin & Asher, 1948). It has since been embraced by the therapeutic world as a tool to measure dexterity. In the survey done by King and Walsh (1990) the Purdue Pegboard was the most widely used dexterity test by hand therapists. Normative data is available for student, industrial, and military veteran populations (Tiffin & Asher). Tiffin and Asher provided detailed procedures for the application of each of the five tests and scoring each test (scoring is basically the number of pegs placed in 30 seconds).

Cederlund et al. (1999) used the Purdue Pegboard test as one of their 16 objective tests in a study of hand function in 20 symptomatic men with hand-arm vibration syndrome. Subjects' test results were compared with normative data to detect indications of pathologic outcome. The three tests most sensitive to detecting impaired hand function were all sensory in nature (Semmes-Weinstein Monofilament test, small shape identification with vision occluded, and the moving two-point discrimination test). Of the other 13 tests, the Purdue Pegboard was the most sensitive (17 of 20 subjects scored greater than 14, which was identified as the normal score for the two subtests performed). See Appendix E for a sample of the dexterity tests used. Though the purpose of the study by Cederkund et al. was to describe the nature and character of a homogeneous population (workers with hand-arm vibration syndrome, HAVS), it reflects the potential for the Purdue Pegboard test to be sensitive to changes in dexterity.

In another study using the Purdue Pegboard, Field, Herbert, and Prosser (1996) studied the outcome of 20 subjects following wrist fusion. The Purdue Pegboard and the Jebsen were used to measure function. The results from the Purdue Pegboard were reported as a percentage of normal for both the fused and non-fused/non-involved wrists.

The authors did not report the normative values nor the source of the normative values. The authors reported low Purdue Pegboard results following wrist fusion, when compared to normative data. Wrist fusion subjects fell in the 3.5 percentile of normative data (SEM=1.6 for the fused wrists). The authors cautioned that these results were fairly meaningless based on a high standard error of the means. This might be attributed to a small sample size. The results demonstrated that in a sample of patients with wrist fusion, the Purdue Pegboard scores changed and differed from the reported norms.

Tiffin and Asher's 1949 summary of various Purdue Pegboard studies is frequently sighted as a source of reliability and validity statistics. Even though all of the studies sighted in Tiffin and Asher's summary are directed toward industrial uses, it is the single best source of studies concerning the reliability of use of the Purdue Pegboard. In studies on men and women college students and women radio tube mounter trainees, test-retest reliability coefficients were reported as r=.60-.76 for a single trial. For the same two groups test- retest reliability using the Spearman-Brown prophecy formula (in each case the one trial reliability was "stepped up") was reported as r=.82 - .91 for three trials. These levels of test-retest reliability reflect moderate to good reliability for the single and three trial Purdue Pegboard test, respectively. Tiffin and Asher discussed that a higher reliability existed for the three-trial method, but this method had a minimal effect on the validity coefficient and, as such, made the single trial method satisfactory.

The validity of the Purdue Pegboard score as a measure of hand dexterity is not simple to address. The score is an indirect measurement (number of pins, washers, and or collars placed) of a complex variable. If the goal of a measure of dexterity is to quantify the ability of the hand to integrate strength, ROM, and sensation for a task, then the Purdue Pegboard is one tool capable of that, i.e., it has face validity. In Tiffin and Asher's (1949) summary, concurrent validity is addressed in a table that compares Purdue Pegboard subtest results with other criteria such as production indexes. The authors report these correlations as validity coefficients, and they ranged from $\underline{r} = .07$ - .76. The reliability and validity of the Purdue Pegboard test is well documented in healthy college, industrial, and veteran populations. Further investigation of its reliability and validity in populations with impairments is needed.

The measurement of dexterity is complex, and the tools available for its evaluation are diverse in design. The Purdue Pegboard test was best suited for this study because of its availability in the clinical setting, frequent use in studies that involve the hands, ease of application, specific procedures for administration, and the existence of reliability data, albeit from a different population.

Hand Function

The measure of hand function has been the topic of many studies and is debated to this day. In Nicholson's (1992) review of hand function for the ASHT, she reminds readers that the assessment of hand function is advocated by hand therapist and surgeons, but points out that existing tests have repeatedly been found inadequate. Nicholson goes on to discuss the American Occupational Therapy Association's (AOTA) and the US Department of Labor's terminology and definitions as they relate to hand function.

Basically, hand function is defined by the AOTA as: the ability to move the hands effectively in activities with both fine and gross motor coordination. The US Department of Labor defines hand function in terms of physical demands (reaching, handling, fingering, and feeling) and aptitudes of motor coordination, finger dexterity, and manual dexterity (measured in levels of difficulty). It is no small task to measure what is difficult to define or describe.

Many tests are currently available to measure hand function, and they range from self-reports to multi-component tools. These measurement tools may be general, body-part specific, or disease/condition specific. Self-reports vary in their scaling (descriptors, VAS, or numerical values), administration (paper and pen, proxy, or an interview), standardization (some have established procedures, norms, reliability, and validity data and others have little standardization), and the populations they address (patient-specific, disease-specific, or body region). Multi-component physical assessment tools are equally as varied in scaling (timed, numerical ratings of the quality of performance or number of tasks completed, or verbal rating), administration (they may be one or several tasks, they may require the use of tools or implements, they may be task/job specific or generic in design, and they may require the use one hand or both hands), standardization (some have established procedures, norms, reliability, and validity data and others have little standardization), and target populations (patient-specific, disease-specific, or body region involved). Jacobs et al. (1992) reported a substantial (Cohen's weighted x) strength of agreement between therapist's evaluation of functional status and rheumatoid arthritis patients' self-reports of functional status with respect to physical activity, dexterity, household activities, and activities of daily living. The only area of poor agreement was general mobility. O'Connor, Kortman, Smith, Ahern, Smith, and Krishnam (1999) found similar agreement with self-reports of function and therapist-administered functional tests; specifically, correlation coefficients were high between subject self-reports using a VAS rating of function and therapist-administered Sollderman and Sequential Occupational Dexterity Assessment in subjects with RA. Tomaino, Miller, and Burton (1994) reported in non-rheumatoid subjects with wrist fusions that self-reports of performance were uniformly predictive of functional outcomes. The use of a self-report versus a multi-component physical assessment tool is favorable for several reasons: the self-report is easily administered, requires minimal time for subjects, requires no special equipment, and has been shown to produce results comparable to other measures.

Many self-reports exist for the examination of hand function. There are many excellent standardized tests that provide outcome measures, but they either provide too much information incorporating several different types of measurements, like the Disabilities of the Arm, Shoulder, and Hand (DASH) (which combines both pain and function) or the Carpal Tunnel Syndrome Questionnaire (which is condition/disease specific). No existing test was found that could be used to examine only the areas of function investigated during this study, specifically, toileting, dressing and grooming, and meal preparation and feeding, and is applicable for a diverse population of patients with hand impairments. For the purpose of this study a simple self-report questionnaire covering toileting, dressing and feeding was designed. Several different scaling options were available (see Appendix F). The self-report questionnaire can give very specific guidelines for each distinct level or only the endpoints of a scale might have descriptors. The VAS was not used because it was used to rate pain and a second scale with different descriptors might have been confusing to the subjects.

Badley, Wagstaff, & Wood (1984), in a study similar to this current study, investigated the relationship between function and impaired ROM. Their study population consisted of patients (n=95) with both rheumatoid arthritis (RA, n=40) and osteoarthritis (localized, n=39 and generalized throughout the joints of the body, n=16). Subjects ranged from 28 to 84 years of age with a mean of 61. There were 63 women and 32 men. The investigators developed a 41-item disability questionnaire, of which 24 items accounted for most of the variation in function. They scaled their 41-item disability questionnaire in accordance with the World Health Organization (WHO) disability scale with a modification for performance of a task in an abnormal manner (0=no difficulties, 1=difficulty, 2=abnormal performance, 3= aids required, 4=aids with a helping hand, 5=personal assistance, 6=personal help plus an aid, and 7=impossible). From the 41 items, analogous groups were constructed: mobility, bending down, dexterity, bending arm, and reaching up. The investigators then compared the sum of the full 41-item disability questionnaire to the 24 most influential items. The sum for the 24 items accounted for 96% of the variation in the sum of the 41 items, Pearson's r = .98. The authors also reported correlation coefficients between ROM and scores for the five functional groups. Not surprisingly, correlations were found among all three of the functional groups that primarily involved the upper extremities and ROM of the shoulder, wrist, and fingers. Badley et al. provided a table of thresholds of ROM for each of the 24 items. Their study illustrates that a self-report measure of function designed for a specific study can provide useful data. In Fisher's (1992) article on functional measures, she suggested that the measures should address what we hope to change and reminds the reader that no gold standard exists for the measurement of function.

An adapted version of the numbered scale with specific descriptors at each end of the scale presented by Binkley (2000), patient-specific functional scale (PSFS), was ideal for this study. Binkley reported the minimally detectable change (MDC) value for the PSFS scale as MDC = 3. In this study using the GPST, a larger number needs to be associated with the better, less impaired score, and the PSFS scale is formatted in this manner.

In summary, there is support for the use of a patient's self-report of function as a measurement of function (Alderson & McGall, 1999; Cederlund et al, 1999; Dellhag & Burckhardt, 1995; Jacobs et al., 1992; Stewart, Palmer, Knight, & Highton, 1993; Tomaino et al., 1994). In general, the self-report should address functional concerns of patients and specifically, for this study it should address the functions/activities that are most likely to be effected by hand pathology and injury. The use of a study-specific functional measurement tool is widely practiced (Badley et al., 1984; Bergström, Aniansson, Bejella, Grimby, Lundgren-Lindquist, & Svanborg, 1985; Cederlund et al, 1999; Guccione, Felson, & Anderson, 1990; O'Connor et al, 1999). For the purpose of this study a self-report of function, designed specifically for this study, was used for the measurement of hand function with which ROM, grip and pinch strength, pain, and dexterity were compared.

General Systems Performance Theory (GSPT), Elemental Resource Model (ERM), and Non-Linear Causal Resource Analysis (NCRA)

A relationship between ROM, strength, dexterity, and/or pain and function of the hand has been demonstrated (Alderson & McGall, 1999; Cederlund et al., 1999; Dellhag & Burckhardt, 1995; O'Connor et al., 1999; Vliet Vlieland et al., 1996). This relationship has traditionally been examined with exploratory research using correlation methods to determine associations and regression procedures to predict outcome variables (Portney & Watkins, 2000). These methods and procedures produce information that is general at best. The interpretations that can be made from these traditional statistics are good, moderate, fair, or little correlation. Clinically, more specific information is needed on how much ROM, strength, or dexterity is necessary for a given level of function with respect to a specific task and/or how much pain will change that level of function. Knowledge of which of the resources is limiting function is also needed, thereby allowing the clinician to direct interventions toward that resource. A method for quantitative assessment of the role that each of these elements contributes to in a specific activity and the ability to identify which of the elements is limiting the specific activity for an individual patient would be useful clinically.

Kondraske (2000) proposed the use of a different approach that can predict performance of an activity/task based on the measurements of the basic elements available and can determine which of the basic elements is limiting the performance of the activity/task. He developed a theory, a model, and an analysis method, General Systems Performance Theory (GSPT), Elemental Resource Model (ERM), and Non-Linear Causal Resource Analysis (NCRA), respectively, for task analysis and prediction of task performance that can provide the more specific clinically important information. This literature review will provide a general description of GSPT, ERM, and NCRA. The reader is directed to Kondraske for a more in-depth explanation.

The GSPT was developed to encompass three broad objectives: (a) a conceptual foundation for the defining and measuring of all aspects of performance of any system, (b) a common analysis method to assess task and system interface, and (c) identification of cause-and-effect principles (Kondraske, 2000). The underlying principle of the GSPT is that "any task can be viewed from the perspective of the human system that executes it, which is in turn viewed as a set of subsystems" (Kondraske et al., 1997). The subsystems are dictated by the demands of the task and are referred to as basic performances resources (BPR). Tasks are accomplished through coordinated utilization of the BPRs. The BPRs are the cause, and the task is the effect in the cause and effect principles this theory addresses. The development of this theory was to provide a theoretical basis for the examination of quantitative human performance.

Key constructs of the GSPT include: (a) identification of the system and task, (b) identification of the resources associated with the system in the performance of the task, (c) defined resource measurements (parametric and positive with larger values equal to more performance capacity), (d) resources measured outside of the task (maximally stress the system's ability to produce the resource and define the performance resource availability), (e) determination of the task demands on the system's performance resource availability, and (f) use of the resource economic principles to evaluate the system-task interface (require $R_A \geq R_D$ for success where R_A is resource availability and R_D is resource demand) (Kondraske, 2000). The most attractive aspect of this theory, for this current study, is its ability to demonstrate a threshold effect and to identify the elements limiting performance.

The Elemental Resource Model (ERM), which is used within the GSPT, addresses the relationship between the task and the basic performance resources (BPRs) from the perspective of performance. In the ERM, certain BPRs are required in the performance of high level tasks (HLTs), and threshold levels of the BPRs determine the level of task performance. It is therefore evident that any one BPR that is insufficient can be the limiting factor. The ERM divides all aspects of human performance into three basic levels: (a) basic element level, (b) generic intermediate task level, and (c) high task level (Kondraske, 2000). Inherent in the ERM is monadology, the concept of representing complex phenomenon with a basic set of elements. Chemistry is an example of a basic set of elements used to represent all the simple and complex compounds the basic elements can produce.

In the ERM, the entire human system is viewed as a pool of resources. The pool of resources are divided into basic elements of performance (BEP) that are defined by a basic functional unit and one of its dimensions of performance. For example: right index finger flexion, a basic functional unit can have several BEPs, one for each dimension of performance (one for ROM, one for strength, one for speed, and one for endurance). Each functional unit can have similar and/or different dimensions of performance. Appendix G shows the components of this study expressed in the ERM. Kondraske et al. (1997) discussed how the resource economic principles govern task performance. The performance of a high level task (HLT) depends on the amounts of the resources available that mathematically involve non-linearities of the resource thresholds. In other words, the resource most stressed will constrain the task performance. An individual may have above threshold levels in several resources but not meet threshold requirements for one or more resources and therefore be unable to perform the task. Kondraske (2000) discussed the potential application of this model in term of its flexibility. The ERM can be used rigorously or conceptually with only certain aspects being used. For the purposes of this study, it was the latter.

Non-linear Causal Resource Analysis (NCRA) is a method for analysis of task performance, prediction, and identification of limiting resources that applies the resource economic principles. Specifically, the NCRA method is based on the principle that performance is governed by the resources available for the production of task performance (Kondraske, 1999). Assuming the intrinsic nonlinear relationships of resource demands to task performance, NCRA uses data sets representing resource availability and task performance to identify task demands. This method was initially developed to be used with instruments developed by the Human Performance Institute, but other instruments are equally suitable for use with this analysis method. Some transformation of data may be required with the use of other instruments, in that the basic construct of a greater amount of a basic element represents more availability of the resource for performance. NCRA requires the measurement of both the task performance and the basic elements linked to the task performance. The measurements are represented by a set of curves, Resource Demand Functions (RDFs). The RDFs are basically scatter plots of each element in relation to the task performance. The RDFs provide a model of the task with the least amount of the basic resources required to support the performance of that task. In this study ROM, grip strength, pinch strength, dexterity, and pain were the basic elements examined in relation to the subjects' self-report of function. The interpretation of the RDFs allows for the prediction of task performance based on available basic elements and identification of limiting resources. The potential for prediction of task performance and identification of limiting resources of a task has clinical applications and seemed aplicable for this study.

In several different studies, Kondraske investigated the use of GSPT, ERM, and NCRA in the examination of human performance. In a retrospective study aimed at investigating the constructs of the GPST, Kondraske examined 1,728 data records of both healthy and pathologic subjects with respect to an upper extremity reciprocal task and six different basic performance resources (BPRs) (Kondraske, 1999). Performance was measured on a scale of 0 (cannot do) to 6 (highest level of performance). The BPRs used were central visual efficiency, visual spatial memory, visual response speed, shoulder internal/external rotator speed, and visual-arm tracking accuracy. The minimal amount of each BPR was calculated for each performance level, producing 42 threshold values (each of the seven performance levels with the minimal amount of the each BPR to achieve that level). Threshold demands increased monotonically as the performance level increased. Kondraske then examined several subject databases, selected at random, to determine whether the subjects had sufficient BPR measurements to place them in a higher performance level group than they had actually scored. The BPR measurements were compared to the data collected for the entire group. These subsequent subject databases revealed that the subjects did not have sufficient BPR measurements to place them in the next higher performance level, and one BPR was found to be the limiting factor in the subject's performance level. These results were repeated on another sample of records selected randomly. In this retrospective study, Kondraske demonstrated evidence in support of the resource economic principles and laid the ground work for the development of the NCRA method.

In another study, of potential rehabilitation interest, Kondraske et al. (1997) investigated mobility tasks, specifically gait, stair climbing, and obstacle course negotiation. Healthy and pathologic subjects (n=30) were included, ranging in age from 19 to 82 years. The basic elements examined were: (a) extremes of motion for hip and knee flexion and extension, and ankle dorsi- and plantarflexion; (b) isometric strength of hip and knee flexors and extensors, and ankle dorsi- and plantarflexion; (c) lower extremity neuromotor channel capacity; and (d) unilateral postural stability. Each mobility task was videotaped and examined by three physical therapists. The therapists were asked to rate the performance of the task on a 20 cm VAS, with "unable to perform" at one end and "ideal performance" at the other end of the scale. The raters were not given instructions; rather, they were to use their own discretion as how to rate the performance. The ratings were converted into numbers ranging from 1-100. The two expert rater's scores in most agreement for each given task were averaged to produce a task rating. Eighty-four scatter plots were obtained relating each BPR to each performance task rating (three tasks with each of the 28 BPRs). Each scatter plot was examined to determine a threshold of the BPR for each performance level, that is, what was the minimal amount of a BPR necessary for the performance of a task at a given level. For each task, a RDF was created for each of the 28 BPRs, a database was created to investigate the ability of the system to predict performance and identify the limiting resource. Using the same data, each subject's BPRs were compared to the corresponding RDF to obtain a predicted level of performance (assuming none of the subject's other BPRs were limiting) and when considering all BPRs for a given task, the BPR with the most limiting performance prediction was identified as the limiting BPR for the performance of that task. The NCRA-predicted level of performance was compared to the expert-rated level of performance. The results are presented in Appendix H and highlight the correlation between the rated (by VAS) and predicted level of performance. The reported coefficients were r=.92 for gait, r=.95 for stair climbing, and r=.96 for obstacle course negotiation. The investigators concluded that the NCRA system was able to predict performance and identify limiting resources, which has potential for application in the clinical setting. The measurements routinely used in an initial evaluation could be used to identify a limiting resource in individual patients and help to direct treatment.

