PREDICTING CARPAL TUNNEL PRESSURE

PREDICTING CARPAL TUNNEL PRESSURE:

AN ERGONOMIC TOOL TO PREDICT CARPAL TUNNEL SYNDROME RISK

By

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ABSTRACT

A model to predict carpal tunnel syndrome (CTS) risk would improve ergonomic assessments and help reduce the incidence of occupational CTS and its associated costs. Research spanning over sixty years has shown that deviated wrist, forearm, and hand posture has on the hydrostatic pressure within the carpal tunnel (also known as carpal tunnel pressure, CTP). Elevated CTP is a mechanism of the development, or aggravation of CTS symptoms. The purpose of this thesis was to develop a model to predict CTS risk, based on CTP, and incorporate the model into an ergonomic tool for use by ergonomists. An extensive literature review identified additional studies that investigated the effects of pronation/supination, finger posture, and fingertip loading on CTP. The effect of wrist, forearm, and hand posture was then incorporated into the model via a series of regression equations developed for each plane of movement. The effect of fingertip loading (independent to the posture effects) was included using a multiplier based on the hand posture and load magnitude. To provide a user-friendly tool for ergonomists, a graphical-user-interface was developed to predict CTS risk based on the developed model. Input variables were wrist, hand, and forearm posture, and fingertip loading. CTP program estimated CTP, and compared the predicted pressure to a known threshold beyond which median nerve function has been shown to degrade. The tool was then evaluated by comparing the output of the tool (CTS risk) to the incidence of CTS in a large automotive manufacturing environment. There was no significant difference between the two groups (workers completing jobs with an incidence of CTS and workers completing jobs with no incidence of CTS). The tool marks an important first step

towards providing ergonomists with a much-needed tool to predict CTS risk based on posture, frequency, and fingertip force.

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CHAPTER 1 – INTRODUCTION

Carpal tunnel syndrome (CTS) continues to be a burden to the workplace and the healthcare system. In Ontario, the cost of treatment and lost-time benefits to the WSIB associated with CTS was approximately $13,000,000 in 1996 (Manktelow *et al.*, 2004) while the incidence of occupational CTS almost doubled from 1981 to 2005 in the state of Minnesota (Gelfman *et al.*, 2009). These reports indicate the need for proactive solutions to reduce the incidence of CTS and associated costs to both employers and employees. CTS is a peripheral nerve disorder in which the median nerve is compressed within the carpal tunnel. Occupational epidemiological studies have shown relationships between posture, force, repetition, and vibration (NIOSH, 1997). That being said, the specific etiology of most work-related cases of CTS is unknown, thus these cases are often considered “idopathic”.

Two main non-competing constructs for the pathomechanics of CTS have been proposed. The first is increased hydrostatic pressure within the carpal tunnel, also known as carpal tunnel pressure (CTP) or intracarpal canal pressure. Individuals with CTS have higher CTP than those with healthy wrists. Furthermore, CTS symptoms have also been produced in healthy wrists by increasing CTP. In CTS patients and healthy wrists, non-neutral wrist, finger, and forearm postures as well as fingertip loading have been shown to increase CTP. In addition to CTP, increased contact stress or impingement acting on the nerve by its surrounding structures is an additional proposed mechanism for the development of CTS. The carpal tunnel is a small opening through which nine extrinsic flexor tendons and the median nerve pass through. Stress applied to the median nerve may be due to contact from the flexor tendons, carpal bones, and/or transverse carpal ligament. Similar to CTP, non-neutral wrist, finger, and forearm postures as well as fingertip loading have been shown to increase contact stress.

Given that both hydrostatic pressure and contact stress have been directly related to CTS symptoms, they likely hold promise in prediction and prevention of median nerve trauma (Keir *et al.*, 2007). While attempts at modelling CTP or contact stress have been made, these models consider only one aspect of median nerve trauma and have been based on the results of a single study. Unfortunately, these efforts have not been effectively distributed to the groups or individuals that may find them useful (such as ergonomists). Keir *et al.* (2007) identified postural thresholds outside of which CTP may compromise nerve function in susceptible members of the sample. This study marked the first attempt to identify postural thresholds based on CTP, and took a step closer to providing an ergonomic tool capable of predicting CTS risk. The accumulated research investigating CTP and contact stress provides a comprehensive description of insult to the median nerve, yet there is little in the way of predictive or proactive solutions based on this wealth of knowledge. This thesis expands on a previous evaluation of posture thresholds and develops a tool for use in the ergonomic field. The construct used for predicting pressure with risk thresholds for CTS is found in Figure 1.1. Inputs include known risk factors such as deviated wrist, hand, and forearm posture, as well as fingertip loading. By predicting CTP in healthy wrists, based on these inputs, CTS risk may be evaluated based on in vivo and isolated nerve studies in the literature.

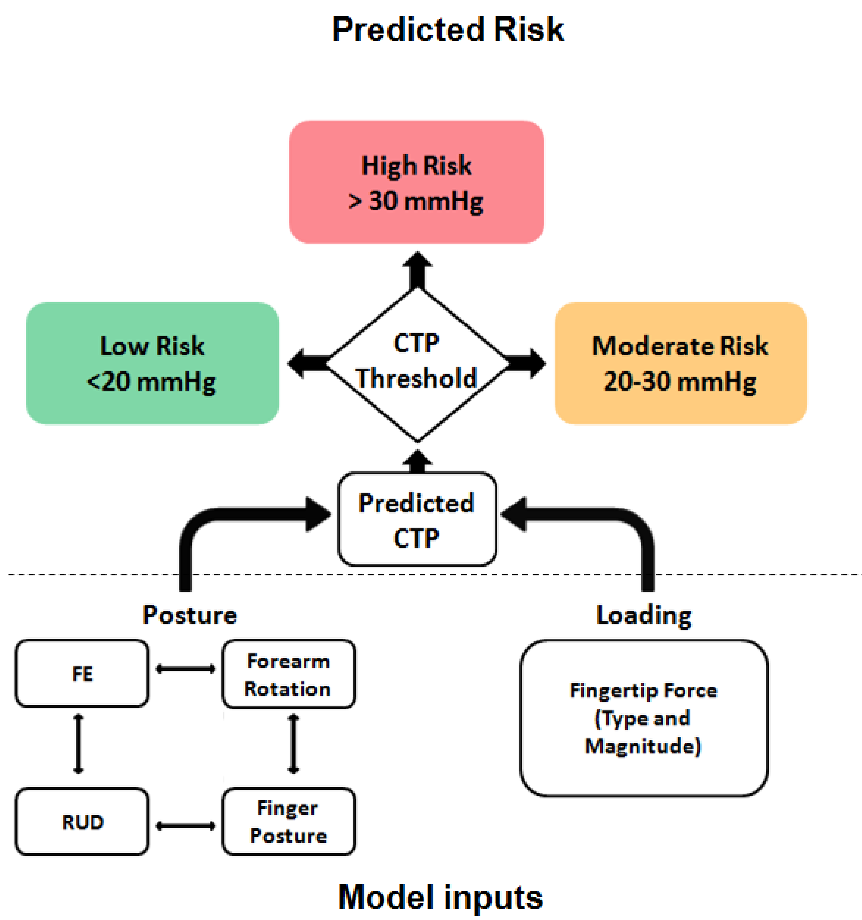

Figure 1.1 Construct of algorithm to predict CTP and CTS risk. Items below the dashed line represent inputs, while the objects above the line represent calculated variables and outputs.

CHAPTER 2 – REVIEW OF LITERATURE

2.1 The Carpal Tunnel

The dorsal aspect and walls of the carpal tunnel consist of the eight carpal bones (scaphoid, lunate, pisiform, triquetrum, trapezium, trapezoid, capitate, and hamate) and their ligaments. The palmar aspect, or roof, of the carpal tunnel is formed by the transverse carpal ligament, which spans from the hook of the hamate and pisiform on the ulnar side to the tubercles of the scaphoid and trapezium on the radial side. In addition to the median nerve, nine flexor tendons (four flexor digitorum superficialis, four flexor digitorum profundus, and the flexor pollicis longus tendon) pass through the carpal tunnel (Figure 2.1).

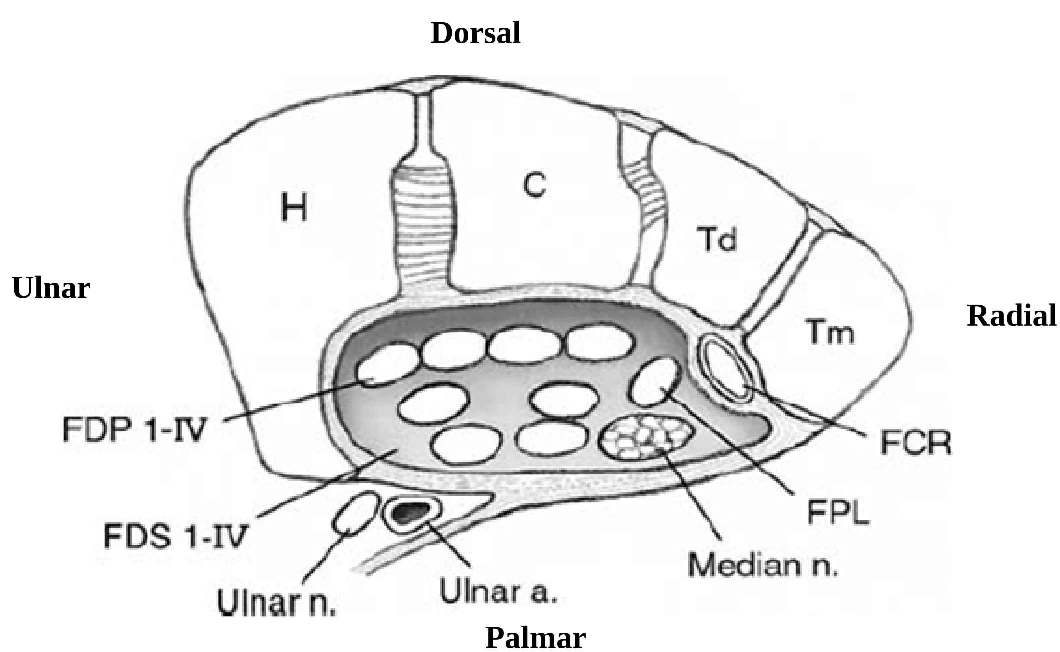

Figure 2.1. Cross sectional view of carpal tunnel anatomy at the level of the distal carpal bones. H, Hamate; C, capitate; Td, trapezoid; Tm, trapezium; FDP I-IV, tendons of flexor digitorum profundus; FDS I-IV, tendons of flexor digitorum superficialis; FPL, tendon of flexor pollicis longus. From Luchetti and Amadio, 2006.

2.2 Carpal Tunnel Syndrome

CTS is a compression neuropathy of the median nerve at the wrist and was first documented by Sir James Paget in 1865 (Paget, 1865; Phalen, 1966; Phalen, 1970). Common clinical signs of CTS include numbness, paresthesia and/or a tingling/burning sensation in the area of the hand innervated by the median nerve, or a positive result in clinical tests (such as Tinel's or Phalen's signs) (Phalen, 1972; Chhabra and Frelich, 2007). The sensory branch of the median nerve innervates the skin on the palmar aspect of the thumb, index, and middle fingers as well as the thenar half of the ring finger while the motor branch of the median nerve innervates the muscles of the thenar compartment (flexor pollicis brevis, abductor pollicis brevis, and opponens pollicis). Non-work related risk factors associated with CTS include previous trauma, cysts, diabetes mellitus, and rheumatoid arthritis. In the workplace, however, CTS risk factors include applied force, repetitive movement, non-neutral wrist postures, and vibration. These cases technically have no known cause and have been called "idiopathic" (NIOSH, 1997; Mattioli *et al.*, 2009).

2.3 Median Nerve Trauma

Median nerve trauma arises from compression of the median nerve by increased hydrostatic pressure within the carpal tunnel, or physical compression of the nerve by the structures surrounding it. It has been well established that CTS patients have significantly higher CTP (Gelberman *et al.*, 1981; Weiss *et al.*, 1995a; Szabo and Chidgey, 1989; Okutsu *et al.*, 1989; Seradge *et al.*, 1995; Brain *et al.*, 1947; Rojviroj *et* *al.*, 1990). As such, increased CTP has been proposed as a mechanism of aggravation or cause of CTS. This is supported by the ability to cause CTS symptoms in healthy subjects by altering CTP. By increasing the CTP in participants via external compression applied to the distal end of the carpal tunnel, Lundborg et al. (1982) were able to reproduce CTS-like symptoms. Since removal of external compression allowed nerve function returned to normal the authors hypothesized that ischemia of the capillaries supplying the median nerve as opposed to structural damage was the proposed mechanism of the altered nerve function. Furthermore, the authors also found that between 30 and 60 mmHg there appeared to be a critical threshold at which subjects displayed changes in motor and sensory function.

Research using animal models has allowed researchers to determine the effect of mechanical compression on peripheral nerves. Applying a compressive force in a rabbit tibial nerve via inflatable cuff at pressures as low as 20-30 mmHg decreased epineurial venular flow, and compression of 80 mmHg lead to complete intraneurial flow stasis (Rydevik *et al.*, 1981). As well, compression of 50 mmHg of the vagus nerve in rabbits for two hours showed inhibited axonal transport in all animals (Rydevik *et al.*, 1980). Also, the results of another study showed that effect cyclic loading of a nerve between two compression levels is similar to the mean compression of the two levels (Szabo and Sharkey, 1993).

2.3.1 Carpal Tunnel Pressure

In a neutral wrist posture, mean CTP is typically 10 mmHg or below in a healthy wrist (no signs or symptoms CTS) while a wrist with CTS is often reported at 30 mmHg (Brain *et al.* 1947; Gelberman *et al.*, 1981; Okutsu *et al.*, 1989; Rojviroj *et al.* 1990; Keir *et al.* 2005). (Note pressure is typically reported in mmHg even though kPa is the S.I. unit of measure, 1 kPa = 7.5 mmHg.) CTS symptoms have also been elicited in healthy subjects by increasing CTP through external compression applied to the palm of the hand. The effects of compression (e.g. paresthesia and decreased nerve conduction velocity and amplitude) were found when CTP exceeded 30 mmHg for sixty minutes, indicating prolonged increases in CTP could have a greater impact on CTP as opposed to the individual peaks over the same duration. Nerve function was restored upon removal of compression (Lundborg *et al.*, 1982). Wrist, hand, forearm, and finger posture, as well as fingertip loading have been shown to affect CTP, in both healthy and wrists with CTS. However, the focus of this thesis was on CTP in healthy wrists. Table 2.1 is a tabular summary of CTP research identified during the course of this thesis.

Table 2.1 List of CTP Studies by Author (FE= flexion-extension, RUD = radioulnar deviation)

Author	Year	n (healthy)	n (CTS)	Movement	Dependent Variables
Ahn et al	2009	0	48	passive	CTP in different locations along the wrist (distal to proximal)
Gelberman et al	1981	12	15	passive	CTP at the end-ranges of FE and neutral wrist.
Goss and Agee	2010	0	182	active	CTP at 5 different "standardized" locations along the tunnel. Found max grip, resting CTP, CTP with fully extended and flexed fingers, no grip, and 75, 50, as well as 25% of MGF, MPF, and MKF
Hamanaka et al	1995	55	957	active	Pre & Post-op CTP in neutral wrist with relaxed fingers & power-grip
Ikeda et al	2006	0	15	active	Resting CTP at selected distance from the distal wrist crease
Keir et al	1997	8	0	passive	Measured both Catheter (CTP) & Bulb (contact stress) in the same postures: Wrist: 45° to 45° in FE and -20° to 30° in RUD. Loading conditions: no load, FDP, FDS 2-3, PL, & FPL. CTP in end-ranges of FE and neutral wrist. CTP with flexed & extended fingers. CTP in end-ranges of FE and neutral wrist.
Keir et al	1999	14	0	passive	CTP during mousing activities.
Keir et al	2007	37	0	active	CTP while subjects cycled through full ROM in FE & RUD independently.
Keir et al	1998	20	0	active	Found the wrist posture with the lowest CTP. Loading: 0,5,10, & 15N finger-pressing & pinching tasks.
Keir et al	1998	14	0	active	CTP in neutral wrist posture, CTP from -45^{o} to 45^{o} of FE, -20^{o} to 30^{o} of radioulnar deviation, and 0° to 90° of flexion.
Luchetti et al.	1990	4	19	active	CTP in neutral wrist posture in 5mm linear increments from 10 mm distal to site of skin incision to 45 mm.
Luchetti et al.	1998	12	39	passive	CTP in neutral wrist , end ranges of FE, relaxed hand & 45^{o} passive F & E, gripped hand with neutral wrist , & gripped hand with 45^{o} passive F & E

Okutsu et al	2004	0	157	passive	CTP during the OKUTSU test and intraneural pressure during resting and power grip by inserting an angiocatheter into the epineurium of the median nerve between the funiculi
Okutsu et al	2009	0	66	passive	CTP during an active power grip and "resting position."
Okutsu et al.	1989	16	62	active	CTP at end-range in FE, & neutral wrist.
Rempel et al	1994	19	0	passive	CTP during a simulated working activity.
Rempel et al	1997	15	0	active	CTP in -45^{o} to 45^{o} of FE and -20^{o} to 10^{o} of radioulnar deviation. Static Finger Loading: 0,6,9, & 12N at each posture.
Rempel et al	1998	17	0	active	CTP from neutral wrist, -90^{o}-90^{o} of RUD and 0^{o}-90^{o} of MCP flexion.
Rempel et al	2008	20	0	active	CTP from -45^{o} to 15^{o} of FE, and -15^{o} to 15^{o} RUD during typing.
Rojviroj et al.	1990	32	61	active	CTP at end-range in FE, & neutral wrist.
Schuind	2002	0	22	active	CTP in neutral, 20, 40 F, full E, and full R and U.
Seradge et al	1995	21	72	active	CTP at end-range in FE, neutral wrist , isometric finger extension, holding object, active full fist
Sommerich et al.	1998	4	0	passive	CTP while typing, time spent over 30 mmHg (almost half the time for only 1 participant), also found split keyboard to be better. Published negative pressures.
Szabo and Chidgey	1989	6	22	passive	CTP in end-ranges of FE and neutral wrist Patients under general or local anaesthetic depending on type of surgery.
Thurston and Krause	1988	0	8	active	CTP in end-ranges of FE and neutral wrist.
Weiss et al	1995	20	4	active	Using visual feedback, controls & patients were instructed to find the wrist posture with the lowest CTP.
Werner et al	1983	0	16	passive	CTP in end-ranges of FE and neutral wrist. CTP with flexed & extended fingers.
Werner et al	1997	7	0	passive	CTP in FE, RUD, and hand postures and derivations except RUD and FE.

2.3.1.1 CTP: Effects of Wrist Flexion and Extension

Wrist deviation in the sagittal plane (flexion–extension) is the most studied variable for CTP both *in vivo* and in cadaveric studies. There is a clear U-shaped relationship with posture and CTP, with deviation from neutral posture acting to increase CTP (Figure 2.1). While CTP magnitude differs between studies due to specific *protocols* and equipment, the response of CTP to wrist posture is similar. CTP maintains a roughly quadratic increase in wrist extension up to 40 mmHg during active wrist extension up to 50°. Beyond a "comfortable" range of motion (e.g. 50°), the wrist moves into a passive range of motion, which results in a flatter, more muted CTP response (see Figure 2.2 [Gelberman *et al.* 1981; Szabo and Chidgey, 1989; and Rojviroj *et al.* 1990]). The "active" tension in the tendons crossing the wrist may explain the discrepancy of the effects of passive and active motion on CTP. Tendon loading (which causes to wrist motion) has been shown to increase CTP, while passive motion relies on an external cause of motion, and therefore may not have a tendon-loading related increase in CTP.

A similar, but less marked increase in CTP has been found for the same degree of wrist flexion. Of the ten studies represented in Figure 2.2, three studies measured CTP with the wrist in passive flexion or extension (Gelberman *et al.*, 1981; Szabo and Chidgey, 1989; Rojviroj *et al.*, 1990) while the remaining seven measured CTP during active ranges of motion (Szabo and Chidgey, 1989; Okutsu *et al.*, 1989; Seradge *et al.*, 1995; Rempel *et al.*, 1997; Keir *et al.*, 1998a; Keir *et al.*, 2007; Rempel *et al.*, 2008). While CTP during passive motion is similar to CTP due to active motion, it does not require muscle activity which may affect the pressure, thus only active motion studies will be incorporated in this thesis.

Since the proposed ergonomic tool is applicable to healthy wrists, the pressure data from CTS patients will not be included. However, similar relationships, albeit heightened, have been shown in studies restricted to individuals with CTS (Werner *et al.*, 1983; Thurston and Krause, 1988; Okutsu *et al.*, 1989; Schuind, 2002). In addition to the studies discussed thus far, two studies were not included Figure 2.1 but are included in Table 2.1 due to reporting pressures between 90 and 600 mmHg (Okutsu *et al.*, 1989; Seradge *et al.*, 1995).

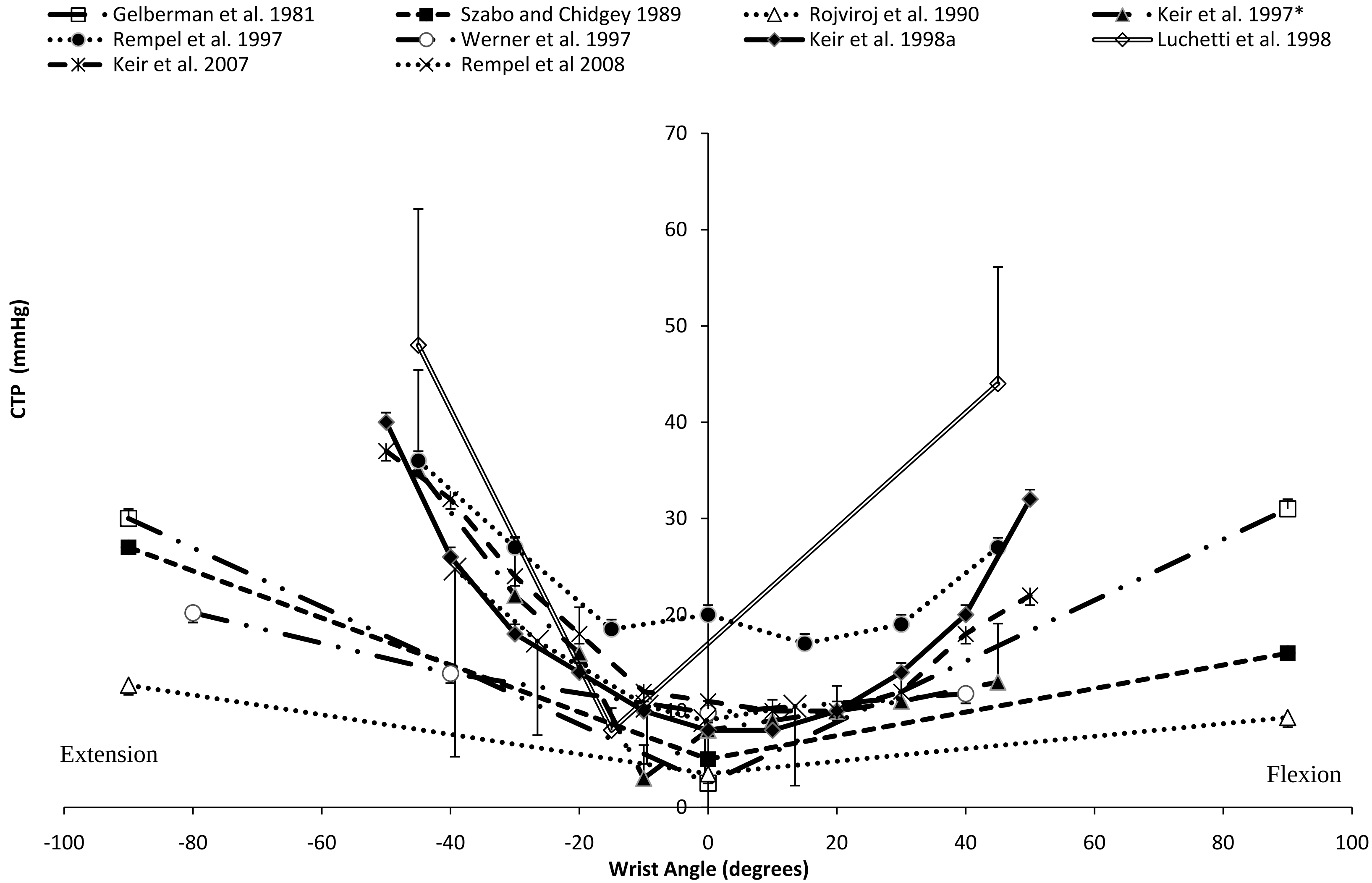

Figure 2.2. CTP (mmHg with SEM) versus wrist flexion-extension angle for selected studies of healthy wrists. An asterisk (*) indicates cadaveric studies. Additionally, studies with substantial differences in scaling (Tanzer, 1959; Okutsu *et al.*, 1989; Seradge et al., 1995) were not included so that these data could appear appropriately.

2.3.1.2 CTP: Effects of Wrist Radioulnar Deviation

There are relatively few reports on the effects of wrist radioulnar deviation on CTP. Mean CTP is typically 30 and 40 mmHg at the comfortable end range of radial and ulnar deviation, respectively. This results in a roughly quadratic relationship shown in Figure 2.2 (Keir *et al.*, 1997; Werner *et al.*, 1997; Keir *et al.*, 1998a; Keir *et al.*, 2007; Rempel *et al.*, 2008). One study (Rempel *et al.*, 1997) found that radial deviation elicited greater CTP than ulnar deviation (28 and 15 mmHg respectively). This discrepancy could be due to testing posture (fully pronated forearm posture with extended fingers); which could affect the relationship between radioulnar deviation and CTP. It should also be noted that the absolute angular displacement in radial and ulnar deviation differ likely accounting for the greater pressures found in ulnar deviation. In a recent study, participants were able to achieve 29° ± 8.3° of active radial deviation and 45° ± 7.5° of ulnar deviation (Kitsoulis *et al.*, 2010).

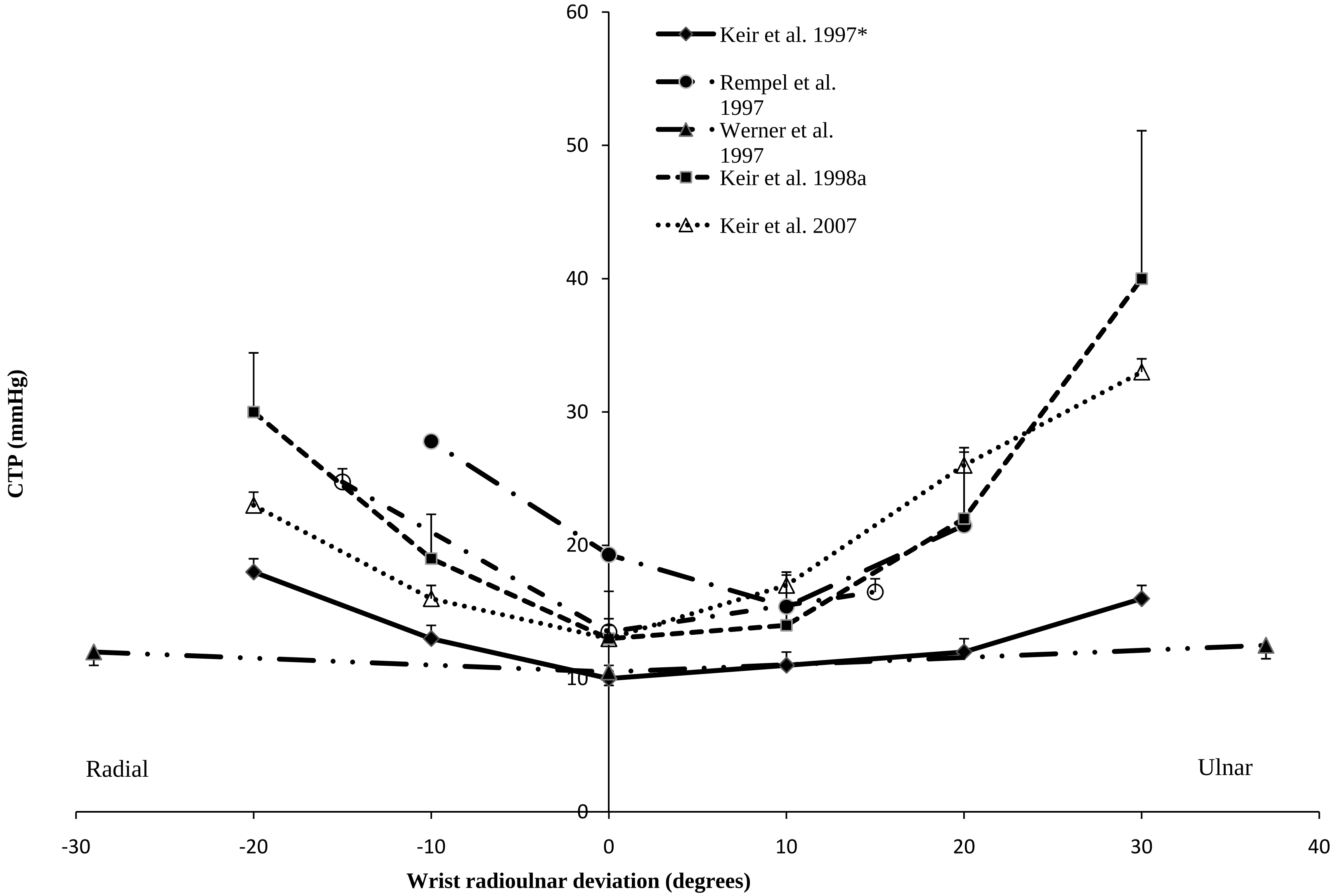

Figure 2.3 CTP (in mmHg with SEM) versus wrist radioulnar deviation angle for selected studies of healthy wrists. An asterisk (*) indicates data was obtained from cadaveric specimens. A negative wrist angle indicates radial deviation while a positive wrist angle indicates ulnar deviation.

2.3.1.3 CTP: Effects of forearm rotation

Only two studies have examined the effects of forearm rotation on CTP in healthy wrists (Werner *et al.*, 1997). Figure 2.4 shows that, while both studies found supination to elicit greater CTP than a similar degree of pronation, the response magnitude differed drastically between the studies. Werner *et al. (*1997) reported a relatively linear decrease in CTP from full supination to full pronation (from 14 to 8 mmHg), while Rempel *et al.* (1998) found a saucer-like relationship with higher CTP in full supination than in full pronation (34 mmHg and 14 mmHg, respectively) and lowest CTP at 45° of pronation (13 mmHg). The studies used similar methods except for the number of subjects (7 for Werner at al. versus 15 for Rempel *et al.*).

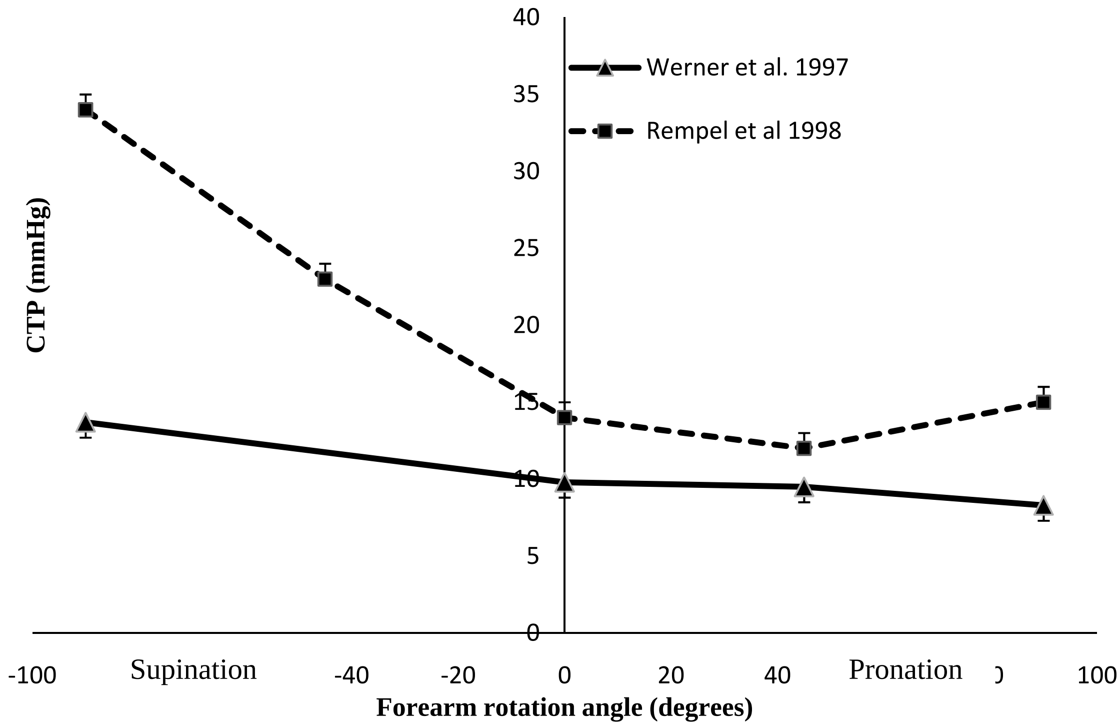

Figure 2.4 CTP (in mmHg with SEM) versus forearm posture for selected studies of healthy wrists. Supination has a greater effect on CTP than pronation. A negative angle indicates supination while a positive angle indicates pronation.

2.3.1.4 CTP: Effects of finger posture

Three studies were found that investigate the impact of wrist posture on CTP (Werner *et al.*, 1997; Rempel *et al.*, 1998; Keir *et al.*, 1998a). In a neutral wrist posture, CTP was lowest in 45° of MCP flexion (relaxed fingers) and increased in MCP extension and flexion (Keir et al., 1998b; Rempel et al., 1998a). The three studies show similar responses with drastically different gains between studies from different laboratories (Werner et al.) and between flexion and extension (Figure 2.5). Werner *et al.* (1997) found that hand positions with either relaxed fingers or a pinch grip had the lowest CTP

(10 mmHg) while finger extension and a full fist increased CTP (11 and 12 mmHg, respectively). A fourth study, Cobb *et al.* (1995) was not included as they accounted for both CTP and mechanical compression of the median nerve using a catheter-containing balloon into the carpal tunnel. Cobb *et al.* (1995) showed that median nerve compression was lowest in finger extension and highest in finger flexion during a full fist.

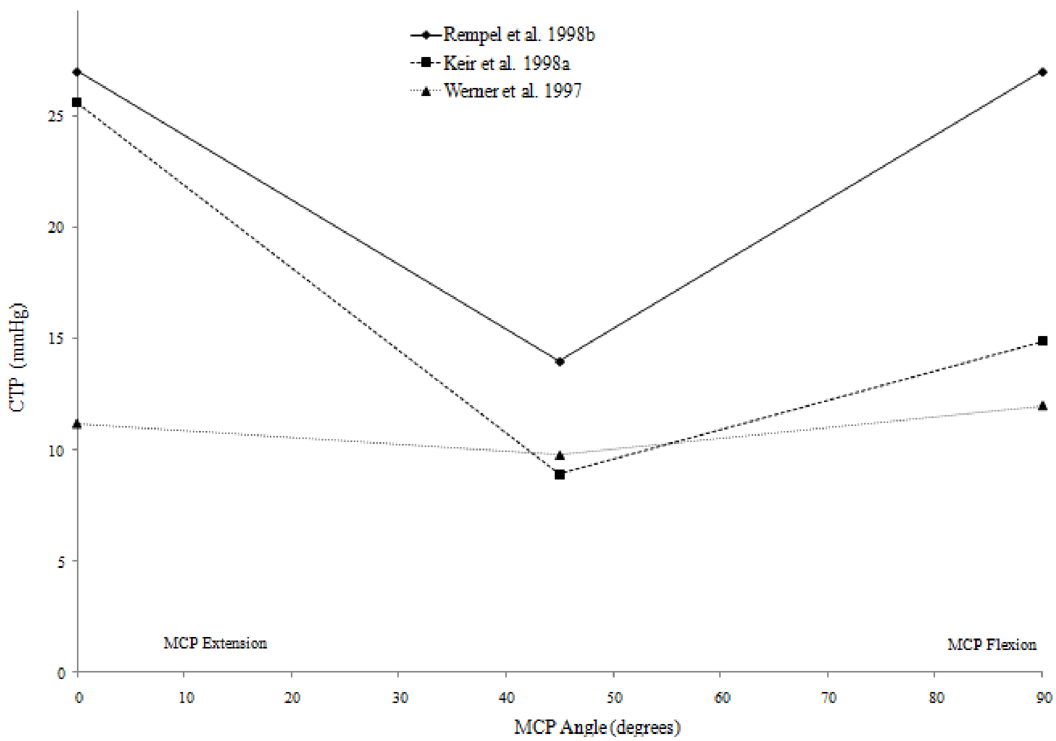

Figure 2.5 CTP (in mmHg with SEM) versus MCP angle for selected studies of healthy wrists. There is a general trend that full MCP flexion or extension increases CTP during wrist motion and in a neutral wrist.

The effect of finger posture appears to be maintained during wrist motion. Keir et al (1998a) found both straight fingers and MCP joints flexed to 90° both significantly increased CTP in extended postures but not in flexion. Straight fingers with the wrist extended beyond 10° exceeded 30 mmHg. Figure 2.6 illustrates that from (-)50° extension to 10° flexion, changing MCP posture significantly gains CTP up or down similar to finger motion in a neutral wrist posture. There was no significant difference in CTP beyond 10° of wrist flexion (Werner *et al.*, 1997; Keir *et al.*, 1998a; Rempel *et al.*, 1998). Although they did not report joint angles and reported only broad categories associated with their finger postures (closed fist, relaxed, straight fingers, pinch-grip), Werner *et al.* (1997) found a similar relationship between finger postures and CTP during wrist motion. At all wrist postures, relaxed fingers had the lowest CTP, followed by extended fingers, while a closed fist had the highest CTP.

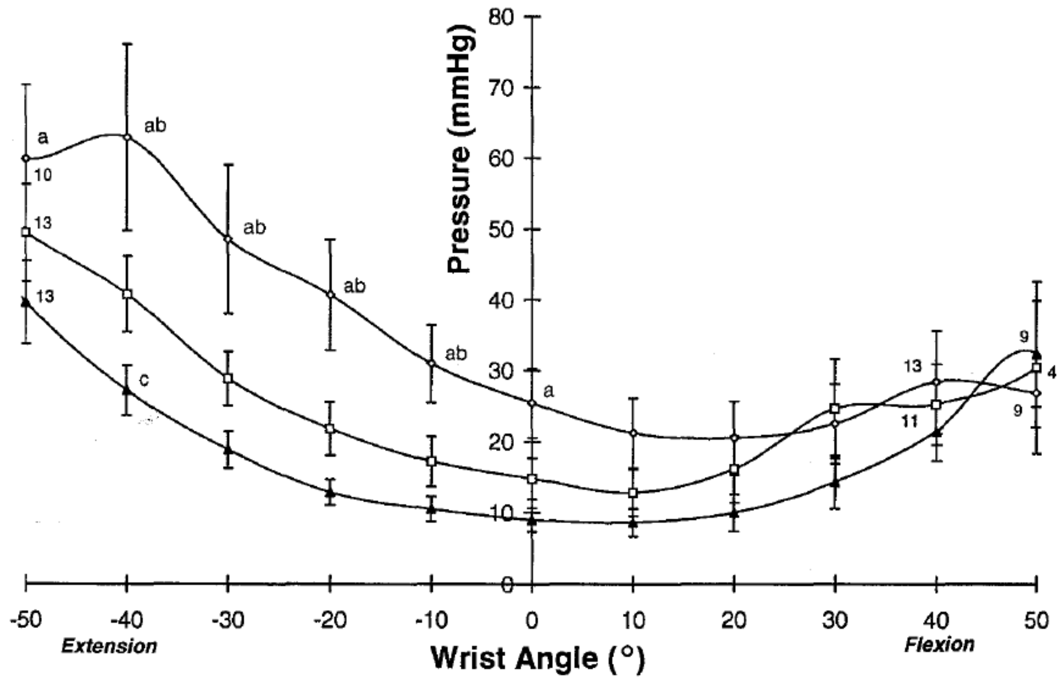

Figure 2.6 CTP (in mmHg with SEM) versus MCP angle for selected studies of healthy wrists. There is a general trend that full MCP flexion or extension increases CTP both during wrist motion and in a neutral wrist. From Keir *et al* 1998a.

2.3.1.5 CTP: Tendon loading/fingertip force

Tendon loading has been shown to increase CTP to a greater extent than wrist and hand posture. As well, this increase has been shown to be independent to the effects of wrist and hand posture (Rempel *et al.*, 1997). In a follow up study, Keir *et al.* (1998b) found that, in a neutral finger and wrist posture, a 5, 10, and 15 N of finger pulp press force increased CTP to approximately 14, 20, and 34 mmHg, respectively. While the 1997 study found higher CTP relative to their 1998 study results, the results of Rempel *et al.* (1997) may be larger due to an extended finger posture. The data of Rempel *et al.* (1997) are shown in Figure 2.7 to illustrate the effect of tendon and fingertip loading on

CTP (independent of the effects of wrist posture). Figure 2.7 illustrates this independent effect of fingertip (and therefore tendon) loading *in vivo.* Each line in Figure 2.7 represents a different fingertip load.

In addition to a pulp press, a pulp pinch grip (pinch between index finger and thumb) almost doubled CTP when compared to a pulp finger press of the same magnitude at fingertip loads of 5 and 10 N (30, and 41 mmHg, respectively) while the increase at 15 N was less pronounced (increased to 50 mmHg) (Keir *et al.*, 1998b).

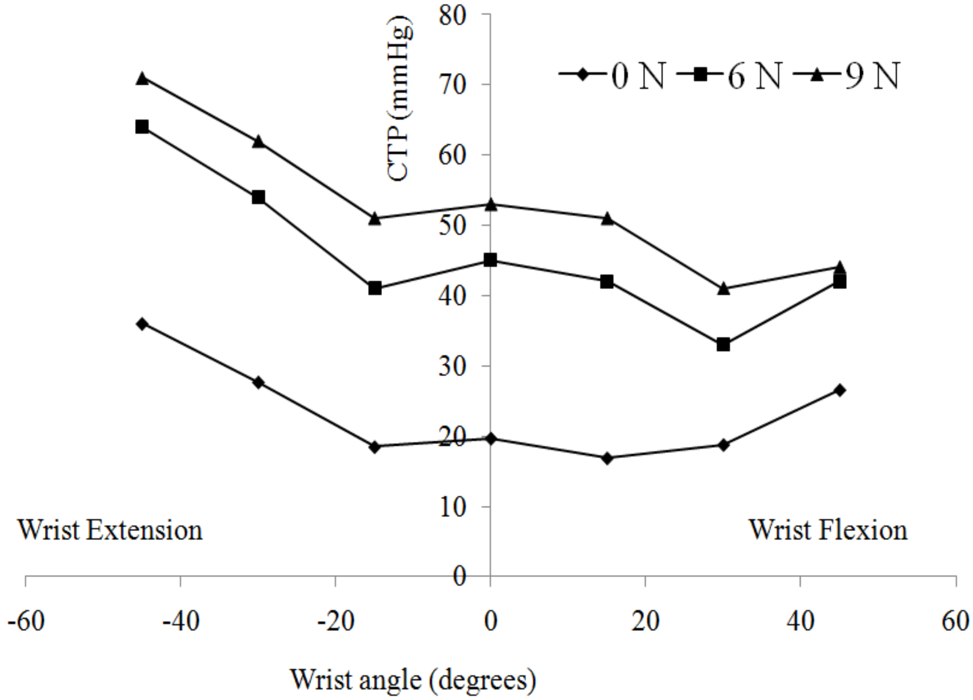

Figure 2.7. The independent effects of fingertip loading (in Newtons) on CTP as adapted from Rempel *et al*. (1997). (The additive effect of fingertip loading is clear across all wrist flexion-extension angles.)

2.3.1.6 CTP during functional activities

CTP has been measured while performing functional activities (computer and mouse use [Keir *et al.*, 1999; Rempel *et al.*, 2008]) and has also been implicated with the use of wrist splints (Rempel *et al.*, 1994 and Weiss *et al.*, 1995). Although the forces associated with typing are relatively low (approximately 1 N) the dynamic activity of typing has been found to further increase CTP by approximately 4 mmHg independent of wrist posture (Rempel *et al.*, 2008). As well, the same study showed that CTP while typing with 40° of wrist extension was approximately 30 mmHg. Using a computer mouse has also been shown to increase CTP to a greater extent (increased to 29 mmHg) than the static postures associated with mouse use (19 mmHg). This increase in CTP was attributed to increased fingertip force (approximately 2 N).

In addition to computer use, CTP has also been implicated in the design of wrist splints. Wrist splints have been used as a conservative method of treating CTS. Despite the findings that CTP is at a minimum in near-neutral wrist flexion-extension and ulnar deviation, some common splint designs maintain extended wrist postures that may actually increase CTP (Weiss *et al.*, 1995; Keir *et al.*, 1998a). As well, a later study found that 45° of pronation had the lowest CTP (Keir *et al.*, 1998b).

2.3.2 Mechanical Compression (Contact Pressure)

Development and/or aggravation of CTS may also occur by mechanical compression of the median nerve by local structures. Isolated animal nerve studies have shown that mechanical compression of 20 mmHg decreases blood flow within the nerve at while compression of 30 and 80 mmHg led to edema (Rydevik *et al.*, 1984; Powell and Myers, 1986). In humans, the implications of contact stress are illustrated by provocative tests designed to exacerbate CTS symptoms through sustained wrist flexion increasing contact stress on the median nerve (Phalen's and modified Phalen's test).

The mechanical compression of the median nerve can be measured directly or estimated through modeling. Contact stress has been measured in cadavers by excising the median nerve and replacing it with a liquid filled bulb-transducer. Contact stress has been modelled by likening the carpal tunnel to a belt (finger flexor tendons) wrapping around a pulley (transverse carpal ligament or carpal bones) (Armstrong and Chaffin, 1979). Based on the results of 4 subjects, this long standing model was used to determine the normal force applied to the pulley by the belt (Armstrong and Chaffin, 1979). The model created by Armstrong and Chaffin (1979) served as the basis for a number of subsequent studies, two of which are relevant to this thesis. The first predicted frictional work done on the tendon as well as the direction and magnitude of the normal force on the median nerve in an occupational setting (Moore *et al.*, 1991). A subsequent study examined the assumptions of the original model (namely constant radius of tendon curvature) (Keir and Wells, 1999). They found that the radius of curvature was not constant and changed due to wrist posture and tendon load.

2.3.2.1 Contact Pressure: Effects of wrist posture

Most reported that passive extension has a greater impact on contact pressure than full flexion (Brain *et al.*, 1947; Smith *et al.*, 1977; Keir *et al.*, 1997). Furthermore, Keir *et al.* (1997) report a “U-shaped” relationship between contact pressure and wrist flexion-extension; similar to CTP and wrist posture. Smith et al. (1977) found that wrist flexion had a greater effect on contact pressure than extension (165 mmHg versus 140 mmHg). Figure 2.8 plots not only illustrates the results of contact pressure studies, but also that that the results between transducer studies cannot be directly compared since the nature of the bulb-transducers (thickness of the bulb and material used to make the bulb) affect the magnitude of the pressure recorded (Keir *et al.*, 1997). While only one study (Keir *et al.*, 1997) investigated the effects of radioulnar deviation, a neutral wrist had the lowest contact pressure while both 20° of radial deviation and 30° of ulnar deviation both showed similar increases (approximately 4 mmHg above the baseline measure) (Keir *et al.*, 1997).

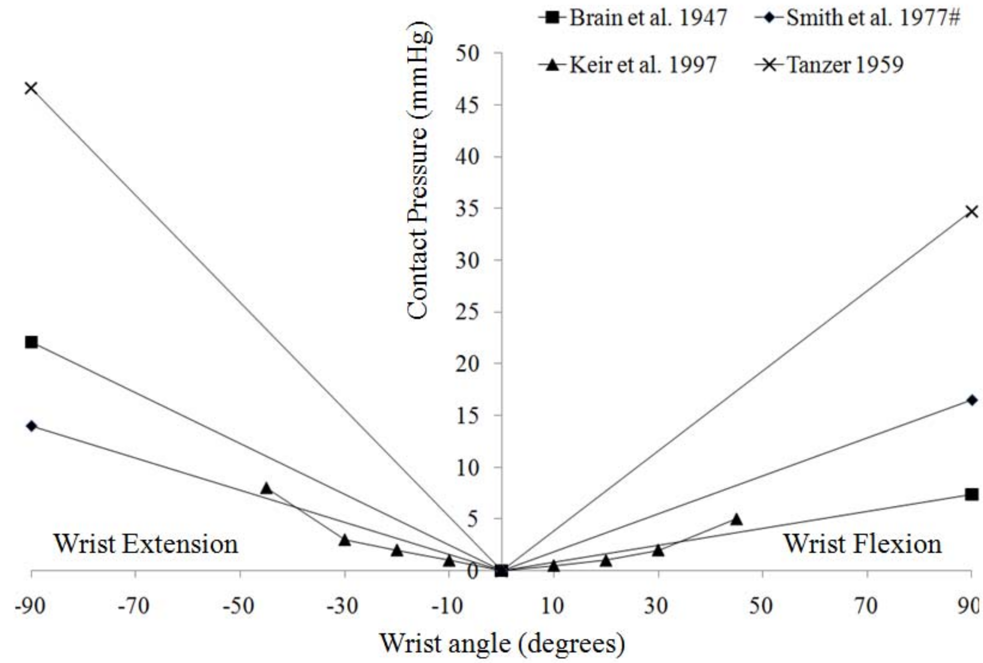

Figure 2.8. Contact pressure (in mmHg with SEM) versus wrist flexion-extension angle for selected studies of healthy cadaveric wrists. A negative wrist angle indicates wrist extension while a positive wrist angle indicates wrist flexion. The data of Smith *et al.* (1977) and were divided by 10 in for scaling purposes (#).

2.3.2.2 Contact Pressure: Effect of tendon load

Cadaveric studies have shown that tendon loading has a greater effect on contact pressure than wrist posture alone (Smith *et al.*, 1977; Keir *et al.*, 1997). Loading the finger flexor tendons has shown an increase in contact pressure at all wrist postures (Smith *et al.*, 1977; Keir *et al.*, 1997). For example, Keir *et al.* (1997) found that loading the flexor tendons (with a 10 N tendon load) in a neutral wrist increased contact stress to the same extent as full passive wrist extension (9 mmHg) with no tendon load. While loading the palmaris longus tendon also increased contact pressure (by 4-8 mmHg above the no load condition), the most marked increase in contact stress appeared when the finger flexor tendons were loaded (8-15 mmHg above the no load condition). In addition to increasing contact pressure, loading the flexor tendons also changed the relationship between wrist flexion-extension and contact pressure. Full wrist extension had a higher contact pressure than wrist flexion (as illustrated in Figure 2.8). (This point in particular is an important argument for the role of contact stress in carpal tunnel syndrome since loading the finger flexors in wrist flexion [Modified Phalen's Test] is a provocative test for CTS.)

Similarly, the relationship between contact pressure and wrist posture in radioulnar deviation changed as a result of tendon loading. With unloaded flexor tendons, full radial and ulnar deviation produced similar contact pressures (approximately 4 mmHg). During flexor tendon loading, however, contact pressure in full ulnar deviation was almost twice the contact pressure found in radial deviation (10 and 22 mmHg) (Keir *et al.*, 1997).

2.3.2.3 Predicting Contact Pressure (belt-pulley model)

The first study to predict contact stress applied to the median nerve modelled the flexor tendons as a belt wrapping around a pulley (transverse carpal ligament or carpal bones) (Armstrong and Chaffin, 1979). In this model, the normal force applied to the pulley by the flexor tendons was found by estimating the force per unit length of the flexor tendons based on joint anthropometrics, gender, and tendon load. In a later study, Keir and Wells (1999) found that the radii of curvature changes depending on wrist posture and tendon load. In a detailed analysis, Moore *et al.,* (1991) recorded EMG, wrist and finger posture, and grip force in 6 healthy subjects performing a novel work task with varied postural constraints and force levels. Using an adapted version of the model presented by Armstrong and Chaffin (1979) and their collected data, they were able to predict the frictional work done on the tendon sheaths as well as the direction and magnitude of the normal tendon forces during repetitive motion (Moore *et al.*, 1991). Further, they were able to quantify the effect of force, motion, and upper extremity posture over the duration of a task, providing a temporal profile of the task. In a later study that aimed to provide a comprehensive analysis of typing, the belt-pulley model was also used in conjunction with an estimate of tendon travel (Sommerich *et al.*, 1998).

2.4 Summary

The increased incidence of occupational CTS and its impact on both employers and employees confirms the growing need for preventative interventions. Increased CTP is a proposed mechanism for the development of CTS. CTP is lowest in a neutral wrist (at or near 0° flexion-extension, radioulnar deviation, and 45° pronation). Additionally, the effect of tendon loading on CTP is greater than, as well as independent to, that of wrist posture. This thesis cites a number of different papers that have investigated the effect of wrist, hand, forearm posture, and tendon loading on CTP. There is a need to compile the data in such a manner that it may be useful as an applied ergonomic tool.

2.5 Purpose

The objectives of this thesis were to:

1. Develop a tool to predict CTS risk based on CTP predicted from finger, wrist, and forearm posture as well as fingertip loading.
2. Collect and analyze posture and force data in a large manufacturing environment and compare the output of the tool (CTS risk) to related injury incidence in that environment.

CHAPTER 3:

MANUSCRIPT

AN ERGONOMIC TOOL TO PREDICT CTS RISK BASED ON CTP

Word count: 4586

Keywords: Carpal Tunnel Pressure (CTP), ergonomic tool, Carpal Tunnel Syndrome (CTS) risk

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3.1 Abstract

a. Objective: To develop an ergonomic tool to predict carpal tunnel syndrome (CTS) risk based on the carpal tunnel pressure (CTP) in healthy wrists.

b. Background: CTS remains an issue in the workplace. Increased carpal tunnel pressure (CTP) may lead to the aggravation or development of CTS. CTP of 30 mmHg or higher is associated with CTS symptoms; thus 30 mmHg has been used as a threshold limit value for CTS risk. Deviation from a neutral wrist, neutral forearm, and relaxed fingers results in an increase in CTP. Fingertip loading has also been shown to increase CTP independently of posture.

c. Method: A tool was developed to predict CTS-risk based on CTP. The tool was evaluated by comparing the output of the program (CTS risk) to incidence of CTS in a manufacturing environment.

d. Results: No differences were found for CTS risk between jobs with no incidence of CTS *versus* jobs with an incidence of CTS.

e. Conclusion: While the tool predicted CTS risk based on CTP, too few CTS claims existed to develop a strong correlation. Further refinement and investigation is needed to include combined postures and mechanical compression, and to further validate tool.

f. Application: An ergonomic tool, to predict CTS based on CTP, would be an asset to ergonomists both in job evaluation and (re)design to reduce CTS-risk.

3.2 Introduction

Carpal tunnel syndrome (CTS) is a burden in today's workplace. While insult to the median nerve has long been associated with CTS, its exact etiology is still unknown (Luchetti and Amadio, 2006). Increased hydrostatic pressure within the carpal tunnel (CTP) and mechanical compression are mechanisms for the development and exacerbation of CTS. CTP is lowest in a neutral posture of a semi-pronated forearm, wrist at or near 0° of flexion-extension (FE), 0° radioulnar deviation (RUD), and relaxed fingers (Weiss *et al.* 1995; Keir *et al.* 2007). Deviation from this neutral posture results in greater CTP, especially with concurrent finger and wrist extension. Independent of the effects of posture, fingertip loading also increases CTP to a greater extent than posture itself (Rempel et al, 1997).

While many studies have measured CTP under various conditions in the lab, there have been few attempts at predicting CTP based on posture and fingertip loading. Werner et al. (1997) collected CTP from seven subjects while varying finger, hand, wrist, and forearm posture. They developed a series of stepwise regression models, the most inclusive of which had an $R^2 = 0.81$ and considered all sources of variance radial/ulnar, forearm, hand, and MCP posture. Of the 81 % of the explained variance, roughly half (39%) was due to subject variance. While Werner *et al.* (1997) predicted CTP based on wrist posture, they did not include the known effects of fingertip force. In a study performed by Sommerich *et al.* (1998), data from five touch typists was used to develop a CTP predictive model as part of a biomechanical profile of a typing task. While the authors also presented mean CTP and time spent over a 30 mmHg threshold, their model was based on five subjects completing data entry, did not predict CTS risk, and was not available for use by ergonomists.

While research on CTP has spanned over 60 years, an ergonomic tool utilizing this research has yet to be developed. Figure 3.1 illustrates the variation in posture evaluation between CTP studies. Each arrow represents a single study that investigated the effect of a particular independent variable on CTP. The left column indicates the forearm posture, the center column indicates the finger posture while the right column indicates other independent variables manipulated during the study.

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Figure 3.1

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The impetus for this project was provided by Keir and colleagues (2007) who identified posture thresholds (in flexion-extension and radioulnar deviation) beyond which 75% of their study sample was at or above a 25 or 30 mmHg threshold, above which pressure median nerve function is known to degrade (Lundborg *et al.*, 1982). Given that nerve function is also affected between 20 and 30 mmHg (Lundborg *et al.*, 1982), levels of risk were assumed to be associated with these thresholds in pressure.

Thus, the goals of this project were to:

1) Develop an ergonomic tool to predict CTS risk based on CTP. Risk was defined as low risk (CTP < 20 mmHg), moderate risk

(20 mmHg <CTP < 30 mmHg), and high risk (CTP > 30 mmHg).

2) Evaluate tool effectiveness in a pilot study by comparing its output (CTS risk) to CTS incidence in a large manufacturing environment to provide a benchmark for the tool.

Figure 3.2 depicts the construct used by the tool to predict CTS risk. Inputs include known risk factors such as deviated wrist, hand, and forearm posture, as well as fingertip loading. By predicting CTP in healthy wrists, based on these inputs, CTS risk may be evaluated based on in vivo and isolated nerve studies in the literature.

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Figure 3.2

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3.3 Ergonomic Tool Development

3.3.1 CTP from Literature

A search of the PubMed database (U.S. National Library of Medicine National Institutes of Health, 2010) and subsequent follow up searches of "carpal tunnel pressure" and related terms resulted in 29 articles. Of these, 21 studies measured CTP in healthy subjects, including 2 with cadaveric specimens. Twelve studies examined the effects of flexion-extension, 6 examined radioulnar deviation, 4 studied the effects of finger motion, and 2 studied the effects of fingertip loading on CTP. Data recorded from each study included sample size, posture effects on CTP, and the loading effects on CTP. In some cases, data were digitally estimated from figures (Adobe Inc., 2008). A regression analysis was then performed for each data set using SPSS (PASW, 2009).

Combining the data in a logical manner proved to be a very difficult task. Ultimately, regression equations were developed for each plane of movement (forearm, wrist, and hand posture and loading effects) based on the following selection guidelines:

1) Most conservative estimate of CTS risk, as suggested by the highest mean CTP
2) Largest study sample
3) Presented CTP at more than three wrist angles

It is possible that choosing the data set with the highest mean CTP may lead to an overestimation. However, a conservative estimate of CTP is beneficial since the tool would be more likely to predict a false positive (risk of injury) rather than a false negative (no risk of injury). Large study samples relate better to a population and is also beneficial since the effect of posture on CTP is not uniform across study samples.

Werner and colleagues (1997) found muted postural effects on CTP in their small sample (n=7). It is possible that the CTP response to wrist, hand, and forearm posture was muted, as opposed to other factors (i.e. methodological/equipment differences). In a recent study of 37 participants, 28 (75%) were at or below the 30 mmHg threshold between wrist 33° of wrist extension and 52° of wrist flexion (Keir *et al.*, 2007). In addition, only 15 subjects (40%) never reached the 30 mmHg threshold within the range tested.

3.3.2 Selected Studies: Flexion-extension

Figure 3.3 illustrates the range of data found in the studies investigating wrist flexion-extension. While two studies had higher mean CTP values (Luchetti *et al.* [1998], and Rempel *et al.* [1997]), Keir *et al.* 2007 was selected for a number of reasons. First, a fiber-optic transducer was used by Luchetti *et al.* (1998) and investigated only three FE postures, thus limiting its comparison to other studies and its application to predicting CTP via regression. (It is not clear if measurements from a fiber-optic transducer are directly comparable to that of the liquid-filled catheters used in the majority studies found in the literature.) Second, the data from Rempel *et al.* (1997) and Keir et al. (1998b) were constituent subset of Keir et al. (2007). In the individual papers, Rempel et al. (1997) has a hand posture with extended fingers, which has been shown to increase CTP by approximately 19 mmHg (Keir *et al.*, 1998a). In the flexion-extension plane, the data set from Keir *et al.* (2007) was selected due to the sample size (n=37) and because it reported a higher CTP than other studies such that it, it would provide more conservative estimates of risk.

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Figure 3.3

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3.3.3 Selected Studies: Radioulnar Deviation

The three highest reported mean values in radioulnar deviation were found in Keir *et al.* (2007) (from approximately 10 to 20° ulnar deviation), Rempel *et al.* (1997) (from 10° radial to 10° ulnar deviation) and Keir *et al.* (1998a) (from 20° to 30° ulnar deviation). While Rempel *et al.* (1997) had the highest pressures in radial deviation (as shown in Figure 3.4), their subjects also had a testing posture that likely elevated CTP (extended fingers). As well, the sample from Keir *et al.* (1998) was a subset of the more recent paper from Keir *et al.* (2007). As a result, Keir *et al.* (2007) was selected due to its larger study size (n=37), which was more than twice the size of Rempel *et al.,* (1997).

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Figure 3.4

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3.3.4 Selected Studies: Finger Posture

Three studies investigated the effect of finger posture on *in-vivo* CTP (Keir *et al.*, 1998a; Werner *et al.*, 1997; Rempel *et al.*, 1998). Figure 3.5 illustrates the effect of finger posture on CTP in wrist flexion-extension and the marked difference between Keir *et al.* (1998a) and Werner *et al.* (1997). Note "neutral" posture is not applicable to all three studies since Keir *et al.* (1998a) had a semi-pronated forearm posture with relaxed fingers, Rempel *et al.* (1998b) had a pronated forearm posture with extended fingers, and Werner *et al.* (1997) did not state their baseline finger posture. The data from Keir *et al.* (1998a) were selected for a number of reasons. First, the presented data were a more conservative estimate of risk (i.e. higher CTP) than that of Werner *et al.* (1997) and Rempel *et al.* (1998). Second, the study also presented the combined effect of MCP and wrist posture on CTP. Lastly, Keir *et al.* (1998a) measured their baseline pressure with relaxed fingers. As such, a study with extended fingers as a baseline posture (Rempel *et al.* [1998b]) may have inflated the predicted CTP.

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Figure 3.5

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3.3.5 Pronation/Supination

The effect of pronation/supination is the least studied variable affecting CTP. Two studies (Werner *et al.*, 1997; Rempel *et al.*, 1998) have directly investigated the effect of pronation/supination. In addition to these studies, the relationship between pronation/supination can be illustrated by plotting the resting CTP from each study across their initial resting postures. For example, 4 studies had a pronated forearm as a resting posture (Weiss *et al.*, 1995; