

# H-reflex Plasticity following Cast Immobilization of Distal Radius Wrist Fractures

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By

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## Abstract

**PURPOSE:** The primary purpose of the study was to track changes in the Hoffman (H-) reflex after a period of cast immobilization following a distal radius fracture (DRF) up to 12-weeks post-fracture. Secondary to tracking the H-reflex, functional measures such as muscle thickness, grip strength, wrist flexion strength, range of motion, pain and function were assessed over the same time frame. **METHODS:** The study consisted of a fracture group ( $n = 5$ ) and an age-matched uninjured control (CON) group ( $n = 5$ ). Both groups were tracked over a 12-week period, with the fracture group undergoing four testing sessions (baseline, week 6, week 9 and week 12) and the CON undergoing three testing sessions at least three weeks apart; baseline testing for the fracture group was collected within two weeks of initial fracture date. Testing was completed on both limbs for the CON group, whereas for the fracture group measures were taken at each time point for the non-fractured (NFX) limb, and within the limits of tolerable pain for the fractured (FX) limb. This meant the fracture group's FX limb H-reflex measures were completed only at week 9 and 12. Peak-to-peak amplitudes (and stimulus intensities) of H-reflex,  $H_{\max}$ , and maximal M-wave,  $M_{\max}$ , were the key parameters collected.  $H_{\max}$  was normalized and expressed as a ratio of  $M_{\max}$  ( $H_{\max}:M_{\max}$ ). Additionally, the fracture group completed questionnaires to measure FX limb pain and disability (via patient-rated wrist evaluation [PRWE]) at each time point. **RESULTS:** The fracture group presented a significant effect of time for  $H_{\max}:M_{\max}$  stimulus intensity ( $p < 0.05$ ), where the relative current intensity needed to evoke  $H_{\max}$  increased before decreasing as recovery progressed. The CON group demonstrated no significant effects over time or between limbs for all H-reflex parameters ( $p = 0.859$ ). Functionally, the fracture group demonstrated significant changes over time for all secondary measures ( $p < 0.05$ ), aside from visual analog scale pain scores. With functional measures increasing over time to indicate recovery (i.e. increases in grip strength). **CONCLUSIONS:** The amplitude of H-reflex did not demonstrate significant changes over time as predicted. The fracture group's decrease over time for  $H_{\max}:M_{\max}$  stimulus intensity reflects an unanticipated finding of increased excitability of  $H_{\max}$ . For the control group, this study verifies the stability of  $H_{\max}$  and  $M_{\max}$  over time and between limbs in this population. The fracture group's functional measures show significant improvements over the 12-week span that were coupled with an initial increase and then decrease in the relative stimulus intensity needed to evoke H reflex, in the absence of detectable changes in H-reflex amplitude. The changes in the nervous system can

have a profound impact on function after wrist fracture and cast immobilization. The novel findings in this study can have implications regarding the direction of future studies. As the H-reflex has been shown to have a degree of plasticity, with further study the reflex may be tracked in different interventions such as unilateral training in order to evaluate efficacy or investigate mechanisms of change/recovery.

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*H-reflex plasticity following cast immobilization of distal radius wrist fractures***1. Introduction**

Wrist fractures are of both clinical and health care interest as they are one of the most common fractures treated in the emergency room, and can be costly to both individuals and society (Koo et al. 2013). One in six fractures treated in U.S. emergency rooms are wrist fractures (de Putter et al. 2012; Koval et al. 2008). In a Dutch study, wrist fractures were estimated to cost the economy US\$740 million due to lost productivity, and health care costs (Ramponi 2013). Canada's population is roughly twice that of the Netherlands, with all else being equal, the estimated cost would be well over US\$1 billion. There are no equivalent statistics specifically for wrist fractures in Canada, but the 2009-10 Canadian Community Health Survey notes hand and wrist injuries account for 22% of all injury types, and is second to hip fractures in medical costs (Leslie et al. 2011). In Alberta, 48% of wrist injuries claimed under the Workers' Compensation Board required the claimant to take leave from work (Seland et al. 2006). In a Canadian study, wrist fracture patients missed an average of 9.2 weeks of work (MacDermid et al. 2007).

Distal radius fractures (DRF), also known as Colles' fracture, are common across all age spans and both sexes (Handoll and Elliot 2015). The rate of occurrence does differ between sexes, and age. Fractures are particularly common in females, where active post-menopausal women are at an increased risk due to increased physical activity pattern and in general, those over the age of 65 suffer fractures more easily due to bone loss (Handoll and Elliot 2015; Brogren et al. 2011). Koval et al. (2008) highlights 15% of all women and 2% of all men will experience a DRF during their lifetime. Furthermore, over the course of a lifetime, DRFs represent 25% of all fractures seen in a pediatric population (< 18 years of age), and 18% in the elderly (Nellans et al. 2012). The cause for injury differs, where for younger populations and men, fractures are more likely a result of a high energy impact (e.g. motor vehicle accidents) compared to low energy impact (e.g. bodyweight impact from falls) fractures common in an older population (Handoll 2003). For older females, low energy impact fractures are typically due to falls onto outstretched hands (Handoll and Elliot 2015). In most cases, DRFs are treated on an outpatient basis. DRFs are conservatively treated with immobilization (cast and/or brace) over a six-week period, or shorter, as advised by an orthopaedic surgeon who deems the fracture healed.

Even when healed, patients with wrist fractures requiring immobilization do not regain strength and full functionality for up to 2 years (Tremble et al. 1994), and may experience discomfort for up to a decade (Foldhazy et al. 2007). The degree of chronic pain patients experience can be tied to trauma and amount of pain immediately following the injury (Mehta et al. 2015). The difficulty in regaining functionality is associated with the degree of strength loss accompanying immobilization (Clark, 2009). Significant strength loss occurs within five days of immobilization (Wall et al. 2013). The brief timeline associated with strength loss is significant as a typical cast-immobilization period for a DRF is six weeks (Handoll, 2006).

This current Master's thesis project aimed to shed light on the neuromuscular changes, specifically the Hoffman (H-) reflex (a spinal reflex), following a wrist fracture. The knowledge gained from the project can be used to understand what changes occur at the muscle level, and the neuromuscular system for wrist fracture injuries requiring an extended period of immobilization. This thesis also hoped to add to neuromuscular data captured from orthopaedic fracture patients. Current disuse-immobilization neuromuscular models are built on information from a healthy population undergoing immobilization protocols (Lundbye-Jenson and Nielsen 2008a, 2008b; Clark et al. 2006, 2009; Seki et al 2007; Seyennes et al 2010). Data from clinical populations involving real-life injuries are likely to be more variable compared to immobilization models using healthy participants. The hypothesis was that following the casting period the spinal reflex will exhibit hyper-excitable characteristics, such as greater peak-to-peak amplitude and decreased stimulus intensity needed to reach peak. It was also hypothesized that the secondary functional measures (i.e. grip strength, ROM, etc.) would improve as the characteristics of the H-reflex and M-wave both normalize. It was expected that the most significant muscle thickness gains would occur between the week 9 and 12 time points.

## **1.1 Review of Literature**

### **1.1.2 Physiological Factors and Immobilization**

There is a large amount of research concerning the effects of immobilization on muscle size and strength, force output, fiber type and central nervous system function (for reviews see Clark 2009; Duchateau and Enoka 2002); however, the understanding of what occurs at the neuromuscular level is incomplete, especially concerning motor control and function (Clark et al. 2006, 2009). Control and function may be a key part of the equation to optimizing rehabilitation

protocols (Clark 2009). Muscle control can be described as the variability of force production and coordination of synergistic muscles, with function being the ability to generate force (Clark 2009). This area has not been widely studied, and attempts to navigate the particulars in a clinical population, such as wrist fracture patients, is lacking. Current understanding of these features in forearm and other muscles groups have been largely conducted on a healthy population (Lundbye-Jensen and Neilsen 2008a, 2008b; Clark et al. 2008, Leukel et al. 2014, Seyennes et al. 2008; D'Antona et al. 2003), and in some cases, the immobilization method is removable at the participant's will (Lundbye-Jensen and Neilsen 2008a). Other studies of clinical populations feature stroke patients (Phadke et al. 2012, 2014) or those with spinal cord injuries (Knikou 2013, Clair-Auger et al. 2013), where changes are tied to a pathological neural deficit. It is important to delineate the outcomes associated with healthy and pathophysiological populations from the fracture group of interest. Casting a healthy, injury-free person for a study is different from casting a person with a fracture, as the variable of pain is absent. In a pathological case, the function of what is considered the affected limb is more or less permanent, and the sensory components may be absent or altered. These sensory components may have a role in limiting the movement of the immobilized limb within a cast, or in a pathophysiological case, cortical alterations may be responsible for changes observed globally at the central nervous system (i.e. lesions causing hemiparesis in stroke (Buma et al. 2013; Furlan et al. 2016)).

Reduction in muscle activity and mechanical loading because of immobilization is known to lead to decreased muscle size and strength, decrease in muscle pennation angle and decreased bone mineral density (Vandenborne et al. 1998; Clark and Manini 2008; Deschenes et al. 2002; Kawakami et al. 2001; Clark and Manni. 2008; Ashe et al. 2007; Kazakia et al. 2014). The greatest rate of loss of strength occurs within the first two weeks, and strength loss is often greater than the degree of muscle size loss (Wall et al. 2013); however, the knowledge of such changes cannot be applied universally. The degree of change is not equal across all muscle groups nor is it consistent across different methods of immobilization (i.e. suspension system, where a limb is externally unweighted vs. bed rest) (Clark et al. 2006; Lundbye-Jensen 2008a). Evidence of uneven change is highlighted when upper limb muscles are compared to lower limb muscles, or disuse as a result of physical immobilization (Clark 2009). In general, when looking at disuse, the muscles associated with ambulation, or major anti-gravity muscles, such as plantarflexors (soleus/gastrocnemius) exhibit much greater muscle loss than lumbar muscles

(LeBlanc et al. 1992), and studies on upper limb forearm muscles showed mixed changes in cross-sectional area (CSA), with immobilization periods of up to 3 weeks resulting in 4-10% loss of forearm CSA (Clark 2009).

The combination of the above listed characteristics provides a detailed picture of the physiological change in the muscles and bone that an immobilized limb undergoes. However, the pure physiological findings only provide a partial understanding. With physiological changes, there are alterations in neuromuscular activity as well; which represent the focus of this thesis work.

Neuromuscular changes in immobilization can occur at both the supraspinal and spinal level. Supraspinal changes are those that occur at the cortical or sub-cortical level, while spinal changes involve the plasticity of neurons and interneurons in the spinal pathway. Neural factors are an important element in immobilization models; they have been said to account for nearly 50% of the variability in the associated strength loss (Clark et al. 2006). Some of the neurophysiological parameters include central activation - a measure of maximal voluntary force output; cortical excitability-degree of neuronal pathways that are turned on with associated action potentials; compound muscle action potential (more commonly known as  $M_{max}$ ) - the maximum number of action potentials possible for group of muscle fibres; motor unit firing rate - the rate at which signals can travel down an innervating axon; and motor neuron excitability - a measure of the ease of eliciting action potentials within a group of muscle fibres (Clark 2009). These neural physiological factors often relate to one another.

Studies examining these factors following forearm/wrist immobilization have been limited. Clark et al. (2008) examined wrist immobilization (via removable splints) for a three-week period and found a 20% decrease in wrist flexor central activation (output measured using twitch interpolation) of the immobilized side. This alteration of central drive has also been implicated in the variation of differences that occur between individuals following lower body (plantar flexor and quadriceps) immobilization (Clark 2009). Using a model with the first dorsal interosseus muscle, Seki et al. (2010) also postulated strength deficits are due to declines in the motor-unit (MU) firing rate. The interplay between muscular and neuromuscular properties likely exists on a continuum, where contributions of each may change over time and vary in severity of the changes depending type of muscle (i.e. anti-gravity) or type of injury.

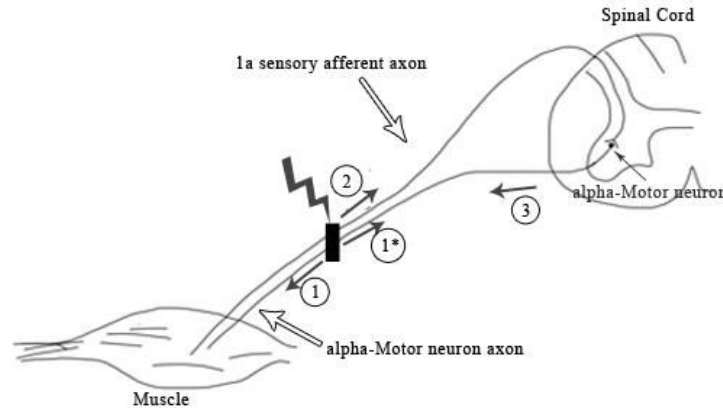
Studies often use more than one measure, or technique, to present a more complete picture of the neuromuscular plasticity in an immobilized state (Rossi-Durand et al. 1999; Clark et al. 2007; Lundbye-Jensen and Nielsen, 2008a, 2008b; Zanette et al. 2004). For example, to examine the corticospinal pathway, cortical and spinal excitability can be measured using Transcranial Magnetic Stimulation (TMS) to elicit motor-evoked potentials (MEPs) or trigger cervicomedullary motor-evoked potentials (cMEPs), along with peripheral nerve stimulation to measure spinal reflex properties (i.e. the Hoffman reflex) (Lundbye-Jensen and Nielsen 2008b). By focusing on central and peripheral neurons, distinct changes along the pathway from motor cortex to muscle can be better quantified.

The Hoffman reflex (H-reflex) is one of the most common measures of neuromuscular change at the spinal level (Zehr 2002). Paul Hoffman identified this reflex in 1910 (Hoffman 1910). The H-reflex is akin to the tendon-stretch reflex, where the former is elicited via electrical stimulus and the latter through mechanical force. This reflex has been widely studied due to its simplicity and ease of elicitation; research has demonstrated that the reflex can be elicited with great success in the following muscles: flexor carpi radialis (FCR), extensor carpi ulnaris, quadriceps, tibialis anterior, and soleus (Zehr 2002; Burke 2016).

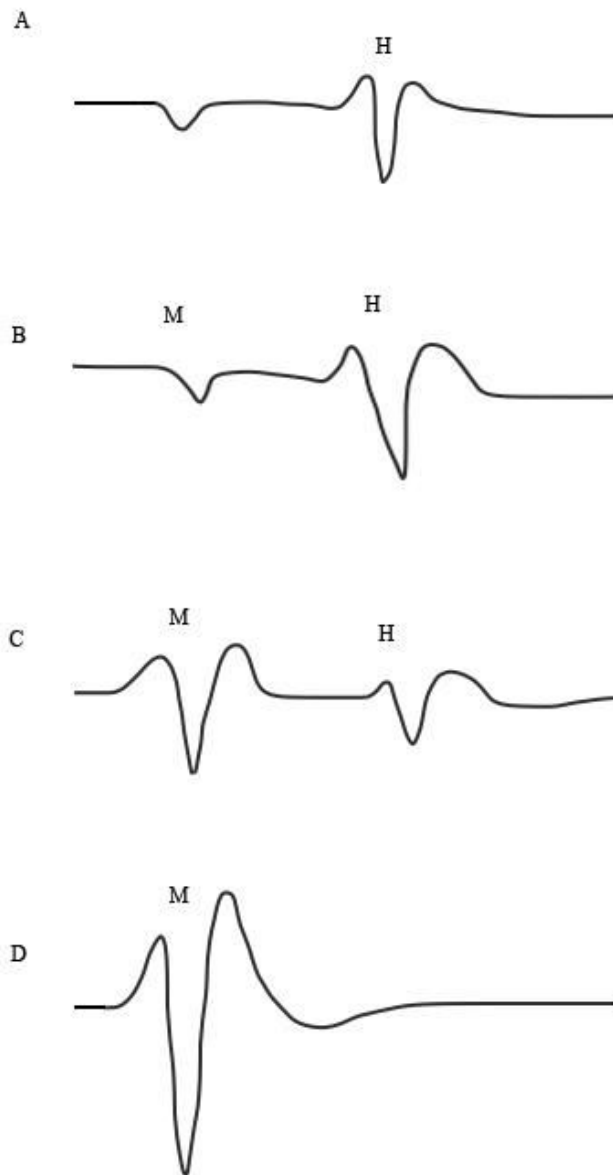
Eliciting the H-reflex can provide a snapshot of the efficacy of the synaptic transmission of an electrical stimulus through an afferent (group 1a sensory) network coupled through the motor neuron (MN) pool and its efferent (motor) fibres (Palmeiri et al. 2004). A peripheral nerve is stimulated (via electrical stimulation) creating action potentials in the 1a sensory axons, which travels toward the spinal cord leading to a reflexive loop, the H-reflex. The H-reflex occurs as the action potentials cause depolarization and release of neurotransmitters to trigger excitatory postsynaptic potentials (EPSPs) at the spinal cord level (Palmieri et al. 2004). This can be an indication of the excitatory properties of the MN pool, and efficiency of the 1a afferent synapses (Aagaard et al. 2002). Electromyography (EMG) can then be used to record the potentiated fibres as the stimulus (i.e. electrical stimulation of peripheral nerve) flows through the fibres of the MN pool. During the onset of electrical stimulus at low-level intensities (of a peripheral nerve), action potentials (AP) are triggered in sensory 1a afferents. The AP from the sensory afferents occurs first due to the large diameter of the axons compared to alpha-MN axons. The 1a sensory AP first travels toward to the spinal cord resulting in EPSPs creating additional AP, which travel down towards the muscle via the alpha-MN axon. This is the spinal

reflex loop responsible for the H-reflex; the H-reflex can be recorded through surface EMG placed on the muscle being innervated. The reflex gradually gets larger until the motor threshold is breached and M-waves are also triggered. When the electrical stimulus is high enough, AP are elicited at the alpha-MN axon level. As these AP are triggered and propagate down to the muscle, a motor response is evoked and recorded as an M-wave. Antidromic collisions between the M-wave AP traveling toward the spinal cord with those AP relaying down from the spinal cord (1a sensory reflex loop) diminishes the H-reflex response, and eventually the H-reflex response is cancelled out altogether as stimulus reaches a maximal motor response ( $M_{max}$ ). See Figure 1.1 and 1.2.

In studying the H-reflex, secondary influences that can affect reflex should be acknowledged. As the 1a sensory afferent is part of the sensorimotor system, spinal inhibitory circuits can have a large influence. These include various interneurons and cells, such as inhibitory Renshaw cells, 1b inhibitory interneurons, and 1a inhibitory interneurons (Knickou 2008). Additionally, body and limb position, cutaneous receptors and pain receptors can also modulate the H-reflex (Seyennes et al. 2010; Gajos et al. 2014; de Oliveira Silva et al. 2016).



**Figure 1.1 Generation of the H-reflex.** Starting at a low-level, an electrical current is delivered over a peripheral nerve triggering AP, which travel toward the spinal cord (2). At the spinal cord changes in membrane potential resulting in EPSPs, which can trigger more AP. These AP then travel down the alpha-MN (3) resulting in a spinal reflex (Hoffmann reflex), which can be recorded via electromyography. As the stimulus intensity increases, enough AP are generated to the alpha-MN axon, which run toward the muscle leading to a motor response, M-wave (1). The AP to the alpha-MN, also travel toward the spinal cord, which results in antidromic collisions between the descending AP from the reflex loop. This collision begins to cancel out the H-reflex, and when a maximal motor response is achieved, the H-reflex is completely obscured (1\*). Adapted from Aagaard et al. (2002).



**Figure 1.2 EMG Output H-reflex to  $M_{max}$ .**

**A.** The H-reflex is generated from the action potentials of Ia sensory afferents as they are triggered by low-level electrical stimulus of a peripheral nerve. **B.** As the intensity of electrical stimulus increases to levels high enough to trigger AP in the alpha-MN axons creating a motor response, a M-wave is recorded along with the H-reflex. **C.** The H-reflex begins to decrease in size as stimulus intensity increases, and M-wave increases. The actions potentials of the alpha-MN travel toward the spinal cord, which causes antidromic collisions of the action potentials traveling down from the spinal cord. **D.** When the stimulus is high enough to evoke a maximal motor response, only the M-wave ( $M_{max}$ ) is recorded, as the antidromic collision completely cancels out the H-reflex. *Adapted from Aagaard et al. (2002).*

### 1.1.3 H-Reflex and Immobilization

In all, there are only a limited number of measures that can be conducted in a wrist fracture population given the sensitive nature of fractures and the need to avoid any procedures with potential to disrupt the healing process. For example, it would not be best practice to ask patients to perform a maximal test on the affected limb during the common immobilization



period. Measuring cortical excitability is often accomplished by measuring MEPs through TMS methods, which are more invasive and not as commonly available. This thesis project focuses on measuring change in the neuromuscular system — specifically the H-reflex properties — at the spinal level through peripheral nerve stimulation.

In the limited number of immobilization studies that have focused on the H-reflex, the outcomes have been mixed especially when comparing across muscle groups. Though some findings have trended toward hyper-excitability (Clark et al. 2006); this increased excitability may not indicate improved, but rather a detrimental adaptation to immobilization. Seyennes et al. (2010) postulated the increase in H-reflex excitability does not equate to an increase in neural response. The theory of mal-adaptation has been brought forth in the studies that have found increases in excitability of the H-reflex in soleus, presenting evidence of increased latency times of the H-reflex post-stimulus (Lundbye-Jensen and Nielson 2008b). The increased latency period is accompanied by increases in stimulus intensity needed to reach maximum H-reflex amplitude ( $H_{max}$ ). The peak-to-peak amplitude change in  $H_{max}$  should not be viewed on its own (Knikou 2008; Burke 2016). When the stimulus intensity and the ratio between  $H_{max}$  and  $M_{max}$  is considered, the increase in amplitude alone can indicate increased excitability, but an alternative conclusion may be made when factoring in testing variables. For example, when determining H-reflex changes, its peak amplitude values need to be normalized to the  $M_{max}$  to account for inter-session variability, and whether there was a change in stimulus needed to achieve peak values. The combination of increased stimulus needs and latency time could be indicative of a less efficient transmission of signal in the neuronal pathway (Clark, 2009).

Only three studies using a wrist/forearm immobilization model have measured H-reflex adaptation. The H-reflex amplitude and  $H_{max}:M_{max}$  peak-to-peak amplitude ratio was found to be increased following a one-week immobilization period (Lundbye-Jensen and Neilsen 2008a), while a three-week (Clark et al. 2008) and six-week immobilization period (Kaneko et al. 2003) showed no change in  $H_{max}:M_{max}$  ratio and H-reflex amplitude from pre-immobilization levels. In lower limb studies of plantar flexors, periods of immobilization also resulted in increases of H-reflex properties. A two-week immobilization period of the lower leg (Lundbye-Jensen and Nielsen 2008b), and a six-week “unweighting” study (Clark et al. 2006) found increases in both H-reflex amplitude and  $H_{max}:M_{max}$  ratios. Lundbye-Jensen and Neilsen (2008b) attributed the increased excitability of the H-reflex to decreases in presynaptic inhibition on the 1a afferent;

however, the facilitation of the H-reflex is not an absolute indicator of Ia fiber properties. H-reflex characteristics can be changed by a number of factors such as neurotransmitter release, Ia transmission efficiency, and change in membrane potential (Knikou 2008).

Application of the H-reflex can be used to understand the neural adaptations associated with injuries; to understand adaptations following resistance training (Aagaard et al. 2002); or to diagnose cervical radiculopathies (i.e. pain caused by irritated cervical nerve roots) such as C7 radiculopathy via the FCR (Lappenen 2012). For example, decrease in H-reflex following an ankle sprain can be indicative of decreased muscle activity (Palmeiri et al. 2004a). Similarly, the study of H-reflex has been used to evaluate different therapeutic modalities (Agostinucci et al. 2006; Chou et al. 2013), various musculoskeletal injuries (Fisher et al. 2009), motor performance (Knikou and Mummidisetty 2014; Alkjaer et al. 2013), and effects of novel training methods such as cross-education (Dragert and Zehr 2011, 2013; Lagerquist et al. 2006).

Studies into the physiological aspects of atrophy following immobilization and injuries could potentially offer more insight into mechanisms of the injury, which in turn allows for development of treatments that can be more effective. The neural underpinning and the effects of immobilization on motor function and control is an under-researched area (Clark 2009). Currently, there has not been an agreed upon method to treat and rehabilitate DRFs (Handoll and Elliot 2015; Bruce et al. 2016). Bruce et al. (2016) attributes the variations in treatment methods to a lack of evidence-based protocols. Developing more concrete methods based on strong mechanistic knowledge, such as a neuromuscular approach has been considered for rehabilitation. Current research into the H-reflex in clinical populations indicates a potential for a new method of treatment in a variety of settings. In DRF patients, instead of focusing on range of motion, strategies such as resistance training using a cross education model can be validated to improve the recovery period (Magnus et al. 2013), and thus reducing the dysfunction time. Cross education is an effect where unilateral training (strength or skill) can benefit the opposite untrained, contralateral limb. Resistance training with the healthy contralateral homologous limb during an immobilized state has been shown to limit the effects of disuse via cross education (Farthing et al. 2009). In general resistance training, Aagaard et al. (2002) has showcased how the human nervous system adapts over a period of training, and plasticity is not isolated to trained regions. Unilateral training over 20 days of bed rest was shown to preserve strength and minimize variations in force output (Shinohara et al. 2003). Specific to single limb injuries,

cross-education, where an uninjured contralateral homologous limb undergoes training to attenuate the strength loss of the opposite injured or neurologically impaired limb, has shown promise as a rehabilitative technique (Magnus et al., 2013; Papandreou et al., 2013; Dragert and Zehr, 2013; Farthing and Zehr, 2014). Insight into the reflex properties would be another layer of proof that cross-education may indeed be a valid protocol to use in specific cases. Positive outcomes of cross-education and its influence on the H-reflex have been tied to different training methods and external modalities, such as eccentric resistance training, and the use of neuromuscular electrical stimulation (Dragert and Zehr 2011; Veldman et al. 2014). Yamanaka and colleagues (1999) found evidence that the soleus H-reflex amplitude is maintained during bed rest when lower body exercise was prescribed during the disuse period. Resistance training has also been demonstrated to elicit a strong increase in the H-reflex following 5 weeks of eccentric-type training in the trapezius muscle (Vansgaard et al. 2014). Additionally, cross-education has been shown to stabilize, or increase, overall net muscle activation (Lepley and Palmieri-Smith 2014), which is highlighted to be a determining outcome in motor control function following immobilization (Clark 2006). Focusing on the fracture type specific to this project, a proof-of-concept for positive functional and strength outcomes utilizing cross-education during wrist fracture recovery has been demonstrated by Magnus et al. (2013), but the study did not include mechanistic measures of underlying neurophysiology.

## **1.2 Hypothesis**

Currently, there are no published findings on neuromuscular characteristics after cast immobilization specific to wrist fractures. The primary hypothesis was that following a six-week casting period for a distal radius wrist fracture; the H-reflex will demonstrate hyper-excitability through increased peak-to-peak amplitude compared to contralateral uninjured limb at baseline. The H-reflex was expected to require greater stimulus intensity, in order to evoke the  $H_{max}$ . Further, the time course of H-reflex recovery after cast removal is hypothesized to coincide with strength and functional recovery, with persistent deficits throughout the follow-up period (Magnus et al., 2013). This corresponds to our secondary hypothesis in that a significant deficit will be seen in all functional measures following immobilization, but will show improvement over the time course of recovery. It was also expected that a full recovery of strength will not be seen at the conclusion of the study. Lastly, stability of measures in the control was predicted, where all measurements were expected to not show difference over time between arms.

## 2. Methods

### 2.1 Participants and Recruitment

Two groups were recruited for the study: a wrist fracture group and an age-matched uninjured control group. The fracture group was recruited from Saskatoon's Royal University Hospital (RUH) fracture clinic. The fracture group consisted of orthopaedic patients of Dr. Geoff Johnston. Fracture patients who had suffered a recent DRF and met the inclusion criteria were identified by Dr. Johnston's office. Patients were excluded if they had other concurrent fractures; diagnosed with neurological conditions or condition that affected the upper limbs; DRF did not require cast immobilization; or they were beyond two-weeks from date of fracture. The researcher was then notified of the possible participants and initiated the recruitment process by phone. The age-matched uninjured control group was recruited from the Saskatoon community; the uninjured control group was recruited at each time point a new participant was enrolled in the fracture group. Control participants were recruited based on a  $\pm 5$  years of age closeness to the matched fracture patient. Another criterion used for match was limb dominance; such that a right-hand dominant fracture was matched with a right-hand dominant control. All participants were fully informed of the study via contact with the graduate student researcher, who also obtained informed consent. The study was approved by the University of Saskatchewan's Biomedical Ethics Review board.

The number of fracture participants recruited was based on a power calculation using on H-reflex outcomes means and variances from Lundbye-Jensen and Nielsen (2008a). The values used represented pre- and post-immobilization  $H_{\max}:M_{\max}$  ratios ( $32.8\pm 8\%$ ,  $44\pm 7\%$ ). The original effect size calculated from those means was 1.5. However, a more conservative effect size of 0.5 was used in the final calculation due to the unpredictable nature of recruiting from a clinical wrist fracture population. From those values, a minimum of 7 fracture participants was required to achieve power based on the critical F-score as determined in G\*Power (G\*Power 3.1.9) using within-factors repeated-measures ANOVA design (power of 0.80, alpha of 0.05, effect size of 0.5 and one group with four levels).

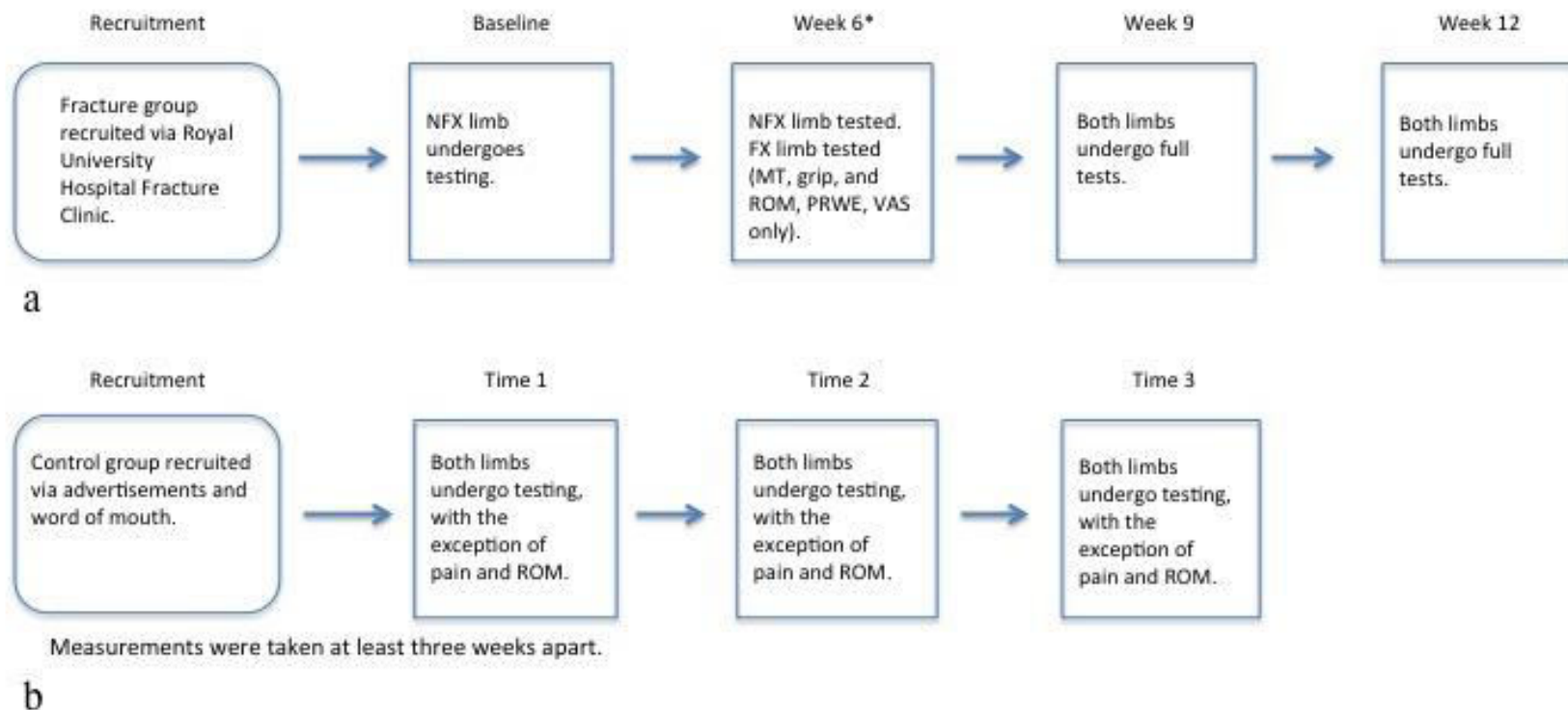
### 2.2 Study Design and Timeline

The recruitment period for the study was February 2015 to June 2015. Fracture patients were recruited first, and age-matched uninjured control group second. The fracture group was tracked over a 12-week period, with four data collection periods over the time span (baseline,

six, nine, and 12 weeks post-fracture). The post-fracture testing dates were tracked from the date of fracture. The testing dates were scheduled as close to each designated time point as possible. For the uninjured control group, three measures were taken at least three weeks apart (baseline, time 2, time 3); time between sessions ranged from three to six weeks. Baseline data for the fracture group was collected within two weeks of the initial fracture diagnosis, and the control group's baseline was their first visit to the lab.

Both groups underwent identical measures on both limbs, unless otherwise indicated. Baseline data for the fracture group was collected on the non-fractured limb, and was used as normative comparator — or *surrogate* baseline — against the fractured contralateral limb. The control group underwent testing on both limbs during baseline, and all subsequent sessions. The measurement time points were not matched between the fracture and control group as it was noticed in the early fracture patients that not all week 6 data was going to be analyzed due to their inability to perform all functional tasks due to pain limitations. Week 6 data for the fracture group was collected only if the participant was able to tolerate the discomfort in the healed fracture during the task, as it was within the first week of cast removal. It was also decided three time points would be sufficient to determine limb-to-limb stability of measures as it still covered a span of nine to 12 weeks.

A flow chart of the design and measurement time points is included in Figure 2.1. The primary measure was the H-reflex. Other functional measures included: grip strength, wrist flexion strength (and peak activation), muscle thickness, and range of motion. The following questionnaires were also collected: Godin leisure time, Waterloo Handedness Questionnaire (WHQ) (Steenhuis and Bryden 1989), injury/training history, visual analog scale of pain and Patient-Rated Wrist Evaluation (MacDermid et al. 1998).



**Figure 2.1 Study Timeline.** The fracture group (a) had four definitive testing sessions. \*Most fracture patients abstained from H-reflex and wrist flexion strength testing at week 6. The uninjured, age-matched control group (b) came in for three testing sessions at least three weeks apart. The recruitment window was from March 2015 until July 2015.

‘NFX’ = non-fractured limb; ‘FX’ = fractured limb; MT = muscle thickness; ROM = range of motion; PRWE = patient-rated wrist evaluation; VAS = visual analog scale.

## 2.4 Measures

### 2.4.1 Primary and Secondary Measures

The primary measure of interest were the H-reflex of the flexor carpi radialis (FCR) and its associated characteristics:  $H_{\max}:M_{\max}$  ratio, peak-to-peak amplitude of the  $H_{\max}$  and  $M_{\max}$ , stimulus intensity required to reach  $H_{\max}$  and  $M_{\max}$ , and  $H_{\max}:M_{\max}$  stimulus intensity ratio. Secondary measures taken were: grip strength; wrist flexion strength and peak muscle activity; wrist range of motion (ROM), flexion, extension, supination and pronation; muscle thickness (MT); and Visual Analog Scale of pain (VAS) and Patient-Rated Wrist Evaluation (PRWE) questionnaires. All procedures took place at the Motor Control Lab at the College of Kinesiology, University of Saskatchewan.

### 2.4.2 H-reflex and M-wave procedures

The participants were all in an upright-seated position in a HUMAC dynamometer (CSMi, Stoughton, MA) for all reflex measures. The arm of interest was placed in a position flexed at the elbow at approximately  $90^{\circ}$ , and slightly abducted at the shoulder, while the arm was supported by an adjustable armrest. The patient was then asked whether the position was comfortable while performing wrist flexion, and adjusted accordingly. Once the optimal arm/wrist and chair position was found, the chair, armrest, and dynamometer arm were locked in place, and all positions and angles were recorded for future sessions. The wrist was placed in a supinated position for all H-reflex testing and wrist flexion strength tests.

The FCR was the muscle of interest, as it is one of the prime movers for wrist flexion. In the fracture group, since baseline reflex measurements were not possible for the fractured arm, a baseline was established for the H-reflex using the data from the uninjured homologous contralateral limb. In the uninjured control group, the H-reflex was measured in both limbs at each time point; a secondary purpose of the uninjured control group was to establish the session-to-session and limb-to-limb variability of the H-reflex to validate the uninjured side as a baseline comparison. Measurements on the injured side took place once the cast was removed (approximately at week 6), and at weeks 9 and 12 post-fracture. The H-reflex values post-immobilization were used to track the effect of casting and the recovery period of the reflex.

The H-reflex of the FCR was elicited through electrical stimulation of the median nerve, and has been reported as reliable and consistent reflex (Zehr, 2002; Miller 1995). The landmark

for the placement of the stimulation electrodes was identified approximately one-third of the distance from the medial epicondyle of the humerus to the long head of the biceps tendon located medial-antero on the glenohumeral head, along the bicipital groove of the proximal arm (Christie et al. 2005). The placement of the stimulation electrodes was confirmed once noticeable wrist flexion movement was obtained at the lowest possible stimulus intensity, and if the participant felt the current primarily through the index and middle fingers. The stimulation intensity (mA) was then recorded, and the intensity was decreased to determine a resting motor threshold (rMT), or smallest motor response. The value was noted, as the H-reflex on the FCR is said to occur when small M-waves appear on electromyography (EMG) output when stimulus nears rMT (Zehr 2002).

Recording EMG electrodes were placed over three muscles: FCR, biceps brachii (BB), and the extensor carpi radialis (ECR). The main recording EMG electrodes were placed over the belly of the FCR. The location of this particular electrode was placed one-third of the distance between the medial epicondyle of the humerus and the distal end of the radial styloid (Zehr, 2002). The EMG for the BB was placed 2/3 of the distance between the acromial process and the cubital fossa — landmarks as recommended by the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles project (SENIAM) — and the EMG electrode for the ECR was landmarked and placed via palpation, as there is not a standardized location for this particular muscle.

All EMG electrode placements were confirmed based on EMG burst activity as the participant went through resisted wrist flexion, elbow flexion and wrist extension — synergistic activation was acceptable, especially in the case of BB activity during resisted wrist flexion.

To gauge when the reflexes would occur on the EMG display, known latency times for both M-wave and H-reflex were used as a guideline. Following electrical stimulation, the latency of the FCR M-wave averages between 4 and 15ms; post-stimulus latency of the H-reflex varies from 16 to 25ms. The estimated latency times are derived from studies conducted by Miller et al. (1995) and Stowe et al. (2008).

In order to account for day-to-day variations in the H-reflex, the reflexes were normalized to  $M_{\max}$ . Knikou (2008) and Zehr (2002) have both suggested in their reviews of the H-reflex, the most accurate way to compare the changes of H-reflex (specifically the  $H_{\max}$ ) over time is to normalize the data of each session to the  $M_{\max}$  value.  $M_{\max}$  was determined through a recruitment



curve, where both H-reflexes and M-waves are recorded; the values of both can be recorded and graphed, offering a picture of when the antidromic collisions occur, as the rising M-waves abolish the H-reflex. The recruitment curve reflected the changes of both the H-reflex and M-wave, as stimulus intensity increased the H-reflex increased until peak, then decreased, while the M-wave continuously increases until it reaches max. The initial stimulus intensities began at levels well below both the H-reflex and M-wave thresholds. Data was recorded until  $M_{\max}$  was reached, where 110% supramaximal stimulus intensity was used to confirm  $M_{\max}$  was achieved. If a further increase in stimulus intensity does not change the peak-to-peak amplitude of the wave,  $M_{\max}$  was assumed.

#### 2.4.3 Stimulation Procedure

The electrical stimulation protocol began at sub-motor threshold levels. The current intensity — and current property — were controlled with a Digitimer high voltage constant current stimulator (Model DS7AH, Hertfordshire, England). All electrical stimulation pulses were delivered at a 500 $\mu$ s pulse width. The intensity was gradually increased until  $M_{\max}$  was reached; intensity needed for  $M_{\max}$  ranged between 7 – 24 mA.

The recruitment curve was built with 0.5mA increments, starting at 0.5mA. When H-reflexes were clearly seen on the monitor, increments switched to 0.2mA, to ensure the ascending limb of the H-reflexes were captured. A 0.2 mA change in increment was used, as pilot data suggested the H-reflex was highly sensitive and demonstrated that a gradual increment was followed by an immediate drop once  $H_{\max}$  was reached, as such, a slower progression was used as a safety net. During pilot testing, it was found that  $H_{\max}$  was missed in some participants with continuous increases at 0.5mA. When the H-reflex was no longer seen, 1.0 mA increments were used until  $M_{\max}$  was reached. The peak-to-peak  $M_{\max}$  amplitude was the value used to normalize that particular session's data.

#### 2.4.4 Facilitation of the H-reflex

To elicit the H-reflex in the FCR, it had been reported the reflex is easier to evoke when there is some form of facilitating background muscle activity (Miller et al. 1995). The 2002 Zehr review, which offered a set of guidelines for successful H-reflex data collection included a section stating a background voluntary contraction of at least 10% of maximal voluntary contraction (MVC) should be used; the 10% MVC suggestion for background muscle activity follows evidence presented by Christie et al. (2005) and Stowe et al. (2008). Christie et al. (2005)

also confirmed a standardized weight could also be used as the facilitating background contraction. This study used a 10% MVC, as it can be individualized, whereas a standardized weight would reflect a greater or lesser effort, depending on the base strength of the participant. This detail is crucial as the peak-to-peak amplitude of the H-reflex responds to the strength of the background contraction, a stronger background contraction results in larger peak-to-peak amplitudes (Miller et al. 1995).

The 10% MVC was determined using a Humac NORM dynamometer (CSMi Solutions, Stoughton, MA). The MVC value for wrist flexion was determined with the dynamometer set up for isometric wrist flexion. The 10% was based on the degree of EMG activation (mV) during an MVC. Once this target was determined, the Labview software was set up to provide a real-time target line for the participant to see on a screen the entire time.

#### 2.4.5 Electromyography and Data Acquisition

Peak activation during wrist flexion MVC, H-reflex, and M-wave measures were all recorded using a three-channel EMG setup to acquire muscle activity of the BB, ECR and FCR (see 2.4.2 for recording electrode placement). Raw EMG data was collected using a Grass Technologies rack outfitted with Grass P511 High Performance AC Amplifier units (Grass Products Warwick, RI). The system consisted of a three-lead setup, where each channel had its own ground paired with two active recording electrodes<sup>a</sup>. The common ground for each lead pair was placed just superior to the olecranon process and in line on the triceps brachii tendon.

Before the EMG electrodes were affixed to their final locations, the participant's skin was prepped for an optimal recording surface. Skin prep consisted of shaving the area to remove hair, dead skin, and other debris, and the area was then cleaned with an alcohol swab.

The EMG amplifier units were individually calibrated before the study began. The calibration was performed as instructed by the Grass manuals using NI-Scope 4.1 (National Instruments, Austin TX). Each amplifier was then set up with identical filter and signal amplification settings; accepted bandwidth of 10 Hz to 1000 Hz, line out filter set for 60 Hz, with the overall amplification set at 1000x per channel.

A data acquisition block (NI BNC 2090, National Instruments, Austin, TX) and an analog-to-digital converter (NI PCI-6034e, National Instruments Austin, TX) were used to

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<sup>a</sup> Data was acquired using a Delsys Bagnoli four-lead system for two subjects' baseline data.

capture the EMG signal. The digital signal was captured through a custom software package written for LabView 8.6.1 (National Instruments Austin, TX), and standard software package was used for wrist flexion MVC data. The HUMAC software package was used to monitor and record torque output for each MVC trial.

The custom LabView software created by Dr. Timothy Carroll (University of Queensland, Australia), allowed for user-controlled variables such as time between stimulations (randomly set for 3 to 5 seconds), number of sweeps averaged (number of stimulations per run), monitor EMG output, sampling rates for EMG collection, and record EMG output. All data were acquired at a sampling rate of 2000Hz, with an average of five sweeps per intensity (length of 350ms).

Before EMG data was analyzed, the raw data was processed through a custom MATLAB software program (MATLAB 2006b, MathWorks, Natick, MA) to filter out electrical noise and stimulation artifacts that could impact the true amplitudes of the reflexes of interest. Prior to selecting which datasets were to be run through the MATLAB software, recruitment curves were graphed in Microsoft Excel to determine the approximate intensities at which the H-max and M-max occurred. The selected tracings ( $\pm 0.5$ mA of visualized peaks) were processed in MATLAB with a low-pass filter of 350Hz and a high-pass filter of 100Hz using a fourth-order Butterworth. The filtered files were then re-analyzed to determine true  $H_{\max}$  and  $M_{\max}$  peak-to-peak amplitude.

The EMG activity recorded during the MVC for each repetition was used to determine mean absolute value (MAV) for peak activation amplitude. The MAV was determined using a second custom MATLAB software program, where the MAV was determined from a root mean square value of a 0.5 s window based on a user-selected location within the EMG burst. The software used the raw EMG from the each MVC repetition to determine MAV. The MAV was reported as millivolt (mV) values, and then normalized to the session  $M_{\max}$  value. The sampling parameters were the same as described above.

#### 2.4.5 Grip Strength

Grip strength was assessed using a Baseline handgrip dynamometer. The participant was seated in the HUMAC dynamometer, but was not strapped in. The grip strength test was conducted according to methods used in Magnus et al. (2013); as such the wrist was placed in a neutral position with the elbow flexed 90 degrees. Elbow flexion was maintained by the armrest

on the dynamometer. The handgrip dynamometer was also fitted for participants, where their second knuckle was lined up with the grip handle.

Before data was recorded, all participants underwent at least two familiarization trials with the handgrip dynamometer to minimize the learning effect. To determine maximum grip strength, three repetitions were performed with 30-seconds between trials. The participants were instructed to squeeze the dynamometer as hard as possible, and were given verbal encouragement. Each repetition was approximately 3-seconds, or until the needle on the handgrip dynamometer ceased to increase.

#### 2.4.6 Muscle Thickness

Muscle thickness (MT) data were taken over the four testing time points (unless noted), and the fracture side was assessed as soon as possible post-cast removal. Recovery of muscle size as measured via MT was a variable hypothesized to be related to the change in H-reflex, in addition to strength gains. MT was determined using the largest muscle bulk on the proximal medial aspect of the forearm, as it is difficult to accurately identify the FCR with the resolution of the ultrasound (US) employed. MT measurements were taken according to protocol established by Farthing et al. (2009). Forearm MT was measured using the B-mode US (LOGIQ e, General Electric, Cleveland OH). The greatest bulk on the medial aspect of the forearm was identified for land-marking purposes. An initial estimate was made through the measurement of the distance between the medial epicondyle and the radial styloid, with the US centering on a spot approximately 1/3<sup>rd</sup> of the distance. The muscle bulk of this spot was then checked again to ensure a proper MT value was obtained.

Once the location was approximated, the landmark was traced onto a transparency sheet. Identifying features such as blemishes on the skin and visible veins were traced onto the transparency, this allowed for a consistent US location session to session, minimizing variability as much as possible.

All MT measures were taken before any functional measures were conducted. To establish a standard timing order for measurements, the non-fractured arm (or left arm for uninjured controls) was measured first at all time points.

#### 2.4.6 Wrist Flexion Strength

Wrist flexion strength was measured as the amount of torque (Nm) each participant was able to generate during an isometric maximal voluntary contraction (MVC), while seated in the HUMAC dynamometer. The participant setup was identical to the H-reflex positioning. During the MVC, the participant was strapped into the seat to minimize contribution of shoulder and elbow flexors muscle activity. To minimize the BB being involved in the movement, the participants were instructed to focus on curling the wrist, resulting in the feeling of driving the forearm into the armrest pad.

All participants were given practice repetitions, in order to minimize the learning effect. Verbal encouragement was provided. Three repetitions were recorded, with 30-seconds of rest in between, each ended when a visible plateau in torque was reached and observed. Participants were also aware of what their torque output was on the monitor, which provided a source of biofeedback. A fourth repetition was performed without recording torque to determine peak EMG activity using the LabView interface. This EMG activation value was used as a guideline for the 10% MVC background contraction during H-reflex.

#### 2.4.7 Range of Motion

Active ROM was assessed using a manual goniometer for wrist flexion, extension, supination and pronation. ROM values were compared to known standards. All measures took place with the participant in a seated position and their wrist off the edge of a table. ROM was measured on the fractured limb post-cast removal (weeks 6, 9, and 12). ROM was assessed only in the fracture group, as it was assumed participants in the control group's wrist ROM was within normal ranges.

Goniometry was performed in accordance to clinical standards established by Clarkson (2012). In general, the procedures were followed (e.g. establishing a fixed arm, joint centre and moving arm), but participant positioning was modified as necessary for pronation-supination due to soreness associated with the fractured limb. In certain cases, it increased the degree of measurement error since the movement may not have been isolated to the wrist (radioulnar joint).

## **2.5 Questionnaires**

### **2.5.1 Visual Analog Scale for Pain**

A VAS, 100mm in length, was used to represent pain/discomfort for a continuum from zero (pain free) to 100 (extreme pain). After all functional tests and H-reflex testing was performed on the fracture side, the participant was asked to record a mark along the line to estimate the amount of discomfort that was felt in the fractured limb while the tests were being performed. The VAS was another way to track pain throughout the recovery process. The participant was notified throughout the procedure that they were free to discontinue the measures if the perceived pain level reached a level they were not comfortable with. A VAS was not used in the uninjured control group.

### **2.5.2 Patient-Rated Wrist Evaluation**

The patient-rated wrist evaluation (PRWE) was used as an assessment of wrist pain and function when performing daily living activities (MacDermid et al. 1998). The PRWE consists of 15 questions, where the participants responded via a scale of 0 to 10 (0, no pain/no difficulty; 10, unbearable pain/unable to perform activities). The maximum score possible is 150, which would indicate severe pain and dysfunction. Scores were recorded during weeks 6, 9, and 12. The PRWE was not assessed with the uninjured control group.

### **2.5.3 Godin-Leisure Time Questionnaire**

The Godin leisure time questionnaire (GLT) was developed to assess exercise behaviour by Godin and Shepard (1985). In this study, the GLT was used to track physical activity (PA) levels pre- and post-fracture. The GLT determined a score for PA levels via an equation, which takes into account the intensity of the type of activities performed on a weekly basis, and how often the activities are performed. The questionnaire was assessed twice (baseline and last session) in both the uninjured control group, and fracture group. In the fracture group, the post-fracture measures were used as a comparator to examine if any relationships existed between measured outcomes and potential change in PA levels.

## **2.6 Standard Rehabilitation Protocol**

All fracture patients admitted to the RUH fracture clinic also received standard rehabilitation exercises from the orthopaedic surgeon in accordance to the standard care

program. The patient remained in contact with the surgeon regarding the progression of the program, and participation in the study. The rehabilitation protocol involved active ROM exercises targeting neck, shoulder, fingers, and thumbs during the casted (or splinted) period. Post-cast removal, the exercises were modified to include wrist function; these exercises consisted of active and passive ROM of the injured wrist and hand. These rehabilitation exercises were completed at the discretion of each fracture patient, and were not tracked over the course of their involvement in the study.

## **2.7 Statistical Analysis**

Due to the low  $n$ , a liberal approach was taken for data analysis. To fully examine the effect of the disuse from cast immobilization on function and neuromuscular properties following a DRF, the fracture group was analyzed separately, and each arm was analyzed independently. Data was collected for all dependent variables on both arms in the fracture group at week 6, 9, 12, with the exception of wrist flexion MVC, and all H-reflex measures. Those two measures were not collected for fracture group's FX limb at week 6 due to patients experiencing pain during the procedure. Additionally, group mean replacement was also used for a single data point during the analysis of H-reflex data (week 9 participant 05); this was performed in accordance to suggestions by Tabachnick and Fidell (2012).

All data were analyzed using the SPSS software package (version 21.0, IBM). In general, within-subjects models were used to analyze the data. Repeated-measures (RM) within-subjects ANOVA was employed to analyze the groups individually; the limbs were also treated separately in the fracture group. To assess change from baseline in the fracture group's FX limb, a surrogate baseline was assigned using the value from their NFX limb (Magnus et al., 2013). In the uninjured control group, a 2 x 3 factorial RM-ANOVA (Arm x Time) was used to analyze data to confirm side-to-side stability of measures in an uninjured population. If no differences between the arms and the across time were observed for the age-matched uninjured control group, this would suggest stability in the measures and yield confidence in using the fracture group's uninjured side as a baseline surrogate for the injured side.

RM-ANOVA was employed across all measures to determine whether a main effect of time existed. If a significant main effect was found, post-hoc pairwise comparisons were conducted using unadjusted Least Significant Difference (LSD) tests versus the more stringent method of adjusting significance using Bonferroni.

Given the small sample size of the study a comparison between groups was not completed, aside from one-way ANOVA used to test whether mean differences existed between the two groups' baseline characteristics.

Following ANOVA tests, partial  $\eta^2$  values were used to run sample size calculations to determine the number of participants needed to achieve desired effect and power, if significance was not found. G\*Power 3.1 was used to determine sample sizes based on partial  $\eta^2$ , and an alpha level of  $p < 0.05$ , and power of 0.8. Given the small  $n$  of this study, effect sizes were used in addition to reported p-values to draw meaningfulness from the data. From the reported partial  $\eta^2$  values, value of the effect size was interpreted based on Bakeman (2005), where partial  $\eta^2 > 0.26$  was considered a large effect. Knowing the  $n$  required would be useful for future studies to achieve power.

### **3. Results**

#### **3.1 Participants**

A total of five patients (1 male, 4 females; age  $45.2 \pm 18.9$ ) were recruited to the fracture group, and five healthy uninjured participants were recruited as the age- and limb dominance-matched controls (1 male, 4 females;  $44.6 \pm 17.3$ ). The last fracture patient was recruited at the six-week mark of their fracture date — an exception was made in this case to increase enrolment numbers. Therefore data was available for only three time points (6, 9, and 12 weeks). As there was no statistical difference between baseline and 6 weeks post-fracture ( $p > 0.05$ ) for any measure collected for their NFX limb and variance was low, the data collected for the NFX arm at six weeks for this participant was also used for their baseline — all other participants' surrogate baseline values were based on enrollment baseline. Additionally, all but one fracture patient presented with dominant limb fractures. There were no significant differences in demographics between the two groups when looking at age, weight, height and WHQ. There was a significant difference between the GLT scores between the two groups before and after follow-up, with the control group being more active than the fracture group. See Table 3.1.



**Table 3.1: Participant Baseline Characteristics**

	Group		<i>p-value</i>
	Fracture (n = 5)	Control (n = 5)	
<b>Age (yr)</b>	45.2±18.9	44.6±17.3	0.97
<b>Weight (kg)</b>	64.4±4.9	68.9±8.8	0.35
<b>Height (cm)</b>	164.1±7.0	171.5±5.5	0.10
<b>WHQ</b>	9.4±14.1	4.4±12.6	0.57
<b>GLT - Pre</b>	44.0±8.2	71.0±16.6	0.01*
<b>GLT - Post</b>	45.0±9.4	80.2±23.5	0.02*

\* Non-injured Control group significantly different than fracture group ( $p < 0.05$ )

NOTE: WHQ: Waterloo Handedness Questionnaire; GLT: Godin Leisure Time

### 3.2 H-Reflex

For the uninjured CON group, there was not a significant difference between arms ( $F_{1,4} = 0.101$ ,  $p = 0.766$ , partial  $\eta^2 = 0.025$ ). There were also no significant differences over time across limbs ( $F_{1,4} = 0.656$ ,  $p = 0.554$ , partial  $\eta^2 = 0.137$ ) or an arm by time interaction ( $F_{2,8} = 0.316$ ,  $p = 0.738$ , partial  $\eta^2 = 0.073$ )

H-reflex amplitude values for the fracture group did not show a significant effect of time for either limb. For the FX limb, there was no significant effect of time when comparing across three levels of time: surrogate baseline, week 9 and 12 ( $F_{2,8} = 0.609$ ,  $p = 0.567$ , partial  $\eta^2 = .133$ ). For the fracture group's NFX limb, there was also no effect of time ( $F_{2,8} = 1.719$ ,  $p = 0.216$ , partial  $\eta^2 = 0.301$ ).

In order to realize an effect of time on the FX limb for mean change of H-amplitude over the course of study, a sample size of 34 is required based on the partial  $\eta^2$  of 0.133.

#### 3.2.2 $M_{Max}$

For the uninjured CON group, there were no significant effects of time ( $F_{2,8} = 0.568$ ,  $p = 0.588$ , partial  $\eta^2 = 0.124$ ) or arm ( $F_{1,4} = 0.095$ ,  $p = 0.774$ , partial  $\eta^2 = 0.023$ ), nor was there an interaction between time and arm ( $F_{2,8} = 0.024$ ,  $p = 0.976$ , partial  $\eta^2 = 0.006$ ).

$M_{max}$  amplitudes were also not significant over time in the fracture group. The fracture group's NFX limb did not show an effect of time across four time points ( $F_{2,8} = 0.347$ ,  $p =$

0.792, partial  $\eta^2 = 0.337$ ). The effect of time for the fracture limb was not significant across three levels: surrogate baseline, week 9 and 12 ( $F_{2,8} = 2.035$ ,  $p = 0.193$ , partial  $\eta^2 = 0.337$ ). To see an effect of time across all measures, a sample size of 10 would be required (Table 3.2).

### 3.2.3 $H_{\max}$ : $M_{\max}$ ratio

The uninjured CON group did not present a significant effect for arm ( $F_{1,4} = 0.724$ ,  $p = 0.443$ , partial  $\eta^2 = 0.153$ ) or time ( $F_{2,8} = 0.156$ ,  $p = 0.858$ , partial  $\eta^2 = 0.036$ ), or the interaction between arm and time ( $F_{2,8} = 0.096$ ,  $p = 0.910$ , partial  $\eta^2 = 0.023$ ).

In the fracture group, the effect of time was not significant for both the FX and NFX limb ( $F_{2,8} = 1.228$ ,  $p = 0.342$ , partial  $\eta^2 = 0.235$ ). The FX limb was analyzed with a surrogate baseline to determine the effect of time ( $F_{2,8} = 0.148$ ,  $p = 0.907$ , partial  $\eta^2 = 0.024$ ). A sample size of 151 would be required to see a significant effect of time in the FX with the given partial  $\eta^2$  of 0.036 (Table 3.2). See Figure 3.1 and 3.2 for graphical representation of amplitude measures of  $H_{\max}$  and  $M_{\max}$ .

### 3.1.4 H-reflex stimulation intensity

In the uninjured control group, there was not an effect of arm ( $F_{1,4} = 0.239$ ,  $p = 0.651$ , partial  $\eta^2 = 0.056$ ) or time ( $F_{2,8} = 4.340$ ,  $p = 0.053$ , partial  $\eta^2 = 0.520$ ), nor was there an interaction between time and arm ( $F_{2,8} = 0.583$ ,  $p = 0.580$ , partial  $\eta^2 = 0.127$ ).

In the FX group neither the FX limb ( $F_{2,8} = 2.001$ ,  $p = 0.197$ , partial  $\eta^2 = 0.333$ ), or the NFX limb ( $F_{1,4} = 0.376$ ,  $p = 0.772$ , partial  $\eta^2 = 0.089$ ) showed a significant effect of time. For the FX limb, the effect of time was examined with a surrogate baseline comparator. To see an effect of time on stimulus intensity in the FX limb, a sample size of 10 would have been required (Table 3.2).

### 3.2.5 $M_{\max}$ stimulation intensity

For the uninjured CON group, there were no significant effects for arm ( $F_{1,4} = 0.059$ ,  $p = 0.820$ , partial  $\eta^2 = 0.015$ ) or time ( $F_{2,8} = 0.981$ ,  $p = 0.416$ , partial  $\eta^2 = 0.197$ ) and there was no significant interaction between arm and time ( $F_{2,8} = 0.024$ ,  $p = 0.426$ , partial  $\eta^2 = 0.192$ ).

In the fracture group, the effect of time was not significant for both the NFX limb ( $F_{2,8} = 0.712$ ,  $p = 0.563$ , partial  $\eta^2 = 0.151$ ) and the FX limb ( $F_{2,8} = 1.092$ ,  $p = 0.257$ , partial  $\eta^2 = 0.151$ ), which was examined with a surrogate baseline. A sample size of 16 would have been

needed to see an effect of stimulus intensity over time for  $M_{\max}$  in the FX limb of the fracture group at the partial  $\eta^2$  of 0.151 (Table 3.2).

### 3.2.6 $H_{\max}$ : $M_{\max}$ stimulation intensity ratio

In the uninjured control group, there were no significant effects found for arm ( $F_{1,4} = 6.508$ ,  $p = 0.063$ , partial  $\eta^2 = 0.619$ ) or time ( $F_{2,8} = 4.439$ ,  $p = 0.053$ , partial  $\eta^2 = 0.521$ ), nor was there an interaction between arm and time ( $F_{2,8} = 0.462$ ,  $p = 0.646$ , partial  $\eta^2 = 0.103$ ).

For the fracture group, there was a significant effect of time for the FX limb when comparing across surrogate baseline, weeks 9 and 12 ( $F_{2,8} = 6.031$ ,  $p = 0.025$ , partial  $\eta^2 = 0.601$ ). Post-hoc pairwise comparisons revealed that the intensity ratio at week 9 was significantly greater compared to the surrogate baseline ( $p = 0.012$ ), and week 12 ( $p = 0.025$ ) (Table 3.2). The NFX limb did not have a significant effect of time ( $F_{2,8} = 0.102$ ,  $p = 0.957$ , partial  $\eta^2 = 0.025$ ). See Figure 3.2 for graphical representation of stimulus intensity measures for  $H_{\max}$  and  $M_{\max}$ .

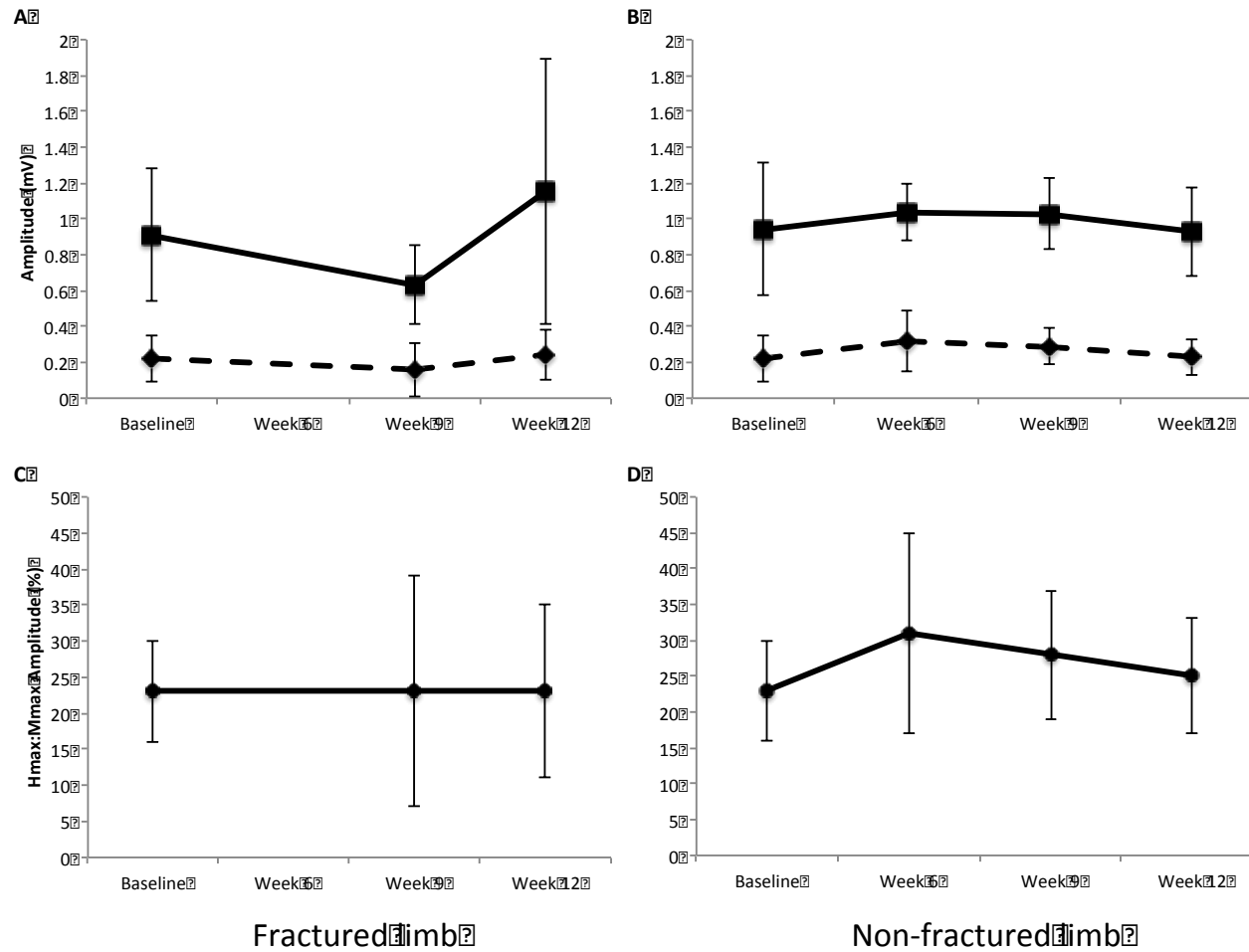
**Table 3.2. H-Reflex Parameters for Fracture Group (n = 5)**

Parameter	Limb	Baseline	Week 6	Week 9	Week 12	p-value	partial eta	required N
<b>H<sub>max</sub> Amplitude(mV)</b>	<b>FX</b>	<i>0.22±0.13</i>	-	0.16±0.15	0.24±0.14	0.567	0.132	27
	<b>NFX</b>	0.22±0.13	0.32±0.17	0.29±0.10	0.23±0.10	0.216	0.301	
<b>H<sub>max</sub> Stimulation Intensity (mA)</b>	<b>FX</b>	<i>12.18±1.8</i>	-	13.8±1.1	10.9±3.0	0.197	0.333	10
	<b>NFX</b>	12.18±1.8	12.28±5.6	11.08±4.9	10.4±3.4	0.772	0.086	
<b>M<sub>max</sub> Amplitude (mV)</b>	<b>FX</b>	<i>0.91±0.37</i>	-	0.63±0.22	1.15±0.74	0.193	0.337	10
	<b>NFX</b>	0.94±0.37	1.04±0.16	1.03±0.20	0.93±0.25	0.792	0.080	
<b>M<sub>max</sub> Stimulation Intensity (mA)</b>	<b>FX</b>	<i>20.1±2.4</i>	-	19.6±2.0	17.2±4.5	0.381	0.214	16
	<b>NFX</b>	20.1±2.4	19.7±5.7	17.7±7.4	16.8±5.9	0.563	0.151	
<b>H<sub>max</sub>:M<sub>max</sub> Amplitude</b>	<b>FX</b>	<i>0.23±0.07</i>	-	0.23±0.16	0.23±0.12	0.907	0.024	151
	<b>NFX</b>	0.23±0.07	0.31±0.14	0.28±0.09	0.25±0.08	0.342	0.235	
<b>H<sub>max</sub>:M<sub>max</sub> Stimulation Intensity</b>	<b>FX</b>	<i>0.61±0.06</i>	-	0.70±0.03*	0.63±0.05	0.025	0.601	
	<b>NFX</b>	0.61±0.06	0.60±0.13	0.61±0.05	0.63±0.10	0.957	0.025	

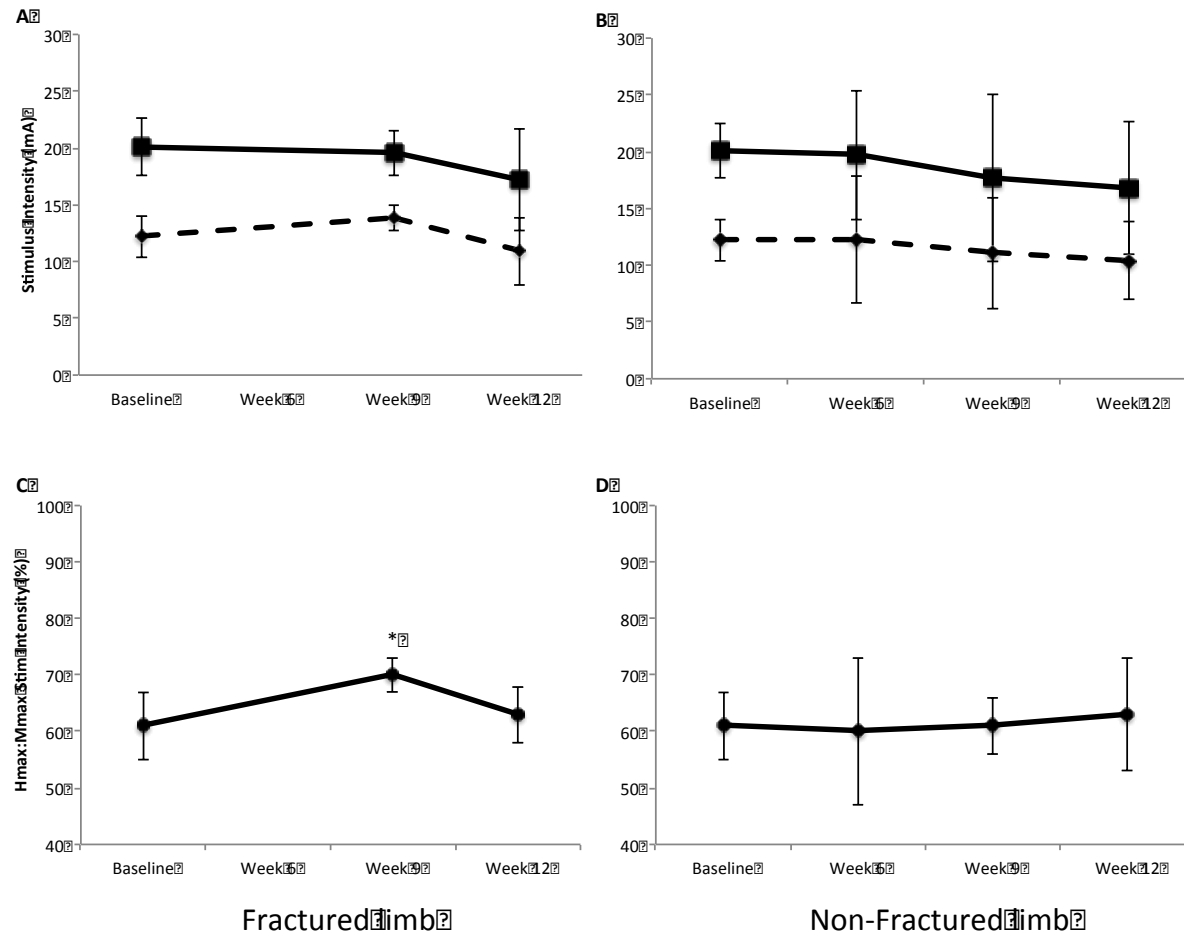
\*Significantly different from baseline and week 12.

Note: Significance accepted at  $p < 0.05$ . Italicized baselines values for FX limb are surrogate baselines based on NFX limb values.

H<sub>max</sub> = largest peak-to-peak amplitude of H-reflex; M<sub>max</sub> = largest peak-to-peak amplitude of M-wave; H<sub>max</sub>:M<sub>max</sub> = ratio of H<sub>max</sub> normalized to M<sub>max</sub>; mv = millivolt; mA = milliamp. Required  $n$  (rounded to the nearest integer) was determined using the associated partial eta value in G\*Power.



**Figure 3.1 H-reflex peak amplitude properties in the fracture group.** (A) and (B) represents peak-to-peak amplitude of M<sub>max</sub> (solid line) and H<sub>max</sub> (dashed line). (C) and (D) represents the ratio between H<sub>max</sub> and M<sub>max</sub> (solid line) peak-to-peak amplitude. NOTE: Fractured limb's baseline values are derived from their non-fractured limb. Values are Means  $\pm$  SD.

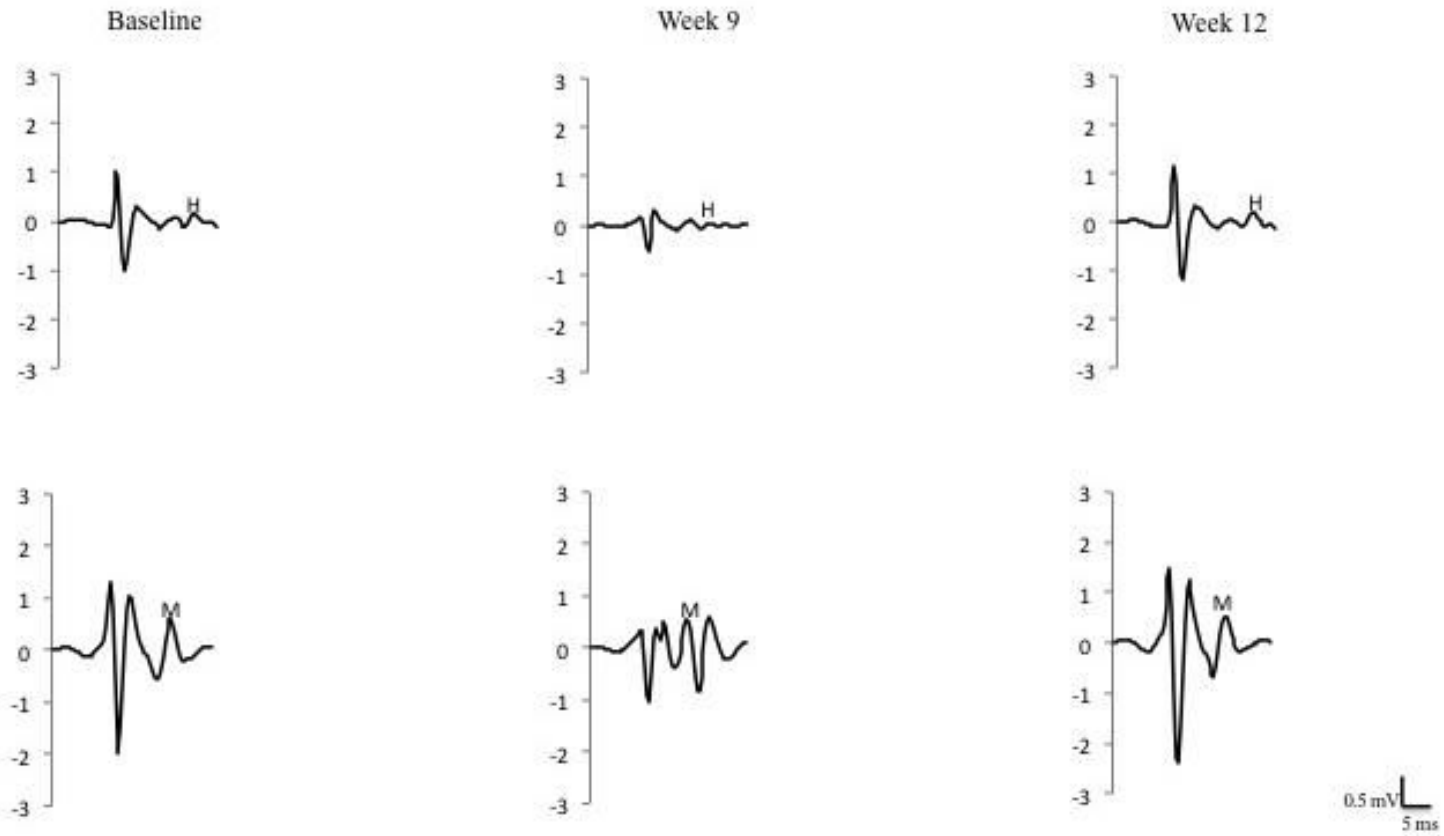


**Figure 3.2 Stimulus Intensity Tracings For Fracture Group.** (A) and (B) represents the stimulus intensity needed to reach  $M_{max}$  (solid line) and  $H_{max}$  (dashed line). (C) and (D) represents the stimulus intensity ratio needed for  $H_{max}$  and  $M_{max}$  (solid line). \*Week 9 was significantly different from baseline and week 12 in the fractured limb ( $p < 0.05$ ). NOTE: Fractured limb's baseline values are derived from their non-fractured limb. Values are Means  $\pm$  SD.

**Table 3.3. H-Reflex Parameters for Control group (n = 5)**

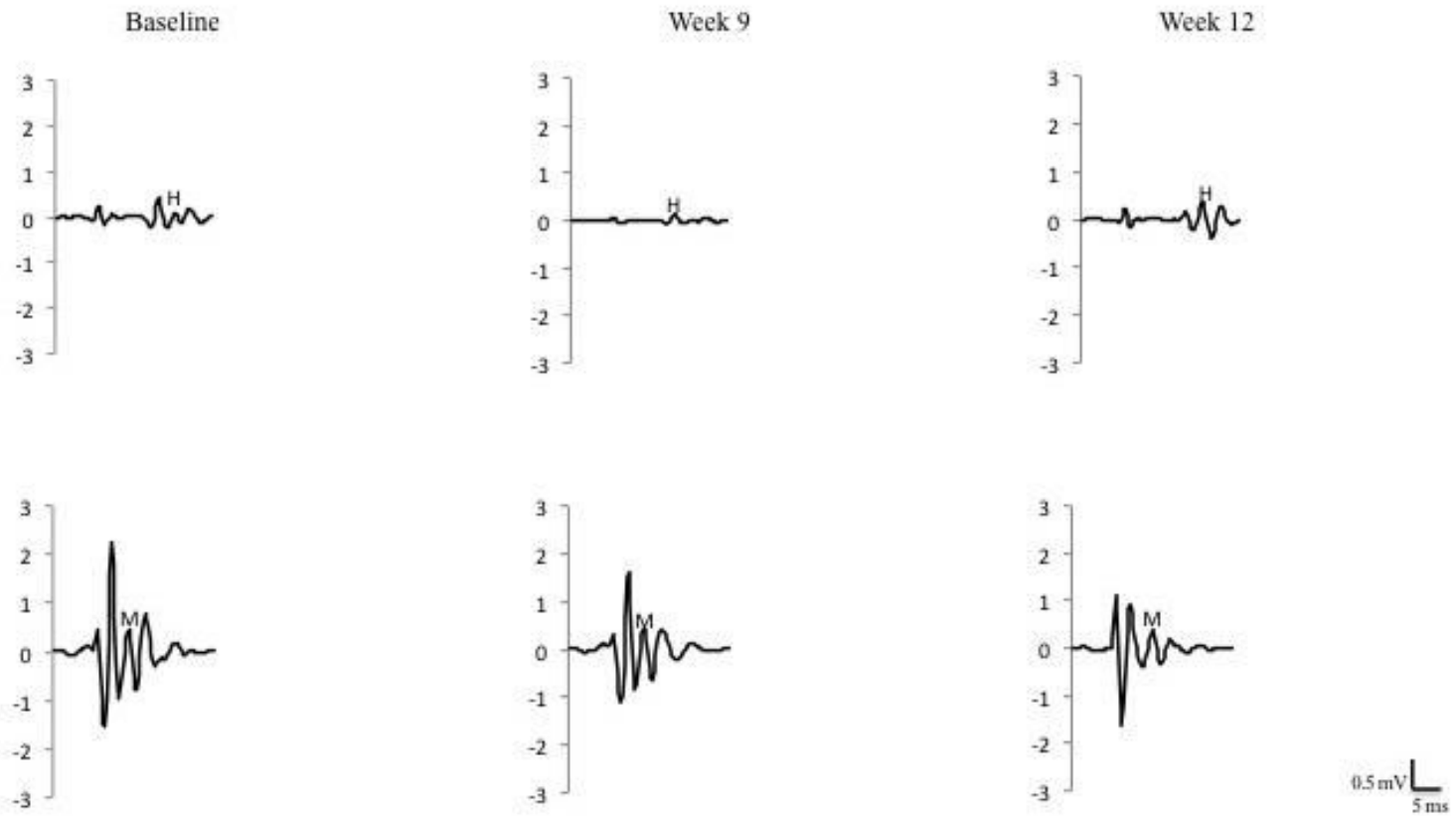
Parameter	Limb	Time 1	Time 2	Time 3	p-value	partial eta
<b>H<sub>max</sub> Amplitude(mV)</b>	<b>FX</b>	0.59±0.41	0.57±0.48	0.60±0.53	0.554	0.137
	<b>NFX</b>	0.57±0.31	0.61±0.41	0.47±0.17		
<b>H<sub>max</sub> Stimulation Intensity (mA)</b>	<b>FX</b>	5.6±2.0	7.2±2.2	7.2±2.8	0.053	0.520
	<b>NFX</b>	5.8±1.4	9.0±3.2	6.9±2.2		
<b>M<sub>max</sub> Amplitude (mV)</b>	<b>FX</b>	1.56±1.06	1.42±0.71	1.38±0.78	0.588	0.124
	<b>NFX</b>	1.58±0.53	1.52±0.83	1.44±0.49		
<b>M<sub>max</sub> Stimulation Intensity (mA)</b>	<b>FX</b>	12.7±5.3	14.1±4.2	14.4±3.4	0.416	0.197
	<b>NFX</b>	12.0±3.4	15.1±3.8	13.2±3.8		
<b>H<sub>max</sub>:M<sub>max</sub> Amplitude</b>	<b>FX</b>	0.37±0.09	0.37±0.12	0.36±0.15	0.859	0.038
	<b>NFX</b>	0.34±0.08	0.36±0.11	0.37±0.09		
<b>H<sub>max</sub>:M<sub>max</sub> Stimulation Intensity</b>	<b>FX</b>	0.46±0.08	0.51±0.04	0.49±0.08	0.053	0.521
	<b>NFX</b>	0.49±0.10	0.58±0.06	0.53±0.08		

Note: Significance accepted at  $p < 0.05$ . For the age-matched uninjured control, limbs were designated either “FX” or “NFX” based on the matched fracture participant. Dominance was also considered in the match. Measures at the three time points were taken at least three weeks apart. H<sub>max</sub> = largest peak-to-peak amplitude of H-reflex; M<sub>max</sub> = largest peak-to-peak amplitude of M-wave; H<sub>max</sub>:M<sub>max</sub> = ratio of H<sub>max</sub> normalized to M<sub>max</sub>; mv = millivolt; mA = milliamp.



**Figure 3.3. H-Reflex Recovery Post-Immobilization.** Note: Baseline graphs are based on surrogate baseline values from NFX limb. Top row represents H<sub>max</sub> and bottom row represents M<sub>max</sub>. H denotes location of H<sub>max</sub> and M denotes location of M<sub>max</sub>.





**Figure 3.4. H-Reflex Over Time In An Age-Matched Uninjured Control.** Note: H denotes location of  $H_{max}$ , and M denotes location of  $M_{max}$ . This output has been matched for the fracture participant in Figure 3.

### 3.3.1 Maximum Voluntary Contraction – Wrist Flexion

For the uninjured CON group, there were no significant differences between arms ( $F_{1,4} = 0.127$ ,  $p = 0.739$ , partial  $\eta^2 = 0.310$ ) nor were there an arm by time interaction ( $F_{2,8} = 0.163$ ,  $p = 0.852$ , partial  $\eta^2 = 0.039$ ); however, analysis did reveal an effect of time ( $F_{2,8} = 4.372$ ,  $p = 0.012$ , partial  $\eta^2 = 0.522$ ).

For the fracture group, there was a significant effect of time for wrist flexion MVC of the FX limb when analyzed with the surrogate baseline value, week 9 and 12 ( $F_{2,8} = 21.890$ ,  $p = 0.001$ , partial  $\eta^2 = 0.845$ ). Post-hoc pairwise comparisons revealed both week 9 ( $p = 0.002$ ) and 12 ( $p = 0.022$ ) were significantly different from the surrogate baseline. Increases were seen at week 9 and 12 compared to week 6, but were both still decreased compared to baseline (See Table 3.4). MVC torque output did not significantly change over time in the NFX limb ( $F_{2,8} = 0.634$ ,  $p = 0.607$ , partial  $\eta^2 = 0.137$ ).

### 3.3.2 Maximal Voluntary Contraction – Wrist Flexion EMG activity

In the uninjured control group, there were no significant differences found between arms ( $F_{1,4} = 0.975$ ,  $p = 0.379$ , partial  $\eta^2 = 0.196$ ) nor was there a main effect of time ( $F_{2,8} = 1.305$ ,  $p = 0.323$ , partial  $\eta^2 = 0.246$ ), or an interaction between time and arm ( $F_{2,8} = 0.248$ ,  $p = 0.786$ , partial  $\eta^2 = 0.058$ ).

For the fracture group, there was no significant effect of time in the FX limb when looking at a surrogate baseline, week 9 and 12 ( $F_{2,8} = 4.285$ ,  $p = 0.054$ , partial  $\eta^2 = 0.517$ ), but since there was a trend, so pairwise comparisons were examined. Week 12 was significantly decreased compared to the surrogate baseline ( $p = 0.012$ ) using unadjusted pairwise comparisons. To see a significant effect of a time for EMG activity based on a partial  $\eta^2$  of 0.517, a sample size of 6 was needed (Table 3.4). For the NFX limb of the fracture group, the effect of time was not significant ( $F_{2,8} = 1.988$ ,  $p = 0.170$ , partial  $\eta^2 = 0.332$ ).

The secondary muscles monitored during the tasks did not show any significant effects in the CON group, or in the either limb of the fractured group.

For the BB, the CON (NFX: time 1:  $0.24 \pm 0.23$ mV, time 2:  $0.33 \pm 0.24$ mV, time 3:  $0.27 \pm 0.23$ mV; FX: time 1:  $0.33 \pm 0.27$ mV, time 2:  $0.23 \pm 0.25$ mV, time 3:  $0.34 \pm 0.26$ mV) did not show effects for arm ( $F_{1,4} = 2.894$ ,  $p = 0.164$ , partial  $\eta^2 = 0.420$ ), time ( $F_{2,8} = 0.913$ ,  $p = 0.439$ , partial  $\eta^2 = 0.186$ ), or present a significant interaction ( $F_{2,8} = 1.185$ ,  $p = 0.354$ , partial  $\eta^2 = 0.229$ ). In the fractured group (NFX: baseline:  $0.12 \pm 0.05$ mV, week 6:  $0.13 \pm 0.03$ mV, week 9:

0.19±0.11mV, week 12: 0.16±0.07mV; FX: week 9: 0.09±0.01, week 12: 0.10±0.02mV), the FX limb ( $F_{2,8} = 2.592$ ,  $p = 0.136$ , partial  $\eta^2 = 0.393$ ) and the NFX ( $F_{2,8} = 2.081$ ,  $p = 0.156$ , partial  $\eta^2 = 0.342$ ) there was no effect of time.

The ECR presented similar findings in both groups. The CON group (NFX: time 1: 0.06±0.02mV, time 2: 0.05±0.02mV, time 3: 0.06±0.02mV; FX time 1: 0.06±0.03mV, time 2: 0.07±0.03mV, time 3: 0.05±0.02mV) did not show effects for arm ( $F_{1,4} = 0.186$ ,  $p = 0.688$ , partial  $\eta^2 = 0.044$ ), time ( $F_{2,8} = 0.544$ ,  $p = 0.606$ , partial  $\eta^2 = 0.118$ ), or present a significant interaction ( $F_{2,8} = 1.604$ ,  $p = 0.259$ , partial  $\eta^2 = 0.286$ ). The fracture group (NFX: baseline: 0.05±0.04mV, week 6: 0.05±0.02mV, week 9: 0.04±0.01mV, week 12: 0.05±0.02mV; FX: week 9: 0.03±0.01mV, week 12: 0.03±0.01mV) did not have a significant effect of time for either the NFX ( $F_{2,8} = 0.230$ ,  $p = 0.874$ , partial  $\eta^2 = 0.054$ ) or FX limb ( $F_{2,8} = 0.234$ ,  $p = 0.797$ , partial  $\eta^2 = 0.055$ ).

### 3.4 Grip Strength

Grip strength measures were taken at all time designated time points; however, two participants in the fracture group were unable to produce enough force for the handgrip dynamometer to register at week 6. These two participants were assigned a score of zero for grip strength for that testing session.

In the uninjured CON group, there were no significant effects of arm ( $F_{1,4} = 0.013$ ,  $p = 0.916$ , partial  $\eta^2 = 0.003$ ) or time ( $F_{2,8} = 0.213$ ,  $p = 0.813$ , partial  $\eta^2 = 0.050$ ). There was also not a significant interaction between arm and time ( $F_{2,8} = 0.784$ ,  $p = 0.489$ , partial  $\eta^2 = 0.164$ ).

For the fracture group, there was a significant effect of time for grip strength of the FX limb ( $F_{2,8} = 31.564$ ,  $p < 0.0001$ , partial  $\eta^2 = .896$ ). Post hoc pairwise comparisons for FX limb revealed that grip strength increases were significantly different from baseline at week 6 ( $p = 0.003$ ), 9 ( $p = 0.005$ ) and 12 ( $p = 0.024$ ), as well, week 6 was significantly different from 9 ( $p = 0.003$ ) and 12 ( $p = 0.040$ ), and week 9 was significantly different from week 12 ( $p = 0.030$ ) with each measurement showing significant increases in grip strength as recovery progressed (see Table 3a). Grip strength for the NFX limb did not change significantly over time ( $F_{2,8} = 2.822$ ,  $p = 0.084$ , partial  $\eta^2 = 0.414$ ). See Table 3.4.

### 3.5 Range of Motion

ROM was analyzed for change in wrist flexion and extension, in addition to change over time for combined flexion and extension. Pronation and supination was measured, but was not

included in the analysis due to variance in measurement procedures used to accommodate the patient's ability to maintain a closed fist (see Appendix A for scores). ROM was only completed on the FX group.

For wrist flexion there was no significant effect of time ( $F_{2,8} = 3.890$ ,  $p = 0.066$ , partial  $\eta^2 = 0.493$ ); however there was a significant main effect of time for wrist extension ( $F_{2,8} = 8.946$ ,  $p = 0.009$ , partial  $\eta^2 = 0.691$ ). The combined ROM of wrist flexion and extension also showed a significant main effect of time ( $F_{2,8} = 5.030$ ,  $p = 0.0380$ , partial  $\eta^2 = 0.557$ ). For both wrist extension and combined ROM, the fracture group showed a trend of increases in ROM over time. Breaking down post hoc pairwise comparisons, for wrist extension week 12 was significantly increased from week 6 ( $p = 0.020$ ), and for combined ROM, week 12 was significantly greater than week 6 ( $p = 0.027$ ). See Table 3a for complete ROM scores.

### **3.6 Patient Rated Wrist Evaluation**

PRWE questionnaire was completed for the FX group only. For mean PRWE scores over the 12-week period, there was a significant main effect of time ( $F_{2,8} = 23.269$ ,  $p = 0.0004$ , partial  $\eta^2 = 0.853$ ). Only week 6 and week 12 means were significantly different ( $p = 0.002$ ) as determined from post hoc pairwise comparisons, where week 12 scores were significantly lower than week 6 (Table 3.4).

### **3.7 Visual Analog Scale**

There were no significant differences across time in VAS scores recorded in the fracture group ( $F_{2,8} = 3.875$ ,  $p = 0.116$ , partial  $\eta^2 = 0.660$ ). To have achieved an effect of time based on a partial  $\eta^2$  of 0.660, a sample size of 5 was needed (Table 3.4).

### **3.8 Muscle thickness**

There were no significant differences in MT for the uninjured CON group between arms ( $F_{1,4} = 1.405$ ,  $p = 0.302$ , partial  $\eta^2 = 0.260$ ), or across time ( $F_{2,8} = 0.750$ ,  $p = 0.503$ , partial  $\eta^2 = 0.158$ ). The interaction between arm and time was not significant ( $F_{2,8} = 0.106$ ,  $p = 0.901$ , partial  $\eta^2 = 0.026$ ).

For the fracture group there was a significant effect of time for MT of the FX limb when compared across four time points: surrogate baseline, week 6, 9 and 12 ( $F_{3,12} = 5.074$ ,  $p = 0.017$ , partial  $\eta^2 = 0.559$ ). Post hoc pairwise comparisons revealed only the surrogate baseline measure and week 6 were significantly different ( $p = 0.047$ ), where week 6 indicated a

significantly lower MT (Table 3.4). The NFX limb did not show a significant effect of time ( $F_{2,8} = 1.105, p = 0.385, \text{partial } \eta^2 = 0.216$ ).

**Table 3.4 Functional Measures in the Fracture Group (n = 5).**

Parameter	Limb	Baseline	Week 6	Week 9	Week 12	p-value	partial eta	required N
Muscle Thickness (cm)	FX	3.20±0.46	2.74±0.51*	3.02±0.42	3.18±0.51	0.017	0.559	
	NFX	3.20±0.46	3.23±0.30	3.31±0.31	3.31±0.43	0.385	0.216	
Grip Strength (kg)	FX	28.4±7.1	6.0±6.8*§	12.4±7.2*^	19.6±8.5*	<0.001	0.888	
	NFX	28.4±7.1	28.8±6.4	30.0±4.9	30.8±5.8	0.084	0.414	
Wrist Flexion MVC (Nm)	FX	17.07±2.97	-	6.37±1.20*	8.49±2.27*	0.001	0.845	
	NFX	17.07±2.97	15.88±2.65	16.06±1.54	15.34±2.33	0.607	0.137	
FCR Normalized EMG (%) <sup>1</sup>	FX	0.29±0.14	-	0.18±0.06	0.14±0.10*	0.054	0.517	6
	NFX	0.29±0.14	0.23±0.05	0.25±0.07	0.24±0.12	0.17	0.332	
Wrist Flexion (°)	FX	-	51.4±8.2	61.6±17.1	66.3±12.1	0.066	0.493	6
	NFX	-	-	-	-			
Wrist Extension (°)	FX	-	36.4±16.1	48.8±23.8	53.1±20.0 <sup>+</sup>	0.009	0.691	
	NFX	-	-	-	-			
PRWE	FX	-	84±23.88	46.40±45.11	27.80±31.9 <sup>+</sup>	0.0004	0.853	
	NFX	-	-	-	-			
VAS (mm)	FX	-	43±24	26±25	26±18	0.116	0.660	5
	NFX	-	-	-	-			

Note: Significance was accepted at  $p < 0.05$ . \*Time point significantly different from baseline. ^Significantly different from week 12. §Significantly different from week 9 and 12. <sup>+</sup> Significantly different from week 6. Required  $n$  (rounded to nearest integer) was determined using the associated partial eta value in G\*Power. <sup>1</sup> EMG activity normalized to  $M_{max}$ , expressed as percentage of  $M_{max}$ . MVC = maximum voluntary contraction of wrist flexion; ROM = range of motion; PRWE: Patient-rated wrist evaluation, higher scores indicate lower function; VAS: Visual Analog Scale. Nm = newton-meters.

**Table 3.5 Functional Measures in the Control Group (n = 5)**

Parameter	Limb	Time 1	Time 2	Time 3	p-value	partial eta
Muscle Thickness (cm)	FX	3.87±0.22	3.91±0.15	3.90±0.12	0.503	0.158
	NFX	3.77±0.36	3.80±0.35	3.78±0.33		
Grip Strength (kg)	FX	43.2±5.8	43.8±7.1	43.6±7.7	0.813	0.050
	NFX	42.8±7.8	45.2±6.6	43.0±7.4		
Wrist Flexion MVC (Nm)	FX	24.74±7.21	22.73±6.60	22.03±6.88*	0.012	0.667
	NFX	24.96±8.89	23.43±8.59	22.07±8.52		
FCR Normalized EMG <sup>1</sup>	FX	0.30±0.17	0.34±0.23	0.31±0.27	0.323	0.246
	NFX	0.22±0.03	0.30±0.20	0.20±0.08		
Wrist Flexion (°)	FX	-	-	-		
	NFX	-	-	-		
Wrist Extension (°)	FX	-	-	-		
	NFX	-	-	-		
PRWE	FX	-	-	-		
	NFX	-	-	-		
VAS (mm)	FX	-	-	-		
	NFX	-	-	-		

Note: Significance was accepted at  $p < 0.05$ .  $p$ -value presented for time effect. For the age-matched uninjured control, limbs were designated either “FX” or “NFX” based on the matched fracture participant. Dominance was also considered in the match. Each time point was at least three weeks apart. MVC = maximum voluntary contraction of wrist flexion; ROM = range of motion; PRWE: Patient-rated wrist evaluation, higher scores indicate lower function; VAS: Visual Analog Scale. <sup>1</sup> EMG activity normalized to  $M_{max}$ , expressed as percentage of  $M_{max}$ . Nm = newton-meters.

#### 4. Discussion

The aim of this study was to determine if neuromuscular plasticity occurs following a period of cast immobilization after distal radius fracture through tracking the H-reflex over time. In addressing the primary hypothesis that the H-reflex would demonstrate hyper-excitability following cast immobilization from a DRF, there was a lack of evidence to support increases in excitability. There was; however, a novel finding regarding the plasticity of the H-reflex in that the stimulus intensity needed to evoke  $H_{max}$ , when expressed as a ratio of stimulation intensity to evoke  $M_{max}$ , significantly increased following a period of immobilization from DRF (week 9). Unexpectedly, the  $H_{max}:M_{max}$  stimulation intensity ratio increased and then decreased during recovery which would point towards *hypo*-excitability of the maximal H-reflex before returning to near baseline at week 12. Importantly the CON group experienced a similar change pooled across both arms (Table 3.3) although the time effect was not significant ( $p = 0.053$ ). This change lends uncertainty regarding the increase in stimulation intensity ratio for the fracture group, but carries less weight because there were no statistical differences between any time points for the CON group. Conversely for the fracture group, week 9 was significantly greater in comparison to both the surrogate baseline and week 12 time points. This could indicate the significance found in the fracture group is likely to reflect a real change rather than a mere artifact within the dataset. Nonetheless, there is only limited evidence to support changes in H-reflex parameters after distal radius wrist fractures.

When considering peak amplitude data, the findings were in contrast to the  $H_{max}:M_{max}$  amplitude, which did not demonstrate significant changes in either direction over time. This would suggest the H-reflex peak-to-peak amplitude itself does not exhibit significant changes over time post-immobilization from a DRF as the amplitude is normalized to  $M_{max}$ , which was stable over the course of the study in both groups. Consistent with the hypotheses for the secondary functional outcomes, there were decreases in overall strength, muscles size and activity, pain and function following the casted period. Over the course of the post-immobilization measurements, each secondary measure significantly improved as recovery progressed, but did not demonstrate complete return to baseline at 12 weeks post-fracture. If full recovery was achieved, week 12 scores should reflect those of the homologous uninjured limb since the uninjured CON group did not present significant differences between limbs.



#### 4.1 Primary Outcome: H-Reflex

The primary outcome of interest was the H-reflex and its properties (amplitude, stimulation intensity,  $H_{\max}:M_{\max}$  ratios) following cast immobilization due to a DRF. Significance was not found for every parameter, but an increase in  $H_{\max}:M_{\max}$  stimulus intensity, when considered alongside no change in  $M_{\max}$  stimulus intensity over time, may reflect a change in H-reflex plasticity. Following a prolonged immobilization period the prediction was that the H-reflex would be *hyper*-excitable, demonstrating increased peak-to-peak amplitude and/or decreased stimulus intensity needed to reach peak. The hypothesis was based on two key studies using similar upper limb forearm immobilization models, but with healthy volunteers (Clark et al. 2008; Lundbye-Jensen and Neilsen 2008a). Both of these studies immobilized each participant's non-dominant limb, with Lundbye-Jensen and Neilsen (2008a) utilizing a traditional cast, and the Clark group using a removable splint. Note that the immobilized limb of those studies did differ from the current study, as the fracture group had only one non-dominant DRF. The H-reflex findings in this study, however, do not reflect those found in Lundbye-Jensen and Neilsen (2008a), but are more in line with Clark et al. (2008, 2010). In comparing findings between the two research groups, the focus was placed on change of the  $H_{\max}:M_{\max}$  amplitude ratio ( $H_{\max}$  normalized to  $M_{\max}$ ) over time, which was also used in this study.

To continue to delve into the two key studies, it is interesting to note that even though Clark et al. (2008) was not able to demonstrate statistically significant hyper-excitability of the amplitude of H-reflex (reported through  $H_{\max}:M_{\max}$  ratios), as seen in Lundbye-Jensen and Neilsen (2008a), they did present similar findings. Following one-week of immobilization, Clark et al. reported a 9% absolute difference in excitability compared to 11% by Lundbye-Jensen and Neilsen (2008a), which the authors considered to be a similar and significant finding. In the current study, the absolute difference in excitability — based on  $H_{\max}:M_{\max}$  amplitude — was near zero (a minuscule 0.1%); however, this value is not reflective of the same post-immobilization time point as the other two studies. So the discrepancy in findings may be due differences in time line. Lundbye-Jensen and Neilsen (2008a) used a one-week immobilization model followed by measurements immediately post-immobilization and one-week following, whereas Clark et al. (2008) assessed participants weekly during a three-week immobilization period, in addition to a one-week post-immobilization measure. In contrast, this study tracked progress for 12-weeks post-immobilization — after a six-week casted period — with key

measurements at week 9 and 12. While in terms of the number of measurements, it is closer in design to the Clark group, these are key differences between the healthy vs. injured immobilization models that could be related to discrepancies in the H-reflex data. In an injured population, it is not possible, or advisable, to have patients in a removable splint.

The lack of evidence to support the hyper-excitability hypothesis in this study may lie in the missing data point (week 6; refer to Table 3.2). Week 6 data collection was attempted, but was not successfully completed due to participant discomfort and therefore was not analyzed. This time point would have represented the time immediately post-immobilization, and this more closely aligns with the time period where the two previous upper extremity studies found strong evidence of hyper-excitability. Lundbye-Jensen and Nielsen (2008a) presented significant increases in excitability immediately post-immobilization before returning to baseline values during the last recovery testing session at 2 weeks. Similarly, Clark et al. (2008) presented a trend towards increased excitability only for the measure immediately following immobilization (week one) before reporting a trend indicating  $H_{\max}:M_{\max}$  amplitude returns to baseline. Interestingly, in both of the key studies highlighted, following a brief period of what the authors' suggested to be hyper-excitability of the H-reflex, their subsequent follow up data ("recovery" measure) pointed the reflex to fall back to baseline levels, or in Lundbye-Jensen and Nielsen's case, the final measure actually fell below the baseline value (~29% vs ~32%  $H_{\max}:M_{\max}$ ). This could be an indication the H-reflex and its various parameters have quick adjustment periods during and post-immobilization. This idea would be supported by similarities between the surrogate baseline values and  $H_{\max}$  properties at week 9 and 12 reported in the current study (surrogate baseline:  $23.2 \pm 7.0\%$ , week 9:  $23.0 \pm 1.6\%$ , week 12:  $23.1 \pm 1.2\%$ ). In all, this fracture study is not able to fill in the gap as to what occurs when the limb is immobilized prior to cast removal and what changes are present immediately following cast removal.

Although there were no large effect sizes reported for the H-reflex properties, the changes in  $H_{\max}:M_{\max}$  ratio for stimulation intensity were significant over the course of recovery (Table 3.2). The  $H_{\max}:M_{\max}$  stimulation ratio changed in the opposite direction (hypo-excitability), and had the largest effect size ( $\eta^2 = 0.601$ ), and was the only H-reflex property to demonstrate a significant time effect. Unexpectedly, a higher not lower relative stimulus intensity was needed to evoke  $H_{\max}$  closer to the end of the immobilization period (week 9:  $13.8 \pm 1.1\text{mA}$ ;  $70.0 \pm 3.0\%$  of  $M_{\max}$  stimulation) as opposed to further along (week 12:  $10.9 \pm 3.0\text{mA}$ ;  $63.0 \pm 5.0\%$ ). The

$H_{\max}$ : $M_{\max}$  stimulus intensity at week 9 was 114% of baseline, and at week 12 it was 103% of baseline. This can be interpreted as a 14% increase in relative stimulus intensity needed to elicit  $H_{\max}$  ( $H_{\max}$ : $M_{\max}$  stimulus intensity scores) before a subsequent decrease of 11% to reach values closer to the surrogate baseline. A similar trend was seen in the uninjured control group where an increase of 14% and subsequent drop of 6% was shown, but these changes were not significant over time, or for pairwise tests comparing individual time points. Despite the significant, and more convincing results in the fracture group, there is only limited evidence in support of changes in H-reflex parameters after distal radius fracture.

Changes in stimulus intensity needed to reach  $H_{\max}$  were tracked by Lundbye-Jensen and Neilsen (2008a), but their methodology differed from this study. Their analysis of stimulus intensity centered on resting motor threshold (rMT) and how  $H_{\max}$  amplitude changed relative to rMT for a given intensity. The authors showed peak-to-peak amplitude of H-reflexes increased between 1.1 and 1.7 times rMT at all selected stimulus intensities post-immobilization. This is markedly different from the approach used in here, as the comparison of stimulus was completed using raw mA values needed to achieve both  $H_{\max}$  and  $M_{\max}$ . Unfortunately, rMT was could not be determined reliably from our protocol.

The intensity (mA) needed to elicit  $H_{\max}$  and  $M_{\max}$  responses can be indicative of the sensitivity of the pathway (Lundbye-Jensen and Nielsen 2008b). In a follow-up paper to their forearm immobilization study, Lundbye-Jensen and Nielsen (2008b) proposed the idea of changes in presynaptic inhibition. Following a period of immobilization of the lower leg, Lundbye-Jensen and Nielsen (2008b) found an increase in amplitude of the H-reflex in the soleus muscle with no change in  $M_{\max}$  amplitude, which they attributed to plastic changes in the presynaptic pathway in the absence of changes in reciprocal inhibition. Reciprocal inhibition occurs when the activation of an agonist group of muscles causes automatic inhibition of the opposing antagonist group (Crone 1993). The idea of changes in presynaptic inhibition on the Ia afferents follows ideas presented by Hultborn and colleagues (2004), where various inhibitory interneurons affect the degree inhibition on the alpha motor neuron (MN), which falls in line with the gain-control theory. Gain-control theory predicts that input-output of MN pools reflect the entire output chain, where signals received stem from higher-order descending control (Hultborn et al. 2004). As such changes in presynaptic processes can indeed moderate the amplitude of spinal reflexes such as the H-reflex (Gajos et al. 2014). In all, even though the

results in the current study show the opposite of what the Lundbye-Jensen group reported, they are indicative that change is happening within the neuromuscular system since  $H_{\max}:M_{\max}$  stimulus intensity did show significant change over time.

The degree of change over time in the neuromuscular properties related to the H-reflex, although not all significant, seem to provide hints as to what is occurring in the system due to the large effect sizes for some of the parameters ( $H_{\max}:M_{\max}$  stimulus intensity:  $\eta^2 = 0.601$ ;  $H_{\max}$  stimulus:  $\eta^2 = 0.333$ ;  $M_{\max}$  amplitude:  $\eta^2 = 0.337$ ).  $H_{\max}$  amplitude ( $\eta^2 = 0.132$ ) and  $M_{\max}$  stimulus intensity ( $\eta^2 = 0.214$ ) also presented with a medium effect size. However, drawing definite conclusions, whether to support or reject the primary hypothesis would not be wise given the likelihood of Type I error due to the small sample size and the number of ANOVAs run on the dataset. Given that the population used in this study is a true fracture population, other factors such as pain need to be explored. Importantly, other studies examining the effects of short-term, or long-term immobilization, on the H-reflex have generally used a healthy uninjured population. In a clinical population, outcomes can be influenced by symptoms associated with injury such as pain.

The variable of pain could be a potential reason why some effects were not observed in the fracture group, as it limited when measures could be taken in this study. Due to discomfort following cast removal, the participants in the fracture were unable to perform many of the tasks required (e.g. supinated wrist flexion) to accurately obtain the H-reflex. Pain was the main factor why data immediately post-immobilization (week 6) was unobtainable. A recent study examining a clinical population has indicated the H-reflex may be sensitive to levels of pain. Studying patients with chronic patellofemoral pain, de Oliveira Silva et al. (2016b) found H-reflex amplitude (excitability) in the vastus medialis muscle to be related to the patient's pain and functional status. Patients exhibiting higher amounts of pain showed decreased H-reflex excitability ( $H_{\max}$  amplitude). Those results re-confirmed findings from their previous work (de Oliveira Silva et al. 2016a) relating the decrease in excitability to impaired transmission within 1a afferents due to pain. There is also evidence to suggest H-reflex characteristics change with chronic low back pain (LBP) or radiculopathies. Mazzocchio et al. (2001) provided evidence that changes in H-reflex properties such as increased threshold (+1.4mA and 12% in H-reflex amplitude at rMT) and latency (+1ms) could be characteristics of low back radiculopathies; though they do explicitly state that changes in the H-reflex cannot be a definitive diagnostic

marker. Ginanneschi et al. (2007) also found changes bilaterally in H-reflex threshold (increased ~16-18% of rMT compared to healthy control) and recruitment curve of the soleus in patients with LBP (higher stimulus needed to reach  $H_{max}$ ). In the diagnostic use of the H-reflex, the distal muscle being investigated must be associated with a specific nerve root. The LBP studies utilized the soleus, this is the case as the L5-S1 nerve roots are common causes in back pathology (Mazzocchio et al. 2001), such that it makes sense to test the spinal reflexes of muscles associated with the associated peripheral nerve (i.e. the FCR would not be used to assess H-reflex as marker of LBP). From a physiological standpoint, Ellrich and Treede (1998) attempted to characterize the convergent effects of nociceptive signals on spinal reflexes, including the H-reflex. The authors found that with a painful heat stimulus, H-reflexes were interrupted, which they hypothesized was due the result of nociceptive input onto common neurons in the spinal pathway such as interneurons. The relationship between the H-reflex and pain would fit into the findings of the current study. As the reported VAS and PWRE improved (Table 3.4), the relative stimulus intensity required to evoke  $H_{max}$  decreased (Table 3.2). Again, this statement would be something that warrants further investigation since the scope of the study did not include tracking of the H-reflex threshold, nor complete recruitment curves including latency times and extracting slopes of the ascending limb of the curve. Further, the fracture patients were not followed until pain was completely or nearly subsided.

From the perspective of the age-match uninjured CON group, the data indicates that over time, in a healthy population, the H-reflex and its properties do not change (Table 3.3). The lack of effect between limbs, also indicates limb-to-limb stability regardless of hand dominance. The tracings of a representative CON participant (Figure 3.4), also indicates EMG tracings of both the  $H_{max}$  and  $M_{max}$ , present with very similar shaping. As such, it solidifies the decision in the current study to use the fracture patient's non-fractured contralateral limb as a surrogate baseline for the reflex measures.

## **4.2 Secondary Outcomes**

The study's secondary purpose was to examine the key functional attributes associated with hand-wrist injuries such as grip strength, isometric strength and activities of daily living. In general, the result was in agreement to previous studies (Trumble et al. 1994; Foldhazy et al. 2007; Magnus et al. 2013) indicating general overall loss of function that does not fully recover up to 12 weeks post-fracture. These factors will be discussed in the following sections.

#### 4.2.1 Muscle Thickness

MT measurement presented an effect of time, as thickness was significantly decreased following the casted period (week 6: -14.4% of baseline), and recovered through the course of the next six weeks (week 9: -5.6%; week 12: -0.7% of baseline). The significant decrease in MT follows what has been reported in upper extremity disuse-immobilization models (Parcell et al. 2000; Magnus et al. 2010). In general more information regarding disuse-immobilization is available for the lower limb compared to the upper limb (Clark 2009). The evidence of change in muscle morphology, particularly regarding atrophy is mixed. In a nine-day immobilization study, Miles et al. (1994) found 4.1% decrease in CSA, and Byl et al. (1999) reported a -1.1cm change in forearm circumference following a DRF and cast immobilization. Kitahara et al. (2003) examined both forearm CSA and circumference and found no significant differences in either measure after participants were casted for a 21-day period. However, the Kitahara group did present evidence that grip strength decreased 18% over the course of immobilization. With the lack of depth of evidence in upper extremity models, this study's set of results adds further support for morphology deficits following cast immobilization.

Although MT may not be the best representation of change in muscle morphology, it can still be indicative of significant atrophy, especially when taken into account with other functional measures, such as grip strength. Isolating the FCR was very difficult with ultrasound imaging, but tissue thickness through the bulk of the forearm muscle can be used to approximate the degree of forearm atrophy and recovery following immobilization. CSA measurements are more commonly used to determine change in muscle morphology, but unfortunately this was beyond the scope of the project. In the above studies that included CSA data, more sophisticated techniques of computed-tomography (Miles et al. 1994) or magnetic resonance imaging (Kitahara et al. 2003) was employed. Both tools can be prohibitively expensive and time consuming unless a research group readily has access to the devices.

#### 4.2.3 Grip Strength

Grip strength was another functional measure that showed significant change over time. Strength increased through each time point measured following the cast immobilization period indicative of partial recovery (week 6:  $6.0 \pm 6.8$ kg; week 9:  $12.4 \pm 7.2$ kg; week 12:  $19.6 \pm 8.5$ kg); however, the fracture patients still showed a strength deficit of 31% compared to the NFX limb at the final time point. The improvement in grip strength was both statistically significant

and clinically important. Showing a change that is clinically relevant indicates the patient's strength is indeed returning and the improvement is predicted to positively impact their recovery and every day function. The suggested clinically important change in grip strength has been stated to be 6.5kg following a DRF (Kim et al. 2014), which was achieved by the fracture group (Table 3.3). This improvement in grip strength could be seen as a positive indicator that the patients' abilities are returning, since the measure can be related to a person's overall ability to perform activities of daily living (Leiv et al. 2014). Additionally, this is an important finding since it is known that grip strength dramatically decreases following DRFs and can be a tool sensitive enough to be an indicator of functional recovery as strength returns slower than ROM (Foldhazy et al. 2007). The prolonged recovery process is important to understand since a person's strength may be returning at a functionally noticeable level, but a deficit can still be present. Other researcher has shown grip strength deficits compared to the NFX limb between 26 weeks, one year and even up to two years (Foldhazy et al. 2007; Magnus et al. 2013; Trumble et al. 1994). In this study, at 12 weeks, the FX limb's grip strength was only 63% of the NFX, which is similar to findings by the Foldhazy and Magnus groups.

#### 4.2.4 Wrist Flexion Isometric Maximal Voluntary Contraction

Overall change in MVC performance post-immobilization in the fracture group was significant, as expected, with a large effect size. As the injured side regained general functionality (i.e. ROM and grip strength) and experienced a decrease in pain symptoms (Table 3.4), their performance improved over the course of the six-week follow up period. However, the results are only from two time points (week 9 and 12) due to the discomfort patients experienced for wrist flexion with a supinated forearm immediately following cast removal (week 6). Testing was attempted for each patient at the week 6 time point, but it was not possible to collect enough data to include week 6 in the final analysis.

In the analysis of EMG activity during the MVC trials, the recorded EMG activity showed a significant effect of time in the FX limb when a surrogate baseline was included (table 3.4). To normalize this data, the amplitude of EMG activity was normalized to the session's  $M_{max}$ . This was another expected result, as the change in EMG activity over time and the differences between the FX and NFX limb were visibly seen on the raw EMG tracings. The raw EMG values were not considered in isolation due to the need to account for session-to-session variability. In general, it is accepted that EMG activity of the muscles following a period of

immobilization shows reduced activity compared to the non-affected side (Booth 1982; Duchateau and Hainault 1991). From a forearm immobilization perspective, Seki et al. (2005) showed decreases in EMG activity of the first dorsal interossei, a relatively large muscle of the hand, along with decreases in MVC. Seki and colleagues found these changes even though their participants only underwent a one-week casted immobilization protocol.

#### 4.2.5 Measures of Pain and Disability

PRWE scores significantly improved throughout the post-immobilization period, which was expected (see Table 3.4). The PRWE scores progressed (as indicated by a decreasing score) from 84.0 to 46.4 to 27.8 at week 6, 9, and 12, respectively. The changes in the PRWE scores were also all considered to be clinically important. The minimal clinically important difference (MCID) for PRWE has been reported by Walenkamp et al. (2015) to be 11.0. This study's fractured group showed a 67% (56.2 units) improvement from immediately post-immobilization to week 12. Also, the change in this self-reported questionnaire for function is considered a reliable resource as it one of the most common questionnaires used to evaluate patient outcomes following DRFs (Changulani et al. 2008; Slutsky 2013).

VAS scores, oddly, contrasted other functional measures. The fracture group did not show a gradual change in pain scores over the course of 12 weeks. The VAS scores decreased between week 6 (43.33mm) and 9 (26.00mm), but stabilized in weeks 9 and 12 (26.67mm). The improvement in VAS score was expected to trend down over weeks 6, 9 and 12 as function was restored, as indicated by the PRWE. Though this occurred in weeks 6 and 9, the trend did not continue to week 12. This could possibly be related to lingering or chronic pain that has been associated with DRFs. Pain, or discomfort, from DRFs has been described to last up to two years (Trumble et al. 1994). However, even if not statistically significant, the decrease in VAS scores can potentially have clinical significance. MCID values for VAS specific to DRFs have not been published to the author's knowledge, but MCIDs for various medical situations have been determined. Lee et al. (2003) published data on emergency rooms, where a MCID of 30.0 mm was indicative of adequate pain control in an acute situation, while a change of 14.0 mm was considered a favorable patient-rated outcome six-weeks post-rotator cuff disease (Tashjian et al. 2009), and a decrease between 11.1 to 19.9 mm was deemed an improved pain outcome for arthritic pain (Stauffer et al. 2011). However, there are also indications that MCID for



orthopaedic pain scores along the VAS depends on a patient's baseline pain score (Katz et al. 2015) suggesting relative MCIDs may be more appropriate for this outcome.

#### 4.2.6 Range of Motion

Only ROM data for wrist flexion and extension were analyzed, as there was too much measurement variability in pronation and supination (see Appendix 1 for scores). Due to some patients' inability to produce a fist, a non-standard procedure was used to measure pronation/supination allowing for greater tester error in measurement. Without a patient making a fist while holding a guidance item (i.e. pen), supination and/or pronation can appear greater due to increased motion at the metacarpals. In general, wrist extension improvements were greater than wrist flexion, with the former being statistically significant (Table 3.4). Wrist flexion showed some improvement from 51.4° to 66.3° ( $p=0.066$ ) over the course of six weeks (week 6 to 12). This improvement may not have been significant as the norm for wrist flexion is 80-90° (Magee 2013). Wrist extension had significant improvement from 36.4° to 48.8° to 53.1° over a six-week period. The normal range for wrist extension is 70-90° (Magee 2013). Given the known norms for both movements, the fracture group did not recover to a normal ROM even after 12 weeks post-fracture. There are no published MCID standards for ROM following DRF, but in a study examining a condition of the hand known as Dupuytren's contracture, Witthaut et al. (2011) indicated a general MCID for ROM to be 13.5°. For future studies, it may be interesting to have an expanded follow-up period to determine when ROM is fully recovered. As mentioned, an extended time frame is pertinent as functional outcomes have been shown to not fully recover for up to two years post-fracture (Trumble et al. 1994).

### **5. Strengths, Limitations and Future Considerations**

#### **5.1 Strengths**

Though the study was limited due to a small sample size, the uniqueness of the population recruited has its merits. This is the first study to my knowledge to investigate neuromuscular properties, particularly the H-reflex, in an immobilization-disuse scenario with true fracture patients. The overall design of the study captures a wide breadth of measures to determine local and global effects of immobilization following a fracture. The large degree of measures taken will be beneficial for future neuromuscular (and intervention) studies using a similar fracture population. Even though the results were mixed, where significance was detected in only one parameter of the primary measure ( $H_{max}:M_{max}$  stimulation intensity), the reported

effect sizes were still of importance given how large they are. The large effect indicates that though the mean difference was not significant, it is yet important to note. Additionally, many of the secondary functional outcomes were statistically significant, and reached a threshold of change for what is considered the MCID for recovery in DRF and other similar orthopaedic injuries. The reported MCID hold value in this study as patient recovery from orthopaedic injuries depend on both decrease in pain and an increase in functionality (Katz et al 2015). More importantly, MCID in general, are values of change that indicate a degree of clinical change that is relevant to the patient (Smith et al. 2012) and arguably outweigh the statistical differences desirable when applying traditional scientific approaches.

## **5.2 Limitations**

A major limitation encountered during the study was the separation of events during the H-reflex nerve stimulation procedure. As fracture patients were recruited into the study, multiple patients were asked to come in for repeat sessions due to the stimulation artifact obscuring the M-wave. To reconcile the fact the stimulation artifact obscured the M-wave, post-hoc filtering was utilized in an attempt to separate the events (see 2.4.5). The collision of the two events was concerning, as this was not encountered during the piloting phase of the study, and the ability to properly identify the M-wave/ $M_{max}$  was necessarily to normalize  $H_{max}$ . The obscuring of the M-wave by the stimulus artifact has been noted in research involving electrical stimulation, whether via direct muscle stimulation, or stimulation of a peripheral nerve (Mandrile et al. 2003). Stimulus artifacts are problematic as they are high frequency and non-traveling events, and because of the frequency characteristic, it can affect the amplitude of the M-wave. Short-latency events (i.e. neural activity) coupled with high-rate electrical stimulation seemingly collide with each other (Heffer and Fallon 2008).

Careful planning regarding stimulator, amplifier and EMG set up can minimize stimulus artifact (Heffer and Fallon 2008). The study initially employed a Delsys Bagnoli 4-channel EMG system, which was found to be problematic for M-waves, particularly in participants with short forearms, because the pre-amplified electrodes were too close in proximity to the stimulating electrodes. The Delsys system has been noted to not be ideal when conducting nerve stimulation protocols (Harel, 2014), but these issues were not encountered in early pilot tests. Researcher speculation is that the factory pre-amp settings of the Delsys system were not conducive to the nature of the stimulus artifact and the latency before onset of M-wave. The system is preferred

by some research groups as it is a “plug and play” system, where the user operates the system within the built-in parameters (i.e. amplifier filters and noise reduction), and it is less complicated than the GRASS system subsequently used in this study.

In this study, the switch of EMG systems proved to be the least complicated solution to minimize the raw stimulus artifact at the collection stage. Converting to a GRASS EMG allowed for each individual channel to be isolated, with low-pass and high-pass filters, pre-amp, and calibration set for each channel. This offered greater user control than the Delsys system, which uses built-in pre-amps in their recording electrodes, in addition to fixed bandwidth filters (50-450 Hz) in their amplifier unit. Researcher observations revealed that the proximity of the stimulation electrodes to the recording electrodes was also found to have a great influence on the size of the stimulation artifact.

Other factors contributing to the stimulus artifact include: electrode contact surface, amount of subcutaneous tissue, length of limb, proximity between the stimulus electrode and recording electrode (Oyama and Itiki 2010). As described in the methods section, a series of user-controlled experimental techniques were employed in order to minimize the stimulus artifact; skin preparation by shaving and cleaning the area, use of derm-pads with an electrolytic gel base, and placing the grounding electrode as close to the recording electrode as possible.

The inability to get useful week 6 data was another detriment. It was hoped week 6 fracture data could be obtained, giving a richer recovery history; immediately post-cast data would have been unique in this type of immobilization/H-reflex study. To the author’s knowledge, the only spinal reflex data that has been recorded immediately following the removal of the cast — in a population with wrist fractures — was achieved using transcranial magnetic stimulation (Zanette et al. 2004). In the current project, the degree of discomfort the participants experienced following the removal of the cast proved to be a major consideration. As researchers, it was determined to be unethical to prompt the participant to push through pain beyond their level of comfort. Therefore, analysis of some functional data for the week 6 time point was excluded. The general recommendation from this experience would be to abstain from attempts to perform fully supinated wrist flexion strength measures immediately following cast removal, unless participants were willing and able. It was found that wrist supination was the most painful position for the fracture patients. ROM data was still obtained, since the associated pain was much lower, and the participant was better able to modulate their movement, thus their

pain level. In most cases, grip strength testing was performed, but the dynamometer was not sensitive enough on some trials. The dynamometer used in the study used a scale, which started at 2 kg, thus, anything less than 2 kg was recorded at the discretion of the researcher; the needle had to visibly move past the halfway point between the 0 mark and 2 kg marker to be considered 1kg, otherwise the attempt was scored as 0. There are digital handgrip dynamometers on the market that may be more sensitive.

The variable pain from the DRF may have been the largest limiting factor to this study. It is understood that pain associated with DRF is longstanding (Trumble et al. 1994), and from Magnus et al. (2013) pain does not completely subside over a 12-week period. Additionally, pain has been said to impact grip strength (Villar et al. 1987); the longevity of pain can explain why the fracture group did not experience a full recovery at week 12. Even if the PRWE scores indicate an increase in functionality accompanied with a decrease in VAS scores, as seen in this study, momentary high levels of pain may still be felt during exertion (Foldhazy et al. 2007). This is interesting for this study, as the VAS scores were assessed during in-lab testing, where the PRWE scores are related to the degree of pain while performing activities of daily living.

In DRFs, a syndrome known as complex regional pain syndrome (CRPS) is commonly seen, but is not well diagnosed (Jellad et al., 2014; Moseley et al. 2014). CRPS is characterized by prolonged periods of pain during the healing phase resulting in disability. The pain associated with CRPS is localized to site of injury. Other characteristics as described by de Mos et al. (2009) include hypersensitivity to tactile stimulus, prolonged (or abnormal) swelling, altered autonomic function, and impaired motor function (i.e. extreme weakness). These signs and symptoms were seen in one participant, although there was no formal diagnosis made by the orthopaedic surgeon. CRPS studies have indicated the condition may be more common in women, especially those whose fracture was a result of a medium or low energy fall. Jellad et al. (2014) describes a low energy event such as a bodyweight fall (i.e. from standing or sitting), while a medium energy event can be classified as a fall up to a 1 m in height. These types of low-energy events represented all of the fracture patients in this study.

The recruitment from a clinical population was also an unforeseen issue leading to a smaller than anticipated sample size. Working with an orthopaedic surgeon, it was hoped that recruitment would be completed during the winter and spring months, when more fractures were anticipated due to icy winter conditions. However, a much smaller recruitment window was

necessary, thus resulting in the small sample size of this pilot study. Additionally, recruitment was targeted to a younger population, with the assumption they better tolerate protocols requiring maximal exertion, which eliminated many elderly fracture patients (> 65 years of age). This was justified, as the lab equipment employed was not sensitive enough to pick up all strength measures (i.e. handgrip dynamometer). At the analysis stage, the low sample size impacted what inferences were possible. In being underpowered, it was not possible to draw meaning from correlations between variables in order to identify possible covariates.

Lastly, the participants in the control group may not have been the perfect matches to the fracture group. The control group was recruited from the Saskatoon community, but was significantly more active as the majority was from the College of Kinesiology. This discrepancy add another element of variability, regardless of how well matched they are in other physiological statistics. Aagaard et al. (2002) has shown certain types of training, such as resistance training, leads to significant changes in the H-reflex. The unexpected effect of time when pooled across arm for wrist flexion MVC may also have been due to changes in routine. In the summer months, it would be expected for the participants to be doing more leisurely activities compared to more structured physical activity.

### **5.3 Future Considerations**

Overall, this feasibility study offers great insight and acts as an accompaniment to current immobilization literature. The understanding of how the H-reflex factors into strength and function recovery could greatly aid in future designs of intervention studies. There is a general understanding that training programs (resistance) has an effect on the H-reflex in both healthy populations and clinical populations such as stroke (Dragert and Zehr 2013). In some ways the study resembles outcomes in a stroke population, as both clinical populations are affected by disuse of one limb, though one is physical immobilization (cast), while the other is a result of a pathological condition (hemiparesis). The Zehr lab at the University of Victoria (Victoria, British Columbia, Canada) has been a leading research group in the modulation of the H-reflex through strength training, specifically cross-education training via the less affected limb. Previous studies have shown significant alteration of the H-reflex of the more affected side, with subsequent strength improvements, following resistance training using the less affected side (Dragert and Zehr 2013).

In the upper limb, very little research has been done regarding this challenging spinal reflex. Referring back to the literature review, the majority of the H-reflex studies use an immobilization model, but not a true clinical model involving injuries. The clinical model as used here, is beneficial as it offers real-world evidence into how immobilization following an injury, with inherent function and strength loss, affects the spinal reflex. The H-reflex results presented in this study, although most parameters were not significant, seem to indicate the reflex does change on some level as the patient regains his/her function in the injured side. Given the limited time frame of the study (12 weeks), it is unknown when the patient would regain full function of their injured limb. Past investigations from this lab had tracked an older clinical population (65+), and found that strength did not fully recover a half a year (26 weeks) out from the initial injury point (Magnus et al. 2013). The Magnus et al. study was designed to use cross-education training as an adjuvant therapy, which showed greater and faster recovery of both strength and function. The current pilot study on the H-reflex, provides some limited evidence that the spinal reflex can potentially be used to as a marker of recovery; as such may be tracked in future cross-education interventions to truly understand some of the neurological underpinnings of how unilateral training truly works. This preliminary evidence does indeed show recovery of strength in the fractured limb may have a neuromuscular component. This component has often been overlooked in exercise science, with a spotlight on the superficial outcomes without truly looking “underneath the hood” of this performance factor.

A more complete understanding of the neuromuscular properties of immobilization is relevant in the clinical population. In the clinical population, understanding the neural mechanisms could result in the development of better protocols to decrease the recovery time, attenuate degree of strength loss and the prolonged dysfunctions often associated with casted distal radius fracture. Finally, to account for discomfort in this population, even though it may not be ideal, consideration should be given to measuring the H-reflex at rest, or devise a method to allow for the patient to complete testing in a neutral wrist position (i.e. the position they are casted in). In this particular fracture group, the participants experienced the greatest amount of discomfort when moving into supination. This study utilized a protocol where the H-reflex and MVC equipment was set up for the participant’s wrist and hand to be fully supinated. This modification may allow researchers to capture data from the exact point of cast removal.

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## Appendices

### Appendix A

	<b>Supination (°)</b>		
	<b>Week 6</b>	<b>Week 9</b>	<b>Week 12</b>
<b>Mean</b>	15	41	36
<b>SD</b>	10	23	18

	<b>Pronation (°)</b>		
	<b>Week 6</b>	<b>Week 9</b>	<b>Week 12</b>
<b>Mean</b>	88	97	101
<b>SD</b>	21	7	14

	<b>Combined Pronation/Supination (°)</b>		
	<b>Week 6</b>	<b>Week 9</b>	<b>Week 12</b>
<b>Mean</b>	83	138	138
<b>SD</b>	49	19	28

Appendix A. Mean values and standard deviations (SD) for the pronation and supination measures of the fractured group's FX limb during the post-immobilization period (week 6 to 12).



## Appendix B

### *Screening*

- 1) Does the patient have a distal radius fracture? Yes No  
*If NO, patient is ineligible.*
- 2) Does the fracture require cast immobilization? Yes No  
*If NO, patient is ineligible.*
- 3) Will they be casted within two weeks of the initial fracture? Yes No  
*If NO, patient is ineligible.*
- 4) Does the patient have any other concurrent fractures? Yes No  
*If yes, the patient is ineligible.*
- 5) Does the patient have any existing neurological disorders? Yes No  
*If YES, the patient is ineligible.*
- 6) Does the patient have any existing conditions that may affect upper limb function? Or interfere with daily living activities? Yes No  
*If YES, the patient is ineligible.*

### *Telephone Script*

Hi <patient name>,

This is <name> from Dr. Johnston's office at the Royal University Hospital. I am calling to inform you both of your appointment and of a new research project regarding your specific type of wrist fracture. The study aims to understand the change in muscle activity levels that occur to your forearm muscles after you have worn a cast. The muscle characteristic being investigated is a feature known as "excitability", or how efficient the muscles are to responding to signals being sent from the brain. This information will help in understanding what happens while you are in a cast and how the muscles recover once the cast is removed.

If you are interested, I can tell you more about the study.

*<Continue if the patient is interested>*

The study involves four visits to the PAC building at the University of Saskatchewan over a 12-week period. The sessions will coincide with your appointments with Dr. Johnston. The study involves testing of the Hoffman reflex, which can tell researchers about your muscles excitability level; along with testing your wrist strength, range of motion and forearm muscle size after your cast has been removed. All these procedures will only take place once it has been cleared by Dr. Johnston.

If you are still interested, we will forward your information to the researchers, and they will contact you to arrange a meeting and provide you with more information. In the meantime, may we ask for your e-mail address, so we can send you the consent form to review before the researchers contact you?

## Appendix C

### **PAWS bulletin**

#### Volunteers needed for a wrist muscle reflex study

A study within the College of Kinesiology is currently investigating the change in reflex following a wrist fracture requiring casting. The study aims to determine how a small spinal reflex changes after a period of casting, and how the reflex recovers after the cast has been removed. The muscle of interest is the flexor carpi radialis, a large muscle in the forearm responsible for wrist flexion and grip strength.

The researchers are currently recruiting for healthy participants that will be age matched to the participants with fractures. If you choose to be in this study, you will be asked to come to the PAC four times over the course of 12 weeks for testing. Each session requires approximately a two hours. You will be undergo testing for the Hoffman reflex (a spinal reflex), which involves low level electrical stimulus applied to the median nerve, which is located just above your elbow near your bicep. The electrical stimulation will elicit a reflex that is recorded by electromyography. You will also be asked to perform additional functional tests to examine grip strength and wrist flexion strength.

You are invited to participate in this study if you:

- Are over the age of 18
- Are currently free of any upper limb injury or pain (shoulder, elbow and wrist)
- Have no neurological conditions (systemic or pathological) that affect your grasping ability

For more information, contact:

Dr. Jon Farthing, Principal Investigator  
jon.farthing@usask.ca, 306-966-1068

Peter Yee, MSc investigator  
peter.yee@usask.ca

## H-reflex study

**Subject #:** \_\_\_\_\_

**Initials:** \_\_\_\_\_

**Group:** \_\_\_\_\_

**Sessions completed**

\_BL    \_6    \_9    \_12

**QUESTIONNAIRES:**

- \_ Demographics
- \_ Injury and training history
- \_ Godin leisure time
- \_ Waterloo
- \_ Mini-cog (if necc)

*Fracture group (post-immobilization):*

- \_ Clock draw → \_6 \_9 \_12
- \_ PRWE → \_6 \_9 \_12
- \_ VAS → \_6 \_9 \_12

**Distal Radial Fracture Study**

**Contact Information:**

Name \_\_\_\_\_ Subject # \_\_\_\_\_  
Phone number \_\_\_\_\_ (home) \_\_\_\_\_ (cell)  
Email \_\_\_\_\_  
Street Address \_\_\_\_\_  
City \_\_\_\_\_ Postal Code \_\_\_\_\_

**Subject Characteristics:**

Age \_\_\_\_\_ Height (cm) \_\_\_\_\_ Weight (kg) \_\_\_\_\_  
Waterloo Handedness Score (+ or -) \_\_\_\_\_ Handedness (circle) right left

**Fracture History:**

Side of Fracture (circle) right left  
Date fracture occurred \_\_\_\_\_ (day / month / year)  
Date cast received \_\_\_\_\_ (day / month / year)  
Date cast removed \_\_\_\_\_ (day / month / year)  
Physiotherapy used for fracture (circle) yes no  
Surgery on fracture (circle) yes no  
Comments \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

## Appendix E

### **Waterloo Handedness Questionnaire**

**INSTRUCTIONS:** Please indicate your hand preference for the following activities by circling the appropriate response. Think about each question. You might try to imagine yourself performing the task in question. Please take your time.

- If you use one hand 95% of the time to perform the described activity, then circle right always or left always as your response.
- If you use one hand about 75% of the time, then circle right usually or left usually.
- If you use both hands roughly the same amount of time, then circle equally.

**1. Which hand do you use for writing?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**2. With which hand would you unscrew a tight jar lid?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**3. In which hand do you hold a toothbrush?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**4. In which hand would you hold a match to strike it?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**5. Which hand would you use to throw a baseball?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**6. Which hand do you consider the strongest?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**7. With which hand would you use a knife to cut bread?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**8. With which hand do you hold a comb when combing your hair?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**9. Which hand do you use to manipulate implements such as tools?**

Left Always      Left Usually      Equally      Right Usually      Right Always

**10. Which hand is the most adept to picking up small objects?**

Left Always      Left Usually      Equally      Right Usually      Right Always





**B. Usual Activities**

Rate the **amount of difficulty** you experienced performing your **usual** activities in each of the areas listed below, over the past week, by circling the number that best describes your difficulty on a scale of 0-10. By “usual activities” we mean the activities you performed **before** you started having a problem with your wrist. A **Zero (0)** means that you did not experience any difficulty and a **ten (10)** means it was so difficult you were unable to do any of your usual activities.

	No Difficulty										Unable To Do
Personal care activities (dressing, washing)	0	1	2	3	4	5	6	7	8	9	10
Household work (cleaning, maintenance)	0	1	2	3	4	5	6	7	8	9	10
Work (your job or usual everyday work)	0	1	2	3	4	5	6	7	8	9	10
Recreational activities	0	1	2	3	4	5	6	7	8	9	10



Appendix G

**Demographic and Medical History Questionnaire  
H-reflex Study**

Screening # \_\_\_\_\_  
Initials \_\_\_\_\_  
SUBJ # \_\_\_\_\_

Name of Family Physician (if applicable): \_\_\_\_\_  
Clinic: \_\_\_\_\_

Which of the following best describes your place of residence? (check off all that apply)  
\_\_\_\_\_ House \_\_\_\_\_ Apartment or condo \_\_\_\_\_ Senior residence \_\_\_\_\_ Other  
\_\_\_\_\_ live alone \_\_\_\_\_ live with another adult

**For the following questions, please fill in the blanks or circle your response**

1. Do you have pain in your legs or back today? YES NO
2. If YES, where is the pain? HIPS KNEES FEET OTHER: \_\_\_\_\_
3. Are you experiencing any of the following symptoms today or have experienced them within the last few days?

Dizziness when getting up from a chair or bed?	YES	NO
Any Light-headedness	YES	NO
Chest pain	YES	NO
Shortness of breath	YES	NO
Nausea or vomiting	YES	NO
Fainting	YES	NO
Blurring of vision	YES	NO
Extreme fatigue	YES	NO
Muscle weakness	YES	NO
Muscle Cramping	YES	NO
Unusual or severe pain of any kind	YES	NO
Any other symptoms or concerns you are worried about (please explain to staff present)	YES	NO

Have you ever been diagnosed as having any of the following conditions?  
(check off all that apply)

		Approximate year of onset
Heart Attack	<input type="checkbox"/>	_____
Transient Ischemic Attack	<input type="checkbox"/>	_____
Angina (chest pain)	<input type="checkbox"/>	_____
High blood pressure	<input type="checkbox"/>	_____
Stroke	<input type="checkbox"/>	_____
Peripheral Vascular Disease	<input type="checkbox"/>	_____
Diabetes	<input type="checkbox"/>	_____
Neuropathies (problems with sensation)	<input type="checkbox"/>	_____
Respiratory Disease	<input type="checkbox"/>	_____
Parkinson's Disease	<input type="checkbox"/>	_____
Multiple Sclerosis	<input type="checkbox"/>	_____
Polio/Post Polio Syndrome	<input type="checkbox"/>	_____
Epilepsy/Seizure	<input type="checkbox"/>	_____
Other neurological conditions:	<input type="checkbox"/>	_____
Osteoporosis	<input type="checkbox"/>	_____
Fractures (describe)	<input type="checkbox"/>	_____
Rheumatoid Arthritis	<input type="checkbox"/>	_____
Other arthritic conditions:	<input type="checkbox"/>	_____
Uncorrected Visual problems:	<input type="checkbox"/>	_____
Inner ear problems/ear infections	<input type="checkbox"/>	_____
Cancer	<input type="checkbox"/>	_____

Joint Replacement  \_\_\_\_\_

Cognitive condition  \_\_\_\_\_

Any other health problems  \_\_\_\_\_

9. Do you require eyeglasses? YES NO

10. Do you require a hearing aid? YES NO

11. Have you required emergency medical care or hospitalization in the past 2 years? YES

NO If YES, explain why \_\_\_\_\_

13. List all medications that you currently take: (including over the counter medications)

Type of medication

For what reason

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Appendix H  
**Godin Leisure-Time Exercise Questionnaire**

INSTRUCTIONS

In this excerpt from the Godin Leisure-Time Exercise Questionnaire, the individual is asked to complete a self-explanatory, brief four-item query of usual leisure-time exercise habits.

CALCULATIONS

For the first question, weekly frequencies of strenuous, moderate, and light activities are multiplied by nine, five, and three, respectively. Total weekly leisure activity is calculated in arbitrary units by summing the products of the separate components, as shown in the following formula:

$$\text{Weekly leisure activity score} = (9 \times \text{Strenuous}) + (5 \times \text{Moderate}) + (3 \times \text{Light})$$

The second question is used to calculate the frequency of weekly leisure-time activities pursued “long enough to work up a sweat” (see questionnaire).

EXAMPLE

Strenuous = 3 times/wk

Moderate = 6 times/wk

Light = 14 times/wk

$$\text{Total leisure activity score} = (9 \times 3) + (5 \times 6) + (3 \times 14) = 27 + 30 + 42 = 99$$

**Godin Leisure-Time Exercise Questionnaire**

1. During a typical **7-Day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line the appropriate number).

**Times Per  
Week**

**a) STRENUOUS EXERCISE**

**(HEART BEATS RAPIDLY)**

(e.g., running, jogging, hockey, football, soccer,

\_\_\_\_\_

squash, basketball, cross country skiing, judo,  
roller skating, vigorous swimming,  
vigorous long distance bicycling)

**MODERATE EXERCISE**

**(NOT EXHAUSTING)**

(e.g., fast walking, baseball, tennis, easy bicycling,  
volleyball, badminton, easy swimming, alpine skiing,  
popular and folk dancing)

\_\_\_\_\_

**b) MILD EXERCISE**

**(MINIMAL EFFORT)**

(e.g., yoga, archery, fishing from river bank, bowling,  
horseshoes, golf, snow-mobiling, easy walking)

\_\_\_\_\_

2. During a typical **7-Day period** (a week), in your leisure time, how often do you engage in any regular activity **long enough to work up a sweat** (heart beats rapidly)?

OFTEN

SOMETIMES

NEVER/RARELY

1.  2.  3.

Appendix I

**Muscle Thickness Data- Mid Biceps**

Fracture side: \_\_ R \_\_ L

**Baseline**

**Right Arm**

Mid Site

Pre

1: \_\_\_\_\_

2: \_\_\_\_\_

3: \_\_\_\_\_

**Left Arm**

Mid Site

Pre

1: \_\_\_\_\_

2: \_\_\_\_\_

3: \_\_\_\_\_

**Muscle Thickness Comments:**

Top of Ultrasound line from cubit fossa \_\_\_\_\_

**Week 6**

**Right Arm**

Mid Site

Pre

1: \_\_\_\_\_

2: \_\_\_\_\_

3: \_\_\_\_\_

**Left Arm**

Mid Site

Pre

1: \_\_\_\_\_

2: \_\_\_\_\_

3: \_\_\_\_\_

**Muscle Thickness Comments:**

Top of Ultrasound line from cubit fossa \_\_\_\_\_

**Week 9**

**Right Arm**

Mid Site

Pre

1: \_\_\_\_\_

2: \_\_\_\_\_

3: \_\_\_\_\_

**Left Arm**

Mid Site

Pre

1: \_\_\_\_\_

2: \_\_\_\_\_

3: \_\_\_\_\_

**Muscle Thickness Comments:**

Top of Ultrasound line from cubit fossa \_\_\_\_\_

**Week 12**

**Right Arm**

Mid Site

Pre

1: \_\_\_\_\_

2: \_\_\_\_\_

3: \_\_\_\_\_

**Left Arm**

Mid Site

Pre

1: \_\_\_\_\_

2: \_\_\_\_\_

3: \_\_\_\_\_

**Muscle Thickness Comments:**

Top of Ultrasound line from cubit fossa \_\_\_\_\_

**H-reflex Stim Testing Set-Up**

Session: BL Week 6 Week 9 Week 12

Fracture side:   R     L  

**NORM Settings- FX Arm**

Chair Rotation: \_\_\_\_\_  
Chair Back angle: \_\_\_\_\_  
Dyna Angle: \_\_\_\_\_  
Dyna Height: \_\_\_\_\_  
Monorail: \_\_\_\_\_  
Attachment setting (wrist): \_\_\_\_\_  
Attachment setting (elbow pad): \_\_\_\_\_  
Fore-aft: \_\_\_\_\_

**NORM Settings- Non-FX Arm**

Chair Rotation: \_\_\_\_\_  
Chair Back angle: \_\_\_\_\_  
Dyna Angle: \_\_\_\_\_  
Dyna Height: \_\_\_\_\_  
Monorail: \_\_\_\_\_  
Attachment setting (wrist): \_\_\_\_\_  
Attachment setting (elbow pad): \_\_\_\_\_  
Fore-aft: \_\_\_\_\_

**Electrode Locations**

**FX Arm:**

Black Electrode Distance from m. condyle: \_\_\_\_\_ cm      Minimum stim intensity (rMT): \_\_\_\_\_  
Red Electrode Distance from m.condyle: \_\_\_\_\_ cm  
BB EMG Distance from fossa cubit: \_\_\_\_\_ cm  
FCR EMG 1/3 distance between m.condyle-radial stylus: \_\_\_\_\_ cm  
ECR EMG distance from olecranon process: \_\_\_\_\_ cm

**Non-FX Arm:**

Black Electrode Distance from m. condyle: \_\_\_\_\_ cm      Minimum stim intensity (rMT): \_\_\_\_\_  
Red Electrode Distance from m.condyle: \_\_\_\_\_ cm  
BB EMG Distance from fossa cubit: \_\_\_\_\_ cm  
FCR EMG 1/3 distance between m.condyle-radial stylus: \_\_\_\_\_ cm  
ECR EMG distance from olecranon process: \_\_\_\_\_ cm

H-reflex onset intensity: \_\_\_\_\_

M-max intensity: \_\_\_\_\_

**Isometric MVC testing (wrist flexion)**

<b>RIGHT arm</b>	<b>LEFT arm</b>
Rep 1: _____	Rep 1: _____
Rep 2: _____	Rep 2: _____
Rep 3: _____	Rep 3: _____
Avg (Nm): _____	Avg (Nm): _____
<b>EMG max:</b> _____	<b>EMG max:</b> _____
<b>EMG 10%:</b> _____	<b>EMG 10%:</b> _____

**Strength Testing Data**

**Grip strength**

<b>RIGHT arm</b>	<b>LEFT arm</b>
Rep 1: _____	Rep 1: _____
Rep 2: _____	Rep 2: _____
Rep 3: _____	Rep 3: _____
Avg (kg): _____	Avg (kg): _____

**Range of motion**

**Wrist Flexion:**

**RIGHT arm**

Rep 1: \_\_\_\_\_

Rep 2: \_\_\_\_\_

Rep 3: \_\_\_\_\_

Avg (°): \_\_\_\_\_

**LEFT arm**

Rep 1: \_\_\_\_\_

Rep 2: \_\_\_\_\_

Rep 3: \_\_\_\_\_

Avg (°): \_\_\_\_\_

**Wrist Extension:**

**RIGHT arm**

Rep 1: \_\_\_\_\_

Rep 2: \_\_\_\_\_

Rep 3: \_\_\_\_\_

Avg (°): \_\_\_\_\_

**LEFT arm**

Rep 1: \_\_\_\_\_

Rep 2: \_\_\_\_\_

Rep 3: \_\_\_\_\_

Avg (°): \_\_\_\_\_

**Supination:**

**RIGHT arm**

Rep 1: \_\_\_\_\_

Rep 2: \_\_\_\_\_

Rep 3: \_\_\_\_\_

Avg (°): \_\_\_\_\_

**LEFT arm**

Rep 1: \_\_\_\_\_

Rep 2: \_\_\_\_\_

Rep 3: \_\_\_\_\_

Avg (°): \_\_\_\_\_

**Pronation:**

**RIGHT arm**

Rep 1: \_\_\_\_\_

Rep 2: \_\_\_\_\_

Rep 3: \_\_\_\_\_

Avg (°): \_\_\_\_\_

**LEFT arm**

Rep 1: \_\_\_\_\_

Rep 2: \_\_\_\_\_

Rep 3: \_\_\_\_\_

Avg (°): \_\_\_\_\_



Appendix J

**Visual Analog Scale**