The use of the GSPT, ERM, and NCRA posed both advantages and disadvantages to this study. The advantages included: a homogenous population was not required (in fact a diverse population is desirable), potential for clinical application, its ability to go beyond relationships into predictions and thresholds of performance, and its application to individuals as well as to groups. The disadvantages included: the requirement of parametric data (ratio and interval), substitutions and accommodations may skew results, and it is a newer and less familar analysis method. For the purposes of this study the advantages seemed to out-weighed the disadvantages.

Summary

There is no question that ROM, strength, dexterity, and/or pain in the hand effect the ability of a person to perform hand functions. The knowledge that a certain percentage of hand function can be attributed to each of these basic fundamental measurements is the information currently available to clinicians, and it is inadequate for the purpose of directing a patient's care. Though many studies have demonstrated this link, the questions of how much finger ROM, how much grip and pinch strength, and how much finger dexterity is necessary to perform a specific task and/or how much hand pain will effect the performance using the hand, have not been answered. Answers to these questions can assist the clinician in directing an individual patient's care. Casanova (1992) pointed out how much easier patient care would be if the patient could be told how much more of a resource is needed to accomplish a desired task. The GSPT, ERM, and NCRA provide a means of answering these questions by examining selected basic elements of the hand (finger ROM, grip and pinch strength, finger dexterity, and pain) and hand function from a different perspective.

This study used the GSPT, ERM, and NCRA with data obtained from the measurements of finger ROM, grip and pinch strength, finger dexterity, hand pain, and hand function to answer the questions posed, that is, (a) how much finger ROM, grip and pinch strength, and finger dexterity is necessary for hand function at a specific level (1 -unable to perform activity to 10 – able to perform activity at the same level as before injury or problem), (b) how much does pain affect hand function, and (c) could limiting resources be identified for each individual and for each task? The GSPT was also used to determine the predictability of task performance based on the measurements of the basic elements using retest measurements with a subset of the sample.

CHAPTER III

METHODS

The relationship of hand ROM, strength, and dexterity to hand function has been demonstrated by many investigators (Alderson & McGall, 1999; Cederlund et al., 1999; Dellhag & Burckhardt, 1995; O'Connor et al., 1999; and Vliet Vlieland et al, 1996). The purpose of this study was to determine whether thresholds of hand ROM, strength, dexterity, and/or pain could be identified for three high level functional task performed with the hands. Further, the thresholds were examined in terms of the task performance rated from 1 to 10 (i.e., unable to perform, to able to perform the activity at same level as before injury or problem). Finally, a sample of the subjects was re-tested to assess the cause and effect relationship, that is, whether changes occurred in the basic measurements, and if so, were those changes reflected in the self-reported measurement of task performance. Nonlinear Causal Resource Analysis (NCRA) was used to predict a given level of function for a specific task given measures of basic elements. A substudy of intrarater reliability of selected measures was also performed. This chapter describes the subjects, tester, instruments, procedures, and data analysis.

Subjects

Participants for this study were recruited using convenience sampling from one facility that specializes in the treatment of hand problems. This setting is common for therapeutic intervention in hand disease/injury. More than 44% of Certified Hand

Therapists work in hospital based hand therapy settings (Muenzen et al., 2002). During recruitment an attempt was made to include subjects with a wide range of impairments. Not fewer than 20 patients who met the inclusion and exclusion criteria were selected. The facility provided the researcher with a list of potential subjects. Once a potential subject was identified and had consented to participate in the study, a testing time was scheduled. Informed consent was required of all participants in accordance with the Institutional Review Boards (IRB) at Texas Woman's University (TWU) and the data collection site (Presbyterian Hospital of Dallas). All subjects were informed that they may be asked to participate in the re-measurement aspect of the study if they completed greater than four hand therapy sessions after the initial measurements for the study were taken.

Inclusion and exclusion criteria of subjects were grossly screened by the clinic's therapists prior to referral to the study. They were also re-screened by the researcher prior to testing. Inclusion criteria were as follows: (a) a patient at the clinic identified in this study, (b) age 18 or older, and (c) an injury or disease affecting one or both hands. Exclusion criteria consisted of the following: (a) insufficient shoulder, elbow, forearm, and wrist mobility so as to be restrictive in the tasks to be measured (specifically subjects had to be able to touch each hand to the back of the head, the opposite acromion, and the small of the back), (b) cognitive deficits or communication barriers that could inhibit the subject's ability to participate in the self-report survey, and (c) neurological pathology of the hand (see procedures for specific details on the screening process).

Tester

The tester for this study had 22 years of clinical experience in physical therapy and completed a post-graduate internship in hand therapy. The tester piloted the procedures with 2 subjects in order to train and streamline the methods. Data from these subjects were not included in the data analysis. In addition, the tester conducted a concurrent substudy of intrarater reliability of the measures as described in the procedures.

Instruments

The following instruments were used in this study. They are similar to those commonly found in hand therapy clinics:

1. The Jamar® Hydraulic Hand Dynamometer (Sammons Preston, Boling Brook, IL) was used to measure grip strength. The adjustable handle was placed in the second position (next to the smallest grip size). The gauge displays in both pounds and kilograms. Kilograms were used for this study.

2. The B&L® Pinch Gauge (B&L Engineering, Santa Fe Springs, CA) was used to measure pinch strength. The gauge registers in both pounds and kilograms. Kilograms were used for this study.

3. The Rolyan® Flexion/Hyperextension Finger Goniometer (Smith & Nephew, Germantown, WI) was used to measure finger ROM. The scale measures in 1 degree increments.

4. The Purdue Pegboard (Lafayette Instrument Co., Lafayette, IL) was used to assess dexterity. The units of measure were the number of parts (pins, collars, and washers) correctly placed.

5. A stop watch was used for timing the sub-test of the Purdue Pegboard test.

6. A self-report of task performance for toileting, dressing and grooming, and meal preparation and feeding, was specifically adapted for this study to evaluate functional tasks. See Appendix A for a sample copy. Task performance was measured on a scale of 1 to 10 with 1 = unable to perform and 10 = able to perform at the same level as before injury or problem.

7. A 10 cm self-report VAS was used for the measurement of pain. See Appendix I for a sample copy. Pain was measured on a scale of 0 to 10 cm (0 cm = no pain and 10 cm = worst possible pain). However, for analysis purposes the scale was inverted so that 10 equaled no pain.

8. A standard treatment table was used during the administration of the written components of the study as well as during the measurements of ROM and dexterity. The table height was 74 cm.

9. A standard straight back chair (seat height of 47 cm) was used for all the testing by all subjects.

10. A small clear plastic universal goniometer was used to measure finger joints that cannot be measured dorsally. Sometimes, due to deformity, edema, scaring a joint of the fingers or thumb, ROM cannot be accurately measured using the dorsal technique. In these cases, the lateral technique is favored using a small clear goniometer also measured in degrees. The small clear plastic goniometer was also used to measure thumb CMC palmar and radial abduction laterally in degrees. Opposition was measured with the metric ruler printed on one of the arms in cm.

Procedures

All testing took place at the Hand Center of Presbyterian Hospital of Dallas, TX. All potential participants were initially identified by the therapists working in the clinic. The clinic therapists were provided with the inclusion and exclusion criteria to assist them in identification of potential participants. Once a potential participant was identified, the patient was provided with a general overview of this study and asked by the therapist if he/she would be willing to participate. If the individual expressed interest, he or she was asked to sign a form allowing the investigator to contact them (see Appendix J for a copy of the contact consent form). All individuals who agreed to be contacted were screened by the investigator either by phone or in person (see Appendix K). If the potential participant met all the inclusion and no exclusion criteria and was still willing to participate, an appointment was scheduled at their convenience for the initiation of the study.

The testing sessions were scheduled prior to any therapeutic interventions on the day of testing to minimize a potential treatment effect on the measurements. The appointment began with the participant receiving a written consent form (see Appendix L) and an oral and written description of the study. After the consent form was signed, the investigator completed an intake assessment with each participant (see Appendix M) to gather demographic data and to further assure all the inclusion and no exclusion criteria were met. At the completion of the intake assessment each participant was given the two self-reports: the VAS for assessment of pain (see Appendix I) and the functional performance assessment (see Appendix A). Overall, the remaining procedures were as follows: (a) finger ROM, (b) grip strength, (c) pinch strength, and (d) dexterity. The order in which each of these basic element measurements were taken was randomized (the order of test determined by the order slips of paper, one each for ROM, strength, and dexterity drawn from a hat) to limit the effect of one measure on subsequent measures.

The procedure for each test measurement was as follows:

<u>Self-report of prior and current hand functional performance</u>: With the subjects seated at the table they were provided with a blank self-report (see Appendix A) and a pen. The subjects were instructed to answer each question marking their answer in the appropriate space.

Visual analog scale (VAS) for pain: While the subjects were still seated they were given a blank 10 cm VAS for the measurement of pain (see Appendix C). The subjects were instructed to draw a mark across the line to indicate their current level of pain. The extremes of the scale were noted as "Worst possible pain" and "No pain."

Finger ROM: Measurements were taken using the guidelines provided by the ASHT (1992). In general, for each motion the subject was instructed to move the finger or thumb as far as possible in the desired direction until motion was stopped by either no further available motion or by pain. Specifically, the subject was seated, with the elbow of the hand to be measured resting on the table with the wrist and forearm in neutral (the thumb of the hand to be tested toward the subject and the small finger toward the investigator). Because active finger ROM was assessed, the subject was asked to fully flex the finger being measured at all three joints. Each joint was measured using the dorsal technique and results recorded. The subject was then instructed to fully extend the finger at all three joints. Each joint was measured using the dorsal technique and results recorded. Any joint that could not be measured with the dorsal technique was measured with the lateral technique as recommended by the ASHT.

For the thumb: (a) MP and IP flexion and extension were measured in the same manner as used for the fingers with both joints fully flexed and then with both joints fully extended; and (b) CMC palmar abduction was measured with the small clear plastic universal goniometer radially to the thumb and 2nd metacarpal (the subject was instructed to fully move the thumb away from the hand in a palmar direction); (c) CMC radial abduction was measured with the small clear plastic universal goniometer placed dorsally on the hand (the subject was instructed to fully move the thumb away from the hand in a radial direction); and (d) CMC opposition was measured with the ruler end of the small universal goniometer (the subject was instructed to reach across the palm with the thumb as far as possible) and a measurement was taken of the distance from the volar surface of the thumb IP joint (at the crease made by IP flexion) to the volar surface of the third metacarpal. This latter measurement required conversion for use with the NCRA method and is discussed in the data analysis section.

Grip strength: Grip strength was measured using the Jamar dynamometer. The dynamometer was calibrated prior to the initiation of the study by the factory as is the recommendation in the owner's manual. The same dynamometer was used throughout the study to ensure consistency of the instrument. The subject was positioned according to ASHT guidelines: subject seated, shoulder adducted, elbow flexed to 90°, forearm and wrist in neutral, and the dynamometer placed in subject's hand while gently supported by the tester. The subject was instructed to squeeze the handle as tightly as possible using a smooth motion. After each grip force was produced, the force was recorded and the opposite side was tested to allow for recovery on each side between trials. A rest interval of 1 minute is recommended (Bohannon, 1991) and was adhered to in this study. All subjects were tested using only the second handle position and the average of three trials was recorded in kilograms.

Pinch strength: Pinch strength was measured using the B&L pinch gauge. The gauge was calibrated at the factory, B&L Engineering. The same gauge was used throughout the study to ensure consistency of the instrument. The three primary types of pinch prehension patterns: palmar, tip, and lateral are descriptions of the finger surface used during the pinch (Flatt, 1983). The pattern must also identify the digits used. This investigator measured palmar pinch (the pads of the digits used in prehension) between the thumb and index and long fingers (also known as three-jaw chuck). Tip pinch (the tips of the digits used in prehension) was tested between the thumb and index finger (also known as two-point or tip-to-tip). Lateral pinch (the lateral border of one or both digits are used in prehension) was tested between the pad of the thumb and the lateral aspect of the index fingers middle phalanx (also known as key pinch). See Appendix O for representations of each of the three pinch patterns. The ASHT does not provide procedural recommendation for the testing of pinch strength, but there are reports of standardized procedures in the literature (Kellor, Frost, Silberber, Iversen, & Cummings, 1971; MacDermid et al., 2001; Mathiowetz, Weber, Volland, & Kashman, 1984). Most investigators used a seated subject with the shoulder adducted and elbow flexed to 90°. There is evidence that forearm, and wrist position effect pinch strength (Woody & Mathiowetz, 1988). Therefore in this study, all three pinch patterns were tested with the subject seated, elbow flexed to 90°, the forearm in neutral, and the wrist in neutral. The tester demonstrated the desired pinch pattern to the subject, then placed the gauge in the subject's hand, and instructed the subject to "squeeze as hard as you can." The testing of pinch strength was alternated between hands, allowing for a minimum of 1 minute between repeated trials on the same hand. Each pinch pattern was tested and recorded three times on both hands. The average force was used in the analysis.

Dexterity: Dexterity was assessed using the Purdue Pegboard. The pegboard was placed on the standard table, centered in front of the subject. The subject was seated in the standard chair. The cups containing the pins, collars, and washers were furthest from the subject. The cups were filled as follows: in the cups on the extreme left and right there were 25 pins each, in the cup to the subject's left of center there were 40 washers, and in the cup to the right of center there were 20 collars.

The dexterity test has four subtests: right hand, left hand, both hands, and assembly. For the right hand test, the subject was instructed to place as many pins in the right row of holes starting at the top and working his/her way down. The subject was given three or four pins to practice with before starting the test. The practice pins were returned to the cup and the subject was instructed to begin placing the pins at the command "start." The subject was given 30 seconds to place as many pins as possible, one at a time in the right hand row. The tester timed the 30 seconds using a stop watch and simultaneously gave the start command while starting the watch. At the end of 30 seconds, the subject was instructed to stop and any pins not in holes were returned to the cups and not included in the score. The score was the total number of pins place in 30 seconds. The same procedure was followed for the left hand test. For the test with both hands, the subject was instructed to simultaneously take pins with both the right and left hands from the corresponding cups and simultaneously place them in the corresponding holes, starting at the top. The subject was allowed to practice this process with three or four pairs of pins. The pins were returned to the appropriate cups and the subject was instructed to begin at the command of "start." The subject was given 30 seconds to place as many pairs of pins as possible, using both hands at the same time. The tester timed the 30 seconds using a stop watch and simultaneously gave the start command while starting the watch. At the end of 30 seconds the subject was instructed to stop and any pins not in holes were returned to the cups and not included in the score. The score for both hands was the number of pairs of pins (not the total number of pins placed) placed.

For the assembly test, the subject was instructed to pick up one pin with the right hand and while placing the pin in the top hole in the right hand row, to pick up a washer with the left hand. After the pin was in place, the subject dropped the washer over the pin while using the right hand to pick up a collar. While placing the collar over the pin and washer with the right hand, the subject picked up a second washer using the left hand and placed it over the first pin, washer, and collar. The first assembly was then completed, and the subject was encouraged to practice two or three completed assemblies. The subject was instructed to keep both hands moving during this test, while one hand was placing a part the other hand was picking up a part. The pins, washers, and collars were returned to the appropriate cups and the subject was instructed to begin on the command of "start." The subject was given 1 minute to complete as many assemblies as possible. The timing process followed the previously described procedure. The score for the assembly test was the number of parts placed by the end of the 1 minute. The difference between one or three trials is not typically large enough to be statistically significant (Tiffin & Asher, 1948) so this investigator only tested each of the dexterity subtests one time.

At the completion of the ROM, strength, and dexterity testing, three measures were retaken for the concurrent sub-study of intrarater reliability of the measures. The three re-measurements included: (a) one measure of ROM (specifically one finger was re-measured), (b) one measure of strength (either grip or one of the pinches), and (c) one of either dexterity (only one of the subtest), pain, or function. Each was randomly selected without replacement by drawing from a hat.

All participants were asked at the end of the testing session whether they would be willing to participate in the re-test portion of the study. If the participant agreed, the investigator conferred with the treating therapist as to whether the participant might complete at least four more therapy sessions prior the termination of therapy. If that inclusion criterion was possible a follow-up appointment was scheduled for the re-test to occur at a point after the completion of at least four additional therapy sessions. The re-test followed the same procedures outlined previously.

Data Analysis

The subjects demographics and characteristics were examined (e.g., age, hand dominance). The median, mean, standard deviation, and the minimum and maximums values were determined for each variable. Intratester reliability was evaluated using an ANOVA-based ICC(3,k). Statistical Products and Service Solutions (SPSS, version 11.0) was used to create spreadsheets and graphs, and to analyze data.

NCRA was used to determine the relationship between the independent variables (ROM of each joint, TAM of each finger, TAM of the thumb including the IP, MP, CMC palmar abduction, and CMC radial abduction, thumb opposition, grip strength, palmar pinch strength, tip pinch strength, lateral pinch strength, dexterity, and pain) and the dependent variables (task performance of food preparation and feeding, toileting, and dressing and grooming). There were 84 different basic resources when left and right sides were considered. For the purpose of model building and prediction, BPR data were, however, not considered as "left" and "right" side data, but rather grouped into "involved" and "uninvolved" sides. NCRA requires that all numbers range from zero to something larger (representing "more" resource availability). The ROM values for extension were often negative and therefore, all extension numbers were transformed by adding 90° to them. Each resource conformed to the construct that a greater value is more desirable (i.e., more of the resource was available). This required conversion of the measurements of opposition and pain by inverting the measurement value obtained. Dexterity measurements for each of the four subtests were converted from parts placed per 30 seconds, to parts placed per second. The three tasks measurements also conformed to the construct that a greater value is more desirable.

NCRA was used to build a model using the initial measurements from 21 subjects and the post-therapy data for 10 of the 12 subjects who were retested. Post-therapy data for Subjects 101 and 102 were excluded in the model building data set (see Chapter V for a discussion of reasons). The pre- and post-therapy data were combined to provide a larger set of cases ($\underline{n}$ = 21 +10 = 31) representing HLT and BPR data at basically the same point in time. This is especially relevant in the present case due to the large number of BPRs (84) involved. Two hundred fifty-two scatter plots (independent variables/basic resources vs. dependent variables/self-report of task performance) were produced (84 basic resources x 3 tasks). For each scatter plot a resource demand function (RDF) was determined. The RDF was determined using a computer algorithm developed at the University of Texas at Arlington, Human Performance Institute , Arlington, TX (NCRA software). For better understanding of the process, several RDFs were constructed "manually." The goal of the RDF is to identify thresholds representing the minimum amount of a basic resource required to support a given level of task performance along the entire continuum of a performance of the task of interest. This is done by finding the lower boundary of points in the scatter plot, including a point at the origin. In the "manual" process the minimum thresholds were identified visually and manually connected to produce a piecewise linear function, RDF. The inference was that at a given level, the resource availability (R_A) must meet or exceed the task's resource demand (R_D), or that the resource availability was equal to or greater than the resource demand ($R_A \geq R_D$). For each of the three tasks a set of 84 RDFs were so obtained and utilized.

