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Measuring Outcomes of Rehabilitation Among Persons with Upper Extremity Traumatic Injuries

Jamie Carl Grede
University of Wisconsin-Milwaukee

MEASURING OUTCOMES OF REHABILITATION AMONG PERSONS WITH UPPER EXTREMITY TRAUMATIC INJURIES

by

Jamie Grede

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ABSTRACT

MEASURING OUTCOMES OF REHABILITATION AMONG PERSONS WITH UPPER EXTREMITY TRAUMATIC INURIES

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Jamie Carl Grede

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Under the Supervision of Professor Bhagwant Sindhu

Grip strength is frequently measured to determine outcomes of rehabilitation among people with upper extremity traumatic injuries (UETIs). UETIs also affect rate of force-production during an isometric grip. However, we do not have a reliable and valid measure for detecting these force changes. The purpose of this study was to determine the validity and responsiveness, i.e. ability to detect change, of the Force-Time Curve (F-T Curve) to determine rate of force production. Nine people with UETIs undergoing rehabilitation were recruited to participate in this study. Using an electronic Jamar dynamometer, each participant performed three maximal isometric grips, each lasting 10 seconds, with their affected hand during an initial session and one month later at a follow-up session. The slopes were calculated using the BioGraph Infiniti software. Our findings found a significant increase in the slopes of force-generation phase (F=5.745, p=0.043) suggesting construct validity, but not for slopes of force-decay phase or peak force. Moderate effect size coefficients were found for slopes of force-generation phase (ES=0.586) and slope of force-decay phase (ES=0.540), indicating moderate responsiveness for these slopes. We recommend the slopes of force-time curve not be

used as outcome measures until studies with larger sample and longer duration produce better findings.

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Chapter 1

Introduction

The Problem

Grip strength is commonly used to assess ability to return-to-work after injury to determine extent of disability, and estimate physical work capacity (Shechtman et al. 2007;Shechtman et al, 2011;Shechtman et al, 2006). Grip strength is a gross measure of active musculoskeletal contraction of intrinsic and extrinsic hand muscles (Shechtman et al, 2011). However, grip strength has several limitations. First, grip strength is not a true measure of hand function (Shechtman & Sindhu, 2007). Second, grip strength does not describe a person's pattern of force production and motor recruitment pattern during a single isometric strength trial (Shechtman, 2007). By learning about changes in force production and motor recruitment patterns, clinicians can provide more effective therapies to improve outcomes of rehabilitation.

In contrast to grip strength, the force-time curve (F-T curve) provides information on force production of a single strength trial over a period of time. A typical F-T curve can be divided into an initial force-generation phase, in which there is a rapid increase in force, and a later force-decay phase, in which there is a gradual decrease in force (Figure 1.1) (Shechtman, Sindhu, Davenport, 2007). Previous research conducted in our lab found these slopes to have sufficient test-retest reliability (r=0.58 to r= 0.82) (Shechtman et al., 2011). The slopes of the force-generation phase and force-decay phase were also found to be less steep among hands with musculoskeletal injuries versus healthy hands, suggesting that musculoskeletal injury affects these slopes (Shechtman et al, 2011). In addition, training has been shown to increase the steepness of these slopes (Shechtman, Sindhu, Devenport, 2007; Hakkinen & Komi, 1985). Consequently, previous research suggests that the slopes of F-T curve can be used as rehabilitation outcome measures. However, to be used as an assessment, we need to know their psychometric properties including construct validity, concurrent validity and responsiveness. To the best of our knowledge, there is no evidence on responsiveness of the F-T curve parameters (Shechtman et al., 2011; Shechtman et al., 2007; Shechtman et al., 2006).

Specific Aims

The overall aim of this study is to determine the ability of the F-T curve to be used as rehabilitation outcome measure. This study will explore how the slopes generated during a 10-second isometric grip strength trials change from pre- to post-intervention among people with traumatic injuries of the elbow and distal of the upper extremity. Specifically, the purpose of this research project is to determine the psychometric properties of the slopes of F-T curve including construct validity, concurrent validity as well as responsiveness.

Our *central hypothesis* is that the slopes of the force-generation phase and force-decay phase will become steeper over time with rehabilitation and that their change will be similar to change in grip strength. This hypothesis is based on previous research. Obviously, grip strength will increase with rehabilitation because of the strengthening exercises included in the treatment. In addition, we expect the slopes of force-time curve to be steeper due rehabilitation-related improvement in injury-related factors. Specifically, we expect the slope of force-generation phase to become steeper with recovery as there is a reduction pain, muscle guarding, and injury related psychological factors such as fear-avoidance related to pain and fear of re-injury. Moreover, recovery with rehabilitation will increase the number of motor units available to result in faster rates of force-development. We expect slope of force-generation phase to increase even in the absence of use of speed training. Speed training is associated with increases in rate of force-development, but, such strategies are commonly not used in rehabilitation settings as fast or explosive tasks can cause re-injury (Shechtman, 2007; Hakkinen et al., 1985). Finally, we expect the slopes of force-decay phase to become steeper over time because of faster onset of fatigue. Reduced muscle guarding and improvement in other injury-related factors, along with greater strength, are likely to allow a person to exert a greater maximal force. Greater maximal force in turn will be associated with faster onset of fatigue and thus steeper slopes of force-decay phase over time. Consequently, the specific aims and related hypotheses are as follows:

Specific Aim 1

To determine the construct validity of the slopes of the F-T curve for measuring rehabilitation outcomes.

Hypothesis 1a: The slope of force-generation phase will become steeper as individuals with upper extremity injuries recover with rehabilitation.

Hypothesis 1b: The slope of force-decay phase will become steeper as individuals with upper extremity injuries recover with rehabilitation.

Specific Aim 2

To determine the concurrent validity of changes in slopes and changes in maximum grip strength of injured hands.

Hypothesis 2a: A positive association will exist between change in the slope of force-generation phase and change in grip strength as individuals with upper extremity traumatic injuries recover with rehabilitation.

Hypothesis 2b: A positive association will exist between change in the slope of force-decay phase and change in grip strength as individuals with upper extremity traumatic injuries recover with rehabilitation.

Specific Aim 3

To determine the responsiveness of the slopes of the F-T curve as compared with grip strength for measuring rehabilitation outcomes.

Hypothesis 3a: The responsiveness of the slope of force-generation phase is similar to grip strength for detecting change with rehabilitation among people with upper extremity traumatic injuries.

Hypothesis 3b: The responsiveness of the slope of force-decay phase is similar to grip strength for detecting change with rehabilitation among people with upper extremity traumatic injuries.

Background

Upper extremity musculoskeletal injuries result in an enormous burden on our society as indicated by a large number of injuries, cost of medical care, as well as disability caused by these injuries. Not only is there a great impact on the lifestyle of the patient themselves, the disorders also create a large economic burden due to its cost for sick leave and health care (Huisstede et al. 2005). Every year, nearly 7% (i.e. 20 million) of Americans experience an upper extremity musculoskeletal injury in the United States. In addition, a third (or 100 million) of Americans will experience an upper extremity musculoskeletal disorder in their lifetime (Huisstede et al. 2005). Medical costs related to musculoskeletal conditions exceed $250 billion per year. In addition, medical care expenditure for persons with musculoskeletal conditions is 50% higher than for people with non-musculoskeletal chronic conditions (Yelin, Hernfdorf, Trupin, & Sonneborn. 2001; Lidgren, 2003). Therefore there is a societal burden associated with upper extremity injuries.

Upper extremity traumatic injury is an umbrella term used to describe a diverse group of disorders of varying severity. Less severe injuries include sprains and strains. A strain is characterized as an injury to a tendon (Mehta, 1997). In contrast, a sprain is characterized as an injury to a ligament. Ligament sprains are graded by severity of damage and amount of joint separation (Dutton, 2004). More severe injuries include tears, fractures, crush injuries, contusions, open wounds, nerve injuries, tendon lacerations, amputations, and burns. Fractures commonly occurring in the upper extremity are: 1) stress fractures, resulting from high or repetitive force, 2) growth plate fractures, which are points on the bone that are the most fragile that undergo high force, 3) Colles' fracture, a fracture of the distal radius, 4) Smiths' fracture, being a reverse fracture of the distal radius, and 5) fractures of the scaphoid bone (Mehta, A.J. 1997). Peripheral nerve injuries are another common injury of the upper extremity. Absence of intact nerves supplying the upper extremities greatly reduces function as well as recovery from an injury (Trombly, 1995).

There are a wide range of rehabilitation approaches used for treating upper extremity injuries. Progressive Resistance Training (PRT) is the most common approach for strengthening muscles post-injury. PRT is implemented by manipulating variables such as frequency, resistance, duration, and intensity to progressively build strength and muscle mass (Liu et al., 2011). Devices used for PRT include the Digiflex, resistance bands, and dumbbells. In addition, physical agents such as hot/cold modalities and paraffin wax treatments are used for relieving pain and reducing muscle tightness. Other treatment approaches include active range of motion, passive range of motion, scar management, assistive devices for functional independence, and splints for supporting and positioning weak body parts (Pendleton & Schultz-Krohn, 2006).

Therapists commonly measure outcomes use self-report assessments to rehabilitation. The outcome of rehabilitation is frequently assessed by measuring outcomes. A frequently used self-report function assessment is the Disabilities of Arm, Shoulder, and Hand (DASH) questionnaire. The DASH assesses upper extremity disability by using questions that do not focus on a specific musculoskeletal condition, and do not focus on a specific joint of the upper extremity (Lehman et al. 2010; Beaton et al., 2001). The DASH questionnaire has been shown to be a reliable and valid measure of upper extremity disability as well as have good test-retest reliability, discriminative validity, and construct validity (Navsarikar et al., 1999; Hudak et al., 1996; Atroshi et al., 2000). With regards to pain intensity, a frequently used assessment is the visual analog scale (VAS) (Sindhu et al. 2011). The VAS is an consists of a10cm line anchored by two extremes of pain, with no pain being represented as ‘0’ and pain as bad as it could be, represented as ‘10’. The VAS has been shown to be highly valid ($r>0.75$). The test-retest reliability has been shown to be high as well ($r=0.96$) (Sindhu, Shechtman, & Tuckey, 2011; Swanston et al., 1993).

In addition to self-report assessments, therapists use performance measures to determine outcomes of rehabilitation. Grip strength is one of the most common performance measures used to determine upper extremity functional ability and overall physical health (Shechtman et al., 2007). Grip strength is also frequently used to assess ability to return–to-work after injury, to determine extent of disability, and estimate physical work capacity (Shechtman et al., 2011). Therapists typically use accurate devices to determine grip strength, such as the Jamar dynamometer (Pendleton & Schultz-Krohn, 2006). By following standardized instructions and positioning, grip strength has been shown to have objective, reliable and valid results (Moran, 1986). Though grip strength is a reliable and valid measure, it is generally recorded as a point measure. That is, grip strength does not show how the patient's rate of force production changes over time, during a single strength trial.

In contrast to grip strength, the force-time curve (F-T curve) describes how force production changes during a single strength trial. The force time curve (F-T curve) is a graphical representation of force generated by a contracting muscle over a period of time during a single strength trial. In this graph, the vertical axis (Y-axis) represents the change in force of the muscle, while the horizontal axis (X-axis) represents time elapsed during a contraction. The grip strength F-T curve is made up of a force generation phase, where there is a rapid increase of force, an initiation peak, where there is a smooth peak curve, and a force-decay phase where there is a decrease in force over time (Shechtman et al, 2007). Different kinds of training have been shown to influence different aspects of the F-T curve. Strength training has been shown to increase peak force and the rate of force production. Heavy weight training causes an increase in the peak force, due to hypertrophy. In contrast, speed-strength training increases the rate of force production, due to adaptation of the nervous system (Shechtman et al, 2007; Hakkinen et al., 1985).

Currently the F-T curve is not used in clinics to evaluate changes in force production because of several reasons. First, it requires specialized equipment and software, which is more expensive than the dynamometers commonly used for measuring grip strength (Shechtman et al., 2007). Second, it is not known how the nature of force-time curves changes with rehabilitation. Most of the research on how force-time curves change with training has been conducted in sports and related fields (Shechtman et al., 2007). However, the training provided to athletes may not always be appropriate in a rehabilitation setting. That is, speed training is usually necessary for improving rate of force production. However, speed training is not appropriate for weak or injured muscles. Finally, there is limited evidence on psychometric properties of the F-T curve, and currently there is little research comparing grip strength with the force-time curve. For example, the slopes of force-generation phase and force-decay phase have been found to be reliable. However, we do not know about their responsiveness. Therefore, the purpose of this study is to determine how the slopes of F-T curve change with rehabilitation as well as to determine their responsiveness.

Significance

This study is significant for the fields of rehabilitation, ergonomics, and biomechanics for the two reasons: First, force-time curves can improve assessment of rehabilitation outcomes. Currently, therapists usually measure muscle strength but not the motor recruitment patterns. By knowing these motor recruitment patterns, one can provide a better understanding of underlying causes of limitations in daily tasks. This study will further our understanding of how motor-unit recruitment changes with rehabilitation among people with upper extremity traumatic injuries (UETIs). Clinicians can provide more effective therapies by targeting force parameters that are affected by any injury. Second, grip strength based tests are commonly used among people with UETIs to determine overall physical health. However, current research does not compare it with the force-time curve. Therefore, a better understanding of the validity, responsiveness, and minimally detectable change of the force-time curve will allow us to better understand its utility in a clinical setting. This study has the potential to result in an assessment that provides additional information about muscle performance changes as a result of rehabilitation post-injury. Second, use of the force-time curves can improve treatment outcomes among people with traumatic upper extremity injuries. Similar assessments have been successfully used by coaches to help improve performance of their athletes. This study also has the potential to extend the use of force-time curves for rehabilitation to allow therapists to target specific force parameters to improve functional performance of a person after a traumatic upper extremity injury.

Previous Study

A previous study was conducted in our lab to examine reliability and validity of the force-time curve (F-T curve) for measuring the impact of upper extremity injuries. The purposes

of this study were 1) to examine differences in slopes of force-generation phase and force-decay phase between maximal efforts of injured and uninjured hands, and 2) to examine test-retest reliability of slopes of force-generation phase and force-decay phase of maximal grip efforts (Sindhu & Shechtman. 2011).

Methods. Forty participants (20 men and 20 women) with upper extremity injuries performed a total of 12 grip trials with each hand in two sessions. During each session, the participant exerted two maximal and four submaximal efforts. We blinded the test administrator to the nature of the effort. For force measurements, we used a modified Jamar dynamometer that converted grip pressure (kilograms Force [kgF]) into an electrical signal (volts[V]). This electrical signal was digitized using the Flex Comp Infiniti analog-to-digital converter (V.3.1; Thought Technology Ltd.) (Sindhu & Shechtman. 2011). Each grip lasted six seconds. A rest period of two minutes was given between two grips and 15 minutes between the two sessions. The slopes of the F-T curve were calculated by sampling the digital signal at a rate of 2,048 Hz, exporting it into Microsoft (MS) Excel.

Data Analysis. For the purpose of this study, only maximal grips were examined.

Statistical Analysis. Repeated-measures of analysis of variance (ANOVA) tests were used to compare differences between maximal and efforts exerted by the injured and uninjured hands. Test-retest reliability was examined by computing intraclass correlation coefficients (ICCs) between average slopes of first sessions versus average slopes of second session.

Results. The slopes of the force-generation phase were significantly steeper for uninjured hands, when compared with injured hands [$F(1,38)==14.35$, $p<0.001$]. Additionally, the slopes of the force-decay phase were significantly steeper for uninjured hands when compared with injured hand [$F(1, 38)=14.86$, $p<0.0004$] (Table 2, Figures 1, 2 & 3) (Sindhu & Shechtman. 2011).

Conclusions. Their findings show that the slope of the force-generation phase was less steep for the injured hand, thus showing there to be a decrease in the rate of force development. This is likely due to a reduction in the number or size of motor units and their capacity to fire together at their highest firing rate. The unexpected finding was that there was a steeper slope of the force-decay phase for the uninjured hands, indicating that the uninjured hands fatigue faster than the injured hands. This may be possible due to the participants not exerting their true maximal effort with the injured hand (Table 1.1, 1.2, Figures 1.2, 1.3).

ICCs identified moderate (r=0.58) to high (r=0.82) test-retest reliability (Table 1.3). Consequently, the slopes of force-generation phase were found to have sufficient test-retest reliability. These findings suggest that the slopes of force-time curve can potentially be used in the clinic as an outcome measure. However, we need to know their responsiveness prior to using in the clinic.

Definition of Terms

This section defines the various terms used in this research project. When appropriate, the conceptual and operational definitions of terms specific to the study have been given.

1. Musculoskeletal system: Also called the locomotor system, the musculoskeletal system consists of the skeletal system (bones and joints) and the skeletal muscle system, and peripheral nerves that innervate the skeletal muscles. This system performs various functions including protection of internal organs, maintain posture, assist in movement, formation of blood cells, and storage of fats and minerals. (Salter, 1999.)

2. Musculoskeletal disorders:

    a. Conceptual definition: Musculoskeletal disorders include a diverse spectrum of diseases and syndromes with varied pathophysiology. However, they are linked anatomically and by their association with pain and impaired physical function. These conditions range from acute onset and short duration disorders to lifelong disorders. They commonly manifest as rheumatoid arthritis, osteoarthritis, osteoporosis, spinal disorders, peripheral nerve injuries, major limb trauma, fibromyalgia, gout, and sprains and strains. (Lindgren, 2003)

3. Musculoskeletal conditions:

    a. Conceptual definition: Musculoskeletal conditions have been defined differently in the literature. Some articles rely on physician provided diagnoses, some on self-report, some include injuries to the musculoskeletal system and some exclude injuries. The National Arthritis Data Task Force defines musculoskeletal conditions as those that include the International Classification of Diseases, Ninth Edition (ICD-9) codes 274 (gout) and 710.0 – 739.9 (diseases of musculoskeletal system and connective tissue) (Yelin et al, 1995)

4. Upper extremity traumatic injuries (UETIs)

   a. Upper extremity traumatic injury is an umbrella term used to describe a diverse group of disorders which include sprains, strains, burns, crushes, fractures or dislocations.

5. Maximal voluntary effort:

   a. Conceptual definition: Also called sincere effort, maximal effort indicates that a person consciously and voluntarily performs to the best of their ability during an evaluation.

   b. Operational definition: In relation to grip strength, maximal effort indicates that a person consciously and voluntarily performs a grip strength trial to the best of their ability.

6. Grip Strength: A valid indicator of musculoskeletal pathology and recovery from pathology only when one exerts a sincere, maximal voluntary effort. Grip strength testing is a force assessment given to individuals to detect their grip force of their flexor, extensor, and intrinsic hand muscles. Grip strength is known to accurately depict overall physical health (Shechtman et al, 2007;Shechtman et al, 2011; Shechtman et al, 2006).

7. Force-Time Curve (F-T curve): The F-T curve is a graphical representation of the force of muscular contraction over a period of time and may be used as a physiologically based sincerity-of-effort assessment. The F-T curve consists of a force-generation phase, peak force phase, and a force-decay phase (Shechtman et al, 2007; Shechtman et al, 2011; Shechtman et al, 2006). The slope of force-generation

phase is the phase between zero and the peak force where there was a rapid development of force. The peak force is identified as the peak point of force where the rapid development of force, or slope of force-generation phase tapers off. The slope of force-decay phase is identified as the period after the peak force where there was a gradual decay of force until the participant let go.Construct Validity: The validity of inferences that observations or measurement tools actually represent or measure the construct being tested (Portney & Watkins, 2000)

8. Concurrent Validity: Is where a test correlates well with a measure that has already been validated. In this case, grip strength (Portney & Watkins, 2000).

9. Responsiveness: Is the ability of an instrument to detect change over a period of time (Portney & Watkins, 2000).

Table 1.1: Average values for F-T curve characteristics of maximal grip efforts exerted with injured and uninjured hands of males (N = 20) and females (N = 20) experiencing unilateral upper extremity musculoskeletal injuries.

	Males (N = 20)				Females (N = 20)			
	Injured Hands		Uninjured Hands		Injured Hands		Uninjured Hands	
F-T Curve Characteristic	Average	SD	Average	SD	Average	SD	Average	SD
Slope of force-generation phase (V/s)	1.690	1.343	1.973	1.061	0.936	0.589	1.354	0.710
Slope of force-decay phase (V/s)	-0.030	0.064	-0.043	0.043	-0.024	0.019	-0.046	0.023

Table 1.2: Results of repeated two-way ANOVA (hand x gender) of various F-T curve characteristics

Source	F	p-value
Slope of force-generation phase		
Gender	4.929	0.032*
Hands	14.348	0.001*
Gender X Hands	0.409	0.526
Slope of force-decay phase		
Gender	0.435	0.514
Hands	14.857	0.0004*
Gender X Hands	0.362	0.551

Hand: injured vs. uninjured
Gender: males vs. females

* Indicates significant differences at $p < 0.05$ alpha level

Table 1.3: Intraclass Correlation Coefficients for the slopes of F-T curve.

	Injured hand	Uninjured hand
	r-value	r-value
Slope of force-generation phase	0.822	0.598
Slope of force-decay phase	0.579	0.592

Figure 1.1 A typical force-time curve showing force-generation and force-decay phases.

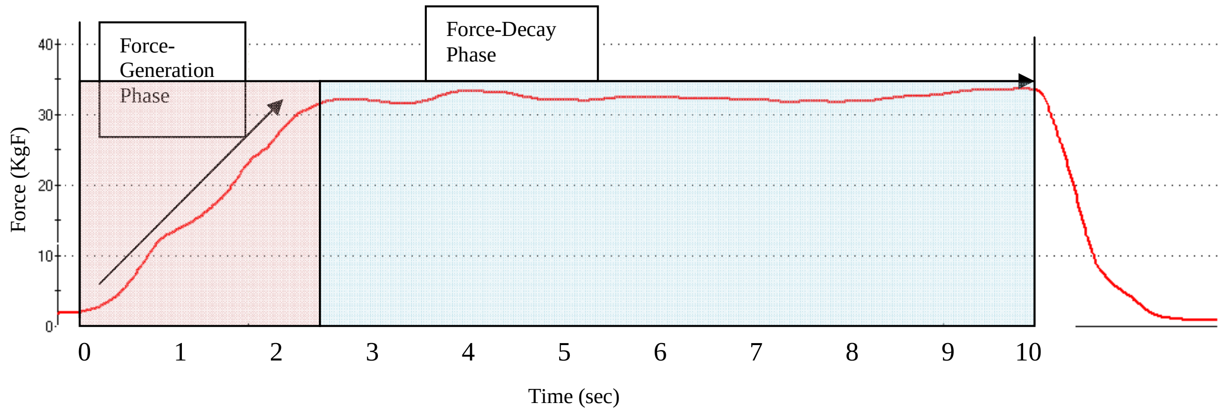


Figure 1.2: Average slopes for the force-generation phase of maximal and submaximal efforts in injured and uninjured hands of men and women.

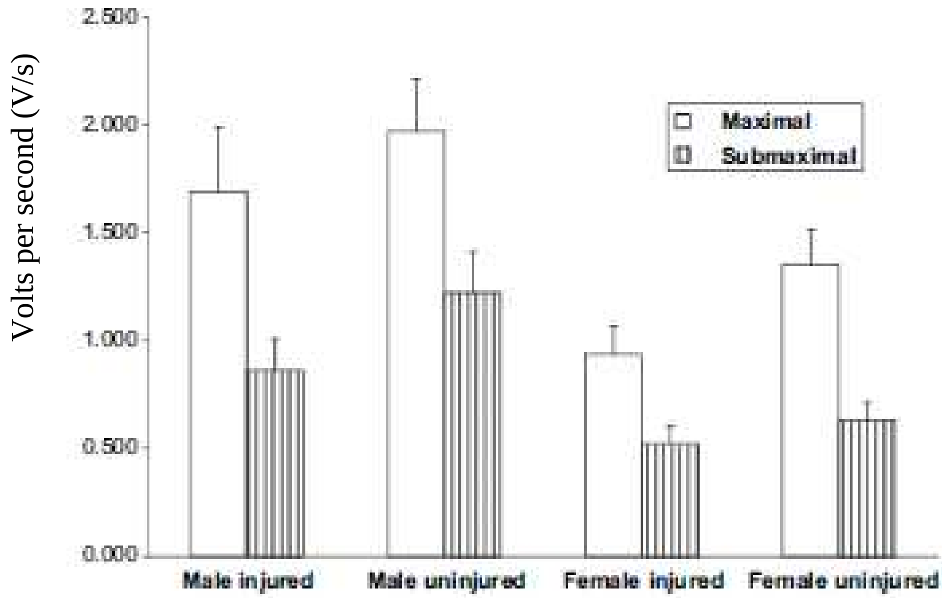
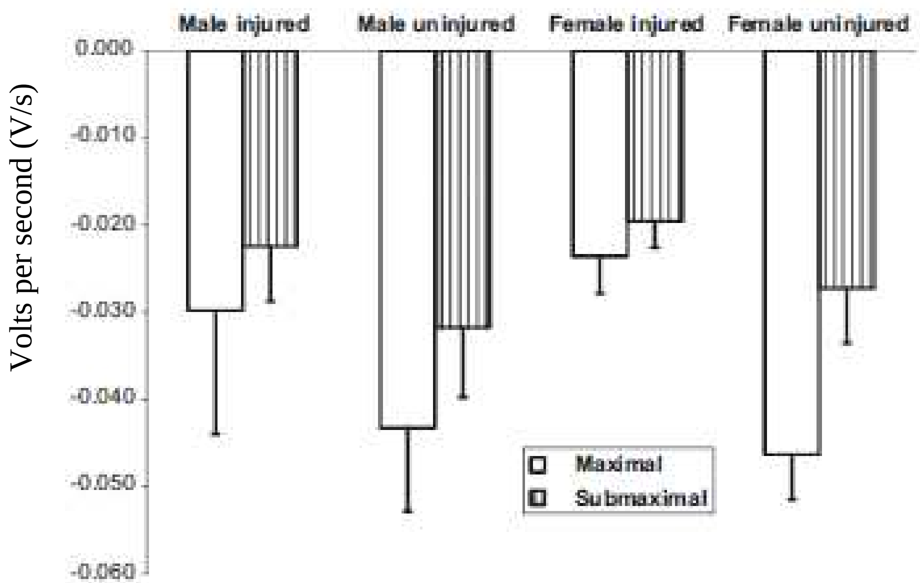


Figure 1.3: Average slopes for the force-decay phase of maximal and submaximal efforts in injured and uninjured hands of men and women.



Chapter 2

Literature Review

In this chapter, the clinical presentation of upper extremity traumatic injuries (UETIs) rehabilitation approaches, and medical management for these UETIs will be covered. Due to the wide nature of UETIs, a wide variety of treatment approaches must be used to specifically tailor to each individuals needs through the use of progressive resistance training (PRT), progressive resistance exercise (PRE), physical agent modalities, scar management, assistive devices, range of motion, splinting, and surgery. Aspects of fear avoidance will also be discussed.

The Clinical Presentation

UETIs are wide and various and account for many injuries including common fractures, sprains, strains, surgeries, nerve injuries, ligament tears and dislocations from the elbow and distal. Common symptoms are mild to severe acute pain, swelling, edema, inflammation, and bruising. A client typically presents with their injury and are often seeking help to decrease the symptoms resulting from the injury, by looking toward therapy or pharmacology. Their quality of life is often affected, disabling them from doing their activities of daily living (ADLs) or instrumental activities of daily living (IADLs). Referral to rehabilitation specialists such as occupational therapists, physical therapists and speech therapists is important in regaining lost independence due to their UETIs. Occupational therapy can help remediate and re-educate the client’s functional abilities (Pendleton et al. 2006).

Rehabilitation Approaches

Upper extremity traumatic injury rehabilitation can cover a wide variety of treatment approaches. Treatments that will be covered include: progressive resistance training, progressive resistance exercise, physical agent modalities, hand strengthening devices, range of motion exercises, splinting, scar management, assistive devices and medical management.

1.) Strengthening. Hand strengthening therapy is a phrase for a wide variety of interventions and is a very vague definition. Progressive Resistance Training (PRT) is most often implemented in order to increase strength. This is a common method among athletes and body builders, and is effective for hand strengthening rehabilitation as well. PRT is implemented by increasing and varying variables such as intensity, frequency, weight, repetitions, sets, rest periods, and duration in order to progressively increase muscular strength and endurance (Liu et al., 2011). Among various types of physical activity and exercise, progressive resistance strength training or PRT has demonstrated significant positive effects on restoring muscle strength and muscle mass. PRT consists of resistance being gradually increased over the course of training. Thorough research trials and systematic reviews show that PRT has high reliability, in both upper and lower extremity exercise (Liu et al., 2011).

Similarly, Progressive Resistive Exercise (PRE) is based on the overload principle of muscles performing more efficiently if taxed beyond usual daily activity in order to improve performance and strength. A popular technique is that of the DeLorme method of PRE. During the Delorme method, loads are increased gradually after each set, thus warming up the muscle to perform a maximal set for a final 10 repetition set. The exercise consists of three sets of 10 repetitions, where the first set is 50% of maximal resistance, the second set is 75% of maximal resistance, and the third set being 100%

maximal resistance. As strength improves, resistance is increased. All variables are typically adjusted to suit the specific needs of the client, such as duration, repetitions, frequency, and resistance. Opposite the Delorme technique is the Oxford method, where the exercise sequence starts with 100% resistance and decreases to 75% and then to 50% on sets of 10 repetitions each (Pedretti et al. 2001).

Muscle strength has become an excellent determinant of overall physical health. Muscle strength reaches it’s peak at 25 years of age and declines there on, between 54% and 89% loss by the age of 75 years of age (Danneskiold-Samsoe et al., 2009). Therefore it is extremely important to maintain muscle strength while aging, in order to prevent accidents such as falls. Luckily, there are several types of exercise that will enable the body to stay strong. The most common strengthening exercises are classified based on change in muscle length and joint angle. Isometric exercises are defined as where the joint angle and muscle length remains unchanged (Duchateau et al., 1984). Isometric strength training has shown to be effective in therapy, after 5-12 weeks of training of the first dorsal interosseus muscle of the hand, maximal force was shown to increase by 20-40% (Davies et al. 1984). Isometric exercises are contraindicated when an individual is suffering from hypertension or have a weakened cardiovascular system, but are indicated when the individual is unable to complete full range of motion or unable to change joint angle. Isotonic exercise is defined as a contraction where the tension is unchanged, but the muscle’s length changes. Isotonic contractions are made up of two parts, a concentric phase and an eccentric phase. The concentric phase is the muscle shortening phase, whereas the eccentric phase is the muscle lengthening phase. In a study comparing isotonic exercise to isokinetic exercise, both groups showed great strength gains. Isotonic exercise has generally been shown to show the best increases in strength (Smith et al., 1981). Isokinetic exercise requires specialized equipment and can be defined as where the muscle contraction velocity remains constant, while force varies. However, optimal repetitions, frequency, and sets are client-dependent and therefore have no standard dosage.

Common hand strengthening devices include using a spring-loaded *Digiflex*, using a squeeze ball, an *Eggserciser*, *NESS Handmaster,* or the *Handmaster Plus* (Macleod & Allen, 2006). The *Digiflex* is a handle device with springs on each side, with one side having buttons for each individual finger to press down on. The *Digiflex* can come in a variety of resistances and is used to develop isolated finger strength, flexibility and coordination (Silagy, 2008). In addition, the therapeutic squeeze ball is a ball made out of foam that provides resistance when gripped. The ball can come in varying resistances and is often used as a hand strengthening exerciser (Chow, 2001). The *Eqqserciser* is the same as a squeeze ball except that it is ergonomically shaped as an egg and therefore provide hand strengthening training more effectively (Davis, 2009). The *NESS Handmaster* is a hand strengthening device that slips over the forearm and the hand. It uses surface electrodes to stimulate the muscles of the forearm and hand in order to flex or extend. This is one of the few devices known to activate all 18 hand muscles and is very effective for C5 tetraplegic patients as well as hemiplegic patients (Snoek, 2000). Finally, the *Handmaster Plus* is another device known to activate all 18 hand muscles and consists of a simple squeeze ball with elastic strings protruding from the ball to loop around each finger. This allows the individual to strengthening their finger and hand extensors as well as the flexors (Snoek, 2000).

The effect of varying speed on training has been shown to have significant effects on both rehabilitation and athletics. It has been shown that slower repetition speed effectively increases intensity during the lifting phase due to decreasing momentum. In a study by Westcott et al (2001), super-slow training resulted in a 50% greater increase in strength in both men and women, compared to regular speed training (Wescott et al., 2001).

2.) Physical Agents. Other rehabilitative treatment methods include the use of physical agent modalities such as thermal modalities. In the clinical setting heat can be used to help increase motion, decrease joint stiffness, increase blood flow and decrease pain. Paraffin and hot packs are common modalities used to provide heat through conduction (Pendleton & Schultz-Krohn, 2006). In paraffin wax treatments, paraffin is stored in a tub at a temperature between 125 F and 130 F, whereas the client repeatedly dips their hands into the tub until a thick, layer of paraffin is applied. After, the hand is then wrapped in a plastic bag for 10 to 20 minutes. Hot packs contain a silicate gel or clay which is wrapped in a cotton bag and submerged in a hydrocollator which maintains a temperature of 160 F to 175 Farenheit (F). Once the hot pack has been heated, it can be applied to the skin after it is wrapped with three layers of towel (Pendleton & Schultz-Krohn, 2006). According to a study by Taylor & Humphry (1991), hot and cold packs are the most used of physical agent modalities in hand therapy. Cryotherapy, the use of cold in therapy, can also be used to effectively treat edema, pain and inflammation. The cold produces a vasoconstriction reaction in the body which decreases the amount of blood flow to the injured tissue. The alternating vasoconstriction and vasodilation of the blood vessels, which produces an increase in collateral circulation, effectively reduces pain and edema (Pendleton & Schultz-Krohn, 2006). Contraindications for thermal modalities involve open wounds, oversensitivity to temperatures and burns. Thermal modalities have been shown to be a highly reliable and valid intervention in the clinic (Taylor & Humphry. 1991).

Ultrasound is also another good intervention to use in the hastening of the healing process of injured soft tissue. It usually is coupled with the goal of enhanced tissue healing and reduction in pain. Ultrasound uses high frequency sound waves to create thermal energy which is absorbed in the tissues to a depth of 2 to 5 cm. This is effective in the management of joint contracture, pain, inflammatory conditions, and tissue healing.(Pendleton & Schultz-Krohn, 2005)

Neuromuscular electrical stimulation or (NMES), has become another popular treatment for paralyzed patients and for the prevention and restoration of muscle function after traumatic injuries. More recently NMES has been used as a modality in strengthening for healthy subjects who have experienced a traumatic injury and the re-education of muscles (Hainaut & Duchateau, 1992). In NMES, an electrical current flows through wires onto electrodes which stimulate target muscles on the body, resulting in muscle contraction. Parameters such as rate, amplitude and waveform can be adjusted for quality contractions. NMES can be used as a training, therapeutic or a cosmetic tool. In therapeutics, NMES is commonly used with a population with any age that has experienced a traumatic injury to any part of the body. The target outcome of the intervention is the contraction of a target muscle, forcing blood into the muscle and forcing it into use. This increases the person's quality of life and function of the target muscle, increasing voluntary motor recruitment allowing for more functional use.

Proximal outcomes depend on the patients severity of injury, proximal outcomes may be small, but when used often, progressive increases in functional use are expected. Long term outcomes involve functional use or near full functional use of target muscle (Hainaut & Duchateau, 1992).

Transcutaneous Electrical nerve Stimulation (TENS) is the act of using an electrical current to decrease pain and is an effective technique for controlling pain without the side effects of medications. Constant electrical stimulation is directed to peripheral nerves through placement of electrodes, and the therapist can then control attributes of the modulation waveform including frequency, amplitude, and pulse width. TENS is often used to decrease pain from inflammations or nerve impingement, as well as for treating trigger points (Pedretti & Early, 2001).

3.) Range of Motion. Joint range of motion (ROM) exercises can also be implemented as an intervention. They help the muscle functionally be used for activities of daily living (ADL) and instrumental activities of daily living (IADL). Traumatic injury often results in significantly decreased use of the affected limb and the individual will begin to loose range of motion of that body part because of shortening or tightness of weak and unused soft tissue (Pendleton & Schultz-Krohn, 2006). To prevent the loss of range of motion, preventing muscle contracture and increase recovery, range of motion exercises are often implemented. Passive range of motion (PROM) is the act of another person or using the uninjured upper extremity to range the patient through their joint range of motion. In contrast, active range of motion (AROM) is the act of the individual ranging their affected limb through the range of motion (Pendleton & Schultz-Krohn, 2006). Active assistive range of motion (AAROM) is where the patient uses the msucles surrounding the joint to perform an exercise, but requires the assistance of a therapist or specialized equipment (Pendleton & Schultz-Krohn, 2006). More range of motion can often be claimed through PROM than AROM, therefore giving an added stretching effect on tendons and muscles. ROM exercises are known to help prevent contracture, maintain or increase ROM and increase blood flow to the limb.

4.) Splints. Splints have been shown to be one of the most important tools that a therapist can use to minimize and correct impairment and/or restore function (Pendleton & Schultz-Krohn, 2006). By immobilizing the hand and fingers after an injury, it allows the tissues to heal properly, and for most hand injuries, a splint rather than a cast is the method of choice. The purpose of the splint is to allow the hand to rest in a safe position, a position that will not lead to hand dysfunction. Typically, the wrist is placed in 20 degrees of extension, the metacarpophalangeal (MCP) joints are at 70 degrees flexion, and the interphalangeal (IP) joints should be straight, this is called the neutral position (Pendleton & Schultz-Krohn, 2006).

5.) Assistive Devices. Assistive devices are another common intervention for hand therapeutics in the clinic. There are many assistive devices that can be implemented for everyday use, especially in the home. Something as simple as changing the door knobs in the home into lever arms can make a huge difference to someone who is experiencing hand weakness or for joint protection. Simple physics explains that by increasing the lever arm of an object, this reduces the amount of torque needed to rotate the arm. Other assistive devices can be implemented such as changing grips on various tools around the house such as a spoon. By making the grip on the spoon bigger, this will allow for a more gross motor grip, as opposed to a fine grip (Pendleton & Schultz-Krohn, 2006; Pedretti & Early, 2001).