The model, the 252 scatter plots with the corresponding RDFs, was used to predict the HLT (high level task) performance and limiting resources (LR) in all 21 cases. The prediction process for each task involved two steps: (a) for each basic resource measured, the highest level of performance for the task was determined with the pretense that all the other basic resources were non-limiting; and (b) the minimum of the 84 predictions obtained for the task was then selected as the prediction of task performance for that subject. The basic resource associated with the minimum level of task performance was identified as the limiting resource. It was possible to identify more than one LR owing to the number of basic resources considered.

The demographics and characteristics of the 12 subjects who were retested were then examined. The median, mean, standard deviation, and the minimum and maximum values were determined for each dependent/independent variable that was retested.

The NCRA model developed was used with the 12 subjects' retest measurements to identify changes in the LR, changes in the level of task performance, and new limiting resources. Further, new predictions of task performance were made with the retest measurements. The changes found in the retest subjects, at both the HLT and BPR levels, were evaluated using a contingency table to determine whether they were consistent with the model (and predicted outcomes as derived from GSPT). In other words, were changes in the selected dependent variables (specifically, those identified as limiting performance resources: pain, ROM, strength, and dexterity) reflected in a change in the independent variables (task performance) and were those changes consistent with GSPT, i.e., resource economic principles? See Table 1 for a sample of how consistency with the model was determined.

Table 1

Evaluation of the Consistency of Nonlinear Causal Resource Analysis Model Based on Changes in High Level Task (HLT) and Limiting Resource (LR)

HLT Change (+, −,Ø)	Change in Initial LR Identified in Evaluation (+, −,Ø)	LR the Same as Identified in Initial and Retest (LR1 = LR2)	Consistent or Inconsistent with Model
+	+	= or ≠	Consistent
+	−	= or ≠	Inconsistent
+	Ø	= or ≠	Inconsistent
Ø	−	= or ≠	Consistent
Ø	+	= or ≠	Inconsistent
Ø	Ø	= or ≠	Consistent
−	+	=	Inconsistent
		≠	Consistent
−	−	= or ≠	Consistent
−	Ø	=	Inconsistent
		≠	Consistent

Note. + denotes a positive change, - denotes a negative change, and Ø denotes no change between the initial value and the retest value; = denotes that the LR was identified as the same in both the initial and the retest analysis, while ≠denotes that the LR identified was not the same between the initial and retest analysis.

The questions concerning the ability of the model to predict changes in performance based on changes in the basic resources was evaluated using the guidelines outlined in Table 1. For example, if a subject's self-reported rating of dressing and grooming performance (HLT) increased from the initial to the retest, and there was a measured increase (improvement) in the identified limiting resource, the changes were considered consistent with the model for this subject. If the LR had not changed, or had decreased, the changes would be inconsistent with the model.

CHAPTER IV

RESULTS

The purposes of this study were to (a) determine threshold values for ROM, strength, and dexterity, and levels of pain in specific functional task performance in people with diseased or injured hands using NCRA; (b) identify whether differing threshold values for each resource were detectable for varying levels of specific functional task performance; and (c) determine whether changes in ROM, strength, dexterity and/or pain would produce predictive changes in function when using the GPST model developed in the initial part of the study. Twenty-one subjects were measured and 12 of the 21 subjects were re-measured for the cause and effect portion of the study. Demographic, medical, and study measurements were collected on the initial visit. Twelve of the subjects were re-measured after receiving a minimum of four treatment sessions.

Each subject's data were examined using the NCRA method. This chapter presents the results in the following subsections (a) Demographic and Subject Characteristics; (b) Descriptive Data on Pain, Performance, Range of Motion, Strength, and Dexterity; (c) Intrarater Reliability of Range of Motion, Strength, and Dexterity; (d) Nonlinear Causal Resource Analysis of Subjects' Initial Data; (e) Demographics and Characteristics of the Retest Subjects; (f) Descriptive Data on Dependent Variables for Retested Subjects; (g) Nonlinear Causal Resource Analysis of Retested Subjects; and (h) Summary.

Demographic and Subject Characteristics

Twenty-one subjects (9 women and 12 men) were measured for this study. All were patients at the Hand Therapy Center of Presbyterian Hospital of Dallas, TX at the time they were measured. Twelve of the 21 subjects met the requirement of a minimum of four treatment sessions following initial evaluation and were re-measured for the cause and effect portion of the study. Table 2 shows the descriptive data on gender, age, hand dominance, involved side, and disease/injury for each of the 21 subjects in the study.

Table 2

Subjects' Gender, Age, Hand Dominance, Involved Side, and Disease/Injury

Subject Number	Gender	Age	Hand Dominance	Involved Side	Disease/ Injury
1[a]	F	65	R	R	Multiple fx[b] of ring & small fingers
2[a]	M	67	R	R	Contusion to hand
3[a]	M	44	R	R	Crush with multiple fx, wounds, and amputation
4[a]	F	55	R	L	Inter-articular fx small metacarpal joint
5[a]	M	51	L	L	Dupytren's contracture
6[a]	F	29	R	R	Flexor tendon laceration

(Table continues)

Table 2 (continued)

Subjects' Gender, Age, Hand Dominance, Involved Side, and Disease/Injury

Subject Number	Gender	Age	Hand Dominance	Involved Side	Disease/ Injury
7[a]	F	28	R	L	Wrist fx with malunion
8[a]	M	70	R	L	Cellulitis
9[a]	M	39	R	L	Wrist fx
10	M	52	L	R	Flexor tenosynovitis
11[a]	M	56	R	L	Infection
12	F	29	R	R	Multiple fx of ring and thumb
13	F	75	R	R	Wrist Fx
14	M	46	R/L	L	Multiple fx ring
15	F	83	R	L	Wrist fx
16[a]	M	70	R/L	L	Dupytren's contracture
17	M	82	R/L	R	Carpal tunnel syndrome
18	F	39	R	R	Old boxers fx with surgical dedridment and tendon transfer
19[a]	M	18	R	R	Boxers fx ring
20	F	55	R	R	Index fx
21	M	79	R	R	Open fx index

Note. [a] denotes subjects who were retested; [b] fx abbreviation for fracture; n = 21.

As can be seen from Table 2, subjects ranged in age from 18 to 83 (M = 53.9; SD = 19.2). Sixteen of the subjects were right-hand dominant, two were left-hand dominant, and 3 described themselves as being ambidextrous. Thirteen of the subjects' injury/disease involved their dominant hand (including the 3 ambidextrous individuals). The disease/injury category illustrates the scope of diseases/injuries these subjects presented with. The most common injury/disease was fracture ($n = 13$), often multiple, and/or with other injuries.

Descriptive Data on Pain, Performance, Range of Motion, Strength, and Dexterity

Pain was measured using the subject's self-report on a 10 cm visual pain scale. Performance was measured using the subject's self-report on a numeric scale. Each subject rated his or her overall use of the right and left hands, and performance on the activities of meal preparation and eating, toileting, and dressing and grooming. Each of these ratings included a before injury/disease (pre) and a current score (post). Range of motion measurements were taken of all digits on both hands and were recorded in degrees. Strength measurements consisted of three trials and the average and were recorded in kilograms. Dexterity was measured using the Purdue Pegboard and was scored based on the number of pegs/parts placed for each subtest.

Table 3

Median, Mean, Standard Deviation, and the Minimum and Maximum for Pain, Performance, ROM, Strength, and Dexterity

Measure	Mdn	M	SD	Min	Max
Pain (0-10 cm scale)	2.3	2.7	2.2	0.0	9.0
Meal preparation and feeding (1-10 scale)					
Pre disease/injury	10	9.9	2.6	9	10
Post disease/injury	5	5.4	.2	2	9
Toileting (0-10 scale)					
Pre disease/injury	10	9.9	.4	8	10
Post disease/injury	7	7.2	2.2	2	10
Dressing and grooming (0-10 scale)					
Pre disease/injury	10	9.9	.3	9	10
Post disease/injury	7	6.2	2.2	2	10

(Table continues)

Table 3 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Pain, Performance, ROM, Strength, and Dexterity

Measure	Mdn	M	SD	Min	Max
ROM of fingers (deg)					
MP extension	10	5	13.1	-55	25
MP flexion	80	77	13.6	20	100
PIP extension	0	-1	11.0	-50	22
PIP flexion	95	92	16.6	0	120
DIP extension	0	2	6.9	-25	17
DIP flexion	68	65	19.0	0	97
ROM of thumbs (deg)					
Palmar abduction	50	49	7.7	32	65
Radial abduction	51	51	10.7	32	80
MP extension	0	2	8.0	-25	20
MP flexion	53	51	16.9	12	84
IP extension	17	17	12.2	-25	40
IP flexion	68	66	15.5	22	90

(Table continues)

Table 3 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Pain, Performance, ROM, Strength, and Dexterity

Measure	Mdn	M	SD	Min	Max
Opposition (cm)	0	.3	.8	0	4
Grip Strength (kg)	28	27	16.7	0	73
Pinch Strength (kg)					
Tip	5	5	2.6	0	12
Key	7	7	3.1	0	13
Three Jaw Chuck	6	6	3.0	0	13
Dexterity (no. of pegs/parts placed)					
Right hand	13	11	4.9	0	15
Left hand	12	12	3.3	7	19
Bilateral	8	8	3.2	0	12
Assembly	24	25	12.8	0	47

Note. n = 21.

Table 3 illustrates that pain was generally rated on the lower end of the scale, suggesting less pain. Subjects' rating of performance tended to be high pre-injury/disease and several levels lower post-disease/injury. For the purpose of this table, ROM was divided into fingers and thumbs and was further divided by joint and movement. The group means for all the movements and for each joint fell well within the normal ROM. The minimums in ROM demonstrated the severity of ROM impairments. Strength demonstrated a pattern similar to ROM in that the group means fell within the normal range, while the minimums demonstrated the severity of the strength impairments. The dexterity scores exhibited a similar pattern.

Intrarater Reliability of Range of Motion, Strength, and Dexterity

Intrarater reliability was assessed on selected dependent variables measured by the rater, specifically ROM, strength, and dexterity. Pain and performance were not assessed for reliability, they are by design self-reports and assumed to be reliable. Data from repeated trials for ROM from all digits was grouped for the analysis. The same grouped data were used for determining the ICCs for strength and dexterity. Table 4 presents the intraclass correlation coefficients ($ICC_{3,\underline{k}}$) for ROM, strength, and dexterity.

Table 4

Intraclass Correlation Coefficients for ROM, Strength, and Dexterity

Variables	No. of Data Points	$ICC_{(3,k)}$
Overall ROM (deg)	60	.99
Overall Strength (kg)	8	.99
Overall Dexterity (no. of pegs/parts placed)	4	.99

Note. $n = 21$; $k = 3$.

The magnitude of the $ICCs_{(3,k)}$ for each measured was .98 - .99. This is considered excellent reliability (Portney & Watkins, 2000).

Nonlinear Causal Resource Analysis of the Subjects' Initial Data

NCRA was used to examine all 21 subjects' ROM, strength, and dexterity in relationship to the subjects' self-report of performance in meal preparation and feeding, toileting, and dressing and grooming. Pain measurements were excluded in the final analysis, because as a whole, the subjects did not report significant levels of pain. NCRA was used to: (a) create Resource Demand Functions (RDFs), (b) identify which of the basic elements were limiting functional performance in the three tasks, and (c) develop a model for the prediction of task performance as explained in Chapter III.

The Resource Demand Function (RDF), as explained in Chapter III, was created for each of the 84 basic elements versus each of the three tasks (252 RDFs). Figures 1 - 3 are a representative sample of the RDFs. Each point represents one of the 21 subjects' measurement values for a given basic element and the solid line represents the RDF for each task versus the basic element. The RDF omits, or discounts, zeros that fall on the x axis, the default is to the next non zero. The theory being that the resource was not zero but some amount that was not measurable.

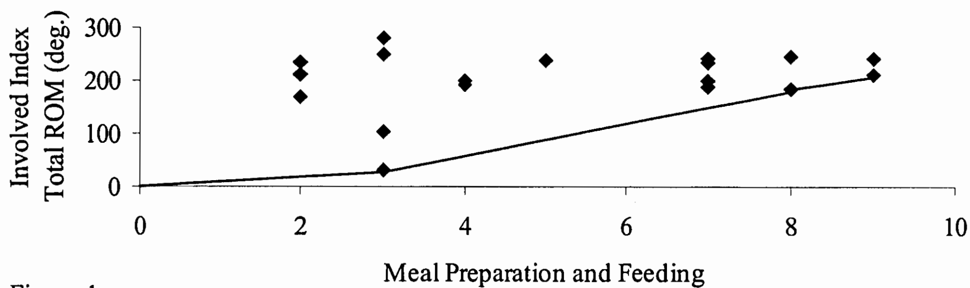

Figure 1a

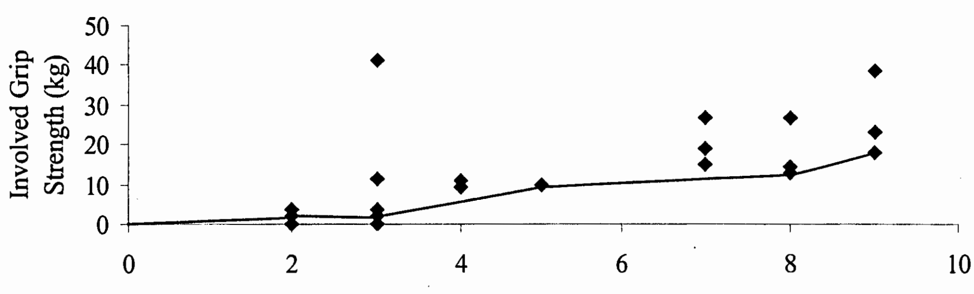

Figure 1b

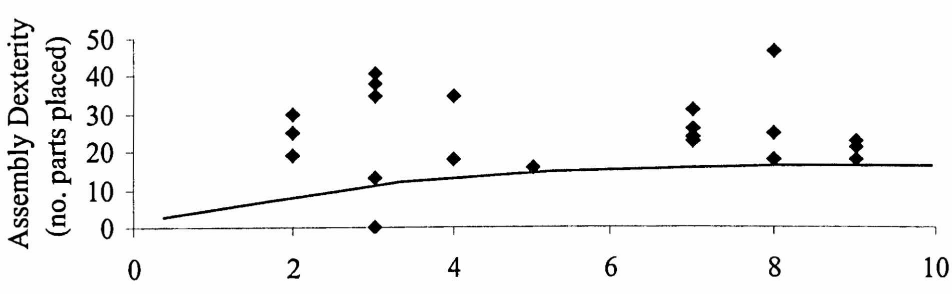

Figure 1c

Figure 1. Scatter post representing the task of meal preparation and feeding (a self-report on a scale of 1-10) versus: 1a. the involved index finger total ROM in degrees (total index ROM is the sum of flexion and extension at each of the three joints); 1b. involved grip strength in kg; and 1c. assembly dexterity in number of parts placed. The solid line represents the Resource Demand Function (RDF) for this task (i.e., the thresholds for involved index total ROM, grip strength, and assembly dexterity for performance at each level).

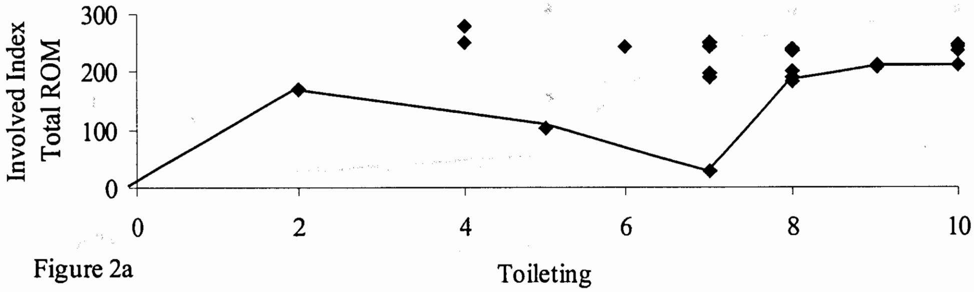

Figure 2a

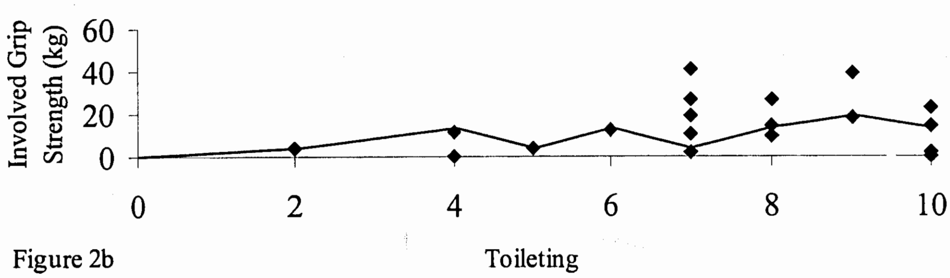

Figure 2b

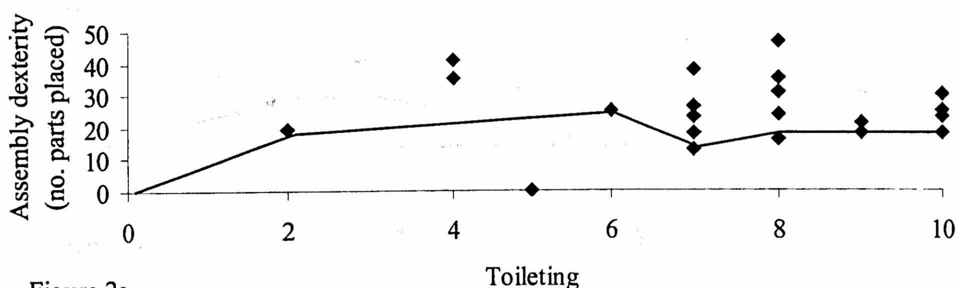

Figure 2c

Figure 2. Scatter plots representing the task of toileting (a self-report on a scale of 1-10) versus: 2a. the involved index finger total ROM in degrees (total index ROM is the sum of flexion and extension at each of the three joints); 2b. involved grip strength in kg; and 2c. assembly dexterity in number of parts placed. The solid line represents the Resource Demand Function (RDF) for this task (i.e., the thresholds for involved index total ROM, grip strength, and assembly dexterity for performance at each level).

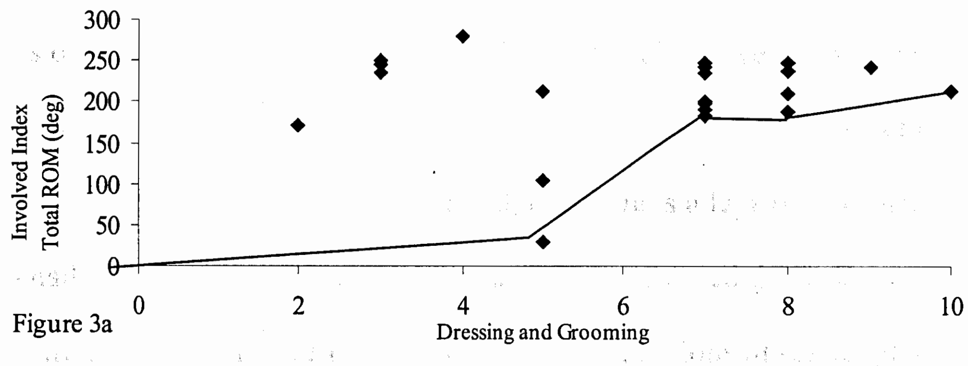

Figure 3a

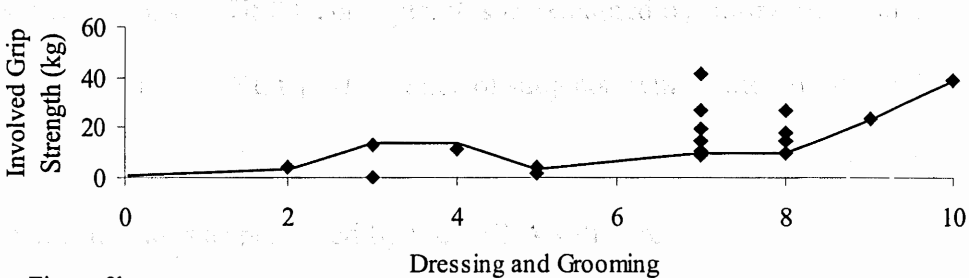

Figure 3b

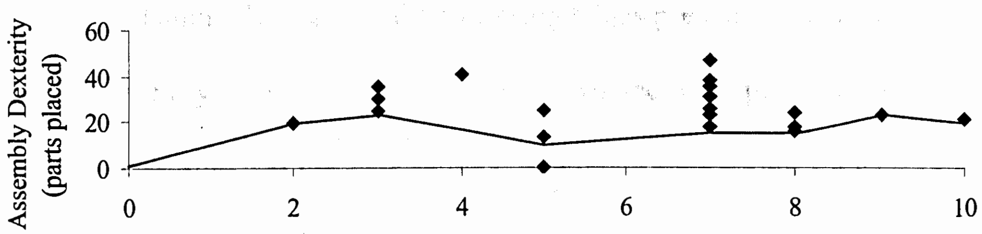

Figure 3c

Figure 3. Scatter plots representing the task of dressing and grooming (a self-report on a scale of 1-10) versus: 2a. the involved index finger total ROM in degrees (total index ROM is the sum of flexion and extension at each of the three joints); 2b. involved grip strength in kg; and 2c. assembly dexterity in number of parts placed. The solid line represents the Resource Demand Function (RDF) for this task (i.e., the thresholds for involved index total ROM, grip strength, and assembly dexterity for performance at each level).

All the scatter plots and corresponding RDFs exhibited the trend of increasing levels of the basic resource and were associated with improvements in the subjects' self-report of performance. This is especially characterized by the absence of data points in the lower right portion of each scatter plot, i.e., there is a lack of evidence of subjects who had very little resource availability and also performed the task very well. Similarly, there is evidence of data in the upper left regions of scatter plots. Here, subjects had a relatively large amount of a given resource available, but performed the task poorly. Using GSPT concepts, this is explained by noting that some other BPR was most likely limiting HLT performance of subjects' represented by those data points. See Appendix P for a complete data file of the (x,y) coordinates for each of the 252 resource demand functions as produced by the NCRA software.

The initial measurements from the 21 subjects were examined and the limiting resources were identified. Though limiting resources were identified on both the involved and uninvolved sides, the following tables present only the involved data because generally the subjects rated their uninvolved hand performance at a 9 or 10, and the uninvolved side was not generally considered critical to the subjects' current limitations.

Table 5 presents the limiting resource for each subject in the performance of the task of meal preparation and feeding. With the exceptions of bilateral dexterity and assembly dexterity (two-handed dexterity tests), all limited resources were on involved side.

Table 5

Limiting Resources (LR) Identified for Meal Preparation and Feeding in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources (Involved Side)	HLT Performance Rating
101	Ring PIP extension, ring total ROM, and small PIP extension	7
102	Thumb palmar abduction, index PIP extension, index PIP flexion, index DIP extension, index DIP flexion, long DIP flexion, ring PIP flexion, ring DIP extension, ring total ROM, small DIP flexion, small total ROM, thumb opposition, and key pinch strength	3
103	Index total ROM, long PIP flexion, long DIP extension, long total ROM, ring DIP extension, grip strength, three jaw chuck strength, fine dexterity, and assembly dexterity	3
104	Small DIP flexion and small total ROM	2
105	No LR identified on the involved side	3
106	Thumb MP extension, thumb IP extension, index PIP extension, index PIP flexion, index DIP flexion, index total ROM, and tip pinch strength	8
107	Thumb IP extension, index MP flexion, ring MP flexion, and small MP flexion	4

(Table continues)

Table 5 (continued)

Limiting Resources (LR) Identified for Meal Preparation and Feeding in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources (Involved Side)	HLT Performance Rating
108	Long MP extension, long total ROM, ring MP extension, ring PIP flexion, ring total ROM, and small DIP extension	4
109	Index PIP flexion, index DIP extension, ring PIP flexion, ring DIP extension, small PIP flexion, and bilateral dexterity	9
110	Thumb MP flexion, long MP flexion, long PIP flexion, long DIP extension, long total ROM, ring MP extension, ring MP flexion, small MP flexion, key pinch strength, and three jaw chuck pinch strength	8
111	Thumb radial abduction, thumb MP extension, thumb MP flexion, thumb IP extension, thumb IP flexion, thumb total ROM, index PIP extension, index total ROM, long PIP extension, long DIP flexion, long total ROM, ring MP flexion, ring DIP flexion, ring total ROM, small PIP extension, small DIP extension, small total ROM, tip pinch strength, key pinch strength, three jaw chuck pinch strength, and assembly dexterity	9
112	Ring MP extension and ring MP flexion	7

(Table continues)

Table 5 (continued)

Limiting Resources (LR) Identified for Meal Preparation and Feeding in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources (Involved Side)	HLT Performance Rating
113	Thumb IP flexion, thumb total ROM, small MP extension, grip strength, bilateral dexterity, and assembly dexterity	5
114	Ring DIP flexion	3
115	Thumb palmar abduction, thumb MP flexion, and index DIP extension	2
116	Ring PIP flexion, ring DIP extension, and grip strength	8
117	Thumb palmar abduction, index MP extension, ring MP extension, and ring DIP extension	9
118	Small MP extension	3
119	Thumb MP extension	2
120	No LR identified on the involved side	7
121	Index DIP extension and small MP extension	7

Note. n = 21.

As can be seen in Table 5, the number of basic elements identified as the LR for the task of meal preparation ranged from 0 to 21. There were 2 subjects without any LR identified for meal preparation and feeding on their involved side. Eleven subjects were identified with LRs in ROM only. Three subjects had limitations in ROM, strength, and dexterity. The other 5 subjects had some combination of ROM and strength or dexterity. Of the basic elements within the LR, ROM was the most frequently occurring LR (70) in meal preparation and feeding.

The initial measurements of the 21 subjects were examined and the limiting resources (LR) were identified for toileting. Table 6 presents the LR for each subject in the performance of the task of toileting.

Table 6

Limiting Resources (LR) Identified for Toileting Performance in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources (Involved Side)	HLT Performance Rating
101	Index MP extension, index PIP extension, index total ROM, and small PIP extension	8
102	Index PIP extension, index PIP flexion, index DIP flexion, long DIP flexion, ring PIP flexion, ring DIP extension, ring total ROM, small DIP flexion, small total ROM, thumb opposition, and key pinch strength	5
103	Index MP extension, index MP flexion, index total ROM, long PIP extension, long PIP flexion, long total ROM, ring PIP flexion, ring DIP extension, ring total ROM, small DIP flexion, small total ROM, and three jaw chuck pinch strength	7
104	Small DIP flexion and small total ROM	2
105	No LR identified on the involved side	4
106	Index PIP extension, index PIP flexion, index DIP flexion, index total ROM, and tip pinch strength	8
107	Thumb IP extension, index MP flexion, ring MP flexion, and small MP flexion	6

(Table continues)

Table 6 (continued)

Limiting Resources (LR) Identified for Toileting Performance in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources (Involved Side)	HLT Performance Rating
108	Long MP extension, ring MP extension, and small DIP extension	7
109	Bilateral dexterity	10
110	No LR identified on the involved side	0
111	Thumb IP extension, index MP flexion, index PIP extension, index total ROM, long PIP extension, ring PIP extension, ring DIP flexion, ring total ROM, small PIP extension, small DIP flexion, and fine dexterity	9
112	Ring MP flexion	7
113	Thumb IP flexion, thumb total ROM, bilateral dexterity, and assembly dexterity	8
114	Ring DIP flexion	7
115	Thumb palmar abduction, thumb radial abduction, thumb MP flexion, index MP extension, index DIP extension, index total ROM, long MP extension, ring MP extension, small MP extension, small DIP extension, grip strength, key pinch strength, and three jaw chuck pinch strength	10

(Table continues)

Table 6 (continued)

Limiting Resources (LR) Identified for Toileting Performance in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources (Involved Side)	HLT Performance Rating
116	No LR identified on the involved side	6
117	Index DIP flexion	9
118	Small MP extension	4
119	No LR identified on the involved side	10
120	No LR identified on the involved side	7
121	Thumb opposition	8

Note. n = 21.

Subjects generally rated toileting higher than meal preparation (toileting M =7.2; SD = 2.2 after injury/disease and meal preparation M = 5.4; SD = .2). Nine subjects had only ROM as limiting resources, while 6 subjects had a combination of ROM, strength or dexterity. Five subjects had no limiting resource identified on the involved side, and one subject had a single LR (dexterity).

The initial measurements of the 21 subjects were examined and the limiting resources (LR) were identified for dressing and grooming. Table 7 presents the limiting resource for each subject in the performance of the task of dressing and grooming.

Table 7

Limiting Resources (LR) Identified for Dressing and Grooming Performance in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources	HLT Performance Rating
101	Ring PIP extension and small PIP extension	7
102	Index PIP extension, index PIP flexion, index DIP flexion, long DIP flexion, ring PIP flexion, ring DIP extension, ring total ROM, small DIP flexion, small total ROM, thumb opposition, and key pinch strength	5
103	Index total ROM, long PIP flexion, long DIP extension, long total ROM, ring DIP extension, grip strength, three jaw chuck pinch strength, fine dexterity, and assembly dexterity	5
104	Small DIP flexion, small total ROM, and tip pinch strength	2
105	No LR identified on the involved side	4
106	Index PIP extension, index DIP flexion, index total ROM, and tip pinch strength	7
107	Thumb IP extension, index MP flexion, ring MP flexion, small MP flexion, small DIP flexion, and grip strength	7

(Table continues)

Table 7 (continued)

Limiting Resources (LR) Identified for Dressing and Grooming Performance in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources	HLT Performance Rating
108	Long MP extension, long total ROM, ring MP extension, ring PIP flexion, ring total ROM, and involved small DIP extension	7
109	Thumb MP extension, index PIP flexion, index DIP extension, long PIP flexion, long DIP extension, ring PIP flexion, ring DIP extension, small PIP flexion, small DIP extension, and bilateral dexterity	9
110	Long PIP flexion, long DIP extension, long total ROM, and ring MP extension	8
111	Index PIP extension long PIP extension, long DIP flexion, ring PIP, involved ring DIP flexion, ring total ROM, small PIP extension, and involved fine dexterity	8
112	Tip pinch strength	7
113	Thumb IP flexion, thumb total ROM, small MP extension, grip strength, dexterity, and assembly dexterity	8
114	Ring DIP flexion	7

(Table continues)

Table 7 (continued)

Limiting Resources (LR) Identified for Dressing and Grooming Performance in Initial Measurements of the Involved Side and the Self-Reported Performance Rating for this High Level Task (HLT)

Subject Number	Limiting Resources	HLT Performance Rating
115	Thumb palmar abduction, thumb MP flexion, index DIP extension, small MP extension, and involved grip strength	5
116	Ring PIP flexion	3
117	Thumb MP extension, index PIP flexion, ring DIP extension, and involved small DIP extension	10
118	Small MP extension	3
119	Thumb MP extension	3
120	No LR identified on the involved side	7
121	Thumb MP flexion, index PIP flexion, index DIP extension, index DIP flexion, index total ROM, small MP extension, and thumb opposition	8

Note. n = 21.

As can be seen in Table 7, 9 subjects had identified limited resources of ROM only, while 2 subjects had no limiting resource identified on the involved side. Nine subjects had a combination of ROM and strength and/or dexterity limitations, and 1 subject had only strength as the identified LR. As can be seen from Tables 5, 6, and 7 for the performance of meal preparation and feeding, toileting, and dressing and grooming the limiting resource was frequently more than one (65%), and a single type of resource (i.e., ROM) was more frequently limited versus a combination (63%).

Demographics and Characteristics of the Retested Subjects

Twelve of the initial 21 subjects met the requirement of a minimum of four treatment sessions after the initial measurements and were re-measured. Table 8 presents the demographic descriptive data for the 12 retested subjects. The number of treatment sessions between initial evaluation and the retest is also presented.

Table 8

Retested Subjects' Gender, Age, Hand Dominance, Involved Side, and Treatment Sessions Between Initial Examination and Retest Examination

Subject Number	Gender	Age	Hand Dominance	Involved Side	No. of Treatments
101	F	65	R	R	5
102	M	67	R	R	9
103	M	44	R	R	12
104	F	55	R	L	10
105	M	51	L	L	12

(Table continues)

Table 8 (continued)

Retested Subjects' Gender, Age, Hand Dominance, Involved Side, and Treatment Sessions Between Initial Examination and Retest Examination

Subject Number	Gender	Age	Hand Dominance	Involved Side	No. of Treatments
106	F	29	R	R	5
107	F	28	R	L	12
108	M	70	R	L	6
109	M	39	R	L	4
111	M	56	R	L	16
116	M	70	R/L	L	8
119	M	18	R	R	8

Note. $\underline{n}$ = 12; refer back to Table 2 for each subject's disease/injury.

As can be seen from Table 8, the retested subjects ranged in age from 18 to 70 ($\underline{M}$=49.3; $\underline{SD}$=17.8). Eight of the subjects were men and 4 were women (i.e., 67% men and 33% women). Ten subjects were right handed (83% right hand dominant), one was left handed, and one was ambidextrous. Seven subjects' dominant hands were also their involved side, while 5 subjects were involved on their non-dominant side. The number of visits between initial evaluation and follow up retest ranged from 4 to 16 ($\underline{M}$=8.9; $\underline{SD}$=3.6).

Descriptive Data on Dependent Variables for Retested Subjects

The 12 subjects were all re-measured for functional performance, pain, ROM, strength, and dexterity. Table 9 presents the median, mean, standard deviation, and the minimum and maximum for their initial and retest measurements. Pain was measured on a 10 cm visual analog scale, performance was measured as a self-report on a scale of 1 to 10, ROM was measured in degrees with the exception of opposition (which was measured in cm), strength was measured in kilograms, and dexterity was measured by number of pegs/parts placed.

Table 9

Median, Mean, Standard Deviation, and the Minimum and Maximum for Retested Subjects' Initial and Retest Measurements of Pain, Performance, ROM, Strength, and Dexterity

Variables	Mdn	M	SD	Min	Max
Pain (cm)					
Initial	3.1	3.3	2.7	0	9.0
Retest	2.8	3.1	2.5	0	7.7
Meal Performance and Feeding after injury/disease (1-10 scale)					
Initial	4.0	5.2	2.8	2	9
Retest	7.0	6.7	2.0	3	10

(Table continues)

Table 9 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Retested Subjects' Initial and Retest Measurements of Pain, Performance, ROM, Strength, and Dexterity

Variables	Mdn	M	SD	Min	Max
Toileting Performance after injury/disease (1-10 scale)					
Initial	7.0	6.8	2.4	2	10
Retest	8.5	8.3	1.7	5	10
Dressing/Grooming Performance after injury/disease (1-10 scale)					
Initial	6.0	5.6	2.2	2	9
Retest	8.0	7.6	1.6	4	10
Finger ROM (deg)					
MP extension					
Initial	10	5	13.1	-55	22
Retest	10	5	14.9	-55	25
MP flexion					
Initial	80	77	13.6	20	100
Retest	82	80	12.2	29	100

(Table continues)

Table 9 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Retested Subjects' Initial and Retest Measurements of Pain, Performance, ROM, Strength, and Dexterity

Variables	Mdn	M	SD	Min	Max
PIP extension					
Initial	0	-1	11.0	-50	22
Retest	5	3	10.4	-34	22
PIP flexion					
Initial	95	92	16.6	0	120
Retest	97	93	17.0	0	111
DIP extension					
Initial	0	2	6.9	-25	17
Retest	0	2	5.6	-18	15
DIP flexion					
Initial	68	65	19.0	0	97
Retest	70	64	20.9	0	94

(Table continued)

Table 9 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Retested Subjects' Initial and Retest Measurements of Pain, Performance, ROM, Strength, and Dexterity

Variables	Mdn	M	SD	Min	Max
Thumb ROM (deg)					
Palmar abduction					
Initial	50	49	7.7	32	65
Retest	51	53	9.2	40	70
Radial abduction					
Initial	51	51	10.7	32	80
Retest	49	51	9.6	31	68
MP extension					
Initial	0	2	8.0	-25	20
Retest	0	3	8.5	-15	20
MP flexion					
Initial	53	51	16.9	12	84
Retest	58	56	15.4	20	85

(Table continues)

Table 9 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Retested Subjects' Initial and Retest Measurements of Pain, Performance, ROM, Strength, and Dexterity

Variables	Mdn	M	SD	Min	Max
IP extension					
Initial	17	17	12.2	-25	40
Retest	16	16	11.7	-16	40
IP flexion					
Initial	68	66	15.5	22	90
Retest	71	70	13.9	42	96
Thumb opposition (cm[a])					
Initial	0	.3	.8	0	4
Retest	0	.1	.3	0	1.3
Right grip strength (kg)					
Initial	35.3	28.9	19.3	0	54.0
Retest	35.5	32.8	17.7	3.3	56.3
Left grip strength (kg)					
Initial	20.7	23.1	14.1	3.7	54.0
Retest	27.2	26.9	11.1	6.7	45.7

(Table continues)

Table 9 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Retested Subjects' Initial and Retest Measurements of Pain, Performance, ROM, Strength, and Dexterity

Variables	Mdn	M	SD	Min	Max
Right Tip pinch strength (kg)					
Initial	4.4	3.9	2.0	0	7.3
Retest	5.1	4.7	2.7	0	9.7
Left tip pinch strength (kg)					
Initial	4.9	4.9	1.8	1.7	7.7
Retest	8.1	5.1	1.7	1.7	7.8
Right key pinch strength (kg)					
Initial	8.1	6.8	3.7	0	10.7
Retest	7.4	7.3	3.8	1.0	12.0
Left key pinch strength (kg)					
Initial	8.1	7.5	2.4	3.5	11.3
Retest	6.5	8.2	1.9	4.8	12.2
Right three jaw chuck pinch strength (kg)					
Initial	6.5	5.8	3.7	0	11.5
Retest	6.6	6.6	3.6	1.0	12.2

(Table continues)

Table 9 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Retested Subjects' Initial and Retest Measurements of Pain, Performance, ROM, Strength, and Dexterity

Variables	Mdn	M	SD	Min	Max
Left three jaw chuck pinch strength (kg)					
Initial	6.6	6.4	2.5	1.8	10.3
Retest	7.1	6.8	2.2	2.2	10.5
Dexterity (pegs/parts placed)					
Right hand					
Initial	12.5	10.7	4.9	0	15
Retest	13	11.8	4.0	0	17
Left hand					
Initial	12.0	11.8	3.3	7	19
Retest	12.5	12.3	2.3	9	17
Bilateral					
Initial	7.5	8.0	3.2	0	12
Retest	10.0	9.5	3.6	0	14

(Table continues)

Table 9 (continued)

Median, Mean, Standard Deviation, and the Minimum and Maximum for Retested Subjects' Initial and Retest Measurements of Pain, Performance, ROM, Strength, and Dexterity

Variables	Mdn	M	SD	Min	Max
Assembly					
Initial	30.0	25.0	12.8	0	47
Retest	55.0	28.9	12.4	0	47

Note. [a]thumb opposition is measured in distance of the thumb pad from the small MP (cm), therefore 0 is an ideal measure and > 0 in indicative of impairment; n = 12.

In Table 9 the self-report of pain changed very little between the initial and retest evaluation, with the exception of a decline in the maximum. Pain was excluded from the analysis of limiting resource and predictability of model, in this study pain was not a major contributing factor to the subjects' self-report of performance. The subjects' self-report of performance increased between the initial and retest measurements in all three tasks measured, and whether examining the median, mean, or the minimum. The measurements of ROM when examined by joint motion generally showed small increases (2 - 8°), large gains in ROM would not be expected due to the number of noninvolved digits included in the data. Three joints did exhibit a decrease in the maximum (2 - 9°). Increases were noted in strength, generally the increases were small (less than 1 to 3 kg), but the time period between the initial and retest was often less than 3 weeks (not generally considered sufficient time to make changes in strength). Dexterity results are somewhat mixed. There were increases in the median and mean for all four dexterity tests, but the minimum and maximum results were inconsistent.

Nonlinear Causal Resource Analysis of Retested Subjects

NCRA was used to build models for the prediction of performance as described in Chapter III. The model was built using the 84 possible basic performance resources (30 individual ROM measurements for each hand, 1 opposition measurement for each hand, 5 TROM measurements for each hand, 4 strength measurements for each hand, and 4 dexterity measurements). A different model was developed for each of the high level performance tasks: meal preparation and feeding, toileting, and dressing and grooming. Table 10 presents the predictions for both the initial and retest data for meal preparation and feeding.

Table 10

Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance in Meal Preparation and Feeding for Both the Initial and Retest Measurements

Meal Preparation and Feeding						
	Initial Measurements			Retest Measurements		
Subject Number	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|
101	7	7	0	7	5	2
102	3	3	0	5	2	3
103	3	3	0	3	3	0
104	2	2	0	4	4	0
105	3	3	0	6	6	0
106	8	8	0	8	8	0
107	4	4	0	7	7	0
108	4	4	0	8	8	0
109	9	9	0	10	10	0
110	8	8	0	-	-	-
111	9	9	0	9	9	0

(Table continues)

Table 10 (continued)

Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance in Meal Preparation and Feeding for Both the Initial and Retest Measurements

	Meal Preparation and Feeding					
	Initial Measurements			Retest Measurements		
Subject Number	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|
112	7	7	0	-	-	-
113	5	5	0	-	-	-
114	3	3	0	-	-	-
115	2	2	0	-	-	-
116	8	8	0	7	7	0
117	9	9	0	-	-	-
118	3	3	0	-	-	-
119	2	2	0	6	6	0
120	7	7	0	-	-	-
121	7	7	0	-	-	-

Note. n = 21 initial subjects; n = 12 retested subjects.

As can be seen in Table 10, the agreement between the subject's self-report and the NCRA prediction of performance was 100% for the initial measurements. There was 83% agreement between the self-report and NCRA prediction for the retest measurements.

Table 11 presents the predictions for toileting. The subject's self-report and the NCRA predictions are listed.

Table 11

Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance in Toileting for Both the Initial and Retest Measurements

Toileting						
	Initial Measurements			Retest Measurements		
Subject Number	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|
101	8	8	0	9	8	1
102	5	5	0	8	2	6
103	7	7	0	6	6	0
104	2	2	0	5	5	0
105	4	4	0	7	7	0

(Table continues)

Table 11 (continued)

Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance in Toileting for Both the Initial and Retest Measurements

Toileting						
	Initial Measurements			Retest Measurements		
Subject Number	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|
106	8	8	0	8	8	0
107	6	6	0	8	8	0
108	7	7	0	9	9	0
109	10	10	0	10	10	0
110	10	9	1	-	-	-
111	9	9	0	10	9	1
112	7	7	0	-	-	-
113	8	8	0	-	-	-
114	7	7	0	-	-	-
115	10	10	0	-	-	-
116	6	7	1	10	9	1
117	9	9	0	-	-	-

(Table continues)

Table 11 (continued)

Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance in Toileting for Both the Initial and Retest Measurements

Toileting						
	Initial Measurements			Retest Measurements		
Subject Number	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|
118	4	4	0	-	-	-
119	10	9	1	10	9	1
120	7	7	0	-	-	-
121	8	8	0	-	-	-

Note. n = 21 initial subjects; n = 12 retested subjects.

As shown in Table 11, the agreement between the subject's self-report and the NRA prediction of toileting performance in the initial measurements was 90% for ± 0 levels of difference (the self-reported and the predicted level of performance were exactly the same) and 100% for ± 1 level of difference (the difference between the self-reported and predicted level of performance was equal to or less than 1). The agreement for the retest measurements between the subject's self-report and NCRA prediction was 58% for ± 0 levels of difference and 92% for ± 1 level of difference.

Table 12 presents the predictions for dressing and grooming performance. The subject's self-report and the NCRA predictions are listed.

Table 12

Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance in Dressing and Grooming for Both the Initial and Retest Measurements

Dressing and Grooming

	Initial Measurements			Retest Measurements		
Subject Number	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|
101	7	7	0	9	7	2
102	5	5	0	8	1	7
103	5	5	0	6	6	0
104	2	2	0	4	4	0
105	4	4	0	6	6	0
106	7	7	0	7	7	0
107	7	7	0	8	8	0
108	7	7	0	8	8	0
109	9	9	0	10	9	1

(Table continues)

Table 12 (continued)

Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance in Dressing and Grooming for Both the Initial and Retest Measurements

Dressing and Grooming						
	Initial Measurements			Retest Measurements		
Subject Number	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|	Self-Rating	NCRA Predicted	Difference |(Meas-Pred)|
110	8	8	0	-	-	-
111	8	8	0	9	9	0
112	7	7	0	-	-	-
113	8	8	0	-	-	-
114	7	7	0	-	-	-
115	5	5	0	-	-	-
116	3	7	4	8	8	0
117	10	9	1	-	-	-
118	3	3	0	-	-	-
119	3	3	0	8	8	0
120	7	7	0	-	-	-
121	8	8	0	-	-	-

Note. n = 21 initial subjects; n = 12 retested subjects.

As shown in Table 12, the agreement between the subject's self-report and the NCRA prediction of dressing and grooming performance in the initial measurements was 95% for ± 0 levels of difference. The agreement for the retest measurements between the subject's self-report and NCRA prediction was 75% for ± 0 levels of difference and 83% for ± 1 level of difference.

The consistency of the model was tested using the contingency format presented in Table 1. Table 13 presents each of the 12 retested subjects' results of the consistency of determination for meal preparation and feeding.

Table 13

Contingency Table for Evaluation of the Nonlinear Causal Resource Analysis (NCRA) Model's Consistency for Each Retested Subject in Performance of Meal Preparation and Feeding using the Involved Side Only

Subject Number	Change in Task Performance	Measured Change in the Initial LR	Initial LR = Retest LR	Consistent/ Inconsistent with the Model
101	No change	Improved	Changed	Inconsistent[a]
102	Increased	Worse	Changed	Inconsistent[a]
103	No change	Improved	Changed	Consistent
104	Increased	Improved	Changed	Consistent
105	Increased	No LR on involved side	-[b]	-[b]
106	No change	No change	Changed	Consistent
107	Increased	Improved	Changed	Consistent
108	Increased	Improved	Changed	Consistent
109	Increased	Improved	Changed	Consistent
111	No change	Improved	Changed	Inconsistent[a]
116	Decreased	No change	Changed	Consistent
119	Increased	Improved	Changed	Consistent

Note. n = 12; [a] See Discussion for subject factors potentially affecting the subject's self-report; [b] Subject had LR identified on uninvolved side, see Discussion for implications.

For this study, in determining whether the limiting resource improved, 50% or better of the identified limiting resources had to demonstrate improvement. In determining whether the limiting resource had changed, any change was considered (both the addition and/or the deletion of a resource was considered a change). For subject number 105, there were no LR identified on the involved side. Therefore, this subject's data were not considered in the determination of consistency. In general the model demonstrated consistency in 73% of the subjects (8 of 11 subjects) for meal preparation and feeding. There were special consideration in 2 subjects' (subjects 101 and 102) retest data that are discussed in Chapter V.

Table 14 presents the consistency of the model for the performance of toileting. The format of the contingency table presented in Table 1 was used.

Table 14

Contingency Table for Evaluation of the Nonlinear Causal Resource Analysis (NCRA) Model's Consistency for Each Retested Subject in Performance of Toileting using the Involved Side Only

Subject Number	Change in Task Performance	Measured Change in the Initial LR	Initial LR = Retest LR	Consistent/ Inconsistent with the Model
101	Increased	Improved	Changed	Consistent
102	Increased	Improved	Changed	Consistent
103	Decreased	Improved	Changed	Consistent
104	Increased	Improved	Changed	Consistent
105	Increased	No LR on involved side	- [b]	- [b]
106	No change	Improved	Changed	Inconsistent[a]
107	Increased	Improved	Changed	Consistent
108	Increased	Improved	Changed	Consistent
109	No change	Improved	Changed	Inconsistent[a]
111	Improved	Improved	Changed	Consistent
116	Improved	No LR on involved side	- [b]	- [b]
119	No change	No LR on involved side	- [b]	- [b]

Note. n = 12; [a] See Discussion for subject factors potentially affecting the subject's self-report; [b] Subjects had LR identified on uninvolved side, see Discussion for implications.

Consistency of the model for toileting was determined using the method shown in Table 1. Subjects 105, 116, and 119 were excluded in the determination because they had no limiting resources identified on the involved side. The model demonstrated consistency for 78% of the subjects (7 of 9 subjects).

Table 15 presents the consistency of the model for the performance of dressing and grooming. The format of the contingency table presented in Table 1 was used.

Table 15

Contingency Table for Evaluation of the Nonlinear Causal Resource Analysis (NCRA) Model's Consistency for Each Retested Subject in Performance of Dressing and Grooming using the Involved Side Only

Subject Number	Change in Task Performance	Measured Change in the Initial LR	Initial LR = Retest LR	Consistent/ Inconsistent with the Model
101	Increased	Improved	Changed	Consistent
102	Increased	Improved	Changed	Consistent
103	Increased	Improved	Changed	Consistent
104	Increased	Improved	Changed	Consistent
105	Increased	No LR on involved side	- [b]	- [b]
106	No change	Improved	Changed	Inconsistent[a]
107	Increased	Improved	Changed	Consistent
108	Increased	Improved	Changed	Consistent
109	Increased	Improved	Changed	Consistent
111	Increased	Improved	Changed	Consistent
116	Increased	Improved	Changed	Consistent
119	Increased	Improved	Changed	Consistent

Note. n = 12; [a] See Discussion for subject factors potentially affecting the subject's self-report; [b] Subject had LR identified on uninvolved side, see Discussion for implications.

The results of the consistency of the model for dressing and grooming is presented in Table 15. Subject 105 was excluded from the determination owing to the lack of an identified limiting resource on the involved side. The model demonstrated 91% (10 of 11) consistency for dressing and grooming.

Summary

Demographic data and subject characteristics demonstrated that in terms of age, sex, and injury/disease this was a diverse subject population. NCRA demonstrated that thresholds could be determined for ROM, strength, and dexterity. Pain was excluded from the NCRA model development owing to the generally low pain scores reported by subjects. Pain did not appear to be a significant factor for this group of subjects. The NCRA model demonstrated that measurements of ROM, strength, and dexterity could predict task performance for this group of subjects: (a) 90% to 100% of the time (± 1 performance level) for the initial group of subjects, and (b) 83% to 92% of the time (± 1 performance level) for the retest group of subjects. Further, the model was consistent with the Resource Economic Principle, i.e., increasing levels of task performance appear governed by increasing levels of the resources demanded by the task.

CHAPTER V

DISCUSSION

Patients with disease and/or injury to the hand are assessed with many different tests and measures of their basic functional resources, such as ROM and strength. In this study, using the NCRA method, a model was developed to identify the basic resources limiting function in individual subjects, to determine whether there were thresholds of performance of those basic resources, and to validate the model created by testing it against retest data. Specifically, the purposes of this study were to (a) determine threshold values for ROM, strength, and dexterity, and levels of pain in specific functional task performance in people with diseased or injured hands using NCRA; (b) identify whether differing threshold values for each resource were detectable for varying levels of specific functional task performance; and (c) determine whether changes in ROM, strength, dexterity and/or pain would produce predictive changes in function when using the GPST model developed in the initial part of the study. Twenty-one subjects were initially measured for functional performance, pain, ROM, strength, and dexterity. Twelve of the initial 21 subjects were retested after a minimum of four treatment sessions. The results suggested that performance thresholds and limiting resources (LRs) could be identified. Further, the model successfully predicted task performance. This chapter contains the following: (a) Summary of Significant Findings, (b) Comparisons with the Literature, (c) Observations, (d) Limitations, (e) Clinical Significance, (f) Conclusions, and (g) Recommendations.

Summary of Significant Findings

The research questions and the results were as follows:

Question: Would threshold values be discernible for each measure of ROM, strength, dexterity, and pain in the hand with respect to the self-rated performance of the task of meal preparation and feeding?

Results: The Resource Demand Functions (RDFs) developed for meal preparation and feeding (84 RDFs) increased with increased self-reported functional levels, as evidenced by the lack of data in the lower right region of scatter plots and presence of data points in the upper left region. This provides evidence for the presence of the resource economic threshold principle, i.e., as increases in the resources were available, increased function was reported. In addition, the NCRA models predicted meal preparation and feeding performance very well. For this to occur, reasonably valid thresholds had to be identified. Thus, the data support an affirmative answer to the question, with the exception of the absence of pain, which was not evaluated.

Question: Would threshold values be discernible for each measure of ROM, strength, dexterity, and pain in the hand with respect to the self-rated performance of the task of toileting?

Results: The Resource Demand Functions (RDFs) developed for toileting (84 RDFs) increased with increased self-reported functional levels, again as evidenced by the lack of data in the lower right region of scatter plots and presence of data points in the upper left region. This provides evidence for the presence of the resource economic threshold principle, i.e., as more of the resource was available, increased function was reported. In this case as well, the NCRA models predicted high level task performance very well. For this to occur, reasonably valid thresholds had to be identified. Thus, the data support an affirmative answer to the question, with the exception of pain, which was not evaluated.

Question: Would threshold values be discernible for each measure of ROM, strength, dexterity, and pain in the hand with respect to the self-rated performance of the task of dressing and grooming?

Results: The Resource Demand Functions (RDFs) developed for dressing and grooming (84 RDFs) increased with increased self-reported functional levels, once more as evidenced by the lack of data in the lower right region of scatter plots and presence of data points in the upper left region. This provides evidence for the presence of the resource economic threshold principle, i.e., as more of the resource was available, increased function was reported. The NCRA model predicted dressing and grooming performance very well again, indicating that reasonably valid thresholds must have been identified. Thus, the data support an affirmative answer to the question, with the exception of pain, which was not considered in the analysis.

Question: Would the self-reported changes in the performance of meal preparation and feeding and the changes in the measures of ROM, strength, dexterity, and/or pain be consistent with the predictions derived from GSPT?

Results: A significant agreement was found between the self-reported changes in the performance of meal preparation and feeding and the changes in the measures of ROM, strength, and dexterity. This is consistent with the predictions derived from the GSPT. The data support an affirmative answer to the question.

Question: Would the self-reported changes in the performance of toileting and the changes in the measures of ROM, strength, dexterity, and/or pain be consistent with the predictions derived from GSPT?

Results: A significant agreement was found between the self-reported changes in the performance of toileting and the changes in the measures of ROM, strength, and dexterity. This is consistent with the predictions derived from the GSPT. The data support an affirmative answer to the question.

Question: Would the self-reported changes in the performance of dressing and grooming and the changes in the measures of ROM, strength, dexterity, and/or pain be consistent with the predictions derived from GSPT?

Results: A significant agreement was found between the self-reported changes in the performance of dressing and grooming and the changes in the measures of ROM, strength, and dexterity. This is consistent with the predictions derived from the GSPT. The data support an affirmative answer to the question.

Comparisons with the Literature

The disease/injury characteristics of the subjects in this study were representative of patients routinely treated by certified hand therapists (CHT) in the United States, as surveyed by the Hand Therapy Certification Commission (Muenzen et al., 2002). In the survey, CHTs reported the percentage of their patient population per major diagnostic categories. Sixty-two percent of the CHTs who responded indicated that greater than 25 to 75% of their patients were diagnosed with fractures. In this current study, 50% of the subjects were categorized with fractures. The other category in the survey with a similarly high percentage of patients was cumulative trauma (63% of the CHTs reported 25-75% of their patients were in this category), which included many shoulder and elbow disorders. Subjects with these injuries/diseases were excluded from this current study. The survey respondents reported 50 to 75% of the CHTs indicated approximately 10% of their patient population was included in each of the following categories: infections, Dupuytren's contracture, and multiple systems trauma. In the present study the preceding categories accounted for: 20% multiple systems trauma, 10% Dupuytren's contracture, and 10% infection. Again, this subject population was representative of patients routinely treated by CHTs.

All subjects in the study presented with measurable limitations in at least one of the basic resources and self-reported limitations in at least one of the three high level performance tasks studied. Though comparable studies with a similarly heterogeneous subject population were not found, the correlation between limitations in ROM, strength, and dexterity with function were present in the literature. Vliet Vlieland et al. (1996) reported that in subjects with rheumatoid arthritis (RA), grip and pinch strength accounted for 54% of functional variance in the hand. In another study of homogenous subjects with RA, Dellhag and Burckhardt (1995) reported that finger ROM deficits, thumb ROM deficits, grip strength, pain on resisted motion, pain on non-resisted motion, and stiffness were significantly correlated with actual and estimated hand function. The present study did not follow the traditional analysis methods used in the study of hand function and therefore direct comparisons with past studies are not possible. Results of this study confirm that the previously mentioned relationships of impairments to function do appear to exist, albeit from a different perspective, NCRA.

The measurement of all 31 traditional movements for assessment of ROM on one hand generated a large volume of data. The practice of summing the degrees of flexion and extension motion of each joint on one finger (Adams et al., 1992) has been used clinically (Bear-Lehman & Abreu, 1989) and in research (Brown et al., 2000; Stegink, Patterson, & Viegas, 2000) to minimize the volume of data. In this study both individual joint and total digit ROM measurements were used. The potential that summing individual measures can distort results was apparent when identifying limiting resources. A review of data in Tables 5, 6, and 7 demonstrates that when total ROM of a digit was used instead of individual measurements, greater than 50% of ROM limitations would not have been identified in this study. As noted by several authors (for example, Carter, 1987 and Adams et al., 1992) total active range of motion is not sensitive enough to detect changes at an isolated joint or may obscure pathological (hyper) extension of a joint.

Pain was excluded from the model development owing to its low subject-reported rating. Reported pain levels did not appear to be great enough to significantly influence the subjects' self-report of function. Dellhag and Burckhardt (1995), in their study of predictors of hand function in rheumatoid arthritis, were unable to report pain as a predictor of function because of its lack of independence from the other variables. This could also be the case in this study, as pain may be reflected in limitations in grip strength, ROM, etc. Although, again, the pain rating for subjects in this study was low ($\underline{M} = 2.7$; $\underline{SD} = 2.2$).

Macey and Kelly (1993) and Swanson et al. (1995) both reported that a grip strength of approximately 4 kg of force was needed for performance of 90% of ADLs and 1 kg of pinch force was sufficient for most simple activities. In the present study, a grip strength force of 4 kg, in general, produced self-rated performance levels near or below a score of 5 for meal preparation and feeding and for dressing and grooming. A grip strength of 10 kg or more was needed in both meal preparation and feeding and in dressing and grooming to improve self-rated performance levels to the 7-10 range. The performance of toileting followed the same general trend, but three subjects (3 out of 21) rated their toileting performance level above a 5 with grip strength force below 10 kg. Refer to Figures 1b, 2b, and 3b for a graphic representation. In this study, a pinch strength (tip, key, or three jaw chuck) force of greater than 1.5 kg was needed for functional performance to be rated at or above a level 5 in all three tasks. In general, for the three ADLs investigated in this study, a grip strength force of 4 kg and a pinch strength force of 1 kg were inadequate to function in the tasks of meal preparation and feeding, toileting, and dressing and grooming above a subject self-reported rating of 5. A key difference in the present study is the incorporation of the "level of performance" at which the HLTs were executed, i.e., BPR requirements were not simply linked to "can" or "can't do," but rather to "how well" a particular ADL was performed.

Observations

Use of the self-reports of performance and the VAS for pain seemed to irritate the subjects in the initial phase of the study. There were frequent comments concerning the number of questionnaires they were asked to complete during the initial session. However, subjects who returned for the retest session did not comment on the amount of paperwork required to complete the self-reports of performance and the VAS for pain. The initial numbers of forms and questionnaires seemed to create a level of tension that may have affected the subjects' answers to the questions and their self-reported performance ratings.

The rating of toileting performance tended to produce many nonverbal responses in the men and few questions to confirm their understanding of what the investigator was asking. Most subjects asked at least one question to clarify their understand on one of the sections of the self-rating of performance. The self-report of performance appeared easier for the subjects on the retest, i.e., fewer questions, less crossing out and changing answers, and fewer general comments about the forms.

All subjects were volunteers and several had asked to be in the study when they saw others being tested. The level and sincerity of effort appeared high and may not be representative of the general patient population of hand therapy patients.

At the time of the retest measurements, two subjects demonstrated decreases in their BPRs from when they were initially measured. These 2 subjects, specifically, reported situations that worsened their condition just prior to the retest. This may have affected the NCRA model in terms of accuracy in predicting performance levels. Although the subjects were asked to rate their function for the day of the retest ("how well can you perform the task yourself, today?"), they may have partially discounted their current exacerbation and reflected on their overall performance prior to the exacerbation.

Table 16 presents information on the 2 retested subjects whose self-reported level of function on all three HLTs at the time of the retest was higher than the performance predicted using NCRA.

Table 16

<u>Retested Subjects' Subjective Information Potentially Impacting Re-Measurements</u>

Subject Number	Self-reported Information Potentially Impacting Retest Measurements	VAS Pain rating (cm)	
		Initial	Retest
101	Subject reported spending 7 hrs driving on the day before the retest measurements were taken. The subject reported that she was pain free prior to drive. (This may represent overuse of her involved hand.)	0.7	7.7
102	Subject reported having a very aggressive therapy session the day prior to the retest. He complained of "a lot" of pain in the involved hand and arm.	1.7	2.5

Both subjects' retest measures of ROM, strength, and dexterity were generally worse suggesting that their level of performance should have also been reduced. As can be seen in Table 16 the subjects reported increased pain at the time of retest. There is no way of knowing the subjects' mind set at the time of the retest, like all self-reports potential exists for the subject's own interpretation of the questionnaire. However, exacerbation does occur and can affect outcome ratings both in research and in clinical practice.

Limitations

Two conditions that were not factored into the study that may have affected some of the subjects, i.e., wounds and edema. Several subjects had wounds that produced impairments not measured. Having wounds seemed to cause a hesitancy in effort. If sutures were present, they often pulled or were bothersome to the subjects. In addition, occasionally gauze or a dressing may have influenced grip or positioning. Edema is a common problem encountered in the treatment of hand injuries/diseases. Edema potentially limits motion and thereby may restrict both hand function and the basic resources such as degrees of ROM. Neither of these impairments were measured and therefore potentially influenced the data. However, both edema and wounds, like pain, may be reflected in the ROM, strength, and dexterity measures.

Subjects with neurological impairments were excluded from this study. The measurement of sensation would have produced approximately 80 more data points per subject and would be a necessary measurement in subjects with neurological deficits. Patients with neurological impairments account for 10-25% of the population in more than 60% of the clinical practices of certified hand therapist (Muenzen, 2002). The findings of this study cannot be generalized to patients with neurological impairments.

Hand dominance was an issue that was considered initially in the study design. Not wanting to limit the possible number of subjects by only recruiting subjects with involvement of their dominant or of their non-dominant side, it was decided to accept all subjects who met the inclusion criteria. In the data analysis, the focus was on the involved side and hand dominance was not considered. The fact that some subjects were involved on their dominant side and others were involved on their non-dominant side could potentially effect the self-reports of functional performance. That is, it may have been easier for subjects to accommodate for involvement on their non-dominant side than on their dominant side. Thus, the potential existed for this issue to skew the data.

The fact that some subjects had impairments of their uninvolved hand was another potential limitation of this study. Specifically, subject 105 had bilateral Dupuytren's contractures and the side of his surgical release was considered his "involved side" for the data analysis because it was the hand receiving treatment. However, his non-operated side at that point had greater ROM limitations, and eventually was to be surgically released as well. Interestingly, the NCRA analysis identified his limiting resources on his non-involved hand. Thus, some tasks were difficult for the subject because of involvement of both hands. The scope of this investigation did not allow for analysis of the uninvolved (i.e., non-treated) side.

The measurements of performance and pain were both self-reports and they present limitations of subjectivity. Most subjects were able to complete the VAS for pain without assistance, but in general most subjects required verbal assistance in completing the self-report of functional performance. Though the investigator tried to provide the same information to all subjects there was potential for her answers to the subject's questions to influence the subject's score. Perhaps for the future, should the same type of performance scale be used, it either needs more written explanation or the investigator should refrain from answering any questions about the scale.

The self-report of functional performance was adapted specifically for this investigation from Binkley (2000). The scale uses a number scale with descriptors at each end. Fisher (1992) pointed out that no gold standard exists for the measurement of function. As noted previously, self-reported function versus an expert rating, or objective functional assessment, might affect the results. Subjects may differ on their interpretation of the task and on their interpretation of "levels" of performance. However, the use of a study-specific tool to measure function has been common practice and the results can provide useful information (Badley et al., 1984).

All subjects who were retested received treatment and that treatment was varied and not controlled. There were different numbers of treatment sessions, varying time between sessions, and treatment was provided by four different therapists. All these factors limit the ability to address the treatment other than to state that it was provided. The changes in measurements may have been attributable to time. However, neither the type of treatment, nor the amount of treatment was important in this study. Only the effect of changes in task performance based on changes in BPR availability were important in the analysis. Retest measures were included for the purpose of validating the model.

Finally, the number of subjects studied is considered to be small. Although more than 8,500 independent measurements were made, more robust NCRA-based models require substantially greater numbers of subjects, especially given the large number of BPRs associated with hands. Models built on at least 100 cases (i.e., more subjects than BPRs) are probably needed. Should the general concept introduced here gain widespread support, the effort to develop models based on even large sample sizes would be warranted.

Clinical Significance

The model developed in this study could be used as a template for identifying thresholds and limiting resources, and/or for performance prediction for individual patients. The measurements needed to use the model for these purposes are routinely taken on patients with hand problems. The model has the potential to provide clinicians with specific values for goal setting and motivating patients by providing patients with a clearer idea of the amount of a basic resource needed to accomplish a specific task. Potentially the model may be used to help reduce disability by identifying limiting resources that might otherwise be overlooked, especially when the limitation is not obvious. Lastly, the model could be used to justify continuation or termination of treatment.

Conclusions

The purposes of this study were to determine threshold values for ROM, strength, and dexterity, and levels of pain in functional task performance in diseased or injured hands using NCRA, to identify whether differing threshold values were detectable for varying levels of performance of a functional task, and further, to determine whether changes in ROM, strength, dexterity and/or pain produced predictive changes in function when using the GPST model developed in the initial part of the study. The resource demand functions (RDF) developed were effective in: (a) determining thresholds of ROM, strength, and dexterity specifically for the three tasks of meal preparation and feeding, toileting, and dressing and grooming, (b) identifying limiting resources for the three tasks, and (c) for accurately predicting functional performance levels for the three tasks. The model was developed using a heterogeneous population of non-neurologically involved subjects with hand injuries, which makes the model applicable in a traditional hand therapy setting. If a larger sample of measures is collected; thereby, creating a more robust model and database, and if a user friendly format for its use could be developed, use of these thresholds could be used to identify performance limiting resources in individual non-neurologically involved hand therapy patients. The model could then become a valuable tool in developing treatment goals and plans and in motivating patients.

Recommendations

A more robust NCRA-based model needs to be developed using greater numbers of subjects. Further, as previously noted, more potential impairments, especially, pain, edema, sensation, may need to be measured and factored into the model to ensure that all limiting resources are identified.

The influence of hand dominance on the effect of the involved side on functional performance was not addressed in this study. This suggests a need for future study to examine the potential effect of hand dominance on performance prediction.

A case series study using the model with numerous patients would provide feedback as to its potential use in the clinical setting. A patient's measurements inputted into the model would produce the limiting resources, thresholds, and performance predictions for that patient. A treatment plan developed specifically according to the model could be used to direct the intervention. Retest measurements could be used to confirm whether the model was successful in directing the treatment and achieving the desired patient outcomes.

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APPENDIXES

APPENDIX A

Self-Report of Prior and Current Hand Activity Performance

Self-Report of Activity Performance
PIN #______

Instructions:
This questionnaire asks you about your ability to perform certain activities and use your hands. Please answer all questions. The first 2 questions are about the overall uses of each hand and the last 3 questions are your ability to do specific activities. In each section the first question is based on your ability before you had a problem with your hand or hands. The second question is based on your ability today. If you have not performed the activity today, please make your best estimate as to how you would perform the activity today.

Circle the appropriate number for each question.

RATE THE OVERALL USE OF YOUR RIGHT HAND.

Before you had a problem with your hand:

1	2	3	4	5	6	7	8	9	10
Unable to use									Best possible

Today:

1	2	3	4	5	6	7	8	9	10
Unable to use									Best possible

RATE THE OVERALL USE OF YOUR LEFT HAND.

Before you had a problem with your hand:

1	2	3	4	5	6	7	8	9	10
Unable to use									Best possible

Today:

1	2	3	4	5	6	7	8	9	10
Unable to use									Best possible

HOW WELL CAN YOU TAKE CARE OF ALL YOUR MEAL AND EATING ACTIVITIES?
(such as: cutting your food, opening containers, feeding yourself, preparing your meals, etc.)

Before you had a problem with your hand/hands?

1	2	3	4	5	6	7	8	9	10
Unable to perform this activity									Able to perform this activity in the same way as before injury or problem

Today?

1	2	3	4	5	6	7	8	9	10
Unable to perform this activity									Able to perform this activity in the same way as before injury or problem

HOW WELL CAN YOU GO TO THE RESTROOM BY YOURSELF?
(such as: removing and replacing your clothing, handling the toilet paper, cleaning yourself, etc.)

Before you had a problem with your hand/hands?

1	2	3	4	5	6	7	8	9	10
Unable to perform this activity									Able to perform this activity in the same way as before injury or problem

Today?

1	2	3	4	5	6	7	8	9	10
Unable to perform this activity									Able to perform this activity in the same way as before injury or problem

HOW WELL CAN YOU DRESS AND GROOM YOURSELF?
(such as: putting on and removing shoes, socks, and all usual clothing, bathing, hair care, brushing teeth, shaving, applying makeup, etc.)

Before you had a problem with your hand/hands?

1	2	3	4	5	6	7	8	9	10
Unable to perform this activity									Able to perform this activity in the same way as before injury or problem

Today?

1	2	3	4	5	6	7	8	9	10
Unable to perform this activity									Able to perform this activity in the same way as before injury or problem

(Adapted from Binkley, 2000)

APPENDIX B

Goniometry and Visual Estimation Reliability Statistics

Goniometry and Visual Estimation Reliability Statistics

Method of measurement for the two joints measured	M	SD	Range	Interrater repeatability coefficients r
Visual / 1st joint	42.1	15.7	65	44.5
Goniometric /1st joint	44.5	1.1	6	4.4
Visual / 2nd joint	9.4	18.0	95	51.0
Goniometric / 2nd joint	7.8	1.7	9	5.9

(Adapted from Bruton, Ellis, & Goddard, 1999)

APPENDIX C

Summary of Studies Examining the Reliability and Validity of Grip/Pinch Strength Measures

Summary of Studies Examining the Reliability and Validity of Grip/Pinch Strength Measures

First Author	Topic Investigated	Statistical Results	Conclusions
MacDermid (2001)	Inter-instrument reliability of three devices used to measure pinch strength.	ICC (2,1) = .80 – .98	Lack of instrument bias. Results from the three devices can be compared with either of the others.
Woody (1988)	Comparison of forearm neutral versus pronation in the measurement of key and palmar pinch.	Two-tailed, paired-data t-test: $t = 3.14 / 3.00$ ($p < 0.01$) for key pinch, right and left respectively; t values were not significant for palmar pinch	Standard positioning is a significant factor in testing key pinch strength.
King (1988)	Correlation analysis of grip as measured by two different devices.[a]	Pearson $r = .869$ ($p<0.0001$)	A high correlation exists between the two devices[a] in the measurement of grip strength.
Nitschke (1999)	Test – retest reliability of grip strength and size of change needed to detect genuine change.	Pearson $r = .93$ - .95	High test-retest reliability was found for both healthy women and patients with upper extremity pain. A change of > 6 kg is needed to detect genuine change.

[a]Jamar® hand held dynamometer (Sammans Preston, Inc, Bolingbrook, IL) and the BTE® computerized dynamometer (Baltimore Therapeutic Equipment, Baltimore, MD).

APPENDIX D

Summary of Assessment of Hand Pain in Recent Studies

Summary of Assessment of Hand Pain in Recent Studies

Study	Sample Size and Diagnosis	Specific Tool Used
Dellhag & Burckhardt (1995)	n=52 rheumatoid arthritis	10 point scale for pain with motion 100 mm VAS[a] for non motion pain
O'Connor, Kortman, Smith, Ahern, Smith, & Krishnam (1999)	n=25 rheumatoid arthritis	10 point NPS[b] (0= no pain, 10= worst possible pain)
Alderson & McGall (1999)	n = 17 carpal tunnel syn.	10 cm VAS
Tomaino, Miller, & Burton (1994)	n=18 non-rhematoid arthritis with wrist fusion	Pain rating scale: None, minimal, moderate, and marked
Field, Herbert & Prosser (1996)	n=20 total wrist fusion (post-traumatic)	Pain rating scale: 1=no pain to 4=severe pain requiring regular analgesics
Vliet Vlieland, van der Wijk, Jolie, Zwinderman, & Hazes (1996)	n=50 rheumatoid arthritis	0-100 mm VAS
Wakefield & McQueen (2000)	n=96 distal radius fractures	10 cm VAS

Note. [a]VAS = Visual Analogue Scale; [b] NPS = Numeric Pain Scale

APPENDIX E

Summary of Results for Measures of Dexterity

Summary of Results for Measures of Dexterity

Test	Norms	Number of Abnormal Responses in HAVS[a] Subjects	Ratio of Abnormal Responses in HAVS Subjects	Mean Score HAVS Subjects	Mean Score of Control Group
Moberg Pickup Test (normal vision)	<13	12	12/20	15	9
Moberg Pickup Test (vision occluded)	<25	16	16/20	36	22
Purdue Pegboard Test	>14	17	17/20	11	15
Crawford Small-Parts Dexterity Test	<6.24	8	8/20	6.49	4.75
Minnesota Manual Dexterity Test	<310	11	11/20	331	255

[a]HAVS - hand-arm vibration syndrome

Adapted from Cederlund, Isacsson, & Lundborg (1999)

APPENDIX F

Functional Scales of Performance Used in Recent Studies

Functional Scales of Performance Used in Recent Studies

Test	Rating	Description
41 item questionnaire (Badley et al., 1984)	0 - 7	No difficulty – Impossible (each of the 8 levels had a written description)
Disabilities of the Arm, Shoulder, and Hand (DASH) outcome measure (Beaton et al., 2001)	1 - 5	No difficulty – Unable (each of the 5 levels had a written description)
Lower Extremity Functional Scale (LEFTS) (Binkley et al., 1999)	0 - 4	Extreme difficulty – No difficulty (each of the 5 levels had a written discription)
Visual Analog Scale (VAS) (Dellhag & Burckhardt, 1995)	100 mm line	No function – Full function (only the ends of the scale had written discriptions)
Patient specific questionnaire (Chatman et al., 1997)	0 - 10	Unable to perform – Performs same as before (only the ends of the scale had written discriptions)

APPENDIX G

Components of this Current Study Expressed in the

Elemental Resource Model (ERM)

Components of this Current Study Expressed in the Elemental Resource Model (ERM)

Complex/High Level Tasks	Intermediate Tasks	Estimated Elements
Toileting (in relation to demands on hands only)	Manipulating clothing (including: zipping, buttoning, pulling clothing off and on) Manipulating toilet paper Cleaning one's self	Finger ROM Pinch strength Finger dexterity
Dressing and grooming (in relation to demands on hands only)	Zip up and down Do and undo buttons Manipulate clothing (including: grasping clothing, pulling on, pulling off)	Finger ROM Grip and pinch strength Finger dexterity
Meal Preparation and Feeding (in relation to demands on hands only)	Grasping food Hand to mouth Cut food Manipulate utensils Hold cup	Finger ROM Grip and pinch strength Finger dexterity

APPENDIX H

Agreement Between Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance and Experts' Rating of Performance on Mobility Tasks

Agreement Between Nonlinear Causal Resource Analysis (NCRA) Predictions of Performance and Experts' Rating of Performance on Mobility Tasks

	Performance Tasks		
Range of Agreement (0-100 scale)	Gait (n)[a]	Stair Climbing (n)[a]	Obstacle Course (n)[a]
Within 2 points	19	22	11
Within 10 points	23	29	23
Within 15 points	26	29	29
>15 points	4	1	1

Notes:
[a]The number of subjects with NCRA predictions and expert rater scores within highlighted range of each other.

Adapted from Kondraske, Johnston, Pearson, & Tarbox (1997)

APPENDIX I

Visual Analogue Sale: Pain

Pin # _____

Pain Scale

Instructions: Please mark on this line how you would rate the severity of your hand pain today.

No pain ____ Worst Possible Pain

APPENDIX J

Consent to be Contacted

Consent to be Contacted

I, _______________________________, give permission to be contacted about a study in hand function by Ann Mitchell.

Name: ___________________________

Phone Number: ____________________

Signature: ___________________________

APPENDIX K

Initial Phone/In Person Screen

Pin # _____

Initial Phone/In Person Screen

Interested in participation in study?	YES	NO
Inclusion Criteria:		
Pt at clinic:	YES	NO
Hand pathology:	YES	NO
>/= 18 years old:	YES	NO
Exclusion criteria:		
Shoulder, elbow, wrist screen:		
1. Touch the back of head with L and R hands	YES	NO
2. Touch the opposite acromion with L and R hands	YES	NO
3. Touch the small of back with L and R hands	YES	NO
Cognitive or communication difficulties:	YES	NO
Neuropathology of hand:	YES	NO

When is your next hand therapy appointment scheduled? ________________________

Would you be able to come in 45 min. earlier to allow for testing? ________________

Scheduled date and time for testing: ____

How much longer will you be receiving hand therapy? __________________________

APPENDIX L

Subject Consent to be in Research Study

Subject Consent To Be In Research

Title of Study:	Hand Range of Motion, Strength, Dexterity, and Pain as Predictors of Hand Functional Performance

Researchers:	Phone:	Cell Phone:
Ann Mitchell, PT	972-317-8715	214-912-1014
Sue Smith, PT, Ph.D.	214-706-2310	

You are being asked to be in a research study. Persons who are subjects in research have certain rights. These rights include your right to:

1. Be told about the nature and purpose of the research,
2. Be told about the procedures and any device to be used in the research,
3. Be told about any discomforts and risks that could occur,
4. Be told about any benefits you may expect,
5. Be told about any other treatments or devices that might be helpful to you,
6. Be told about other medical treatments, if any, available to you during or after the research if problems arise,
7. Ask questions about the research,
8. Stop being in the study at any time,
9. Have a copy of this signed and dated consent form, and
10. To decide to be in the study or not to be in the study without pressure or untruths.

You have the right to privacy. To protect your privacy you will be assigned a personal identification number (PIN) at the beginning of the study. All data collected will be recorded under that PIN. Any information gathered in this study that relates to you personally will be kept private. Only the principal investigators will have access to your personal identifying information, this will be destroyed at the completion of the study. Any information that comes from this study that has your name on it may only be shown to those carrying out the study, the Presbyterian Hospital of Dallas Human Research Committee, the Institutional Review Board at Texas Woman's University, and your doctors. Information that includes your name will be shown to others only as required by law. If the results of the study are published, your name will not be used.

The records about your being in this study may be looked at by members and staff of the Presbyterian Hospital of Dallas Human Research Committee, and you may be asked questions by a member of that Committee about being in this study. If you wish, you may refuse to answer these questions. Your record may be chosen at random (as by drawing straws for review by the Committee).

Ann Mitchell and Sue Smith can tell you about treatment in case of problems from the research, which you should report to them promptly. Phone numbers where the researcher may be reached are listed on the top of this form.

Be sure to ask the researcher any questions you have about the research or about your rights as a subject. If you have questions later, or if you wish to report a problem related to the research (besides telling the researcher, you may call the Human Research Committee of Presbyterian Hospital of Dallas at 214-345-6901).

The Presbyterian Hospital of Dallas Human Research Committee has reviewed this research based on certain laws about research in human subjects. Approval of this research by the Committee does not imply that the Committee is responsible for the conduct of this research or its results.

Being in this research is of your own free will. Choosing not to be in this study will involve no penalty or loss of benefits. If you decide to be in this research, you are free to withdraw at any time. If you withdraw form the study, you can still have standard treatment outside the study.

The information on the next few pages tells you about the research and what you will be asked to do if you decide to be in the study. It also tells you about the risks and benefits of being in the study. Please read this with care and feel free to ask questions.

Purpose of the Study:

It has been shown in other research that hand range of motion (how much movement a joint has), strength, dexterity (how well you are able to handle an object), and pain affect how well you can do an activity (for example, dressing). It is not clear how much of each of these (range of motion, strength, dexterity, and pain) change your ability to use your hands to do an activity. Such as, how much range of motion is enough to dress yourself? We will try to find the specific amounts of hand range of motion, strength, and dexterity necessary to do a specific activity. We will also try to find out if there are certain levels of hand pain that prevent you from doing a specific activity. All the measurements that will be done in this study are typically used in hand therapy to help the therapist identify problem areas. You are being asked to be in this study because you have a problem with your hand or hands.

What You Will Be Asked To Do If You Are In This Study:

If you are in this study you will be asked questions about your problem with your hand or hands. You will be asked to rate your ability to use your hands to feed yourself, dress yourself, and go to the bathroom by yourself. You will be asked to rate your hand pain level. I will measure your hands' range of motion, grip strength, pinch strength, and dexterity. This will take one session lasting approximately 45 min. If you are willing and have at least 4 more hand therapy treatments, I will ask if I can re-measure your hands like I did the first time. The re-testing will also take 45 min. No measurement will be done which is contrary to your physicians orders.

Research Procedures:

None of the measurements you will be asked to do are unusual. All the test and measurements are in common use in hand therapy clinics, including here at Presbyterian Hospital.

Risks And Discomforts:

You may experience brief discomfort during the range of motion, strength, or dexterity testing. You might experience temporary joint or muscle soreness after the tests. You will be required to donate approximately 45 min. of your time on one to two separate occasions.

Benefits:

The results of this research may help therapists to better treat persons with hand injuries. You may also gain a better understanding of your hand function.

Withdrawal From Being In The Study:

You are not required to be in this study. Your being in this study is of your own free will. You may withdraw from this study at any time without penalty or loss of benefits. If you choose not to be in the study, your care will not be affected.

Your being in this study will be stopped by the researcher if, in her opinion, there is any change in your condition which might be made worse by being in the study.

Costs Of Being In The Study:

The only cost to you is your time, 45 to 90 min. on one or two separate occasions.

New Findings:

Any new findings during the research that might affect your wanting to be in this study will be given to you.

Payment For Being In The Study:

You will not be paid for being in this study.

Consenting To Be In This Study:

You are deciding whether or not to be in this study. You should not sign until you understand all the information presented in this form and until all of your questions about this research have been answered. Signing this form shows that you have decided to be in this study, having read (or been read) the information given above.

1. I understand that this is a research study. [ ] Yes [ ] No

2. I understand the risks of being in this study. [ ] Yes [ ] No

3. I understand the length of time I will be in this study. [ ] Yes [ ] No

4. I understand the purpose and hoped for outcomes of this study. [ ] Yes [ ] No

5. I understand that my being in this study is of My own free will. [ ] Yes [ ] No

If you did not answer "yes" to all of the above questions, please review being in this study again with the researcher. You should only sign this consent when you have answered "yes" to all of the questions above.

Signature Lines:

______________________________ ______________
Signature of Subject Date

______________________________ ______________
Signature of Witness Date

______________________________ ______________
Signature of Researcher Date

You Will Be Given A Copy Of This Consent Form To Keep

APPENDIX M

Intake Assessment

PIN #_____

Intake Assessment

Date:____________
Age:_____________
Sex:_________
Hand dominance:_____
Diagnosis:____
Date on onset/injury:____________________
Related surgical procedures:____
Date of above surgeries:______________________
Date therapy started:_______________
Assistive devices used (including splints):_________________________________
Medical restrictions (ex. no active flexion):________________________________
Medications:____
Treating therapist:____

Review inclusion and exclusion criteria:
Inclusion:

Pt. at clinic:	Yes	No
Hand pathology:	Yes	No
>/= 18 years old:	Yes	No

Exclusion:

Shoulder, elbow, wrist screen:		
Touch the back of head with L and R hands	Yes	No
Touch the opposite acromion with L and R hands	Yes	No
Touch the small of back with L and R hands	Yes	No
Cognitive or communication difficulties:	Yes	No
Neuropathology of hand:	Yes	No

APPENDIX N

Performance Measurements

PIN # _____

Initial / reliability / cause & effect

Performance Measurements

ROM:

Digit		Right	Left	Thumb	Right	Left
Index	MP PIP DIP			CMC palmar ABD radial ABD		
Long	MP PIP DIP			MP IP opposition		
Ring	MP PIP DIP					
Small	MP PIP DIP					

Strength:

Grip: R 1st trial _____ 2nd trial_____ 3rd trial_____ average_____
L 1st trial _____ 2nd trial_____ 3rd trial_____ average_____

Pinch:
Tip: R 1st trial _____ 2nd trial_____ 3rd trial_____ average_____
L 1st trial _____ 2nd trial_____ 3rd trial_____ average_____

Key: R 1st trial _____ 2nd trial_____ 3rd trial_____ average_____
L 1st trial _____ 2nd trial_____ 3rd trial_____ average_____

3-jaw: R 1st trial _____ 2nd trial_____ 3rd trial_____ average_____
L 1st trial _____ 2nd trial_____ 3rd trial_____ average_____

Dexterity:
Right Hand: _____ Left Hand: _____ Both Hands: _____

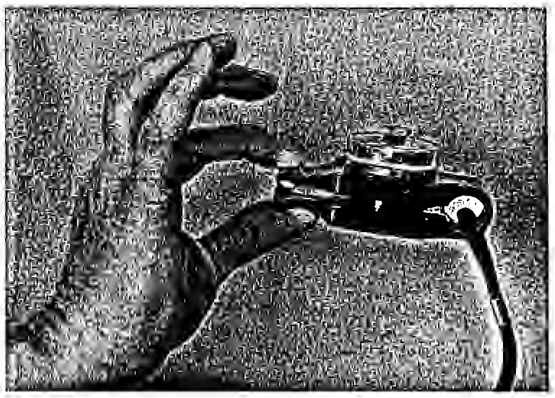
Assembly: _____ Total Score (sum of R, L, both, and assembly): _______

APPENDIX O

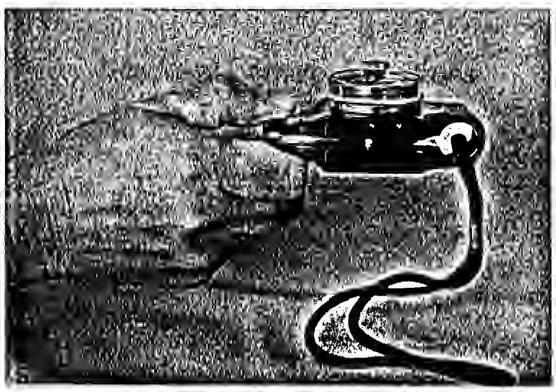
Pinch Patterns

Pinch Patterns:

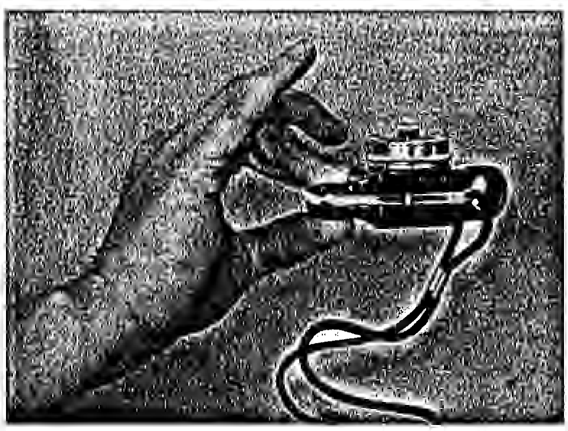
Tip-to-Tip



Key



3 Jaw Chuck



APPENDIX P

Resource Demand Functions
in Coordinate Format

Resource Demand Functions in Coordinate Format for Meal Preparation and Feeding for Each Resource Measured

Basic Resource	(x_1,y_1)	(x_2,y_2)	(x_3,y_3)	(x_4,y_4)	(x_5,y_5)	(x_6,y_6)	(x_7,y_7)	(x_8,y_8)
I Thumb palmer abduction	(2,34)	(3,39.5)	(9,40)	(10,60)				
I Thumb radial abduction	(8,31)	(9,34)	(10,45)					
I Thumb MP ext.	(2,65)	(8,75)	(9,86)	(10,100)				
I Thumb MP flex.	(2,20)	(7,24)	(8,35)	(9,42)	(10,52)			
I Thumb IP ext.	(4,65)	(7,74)	(8,90)	(9,102)	(10,110)			
I Thumb IP flex.	(5,22)	(9,46)	(10,71)					
I Thumb Total ROM	(2,162)	(5,179.5)	(9,180)	(10,258)				
U Thumb palmar abduction	(5,32)	(9,36)	(10,66)					
N Thumb radial abduction	(2,32)	(7,39)	(8,46)	(9,58)	(10,75)			
N Thumb MP ext.	(8,79.5)	(9,80)	(10,90)					
N Thumb MP flex.	(2,12)	(7,30)	(8,38)	(9,44)	(10,63)			
N Thumb IP ext.	(8,95)	(9,104.5)	(10,105)					
N Thumb IP flex.	(3,41)	(9,44)	(10,81)					
N Thumb Total ROM	(2,183)	(3,196)	(9,200)	(10,300)				
I Index MP ext.	(3,60)	(8,80)	(9,95)	(10,102)				
I Index MP flex.	(4,48)	(7,56)	(9,61)	(10,62)				
I Index PIP ext.	(3,70)	(8,78)	(9,82)	(10,93)				
I Index PIP flex.	(3,60)	(8,63)	(9,90)	(10,101)				
I Index DIP ext.	(2,66)	(3,84)	(7,87)	(9,88)	(10,90)			
I Index DIP flex.	(3,13)	(7,34.5)	(8,35)	(9,52)	(10,76)			
I Index Total ROM	(3,29)	(8,183)	(9,210)	(10,252)				
N Index MP ext.	(6,52)	(8,90)	(9,100)	(10,105)				
N Index MP flex.	(8,66)	(9,72)	(10,73)					
N Index PIP ext.	(3,79.5)	(5,80)	(6,89.7)	(9,90)	(10,100)			
N Index PIP flex.	(7,90)	(9,93.5)	(10,94)					
N Index DIP ext.	(2,65)	(3,75)	(8,87)	(9,90)	(10,100)			
N Index DIP flex.	(4,48)	(5,55)	(7,56)	(8,61)	(9,62)	(10,80)		
N Index Total ROM	(2,219)	(6,226)	(7,236)	(8,237)	(9,249)	(10,282)		
I long MP ext.	(4,50)	(8,58)	(9,95)	(10,105)				
I long MP flex.	(7,57)	(8,68)	(10,78)					
I long PIP ext.	(9,69)	(10,95)						
I long PIP flex.	(3,32)	(8,65)	(9,94.7)	(10,95)				
I long DIP ext.	(2,78)	(9,85)	(10,93)					
I long DIP flex.	(3,13)	(9,29)	(10,70)					
I long Total ROM	(3,71)	(4,154)	(8,172)	(9,206)	(10,266)			
N long MP ext.	(6,48)	(7,89.7)	(8,90)	(9,95)	(10,102)			
N long MP flex.	(8,74)	(10,82)						
N long PIP ext.	(3,78)	(5,82)	(7,84)	(8,89.8)	(10,90)			
N long PIP flex.	(7,80)	(9,90)	(10,103)					
N long DIP ext.	(3,85)	(4,89.8)	(10,90)					
N long DIP flex.	(7,53,8)	(8,54)	(9,78)	(10,85)				
N long Total ROM	(3,238)	(5,247)	(8,252)	(9,268)	(10,282)			
I Ring MP ext.	(4,66)	(7,69)	(8,92)	(10,108)				
I Ring MP flex.	(4,30)	(7,44)	(8,52)	(9,72)	(10,77)			
I Ring PIP ext.	(7,54)	(9,59)	(10,90)					
Basic Resource	(x_1,y_1)	(x_2,y_2)	(x_3,y_3)	(x_4,y_4)	(x_5,y_5)	(x_6,y_6)	(x_7,y_7)	(x_8,y_8)
I Ring PIP flex.	(3,45)	(4,74.8)	(8,75)	(9,92)	(10,98)			
I Ring DIP ext.	(3,79.8)	(7,80)	(9,89.9)	(10,90)				

(Table continues)

Table continued

Resource Demand Functions in Coordinate Format for Meal Preparation and Feeding for Each Resource Measured

Basic Resource	(x_1,y_1)	(x_2,y_2)	(x_3,y_3)	(x_4,y_4)	(x_5,y_5)	(x_6,y_6)	(x_7,y_7)	(x_8,y_8)
I Ring DIP flex.	(3,13)	(4,24)	(9,30)	(10,75)				
I Ring Total ROM	(3,83)	(4,166)	(7,178)	(9,200)	(10,268)			
I Ring Total ROM	(3,83)	(4,166)	(7,178)	(9,200)	(10,268)			
N Ring MP ext.	(3,35)	(6,73)	(7,85)	(8,93)	(9,100)	(10,105)		
N Ring MP flex.	(9,73)	(10,74)						
N Ring PIP ext.	(3,40)	(9,80)	(10,94)					
N Ring PIP flex.	(7,86)	(9,95)	(10,97)					
N Ring DIP ext.	(7,75)	(8,89.8)	(10,90)					
N Ring DIP flex.	(5,52.7)	(7,53)	(9,66)	(10,80)				
N Ring Total ROM	(3,140)	(6,244)	(7,248)	(9,263)	(10,207)			
I Small MP ext.	(3,65)	(4,89.8)	(7,90)	(9,95)	(10,112)			
I Small MP flex.	(4,20)	(7,29)	(8,60)	(9,72)	(10,80)			
I Small PIP ext.	(7,45)	(9,70)	(10,78)					
I Small PIP flex.	(8,38)	(9,78)	(10,98)					
I Small DIP ext.	(4,74.7)	(8,75)	(9,87)	(10,90)				
I Small DIP flex.	(2,19)	(3,22)	(4,24)	(7,43)	(9,50)	(10,86)		
I Small Total ROM	(2,98)	(3,118)	(7,159)	(8,199)	(9,203)	(10,274)		
N Small MP ext.	(3,62)	(5,90)	(7,95)	(9,96)	(10,105)			
N Small MP flex.	(7,68)	(9,72)	(10,80)					
N Small PIP ext.	(3,60)	(4,69.8)	(7,70)	(9,83)	(10,100)			
N Small PIP flex.	(4,79.8)	(7,80)	(8,86)	(9,89.9)	(10,90)			
N Small DIP ext.	(2,65)	(3,80)	(4,84)	(7,87)	(8,89)	(10,90)		
N Small DIP flex.	(4,60)	(9,64)	(10,83)					
N Small Total ROM	(3,199)	(7,236)	(9,241)	(10,271)				
I Thumb Opposition	(3,0.23)	(7,0.46)	(8,0.5)	(9,0.83)	(10,10)			
N Thumb Opposition	(7,1.67)	(8,5)	(10,10					
I Grip Strength	(2,1.8)	(3,2)	(4,6.7)	(5,9.7)	(7,12.2)	(8,12.7)	(9,18)	(10,24.3)
N Grip Strength	(2,14)	(5,27.3)	(7,29)	(8,33.7)	(9,35.3)	(10,51.3		
I Tip Pinch Strength	(2,1.65)	(8,1.7)	(9,4.7)	(10,4.8)				
N Tip Pinch Strength	(2,,3.65)	(7,3.7)	(8,4.7)	(9,5.5)	(10,6.7)			
I Key Pinch Strength	(3,1)	(6,2.2)	(7,4.7)	(8,5.8)	(9,6.8)	(10,9.7)		
N Key Pinch Strength	(4,3.8)	(7,6.5)	(9,8)	(10,12)				
I 3Jchuck Pinch Strength	(3,1)	(6,1.8)	(7,4)	(8,4.5)	(9,4.7)	(10,8.7)		
N 3JC Pinch Strength	(2,4.5)	(9,5.7)	(10,12.2)					
I Fine Dexterity	(3,0.07)	(9,0.23)	(10,0.43)					
N Fine Dexterity	(4,0.3)	(9,0.33)	(10,0.43)					
Bilateral Dexterity	(5,0.16)	(9,0.23)	(10,0.33)					
Assembly Dexterity	(3,0.21)	(5,0.27)	(8,0.29)	(9,0.3)	(10,0.57)			

Note. Each variable begins with (x,y) coordinates (0,0), which were not included on the table; I or N preceding each basic resource denotes I = involved side and N = non-involved side. Scores for extension, dexterity, and opposition are derived scores. See Methods section for an explanation of each score.

Resource Demand Functions in Coordinate Format for Toileting for Each Resource Measured

Basic Resource	(x_1,y_1)	(x_2,y_2)	(x_3,y_3)	(x_4,y_4)	(x_5,y_5)	(x_6,y_6)	(x_7,y_7)	(x_8,y_8)
I Thumb palmer abduction	(10.34)							
I Thumb radial abduction	(9,31)	(10,36)						
I Thumb MP ext.	(10,65)							
I Thumb MP flex.	(10,20)							
I Thumb IP ext.	(6,65)	(8,74)	(9,102)	(10,105)				
I Thumb IP flex.	(8,22)	(10,42)						
I Thumb Total ROM	(10,162)							
N Thumb palmar abduction	(9,36)	(10,38)						
N Thumb radial abduction	(10,32)							
N Thumb MP ext.	(9,80)	(10,90)						
N Thumb MP flex.	(10,12)							
N Thumb IP ext.	(10,95)							
N Thumb IP flex.	(7,41)	(9,44)	(10,51)					
N Thumb Total ROM	(10,183)							
I Index MP ext.	(6,60)	(7,68)	(9,80)	(10,84)				
I Index MP flex.	(6,48)	(7,51)	(9,61)	(10,62)				
I Index PIP ext.	(5,70)	(8,78)	(9,82)	(10,84)				
I Index PIP flex.	(5,60)	(8,63)	(10,87)					
I Index DIP ext.	(10,66)							
I Index DIP flex.	(5,13)	(7,34.8)	(8,35)	(9,52)	(10,60)			
I Index Total ROM	(7,29)	(8,183)	(9,210)	(10,213)				
N Index MP ext.	(7,52)	(10,78)						
N Index MP flex.	(10,66)							
N Index PIP ext.	4,79.8)	(8,80)	(9,90)	(10,90)				
N Index PIP flex.	(7,90)	(8,91)	(10,94)					
N Index DIP ext.	(10,65)							
N Index DIP flex.	(5,48)	(8,55)	(10,56)					
N Index Total ROM	(10,219)							
I long MP ext.	(7,50)	(9,58)	(10,66)					
I long MP flex.	(8,57)	(10,68)						
I long PIP ext.	((9,69)	(10,80)						
I long PIP flex.	(7,32)	(10,65)						
I long DIP ext.	(10,78)							
I long DIP flex.	(5,13)	(7,14)	(9,29)	(10,35)				
I long Total ROM	(7,71)	(10,172)						
N long MP ext.	(7,48)	(10,70)						
N long MP flex.	(8,74)	(10,82)						
N long PIP ext.	(4,78)	(8,82)	(9,89.8)	(10,90)				
N long PIP flex.	(7,80)	(8,89.8)	(9,90)	(10,97)				
N long DIP ext.	(5,85)	(6,89.8)	(10,90)					
N long DIP flex.	(6,53.8)	(10,54)						
N long Total ROM	(5,238)	(10,246)						
I Ring MP ext.	(7,66)	(8,89)	(10,90)					
I Ring MP flex.	(6,30)	(7,44)	(8,47)	(10,52)				
I Ring PIP ext.	(8,54)	(9,59)	(10,75)					
I Ring PIP flex.	(5,45)	(7,49)	(10,77)					
I Ring DIP ext.	(5,79.8)	(10,80)						

(Table continues)

Table continued

Resource Demand Functions in Coordinate Format for Toileting for Each Resource Measured

Basic Resource	(x_1,y_1)	(x_2,y_2)	(x_3,y_3)	(x_4,y_4)	(x_5,y_5)	(x_6,y_6)	(x_7,y_7)	(x_8,y_8)
I Ring DIP flex.	(7,13)	(9,30)	(10,41)					
I Ring Total ROM	(5,83)	(7,107)	(8,178)	(9,200)	(10,215)			
N Ring MP ext.	(5,35)	(7,73)	(10,78)					
N Ring MP flex.	(10,73)							
N Ring PIP ext.	(5,40)	(9,80)	(10,85)					
N Ring PIP flex.	(7,86)	(8,90)	(10,95)					
N Ring DIP ext.	(7,75)	(8,89.8)	(10,90)					
N Ring DIP flex.	(8,53)	(10,63)						
N Ring Total ROM	(5,140)	(7,244)	(8,248)	(9,263)	(10,264)			
I Small MP ext.	(4,65)	(10,75)						
I Small MP flex.	(6,20)	(8,29)	(10,60)					
I Small PIP ext.	(8,45)	(9,70)	(10,78)					
I Small PIP flex.	(9,38)	(10,74)						
I Small DIP ext.	(7,74.8)	(9,75)	(10,76)					
I Small DIP flex.	(2,19)	(5,22)	(7,23)	(8,43)	(9,50)	(10,54)		
I Small Total ROM	(2,98)	(5,118)	(7,127)	(8,159)	(9,199)	(10,221)		
N Small MP ext.	(4,62)	(5,75)	(10,84)					
N Small MP flex.	(8,68)	(9,72)	(10,75)					
N Small PIP ext.	(5,60)	(6,69.8)	(8,70)	(9,82)	(10,88)			
N Small PIP flex.	(5,79.8)	(7,80)	(8,89.8)	(10,90)				
N Small DIP ext.	(10,65)							
N Small DIP flex.	(5,60)	(9,64)	(10,66)	(10,250)				
N Small Total ROM	(5,199)	(7,236)	(9,241)					
I Thumb Opposition	(5,0.23)	(8,0.45)	(10,0.77)					
N Thumb Opposition	(8,1.67)	(10,9.8)						
I Grip Strength	(7,1.9)	(10,2)						
N Grip Strength	(10,14)							
I Tip Pinch Strength	(2,1.65)	(8,1.7)	(10,2)					
N Tip Pinch Strength	(7,3.65)	(10,3.7)						
I Key Pinch Strength	(10,2)							
N Key Pinch Strength	(5,3.8)	(10,4)						
I 3Jchuck Pinch Strength	(7,1)	(10,1.8)						
N 3JC Pinch Strength	(10,4.5)							
I Fine Dexterity	(7,0.07)	(9,0.23)	(10,0.3)					
N Fine Dexterity	(7,0.3)	(9,0.33)	(10,0.37)					
Bilateral Dexterity	(8,0.17)	(9,0.23)	(10,0.23)					
Assembly Dexterity	(7,0.22)	(8,0.27)	(9,0.3)	(10,.03)				

Note. Each variable begins with (x,y) coordinates (0,0), which were not included on the table; I or N preceding each basic resource denotes I = involved side and N = non-involved side. Scores for extension, dexterity, and opposition are derived scores. See Methods section for an explanation of each sore.

Resource Demand Functions in Coordinate Format for Dressing and Grooming for Each Resource Measured

Basic Resource	(x_1,y_1)	(x_2,y_2)	(x_3,y_3)	(x_4,y_4)	(x_5,y_5)	(x_6,y_6)	(x_7,y_7)	(x_8,y_8)
I Thumb palmer abduction	(5,34)	(10,40)						
I Thumb radial abduction	(8,31)	(9,40)	(10,45)					
I Thumb MP ext.	(3,65)	(7,75)	(8,78)	(9,89.8)	(10,90)			
I Thumb MP flex.	(5,20)	(8,24)	(9,44)	(10,52)				
I Thumb IP ext.	(7,65)	(8,74)	(10,105)					
I Thumb IP flex.	(8,22)	(9,51)	(10,66)					
I Thumb Total ROM	(5,162)	(8,180)	(9,201)	(10,236)				
U Thumb palmar abduction	(8,32)	(10,36)						
N Thumb radial abduction	(5,32)	(7,39)	(8,44)	(9,58)	(10,60)			
N Thumb MP ext.	(8,79.8)	(10,80)						
N Thumb MP flex.	(5,12)	(8,30)	(9,47)	(10,55)				
N Thumb IP ext.	(8,95)	(10,105)						
N Thumb IP flex.	(7,41)	(10,44)						
N Thumb Total ROM	(5,183)	(7,196)	(10,200)					
I Index MP ext.	(8,80)	(10,95)						
I Index MP flex.	(7,48)	(8,56)	(10,62)					
I Index PIP ext.	(5,70)	(8,82)	(9,84)	(10,88)				
I Index PIP flex.	(5,60)	(7,63)	(8,83)	(9,89.8)	(10,90)			
I Index DIP ext.	(5,66)	(8,87)	(9,88)	(10,90)				
I Index DIP flex.	(5,13)	(7,35)	(8,42)	(10,52)				
I Index Total ROM	(5,29)	(6,40)	(7,183)	(8,189)	(10,213)			
N Index MP ext.	(6,52)	(8,90)	(10,100)					
N Index MP flex.	(8,66)	(10,72)						
N Index PIP ext.	(3,79.8)	(8,80)	(9,90)	(10,95)				
N Index PIP flex.	(7,90)	(8,91)	(9,93.8)	(10,94)				
N Index DIP ext.	(5,65)	(8,87)	(9,89.8)	(10,90)				
N Index DIP flex.	(4,48)	(8,55)	(10,65)					
N Index Total ROM	(5,219)	(6,226)	(8,232)	(10,249)				
I long MP ext.	(7,50)	(8,58)	(10,95)					
I long MP flex.	(8,57)	(10,78)						
I long PIP ext.	(8,69)	(9,80)	(10,95)					
I long PIP flex.	(5,32)	(6,54)	(8,65)	(9,94.8)	(10,95)			
I long DIP ext.	(5,78)	(7,80)	(10,85)					
I long DIP flex.	(5,13)	(6,20)	(8,29)	(9,35)	(10,70)			
I long Total ROM	(5,71)	(6,113)	(7,154)	(8,172)	(9,231)	(10,266)		
N long MP ext.	(6,48)	(7,89.8)	(8,90)	(10,90)				
N long MP flex.	(7,74)	(8,81.8)	(10,82)					
N long PIP ext.	(3,78)	(8,82)	(9,89.8)	(10,90)				
N long PIP flex.	(7,80)	(8,89.8)	(10,90)					
N long DIP ext.	(5,85)	(7,89.8)	(10,90)					
N long DIP flex.	(3,53.8)	(8,54)	(10,78)					
N long Total ROM	(5,238)	(8,247)	(10,268)					
I Ring MP ext.	(7,66)	(8,92)	(10,100)					
I Ring MP flex.	(7,30)	(8,47)	(9,76.8)	(10,77)				
I Ring PIP ext.	(7,54)	(8,59)	(9,75)	(10,80)				
I Ring PIP flex.	(5,45)	(6,72)	(7,75)	(8,77)	(9,92)	(10,94)		

(Table continues)

Table continued

Resource Demand Functions in Coordinate Format for Dressing and Grooming for Each Resource Measured

Basic Resource	(x_1,y_1)	(x_2,y_2)	(x_3,y_3)	(x_4,y_4)	(x_5,y_5)	(x_6,y_6)	(x_7,y_7)	(x_8,y_8)
I Ring DIP ext.	(5,79.8)	(8,80)	(9,89.8)	(10,90)				
I Ring DIP flex.	(7,13)	(8,30)	(9,41)	(10,75)				
I Ring Total ROM	(5,83)	(6,157)	(7,166)	(8,200)	(9,233)	(10,254)		
N Ring MP ext.	(5,35)	(6,73)	(7,85)	(10,100)				
N Ring MP flex.	(9,73)	(10,74)						
N Ring PIP ext.	(10,80)							
N Ring PIP flex.	(7,86)	(8,90)	(9,95)	(10,97)				
N Ring DIP ext.	(7,75)	(8,89.8)	(10,90)					
N Ring DIP flex.	(7,52.8)	(8,53)	(10,66)					
N Ring Total ROM	(5,140)	(6,244)	(7,248)	(8,262)	(10,263)			
I Small MP ext.	(3,65)	(8,90)	(10,95)					
I Small MP flex.	(7,20)	(8,29)	(9,72)	(10,80)				
I Small PIP ext.	(7,45)	(8,70)	(10,78)					
I Small PIP flex.	(8,38)	(9,78)	(10,95)					
I Small DIP ext.	(7,74.8)	(8,75)	(9,89.8)	(10,90)				
I Small DIP flex.	(2,19)	(5,22)	(7,42)	(8,43)	(9,54)	(10,78)		
I Small Total ROM	(2,98)	(5,118)	(8,159)	(9,221)	(10,248)			
N Small MP ext.	(4,62)	(5,75)	(8,90)	(10,96)				
N Small MP flex.	(7,68)	(8,72)	(10,78)					
N Small PIP ext.	(5,60)	(7,69.8)	(8,70)	(10,82)				
N Small PIP flex.	(4,79.8)	(7,80)	(8,89.8)	(10,90)				
N Small DIP ext.	(5,65)	(7,87)	(8,89.8)	(10,90)				
N Small DIP flex.	(4,60)	(8,64)	(9,66)	(10,75)				
N Small Total ROM	(5,199)	(7,236)	(10,241)					
I Thumb Opposition	(5,0.23)	(8,0.45)	(9,9.9)	(10,10)				
N Thumb Opposition	(7,1.67)	(8,9.9)	(9,10)	(10,10)				
I Grip Strength	((5,2)	(6,5.7)	(7,9.3)	(8,9.7)	(9,22)	(10,24.3)		
N Grip Strength	(5,14)	(8,27.3)	(10,36)					
I Tip Pinch Strength	(2,1.68)	(7,3.7)	(8,2.5)	(10,4.8)				
N Tip Pinch Strength	(5,3.68)	(7,3.7)	(8,4.3)	(9,6)	(10,6.2)			
I Key Pinch Strength	(5,1)	(8,2.2)	(9,7)	(10,9)				
N Key Pinch Strength	(4,3.8)	(5,4)	(7,6.5)	(10,8)				
I 3Jchuck Pinch Strength	(5,1)	(8,1.8)	(9,5.7)	(10,7.3)				
N 3JC Pinch Strength	(5,4.5)	(10,5.7)						
I Fine Dexterity	(5,0.06)	(8,0.23)	(9,0.3)	(10,0.33)				
N Fine Dexterity	(7,0.3)	(8,0.33)	(9,0.36)	(10,0.37)				
Bilateral Dexterity	(8,0.17)	(9,0.23)	(10,0.27)					
Assembly Dexterity	(5,0.22)	(8,0.27)	(10,0.35)					

Note. Each variable begins with (x,y) coordinates (0,0), which were not included on the table; I or N preceding each basic resource denotes I = involved side and N = non-involved side. Scores for extension, dexterity, and opposition are derived scores. See Methods section for an explanation of each score.