6.) Scar Management. Scar management is an important part of the healing process, especially in burn victims. As soon as wound closure occurs, scar formation begins. Materials such as intermediate pressure garments are good for desensitization, general skin conditioning, edema control and early scar compression (Pedretti & Early. 2001). Other garments such as self-adherent elastic wraps, tubular elastic support bandages, spandex garments and elastic bandage wraps are commonly administered. Therapy should always begin with scar massage with lotion to prepare for ROM exercises and stretching. Once the scars are thoroughly lubricated with lotion, passive stretching is used to increase the flexibility of the scar tissue. Following the stretching, active ROM, strengthening and endurance training can be implemented. Specific interventions for hand burns sometimes involve the use of hand putty, hand manipulation boards, the BTE Work Simulator, Valpar Work Samples and other fine motor activities. (Pedretti & Early. 2001)

7.) Medical Management. Many of today's hand traumas result in minimally invasive surgeries. This means that treatment of bone or soft tissue injuries are treated using various tools and techniques that do not require traditional open incisions (Wolfe, S. 2009). This decreases the amount of scarring, decreases injury to surrounding healthy tissues, and results in speedier recovery. Minimally invasive surgeries can be classified into two categories: arthroscopic and indirect visualization surgery. Arthroscopic surgery is where the surgeon inserts a tool with a video camera attached into the injury space to obtain a high resolution image of the injury inside. Indirect visualization surgery is where the surgeon only creates small incisions in order to visualize where structures are in the affected area (Wolfe, S. 2009).

Force-Time Curve

The F-T curve has been widely used in the fields of exercise physiology and athletics to assess muscular strength, endurance and performance (Bemben et al., 1992; Nakada et al., 2005; Haff et al., 2005). The F-T curve test has been used to assess maximal voluntary contraction in reaction to neuromuscular adaptations to strength-training programs in both athletics and rehabilitation, showing that the shape of the force-time curve is determined by characteristics of the neuromuscular system and its ability to develop muscular force (Bemben et al., 1992). Muscular adaptation to strength training can be divided into two factors: neural and hypertrophic factors. Heavy-weight training has been showing to increase mostly the peak force , due to hypertrophy, whereas speed-strength training has been shown to primarily increase the rate of force production, due to neural adaptations (Bemben et al., 1992; Nakada et al., 2005; Haff et al., 2005).

In addition, F-T curve characteristics such as force-generation phase and force-decay phase have been used to investigate maximal isometric contractions. F-T curve characteristics, including the rate of force development have reliably identified age related changes in explosive grip strength. Explosive grip strength tests used with the F-T curve test have shown a remarkably increase in the force-generation phase as compared to a slow maximal grip strength (Bemben et al., 1992; Nakada et al., 2005; Haff et al., 2005).

Chapter 3

Methods

Participants

Nine participants with upper extremity injuries were recruited at various hand therapy clinics in Milwaukee, WI. People were included if they were (1) aged between 18 and 65 years, (2) experienced a traumatic injury to their upper extremity elbow or distal within the past one year where trauma refers to body shock, wound, because of physical violence, accident, sudden physical injury, or surgery, (3) currently undergoing rehabilitation (including muscle strengthening) for a traumatic upper extremity musculoskeletal injury elbow or distally, and (4) able to safely perform 3 maximal grips with their affected extremity as determined by their physician or therapist.

People were excluded if they (1) have an injury proximal to elbow, (2) were not undergoing rehabilitation during the four weeks between pre- and post-testing, (3) were unable to safely perform 3 maximal grip trials with their affected extremity as determined by their physician or therapist, (4) verbally reported their current pain intensity to be greater than 7 on a 0 to 10 numerical rating scale (NRS), (5) have other musculoskeletal conditions that may impair grip strength, (6) have impaired cognition, (7) were unable to read or write English at the 8th grade level, and (8) if the participant was being treating for a psychological disorder, such as anxiety or depression, and if the condition is unstable.

Materials and Equipment

Materials that were used in this study included a questionnaire, the DASH assessment, and a data collection form. Major materials involved a Jamar dynamometer, FlexComp Infiniti analog to digital convertor, Biograph Infinity software, and a laptop.

The paper-and-pencil tests included: 1) demographic questionnaire, 2) visual analog scale (VAS) for measuring current pain intensity and for assigning imagined pain, 3) VAS for rating perceived grip effort, and 4) Disabilities of Arm, Shoulder, and Hand (DASH).

Instruments for Generating the F-T Curve

Jamar Hand dynamometer. The F-T curves were generated using a force transducer equipped Jamar dynamometer (Thought Technology, Ltd.). The transducer in the Jamar dynamometer converts grip pressure (measured in pounds; lbs) into an electrical signal (measured in Volts; V). The Jamar dynamometer has an operating range of (0-350 lbs.) and converts 1kg of external force into an electrical potential difference of 23.11 mV (Figure 3.1).

Calibration. Calibration of the dynamometer was examined according to the method of Ewing-Fess (1987). This is where the dynamometer sits on a split-top workbench with a stress tolerance of 350 pounds, with weights hanging so that the application of force is perpendicular to the table. A force collar will be used to standardize the position of the weights and distribute the pressure evenly. The weights (Rice Lake Weighing Systems, Rice Lake, WI) were added incrementally from 0 to 50 Kg while the dynamometer is in the second handle position (Ewing-Fess, 1987).

The analysis of calibration consisted of finding correlation coefficients between the standard mean (weights) for all trials and the actual dynamometer reading mean for all trials as well as graphically plotting the means compared to pounds of force applied.

Analog to digital converter. The A/D converter translates analog data from the dynamometer into digital form so it can be stored and used for data processing. The FlexComp Infiniti A/D converter takes a continuous signal and converts the voltage to discrete values (Figure 3.2). These discrete voltage values are then translated into numerical values and stored (Robertson et al, 2004). BioGraph Infiniti software (version 5.1.0, Thought Technology, LLC) will be used to generate the F-T curve.

Paper-and-Pencil Tests

1) Demographic questionnaire. The demographic questionnaire completed at baseline includes questions on injury and job-related information. The questionnaire included descriptions of injury/condition, whether the condition is work related, cause of injury, and duration of injury (Appendix A & B). A similar follow-up questionnaire will be administered post-intervention. The follow up questionnaire will also include whether they participated in a home exercise program and what kind, and the Global Rating of Change Scale.

2) Visual Analog Scale (VAS) for pain intensity. During this study, a VAS was used to assess the patient’s current pain intensity. The VAS consists of a 10cm line anchored by two extremes of pain, with no pain being represented as ‘0’ and pain as bad as it could be, represented as ‘10’. The VAS was administered at the beginning of the testing session and before each gripping effort in both hands to ensure the pain returns to pre-injury level (Appendix C).

3) Visual Analog Scale (VAS) for perceived grip effort. The perceived exertion of grip effort was rated using a VAS (Appendix C). It consists of a 10 cm line anchored by 2 extremes of effort, with no grip force being represented by ‘0’, and strongest grip force being represented by ‘10’. The VAS for grip effort was administered immediately after each grip. The VAS for grip effort was used to compute perceived effort.

4) Disabilities of Arm, Shoulder, and Hand (DASH) questionnaire. The DASH is a self-report questionnaire that assesses upper extremity disability (Appendix D). The DASH does not focus on a specific musculoskeletal conditions nor any specific joint of the upper extremity. The main portion of DASH is a 30-item disability/symptom scale about a patient’s health status during the preceding week. Each item has five response options. The scores for all the items are then added to calculate a scale score ranging from 0 (no disability) to 100 (most severe disability) (Gummesson, Atroshi, & Ekdahl, 2003).

5.) Fear-avoidance related to pain. A single item screening method was used to assess the level of fear-avoidance beliefs among our study participants at baseline as well as follow up (Appendix A & B). This single-item screening method was used to classify patients into low versus elevated fear-avoidance beliefs. This screening item was selected from the Fear-Avoidance Beliefs Questionnaire physical activities (FABQ-PA) scale, which consists of 16 items describing the association between pain and physical activities (see Figure 3.4). This single item is stated as “I should not do physical activities which (might) make my pain worse.” The item was scored on a five-point scale ranging from zero to four, where zero means “completely disagree,” two means “unsure,” and four means “completely agree.” Responses of two to four were classified as *elevated fear* and responses of zero and one were classified as *low fear*. This single item was identified using advanced statistical methods including Item Response Theory (IRT) methods and receiver operating characteristic analyses. These statistical analyses found this single item to be effective in distinguishing between elevated fear and low fear, with a sensitivity value of 0.82, specificity value of 0.98, and area under the receiver operating characteristic curve of 0.94 (Hart et al., 2009).

Study Design

The present study employed a repeated measures design. Each participant served as their own control for levels of injury (injured vs. uninjured hand) pre- and post-intervention.

Rationale for the Study Design. Stringent controls have been applied to the research design. The stringent controls would identify any significant differences between injured or uninjured hands as well as to identify their association with pain. The steps taken to make the study design conservative and stringent include:

- A repeated measures design provides the ability to control for potential influence of individual differences. We can safely assume that important participant characteristics, such as age and gender will remain constant through the course of the experiment (Portney & Watkins, 2000)

- One disadvantage of a repeated measures design is the potential for carryover effects. Carryover/residual effects, such as fatigue due to grip strength trials, can be reduced by allotting sufficient time between successive grip efforts to allow for complete dissipation of previous effects (Portney & Watkins, 2000). To dissipate carryover effects, study participants will be provided with a rest break lasting 5-

minutes after each grip trial (Kamimura & Ikuta, 2001; Trossman & Li, 1989). To reduce effects of fatigue, data collection will occur on a separate day or before the therapy session.

Procedure

Participant Recruitment

Participants were recruited from various hand therapy clinics throughout Wisconsin. Treating therapists were provided with inclusion and exclusion criteria as well as a standardized script for recruiting participants. The criteria and directions were provided to the healthcare professionals as part of a letter (Appendix D). The script is as follows:

> "A study is being conducted to identify the ability of grip efforts to measure recovery due to rehabilitation among individuals with traumatic upper extremity injuries. Your condition makes you eligible to participate in this study. This study involves gripping a hand dynamometer 3 times with each hand and rating your pain and perceived grip effort. If you agree to participate, you will attend two sessions, each lasting approximately 45 minutes to 1 hour and will be paid $10.00 for the first session, and $30.00 for the second session, for participating in the study. Please let me know if you are interested in participating and I can provide you with information to contact the research group."

The healthcare professionals communicated the information on the study to their patients who they judge to be able to safely perform 2 sessions of 3 maximal grips with the unaffected and affected hand, four weeks apart. Interested participants were asked to call or email the investigators indicating their interest in participating in the study and to setup an appointment for collecting data.

Data Collection Phase

1.) Instrument calibration. The Jamar dynamometer and the FlexComp Infiniti were calibrated prior to each testing session. The calibration of the dynamometer was checked by measuring the electrical output on suspending known weights (10, 20, and 25kg.). The FlexComp Infiniti includes a built-in voltage reference that possesses good temperature stability. This reference voltage was used to self-calibrate the unit. The self-calibration process sets the gain and offset of each channel of the unit to a value within their preset specifications (Thought Technology Ltd., 2006).

2.) Participant preparation. Participants began with signing an informed consent form approved by the University of Wisconsin-Milwaukee. The particpants then filled out a demographic questionnaire (see Appendix A & B). Then the participant received instructions for completing the Visual Analog Scale (VAS).

3.) Protocol. All participation in this study, nine, attended two sessions, four weeks apart with each session lasting approximately 45 minutes to 1 hour. Each participant exerted a total 3 maximal grip efforts with each hand with each grip lasting for 10 seconds. After each grip effort, the participant rested for a period of 5 minutes. For all grips, the participant was seated in an adjustable chair without arm rests. The participant assumed the testing position recommended by the American Society of Hand Therapists (Fess & Moran, 1986). The participant’s feet were fully resting on the floor and the hips were as far back in the chair as possible, with the hips and knees positioned at approximately 90°. The shoulder of the tested extremity was adducted and neutrally rotated, the elbow flexed to 90°, and the forearm and wrist held in a neutral position.

At the beginning of the rest period, the test administrator asked the participant to complete the effort visual analog scale (VAS-E) for reporting their perceived exertion of grip strength. At the end of the rest period, the participant completed the pain intensity visual analog scale (VAS-P) for reporting their pain resulting from the grip. If the reported level of pain was more than 1-point higher than the range of pain usually experienced then the participant will continue to rest until the level of pain returns to within 1-point of the initial level of pain. Appendix C includes examples of the VAS-E and VAS-P.

The participant performed a practice grip with each hand to get used to the dynamometer and to check if the force and EMG signals were being recorded properly. The participant also practiced marking the VAS-E and VAS-P.

4.) Instructions. The instructions given before the 10-second maximal grips were as follows:

> “This task will test your grip strength. When you hear a beep, give your maximum effort in a smooth manner. Be careful not to jerk the tool while gripping. You will exert a maximal effort for 10 seconds. You will be given a rest period after each grip. Before the next three grips I will ask you ‘Are you ready?’ and then you will hear a beep. Upon hearing the beep, start immediately. The beep will last 10 seconds. Stop gripping when the beep stops. If you experience any unusual pain or discomfort at any point during testing, stop immediately. Do you have any questions?”

The participants were also instructed on how to complete effort and pain scales. See examples in Appendix C. Instructions for completing effort scales will be as follows:

> "You will use the Effort Scale for recording the amount of effort you think you exerted during each grip. On this scale, 0 means no grip force and 10 means strongest grip force. Mark a vertical line at a point that indicates the level of effort you just exerted. Do you have any questions?"

Instructions for completing the pain scale will be as follows:

> "You will use the pain scale for recording the pain that you are currently experiencing in your injured upper extremity. On this scale, 0 means no pain and 10 means that the pain is as bad as it could be. Mark a vertical line between 0 and 10 at a point that indicates your pain level. Do you have any questions?"

Statistical Analysis

Specific Aim 1

Repeated measures analysis of variance tests (ANOVA) were implemented with a within-subjects variable being session (baseline vs. follow-up). Two separate ANOVAs were conducted for the slope of force-generation phase and slope of force-decay phase. The results were considered significant at an alpha level of 0.05.

Specific Aim 2

Concurrent validity was determined by calculating Pearson product moment correlations (r) between percent change in slope and percent change in grip strength. Percent change in slope was computed as [(change in slope of injured hand)/(average peak force of injured hand]x100. Percent change in grip strength was computed as [(change in peak force of injured hand)/(average peak force of uninjured hand)]x100. Moderate to high correlation coefficients (0.5 or higher) were be considered sufficient for establishing concurrent validity of the slopes.

Specific Aim 3

Change score (follow-up vs. baseline) was calculated for each participant on each measure (grip strength, slope of force-generation phase, and slope of force-decay phase) and was used to calculate Effect Size (ES) coefficients. The Effect Size coefficients were obtained by dividing the average change score by the standard deviation of baseline scores. Greater effect size coefficients indicate larger change in the measure from baseline to follow-up.

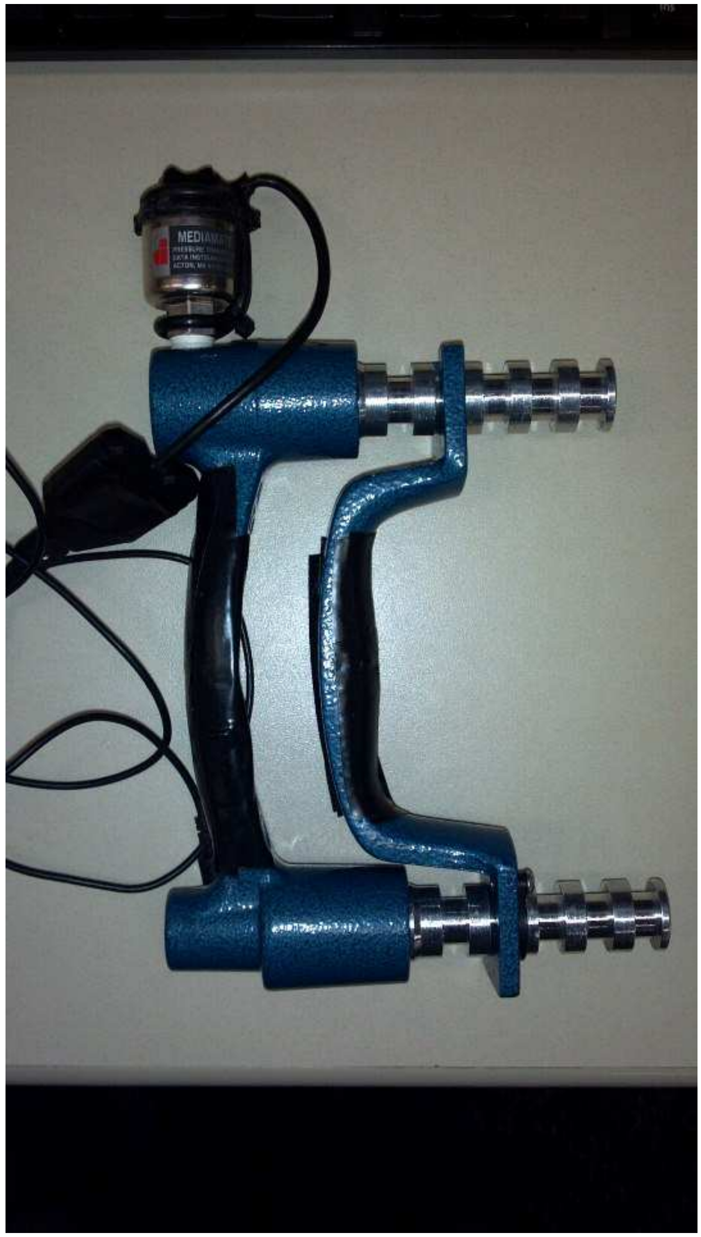


Figure 3.1 Jamar Dynamometer

Figure 3.2 FlexComp Infiniti Analog to Digital Converter

Figure 3.3 FlexComp Infiniti Equipment Setup

Name: ______________________________ Date: ______________

Here are some of the things which other patients have told us about their pain. For each statement please circle any number from 0 to 6 to say how much physical activities such as bending, lifting, walking or driving affect or would affect your back pain.

	COMPLETELY DISAGREE			UNSURE			COMPLETELY AGREE
1. My pain was caused by physical activity	0	1	2	3	4	5	6
2. Physical activity makes my pain worse	0	1	2	3	4	5	6
3. Physical activity might harm my back	0	1	2	3	4	5	6
4. I should not do physical activities which (might) make my pain worse	0	1	2	3	4	5	6
5. I cannot do physical activities which (might) make my pain worse	0	1	2	3	4	5	6

The following statements are about how your normal work affects or would affect your back pain.

	COMPLETELY DISAGREE			UNSURE			COMPLETELY AGREE
6. My pain was caused by my work or by an accident at work	0	1	2	3	4	5	6
7. My work aggravated my pain	0	1	2	3	4	5	6
8. I have a claim for compensation for my pain	0	1	2	3	4	5	6
9. My work is too heavy for me	0	1	2	3	4	5	6
10. My work makes or would make my pain worse	0	1	2	3	4	5	6
11. My work might harm my back	0	1	2	3	4	5	6
12. I should not do my normal work with my present pain	0	1	2	3	4	5	6
13. I cannot do my normal work with my present pain	0	1	2	3	4	5	6
14. I cannot do my normal work until my pain is treated	0	1	2	3	4	5	6
15. I do not think that I will be back to my normal work within 3 months	0	1	2	3	4	5	6
16. I do not think that I will ever be able to go back to that work	0	1	2	3	4	5	6

Figure 3.4 Fear-Avoidance Beliefs Questionnaire Physical Activities Scale (FABQ-PA)

Chapter 4

Results

Sample characteristics

This study consisted of nine participants, including four men and five women. The average age for the entire sample was 46 years (SD=15.86), with the average age of men being 43 years (SD=16.88) and for women being 48 years (SD=18.32). Of the nine participants, eight were right-hand dominant, four being men and four being women. One woman was left-hand dominant. Half (N=5) of the participants were working at the time of injury and continued to work throughout therapy, while one participant worked part-time and three did not work at all after injury. All participants lived in Milwaukee County at the time of the study and were recruited from three hand therapy clinics in the greater Milwaukee area. Further details on demographic characteristics are presented in Table 4.1.

Half (N = 5) of the participants experienced an injury to their right upper limb. Seven of the participants experienced an injury to their dominant upper limb. Five participants experienced an injury to their hand, two participants experienced an injury to their wrist, and two participants experienced an injury to their forearm. The most common referral for injury was a traumatic cut or tear of a muscle. Of all nine participants, the cause of their injury was work-related. Regarding rehabilitative treatment provided to study participants, muscle strengthening exercises were the most common component given to all participants (N = 9; 100%), with the second most common strategy being range of motion (ROM) exercises provided to eight participants (89%), and the third most common strategy being physical agents provided to six participants (66.6%).

During testing, pain intensity, fear avoidance score, global rating of change score, and Disabilities of Arm, Shoulder and Hand score were calculated. The average pain intensity score, at initial evaluation, as measured using a 0-10 visual analog scale, was 1.61 (SD=1.58) for the overall sample, 1.25 (SD=1.26) for men, and 2.6 (SD=1.67) for women. At the four week follow-up (post-testing), the average pain intensity for the overall sample was 1.22 (SD=1.64), for men was 1.5 (SD=2.38), and for women was 1 (SD=1).The average pain intensity after the third and final grip was 3.45 and pain increased an average of 2 points from first to third grip. The average fear avoidance score, during initial evaluation (pre-testing), as measured using a 0-4 scale, was 1.61 (SD=1.59) for the overall sample, 1.25 (SD=2.5) for men, and 1.28 (SD=1.61) for women. During the four week post evaluation (post-testing), the average fear avoidance score for the overall sample was 0.11 (SD=0.33), 0 (SD=0) for men, and 0.2 (SD=0.45) for women. This indicated an average decrease in levels of fear, from low during pre-testing to no fear during post-testing. For initial evaluation, the average Disabilities of the Arm, Shoulder and Hand (DASH) score was 29.94 (SD=14.49), with men's average being 24.15 (SD=14.3), with women's average being 37.19 (SD=12.26). For post-testing, the total average value was 15.74 (SD=11.02), with the men's average value being 12.7 (SD=15.93), and the women's value being 18.17 (SD=5.99). Further details on injury related characteristics can be found in Table 4.2 and Table 4.3.

Force-time curve characteristics

Table 4.4 and Table 4.5 summarizes the various force-time curve characteristics of the maximal grip efforts exerted by injured and uninjured hands during initial evaluation (pre-test) and at four weeks follow-up (post-test). When calculating the different parameters of the force-time curve, we identified the slope of force-generation phase as the phase between zero and the peak force where there was a rapid development of force. The peak force was identified as the peak point of force where the rapid development of force, or slope of force-generation phase tapers off. The slope of force-decay phase was identified as the period after the peak force where there was a gradual decay of force until the participant let go. Each phase was identified visually for each participant. For specific aim 1, repeated measures of analysis of variance (ANOVA) tests were conducted to determine construct validity of slopes of force-time curve as outcome measures. In other words, repeated measures ANOVA tests were used to determine changes in force-time curve characteristics of injured hands from pre-test to post-test, with results deemed significant at an alpha level of 0.05. We found a significant increase in slope of force-generation phase from pre-test (13000 grams/sec) to post-test (18900 grams/sec) ($F=5.745$, $p=0.043$). The average increase slope of force-generation phase from pre- to post-test was 5290 grams/sec. In contrast, we did not find significant changes in peak force and slope of force-decay phase. Peak force increased an average of 2140 grams from pre-test (23550 grams) to post-test (25690 grams) ($F=3.494$, $p=0.099$). Slope of force-decay phase became steeper on average 0.24 grams/sec from pre-test (-620 g/sec) to post-test (-380 g/sec) ($F=4.247$, $p=0.073$) (Tables 4.4-4.6).

For specific aim 2, Pearson product-moment correlation coefficients were calculated to determine concurrent validity of slopes of force-time curve as outcome measures of rehabilitation. Pearson correlations were calculated between change scores of peak force, slope of force-generation phase, and slope of force-decay phase. Moderate to high correlation coefficients (0.5 or higher) were considered sufficient for establishing concurrent validity of the slopes. We found low correlation coefficients (r=0.108 to r= 0.300) between peak force, slope of force-generation phase and slope of force-decay phase (Table 4.9).

For the specific aim 3, Effect Size (ES) coefficients were calculated to determine the responsiveness of the three force-time curve characteristics as outcome measures of rehabilitation. Effect size coefficients of 0.2 and less indicate low responsiveness, coefficients of 0.5 indicate moderate responsiveness, and coefficients of 0.8 or larger indicate large responsiveness (Portney & Watkins, 2000). For peak force, we found a small Effect Size coefficient (*ES = 0.185*). In contrast, the Effect Size coefficients were found to be moderate for both slope of force-generation phase (*ES = 0.586*) and slope of force-decay phase (*ES = 0.540*). The Effect Size coefficients for the slopes were similar, and they were larger than peak force. These values can be viewed on Table 4.10.

Table 4.1
Demographic Characteristics of the 9 Study Participants With Upper Extremity Traumatic Injuries

	Men (N=4)		Women (N=5)		Total (N=9)	
Characteristics	Mean or Number	SD or %	Mean or Number	SD or %	Mean or Number	SD or %
Age (years)	42.75	16.88	48	18.32	45.9	15.86
Height (inches)	71.25	2.22	62.6	4.16	66.44	5.59
Weight (lbs)	189.25	22.23	162.6	42.35	174.44	35.77
Dominant Hand						
Right	4	100	4	80	8	88
Left	0	0	1	20	1	11
Injured Extremity						
Right	3	75	2	40	5	56
Left	1	25	3	60	4	44
Current Work						
Full-time	4	100	1	20	5	56
Part-time	0	0	1	20	1	11
Not Working	0	0	3	60	3	33

Table 4.2

Treatment Related

Characteristics of Study Sample

	Men (N=4)		Women (N=5)		Total (N=9)	
Characteristics	Mean or Number	SD or %	Mean or Number	SD or %	Mean or Number	SD or %
Pain Intensity						
Pre-Test	1.25	1.26	2.6	1.67	1.93	1.58
Post-Test	1.5	2.38	1	1	1.22	1.64
Change (Pre-Post)	0.25	1.5	-1.6	1.14	-0.55	1.56
Fear Avoidance (0-4)						
Pre-Test	1.25	2.5	1.9	1.28	1.61	1.59
Post-Test	0	0	0.2	0.45	0.11	0.33
Change (Pre-Post)	-1.25	2.5	-1.7	1.2	-1.5	1.78
DASH						
Pre-Test	24.15	14.3	37.19	12.26	29.94	14.49
Post-Test	12.7	15.93	18.17	5.99	15.74	11.02
Change (Post-Pre)	11.45	11.52	12.77	15.87	14.21	10.74

Table 4.3

Treatment Related Characteristics

of Study Sample

Characteristics	Men (N=4)		Women (N=5)		Total (N=9)	
	Mean or Number	SD or %	Mean or Number	SD or %	Mean or Number	SD or %
Global Rating of Change	6	1.41	5.6	1.14	5.78	1.2
Components of Intervention						
Muscular Strength	4	100	5	100	9	100
Stretching/ROM	4	100	4	80	8	88.88
Physical Agents	1	25	5	100	6	66.66
Splinting	0	0	3	60	3	33.33
Sensory Re-education	1	25	1	20	2	22.22
Massage	2	50	5	100	7	77.78

Table 4.4

Descriptive Statistics of Various Force-Time Curve Characteristics for Injured and Uninjured Hands of Men and Women during Baseline (pre-test) and Follow-up (post-test) Evaluation

	Men (N=4)				Women (N=5)			
	Injured Hands		Uninjured Hands		Injured Hands		Uninjured Hands	
	Average	SD	Average	SD	Average	SD	Average	SD
Baseline								
Peak force (kgf)	32.75	9.570	45.21	12.76	16.19	6.63	19.80	6.78
Slope of force-generation phase (kgf/sec)	14.00	.600	32.00	16.00	12.00	12.00	17.00	16.0
Slope of force-decay phase (kgf/sec)	-.800	.500	-.400	.100	-.500	.400	-.200	.200
Follow-up								
Peak Force (kgf)	34.52	10.74	49.39	13.22	17.77	7.92	23.4	5.83
Slope of force-generation phase (kgf/sec)	19.90	6.60	28.99	6.80	16.90	13.3	20.8	16.5
Slope of force-decay phase (kfg/sec)	-.500	.400	-.750	.100	-.200	.100	-.200	.010

Table 4.5

Descriptive Statistics of Various Force-Time Curve Characteristics for Injured and Uninjured Hands of All Participants during Baseline (pre-test) and Follow-up (post-test) Evaluation

	All (N=9)			
	Injured Hands		Uninjured Hands	
	Average	SD	Average	SD
Baseline				
Peak force (kgf)	23.55	11.52	31.09	16.232
Slope of force-generation phase (kgf/sec)	13.02	9.025	23.77	16.97
Slope of force-decay phase (kgf/sec)	-.620	.460	-.292	.180
Follow-up				
Peak Force (kg)	25.69	11.74	34.95	16.43
Slope of force-generation phase (kgf/sec)	18.30	10.39	24.47	13.15
Slope of force-decay phase (kgf/sec)	-.370	.355	-.479	.270

Table 4.6

Repeated Measures Analysis of Variance Results for Peak Force

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Within-Subjects					
Session	20.523	1	20.523	3.494	.099
Error	46.994	8	5.874		

Table 4.7

Repeated Measures Analysis of Variance Results for Slopes of Force-Generation Phase

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Within-Subjects					
Session	.000126	1	0.000	5.745	.043
Error	.000175	8	0.00002195		

Table 4.8

Repeated Measures Analysis of Variance Results for Slopes of Force-Decay Phase

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Within-Subjects					
Session	2.788x10^-7	1	2.788x10^-7	4.247	.073
Error	5.251x10^-7	8	6.563x10^-8		

Table 4.9

Pearson Correlations of Change in the Three Force-Time Curve Characteristics from Initial (pre-testing) to Follow-up (post-testing) Sessions

Correlations	Injured Peak Force	Injured Force Generation	Injured Force Decay
Injured Peak Force	1	0.162	0.108
Injured Force Generation	0.162	1	0.300
Injured Force Decay	0.108	0.300	1

Table 4.10
Effect Size Coefficients for the Peak Force, Slopes of Force-Generation Phase, and Slopes of Force-Decay Phase

Measure	Effect size coefficients
Peak Force	0.185
Force Generation	0.586
Force Decay	0.540

Figure 4.1
Average Peak Force for Injured and Uninjured Men and Women for Initial (pre-testing) and Follow-up (post-testing) Sessions.

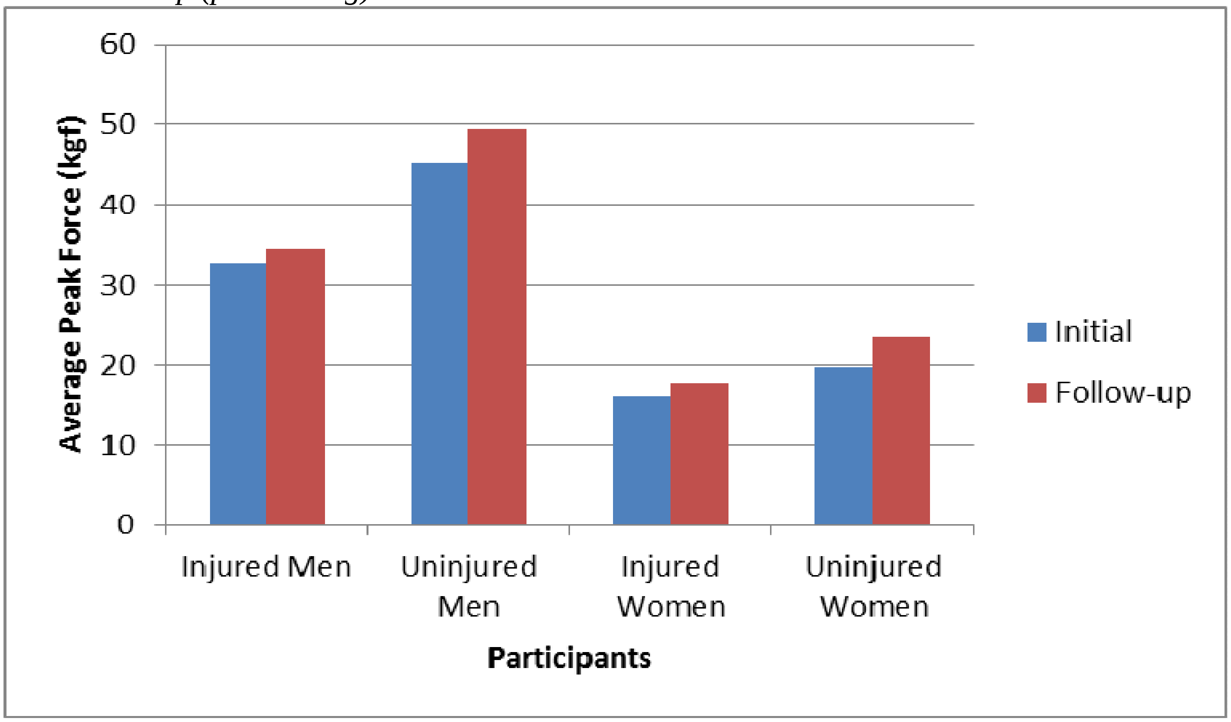


Figure 4.2

Average slope of Force-Generation phase for Injured and Uninjured Men and Women for Initial (pre-testing) and Follow-up (post-testing) Sessions.

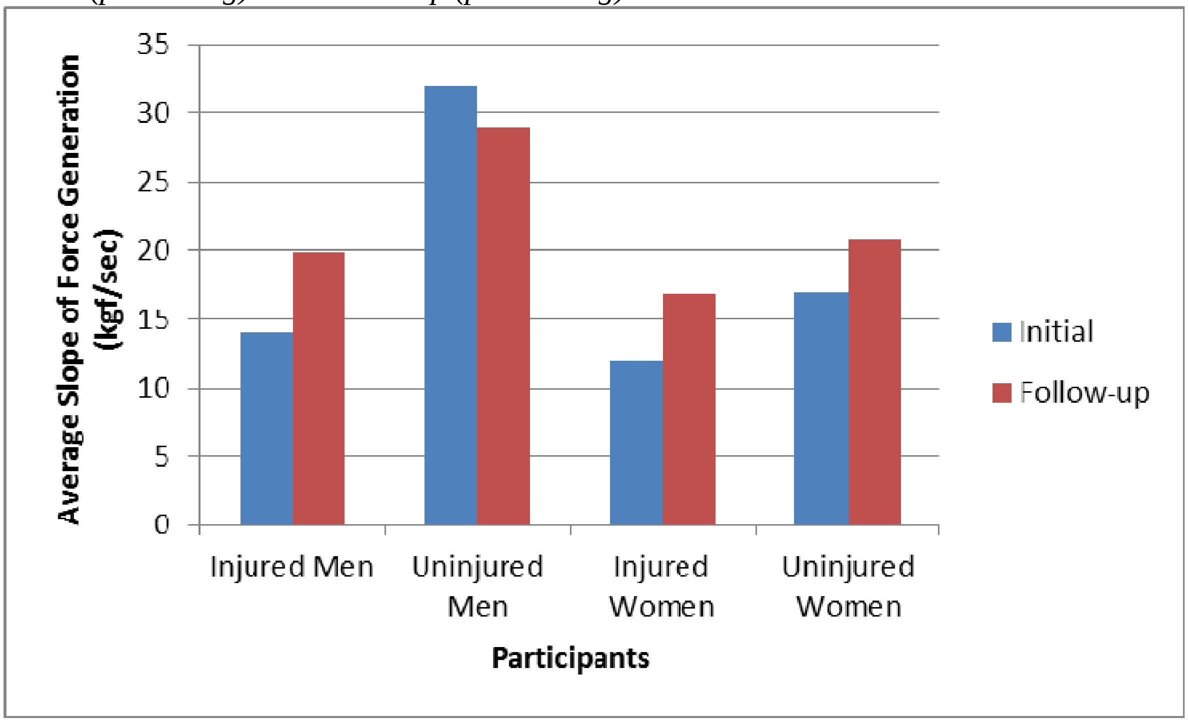
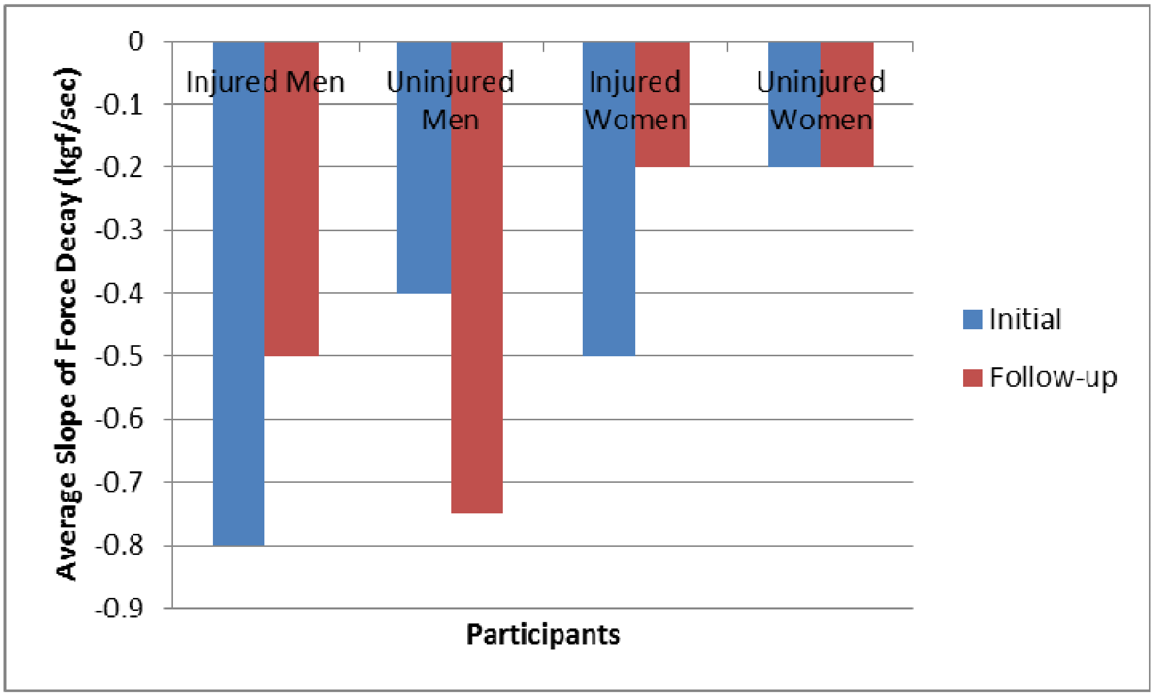


Figure 4.3

Average Slope of Force-Decay Phase for Injured and Uninjured Men and Women for Initial (pre-testing) and Follow-up (post-testing) Sessions.



Chapter 5

Discussion

There is a need for developing new measures that can better identify patient recovery post-rehabilitation, as mandated by the Patient Protection and Affordable Care Act (PPACA; Internal Revenue Code, 2013). The PPACA is a federal statute signed into law by President Barack Obama in 2010. The PPACA consists of ten titles, with the most widely known and publicized title being Title I “Quality, Affordable Health Care for All Americans.” Title I aims at increasing the affordability of healthcare by reducing rates of health insurance coverage for Americans. Beginning in 2014, almost all Americans will be required to have health insurance, either purchased at affordable rates from health exchanges or sign up for insurance coverage provided by their employers (Pub.L. 111-148, 124 . Stat 1011, 2013). Therefore, the Act will save taxpayer dollars by reducing the numbers of Americans without insurance, which in turn will reduce Medicare’s need to pay hospitals to care for individuals without insurance (U.S. Department of Health & Human Services, 2013; Pub.L. 111-148, 124 . Stat 1011, 2013). A not so widely publicized part of the PPACA is Section 10303 “Development of outcome measures” of Title III “Improving the Quality and Efficiency of Health Care.” Section 10303 requires the development of new healthcare provider-level outcome measures. These measures need to address the most prevalent and resource-intensive acute and chronic medical conditions and care for distinct patient populations such as healthy children, chronically ill adults, or infirm elderly individuals (Thorpe & Weiser, 2013). In other words, the PPACA aims to improve healthcare outcomes and hasten the delivery of healthcare. A prerequisite for improving healthcare outcomes is to use outcome measures that are reliable, valid, and sensitive to detecting change with treatment.

Hand therapists commonly use grip strength as a measure of gross function of the upper extremity and overall physical health (Shechtman et al., 2007). Grip strength is also used to determine return to work after injury and to estimate physical work capacity and to determine extent of disability. Physical and Occupational Therapists typically use the Jamar dynamometer to assess grip strength. By following standardized instructions and positioning, grip strength has become a reliable and valid measure of rehabilitation outcomes (Moran, 1986; Pendleton & Schultz-Krohn, 2006). However, grip strength has several limitations. First, grip strength is not a true measure of hand function. Grip strength indicates strength of isometric contraction of extrinsic forearm flexor and extensor muscles and intrinsic muscles of the hand, which is correlated with hand function but does not describe which daily activities can be performed and daily activities cannot be performed (Shechtman & Sindhu, 2007). Second, grip strength does not describe a person's pattern of force production and motor recruitment pattern during a single isometric strength trial. Generally, grip strength is limited to only giving information on peak force and does not allow a therapist to identify a specific problem since it measures both extrinsic forearm flexor and extensor muscles and intrinsic muscles of the hand (Sindhu & Shechtman, 2007). In addition, in recent years, insurance companies are not covering full rehabilitation, they are only covering about 10 treatment sessions. As a result, therapists discharge patients when their grip strength is about 50% of the uninjured hand (L. Klein, personal communication, May 19, 2013). However, to increase muscle strength, a person needs to perform muscle contractions at approximately

70% of maximal voluntary contraction (Shechtman et al., 2007; Shechtman et al., 2011; Sindhu et al., 2011). Due to shorter rehabilitation phases, patients may not have healed enough to perform exercises that are necessary to increase muscle strength. Consequently, there is a need to develop measures that more accurately measure and document changes occurring during shorter duration rehabilitation.

The force-time curve (F-T curve) is a graphical representation of force generated by the contraction of muscles over a period of time during a single strength trial. In the graph, the vertical axis (Y-axis) represents the change in force of the muscle and the horizontal axis (X-axis) represents time elapsed during a contraction. The force-time curve describes rate of force production, rate of force decay, muscle recruitment, in addition to peak force (Shechtman et al., 2007; Shechtman et al., 2011; Sindhu et al., 2011). The rate of force production or force generation phase is the point where there is a rapid acceleration of force before reaching a peak force. The slope of force-generation phase is a graphical representation of the rate of force production over a period of time beginning when the user squeezes the dynamometer to the time where rate of force generation tapers off. The rate of force decay or force decay phase is where there is a gradual decrease in force after peak force often due to fatigue. The slope of force-decay phase is a graphical representation of the rate of force-decay beginning where peak force is achieved to when the user lets go of the dynamometer at the end of a ten-second trial. Strength training, heavy weight training, and speed-strength training have been shown to influence peak force and rate of force production differently (Shechtman et al., 2007; Hakkinen et al., 1985). Today, the slopes of the F-T curve are not used in clinics to evaluate changes in force production and force decay due to a couple reasons. First, it requires specialized equipment and software, which is more expensive than the dynamometers commonly used for measuring grip strength (Shechtman et al., 2007; Shechtman et al., 2011; Sindhu et al., 2011). Second, it is not known how the nature of force-time curves change with rehabilitation. There has been much research on how the slopes of the force-time curve change with training in sports and related fields (Hakkinen et al., 1985; Shechtman et al., 2007). That is, speed training is necessary for improving rate of force production, though speed training is not appropriate for weak or injured muscles. But, there is limited evidence on the psychometric properties of the slopes of the F-T curve and on the comparison between the slopes of the F-T curve and grip strength. The F-T curve slopes have been found to be reliable, and there is preliminary evidence on construct validity. Three studies have been performed that show test-retest reliability for the slopes of the F-T curve. These values have shown to have moderate to high reliability coefficients (r=0.58 to r=0.82) (Bemben et al., 1992; Househam et al., 2004; Demura et al., 2001; Sindhu & Shechtman, 2011). A previous study was conducted in our lab to determine the reliability and validity of the force-time curve (F-T curve), to examine differences in the slopes of force-generation and force-decay phase between maximal efforts of injured and uninjured hands, and to examine test-retest reliability of slopes of force-generation phase and force-decay phase of maximal grip efforts. Their findings showed that the slope of force-generation phase was less steep for the injured hand, therefore showing a decrease in the rate of force development. Their other finding showed a steeper slope of the force-decay phase for the uninjured hands, indicating that the uninjured hands fatigue faster than the injured hands. This last finding may be due to the participants not exerting their true maximal effort (Sindhu & Shechtman. 2011).

However, we do not know the responsiveness of the slopes of the F-T curve. Responsiveness is the ability of an instrument to detect change in a measure over a period of time. This is important to determine with the slopes of the F-T curve as it shows that the instrument is responsive to changes in an individual's recovery. The purpose of this thesis was to identify the construct validity, concurrent validity as well as responsiveness of the F-T curves.

Construct Validity

The present study suggests construct validity of the slope of force-generation phase as hypothesized. However, contrary to our hypothesis, we did not find construct validity of slope of force-decay phase or grip strength for measuring change during early phases of rehabilitation. In the present study, construct validity of the slopes of force-time curve was determined by examining if they showed significant changes with rehabilitation and how these changes compared to changes in grip strength. We conducted three separate repeated measures analysis of variance (ANOVA) tests to determine changes in peak force, slope of force-generation phase, and slope of force-decay phase from pre-testing (baseline) to four week follow-up test. We found that the slope of force-generation phase became steeper from initial testing (13000g/sec) to follow-up (18900 g/sec), a 5290g/sec increase ($F=5.745$, $p\leq 0.043$). In contrast, we did not find a significant increase in slope of force-decay phase (0240g/sec) ($F=3.494$, $p\leq 0.099$) as well as peak force (2140g/sec) ($F=4.247$, $p\leq 0.073$) (Table 4.3, and Figures 4.1-4.3). Our findings are similar to those of previous studies that have indicated that grip strength does not predict injury or is not an adequate outcome measure. For example, Dale et al. (2013) showed that there was no consistent association between grip strength and health outcomes during 3 year follow-up of new young workers, regardless of the physical demands of a job.

A likely reason for observing an increase in steepness of the slope of force-generation phase could be a reduction in injury-related factors. From baseline to four-week follow-up, we observed that study participant fear dropped on average 1.50 units while pain intensity reduced by 0.71 units, these values can be viewed in Table 4.2. These changes could be considered to be indicators of reduced muscle guarding. Reduced muscle guarding, in turn, could have allowed study participants to exert grip forces at a faster rate. There is a likelihood that participants participated in speed training that could have affected their grip strength. This is due to working with the Baltimore Therapeutic Equipement (BTE) machine, where distance and time can be manipulated which can have an effect on how the individual participates in their exercise, which could have influenced a speed training effect, which increases the rate of force development. We could be more confident of this effect if an interview was provided with the treating therapists regarding the various components of treatment.(Shechtman, 2007; Hakkinen et al., 1985). However, our study participants did not report any kind of speed training as part of their therapy. Therefore, reduction in pain and fear-of-pain are the most likely reasons of increase in slope of force-generation phase.

In contrast, there are three likely reasons for not observing significant changes in peak force and slope of force-decay phase: 1) type of muscle strengthening, 2) duration between baseline and follow-up testing, and 3) study sample size. First, peak force and slope of force-decay phase may not have improved because of inadequate amount of strength training provided in the first four weeks of therapy. Strength training has been shown to increase peak force and the rate of force production. Heavy weight training causes an increase in the peak force, due to hypertrophy (Shechtman, 2007; Hakkinen et al., 1985). During initial phases of treatment, hand therapists usually avoid strenuous strength training because of risk of re-injury. Consequently, it could be that we did not see changes in peak force due to inadequate amount of strength training during this initial phase of therapy. Second, our pre- and post-testing were conducted four weeks apart. A short duration between pre- and post-testing was chosen due to the pilot nature of the study and due to scope of this thesis. Our findings are in contrast to previous studies performed to examine psychometric studies on grip strength testing. Previous studies have shown significant improvements in grip strength with rehabilitation (Beaton et al., 1995; Crosby et al., 1994; Richards et al., 1996; Richards, 1997). However, previous studies have used a longer duration between pre- and post-testing. To the best of our knowledge, the present study is the first in examining the change in grip strength during the initial phases of therapy and not in performing grip strength testing at baseline and discharge. It could be that grip strength shows non-linear increases during rehabilitation, with a smaller increase in the initial phase of rehabilitation and a greater increase in later phase of rehabilitation. Finally, we may not have observed changes in peak force and slope of force-decay phase due to a small sample size. We only included nine participants in this study because of pilot nature of the study as well due to scope of this thesis. Although we did not find significant changes, the p-values were approaching significance for both peak force ($p=0.073$) and slope of force-generation phase ($p=0.099$). Therefore, it could be that a larger sample study would have shown significant increases in both peak force and slope of force-generation phase.

Concurrent Validity

The present study is the first to examine concurrent validity of slopes of force-time curve and grip strength. In the present study, we did not identify concurrent validity of the slopes of force-time curve with grip strength. Concurrent validity was determined by calculating Pearson-moment correlation coefficients between percent change scores of peak force, slope of force-generation phase and slope of force-decay phase were calculated to determine concurrent validity. The change scores were normalized as they were divided by scores of uninjured hands. We found low correlation coefficients between slope of force-generation phase and peak force ($r = 0.162$), between slope of force-decay phase and peak force ($r = 0.108$) as well as between slope of force-decay phase and slope of force-generation phase ($r = 0.300$). These values can be viewed in Table 4.7. Low correlation coefficients indicate that the three change scores of the slopes of force-time curve do not have concurrent validity with grip strength change scores.

A likely reason for finding low correlation coefficients is that the three force-time curve parameters measure three different constructs. That is, peak force represents the overall ability of gripping muscles to produce a maximal force, the slope of force-generation is the ability of gripping muscles to rapidly produce increasing force, and the slope of force-decay indicates that rate of fatigue development during a maximal grip (Shechtman et al., 2007; Sindhu & Shechtman., 2011). Another reason for low correlation coefficients is the differential effect of various injury-related factors on the three force-time curve parameters. The repeated ANOVAs of the change scores conducted to determine construct validity suggest that decrease in pain intensity and fear-of-pain result in greater change in slope of force-generation phase as compared to peak force and slope of force-decay phase (Tables 4.2 and 4.3). These unequal changes could result in low correlation coefficients and thus inadequate concurrent validity. Yet another reason for low correlation coefficients might be related to our study design. Our small sample size could have resulted in low correlation coefficients. In addition, a short duration of four weeks between pre- and post-test could result in different amounts of changes and thus low correlation coefficients. It could be that that a study with a larger sample size that compares change between intake and discharge would result in better concurrent validity.

Responsiveness

In the present study, we found the slopes of force-time curve to have better responsiveness than grip strength. To the best of our knowledge, the present study is the first to determine responsiveness of the slopes of force-time curve. Responsiveness is the ability of an instrument to detect change in a measure over a period of time. This is important to determine with every clinical tool as it shows that the instrument is responsive to changes in an individual's recovery. We used Effect Size (ES) coefficients to determine responsiveness of the three force-time curve parameters. Effect size coefficients of 0.2 and less indicate low responsiveness, coefficients of 0.5 indicate moderate responsiveness, and coefficients of 0.8 or larger indicate large responsiveness (Portney & Watkins, 2000). We found effect size coefficients to be low for peak force ($ES = 0.185$) but moderate for slope of force-generation phase ($ES = 0.586$) and slope of force-decay phase ($ES = 0.540$). Consequently, our study findings suggest that during initial phase therapy, change in patients with upper extremity traumatic injuries can be better detected by the slopes of force-time curve than grip strength, the current accepted gold standard for measuring change with rehabilitation.

The slope of force-generation phase and slope of force-decay phase were more responsive than peak force can be explained by a number of reasons. The first reason this may be is due to the study only being four weeks in length, from initial testing to follow-up. A longer duration study may not show the same differences. This is likely since in previous studies, grip strength testing has been shown to have moderate to high responsiveness, in contrast to our present findings (Crosby et al., 1994; Richards et al., 1996; Richards, 1997). Another reason may be that our sample size of nine participants was not an adequate representation of the population and that a larger sample size may have given different results. This may explain why our study did not identify significant increases in slope of force-decay phase in the ANOVA, but did show responsiveness similar to the slope of force-generation phase. Finally, slope of force-generation phase had greater responsiveness than grip strength due to differential effect of reduction in pain intensity, fear of pain, and muscle guarding.

Limitations

This study has several limitations. First, the sample size was small. We only included nine participants, which could have confounded our study findings and influenced on the results of the present study. This could have confounded the study since smaller sample sizes typically do not adequately represent the general population of persons with upper extremity traumatic injuries and sometimes a small amount of variability can have large effects in a small sample study. Secondly, the location of injury in our sample was specific, with all individuals having an upper extremity traumatic injury elbow or distal, this reduces full representation of the general population. Third, our study was limited by a short duration of four weeks between pre-testing and follow-up testing, thus not allowing enough time for full recovery and changes to occur. Fourth, study participants may have inaccurately reported their types of treatments whereas therapists have better understanding of what treatments participants underwent. Lastly, this study was limited in scope as it compared only performance measures and did not concurrently examine self-report assessments such as the DASH questionnaire. These limitations exist in part due to constraints of a thesis and pilot nature of the study.

In contrast, future studies should test at baseline, mid-rehabilitation, and at discharge to more accurately determine recovery outcomes and provide further data on peak force, slope of force-generation phase and slope of force-decay phase. Also, future studies should include equal numbers of men and women and also include a control group. In addition, the development of norms to compare the slopes of the force-time curve would better enable researchers and therapists alike to determine whether their findings accurately reflect those of the general population and to determine level of injury. From the norms, researchers would be able to possibly discover future uses of the slopes of force-time curve and can be compared with other outcome measures to better indicate levels of recovery and injury. In the future, treating therapists need to be questioned regarding the treatment being provided to reduce this reporting bias in the case of participants themselves describing their treatments. Also compare responsiveness of slopes of force-time curve with self-report assessments such as DASH, which will provide further measures of recovery for individuals. Finally, future studies need to have a larger sample size to control for outliers and variability provided in the data by participants. By having a larger sample size, the data would better represent the overall general population.

Conclusions

Our study findings suggest that recovery during the initial stages of rehabilitation is better measured by the slope of force-generation phase than grip strength and slope of force-decay phase. These findings are based on significant increases in slope of force-generation phase from pre- to post-test ($F=5.745$, $p=0.043$) as well as the best responsiveness index among the three measures ($ES = 0.586$). A major limitation of the present study is that results are based on a small sample ($N = 9$) and a short duration (4 weeks). We recommend that the slopes of force-time curve not be used as outcome measures in the clinic until studies with larger sample and of longer duration produce similar or better findings.

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Appendix A: *Initial Session Demographic Questionnaire*

University of Wisconsin-Milwaukee
Department of Occupational Sciences & Technology,

Demographic Questionnaire (Initial Session)

Participant ID#: _______________ Date Completed:_____________ Time:__________

DEMOGRAPHIC INFORMATION

1. Please fill out or circle the correct answer(s) for the following questions about yourself.

Year of birth? ______ Height? ___ft ___inches Dominant hand/arm? R L

Gender? M F Weight?______ lbs Injured hand/arm? R L

INJURY-RELATED INFORMATION

1. What injury/condition are you in therapy for?

____

____

2. Do you think your condition was caused by work? YES

NO

If so, please explain:

____

3. Do you think your condition is aggravated by work? YES

NO

If so, please explain:

____

4. What do you think is the cause of your injury?

____

____

5. How long have you had this condition (in years and months)? ____Years ____Months

6. How long have you been in therapy? ___________Weeks___________ Times per week

7. Do you experience similar symptoms on the uninjured side? YES NO

8. Do you have any other condition that affects your hand grip? YES NO

If so, please explain:

____

9. Do you experience any sleep disturbances due to your condition? YES NO

If so, how often? ___________Times per week

If so, please describe the kind of sleep disturbances.

____

____

10. Are you taking any pain medications? YES NO

11. Do you have any limitations in Activities of Daily Living, such as walking, dressing, bathing, etc.?

YES NO

12. Have you had surgery for your injury? YES

NO

If yes, did you benefit from the surgery? YES

NO

13. Have you seen any improvement with therapy? YES

NO

14. What was the average range of pain over the last week on a scale of 0 to 10? (please cross the line below at the most appropriate point)

0 1 2 3 4 5 6 7 8 9 10

No Pain — Pain as bad as it could be

15. What is the level of your current pain on a scale of 0 to 10? Mark separate lines for left and right hand, labeled L or R. (please cross the line below at the most appropriate point)

0 1 2 3 4 5 6 7 8 9 10

No Pain — Pain as bad as it can be

16. Do you experience increased pain during a specific time of the day?

YES NO

17. Please rate the following question on a scale of 0 to 10 to indicate your fearfulness of pain:

"I should not do physical activities which (might) make my pain worse."

0 1 2 3 4

Completely disagree — Completely agree

JOB-RELATED INFORMATION

1. What was your occupation when you were injured?

____

____

2. How long have you held that position?

____

3. Please describe your duties at that position.

____

____

4. Are you currently working? YES

NO

If yes: Full-time Part-time

If part-time, how many hours? ______

5. Are you performing the same job duties as prior to your injury? YES

NO

If no, describe changes. _______________________________________

____

Appendix B: Follow-up Session Demographic Questionnaire

University of Wisconsin-Milwaukee
Department of Occupational Sciences & Technology,

Demographic Questionnaire (Follow-up Session)

Participant ID#: ______________ Date Completed:____________ Time:_________

TREATMENT-RELATED INFORMATION

1. How many sessions of therapy have you had since the last meeting?_____Sessions____Hours
2. What treatment did you undergo over the past four weeks?
3. If you participated in a home exercise program, what kind did you undergo? (circle yes or no)

a. Muscle Strengthening Yes

No

b. Stretching/ Range of Motion Yes

No

c. Physical Agents (hot/cold, fluidotherapy, Yes

No

paraffin wax, etc.)

d. Splinting Yes

No

e. Sensory Re-education Yes

No

f. Massage Yes

No

g. Other:___________________

4. Global Rating of Change Scale

Please rate on a scale from –7 to +7 how much you think your condition has changed since your first therapy session. –7 indicates that your condition is much worse, while +7 indicates that your condition is much better. Please fill in the circle above your answer choice.

O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7
WORSE														BETTER

5.

Please rate on a scale from –7 to +7 how much you think your condition has changed since your initial data collection session. –7 indicates that your condition is much worse, while +7 indicates that your condition is much better. Please fill in the circle above your answer choice.

O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7
WORSE														BETTER

6. How successful is (was) your therapy?

a) Very successful

b) Successful (average)

c) Somewhat successful (less than average)

d) Not successful at all

7. What was the average range of pain over the last week on a scale of 0 to 10? Mark separate lines for left and right hands, labeled L or R. (please cross the line below at the most appropriate point)

0 1 2 3 4 5 6 7 8 9 10

No Pain — Pain as bad as it could be

8. What is the level of your current pain on a scale of 0 to 10? Mark separate lines for left and right hands, labeled L or R. (please cross the line below at the most appropriate point)

0 1 2 3 4 5 6 7 8 9 10

No Pain — Pain as bad as

9. Please rate the following question on a scale of 0 to 4 to indicate your fearfulness of pain:

"I should not do physical activities which (might) make my pain worse."

0 1 2 3 4

Completely disagree — Completely Agree

Appendix C: Data Collection Forms

Participant ID: ______________________ Date: _______________ Time:_________

Initial Session/Final Session

Activity 1: Extensor Contraction Uninjured Hand

Effort

0% ———————————————— 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 ———————————————— 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 2: Extensor Contraction Injured Hand

Effort

0% — 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________ Date: _______________ Time:_________

Activity 3: F.D.I Uninjured Hand

Effort

0% ——————————————————— 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 ——————————————————— 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 4: F.D.I. Injured Hand

Effort

0% 100%

No Grip Force

Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 10

No pain

Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 5: Practice Grip Uninjured Hand

Effort

0% — 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 6: Practice Grip Injured Hand

Effort

0% — 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 7: First 10-second Uninjured Max Grip

Effort

0% 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 8: First 10-second Injured Max Grip

Effort

0% 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 9a: Pain Scales After Rest

Pain Uninjured

0 10

No pain

Pain as bad as
it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Pain Injured

0 10

No pain

Pain as bad as
it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: _______________________

Activity 9b: Second 10-second Uninjured Max Grip

Effort

0% — 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Activity 10a: Pain Scales After Rest

Pain Uninjured

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Pain Injured

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 10b: Second 10-second Injured Max Grip

Effort

0% — 100%

No Grip Force — Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 11a: Pain Scales After Rest

Pain Uninjured

0 ———————————————— 10

No pain ... Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Pain Injured

0 ———————————————— 10

No pain ... Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 11b: Third Uninjured 10-Second Max Grip

Effort

0% 100%

No Grip Force | Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 10

No pain | Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Activity 12a: Pain Scales After Rest

Pain Uninjured

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Pain Injured

0 — 10

No pain — Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Participant ID: ______________________

Activity 12b: Injured 10-Second Max Grip To Exhaustion

Effort

0% 100%

No Grip Force

Strongest Grip Force

Please mark a vertical line at a point that indicates the level of effort you just exerted.

Pain

0 10

No pain

Pain as bad as it could be

Please mark a vertical line at a point that indicates the level of pain that you are currently experiencing.

Appendix D: Disabilities of the Arm, Shoulder and Hand (DASH) Questionnaire

DISABILITIES OF THE ARM, SHOULDER AND HAND

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Write.	1	2	3	4	5
3. Turn a key.	1	2	3	4	5
4. Prepare a meal.	1	2	3	4	5
5. Push open a heavy door.	1	2	3	4	5
6. Place an object on a shelf above your head.	1	2	3	4	5
7. Do heavy household chores (e.g., wash walls, wash floors).	1	2	3	4	5
8. Garden or do yard work.	1	2	3	4	5
9. Make a bed.	1	2	3	4	5
10. Carry a shopping bag or briefcase.	1	2	3	4	5
11. Carry a heavy object (over 10 lbs).	1	2	3	4	5
12. Change a lightbulb overhead.	1	2	3	4	5
13. Wash or blow dry your hair.	1	2	3	4	5
14. Wash your back.	1	2	3	4	5
15. Put on a pullover sweater.	1	2	3	4	5
16. Use a knife to cut food.	1	2	3	4	5
17. Recreational activities which require little effort (e.g., cardplaying, knitting, etc.).	1	2	3	4	5
18. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5
19. Recreational activities in which you move your arm freely (e.g., playing frisbee, badminton, etc.).	1	2	3	4	5
20. Manage transportation needs (getting from one place to another).	1	2	3	4	5
21. Sexual activities.	1	2	3	4	5

Appendix D: Disabilities of the Arm, Shoulder and Hand (DASH) Questionnaire

DISABILITIES OF THE ARM, SHOULDER AND HAND

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
22. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? *(circle number)*	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? *(circle number)*	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*

	NONE	MILD	MODERATE	SEVERE	EXTREME
24. Arm, shoulder or hand pain.	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. Stiffness in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. *(circle number)*	1	2	3	4	5

DASH DISABILITY/SYMPTOM SCORE = $\left[\frac{(\text{sum of n responses})}{n} - 1\right] \times 25$, where n is equal to the number of completed responses.

A DASH score may not be calculated if there are greater than 3 missing items.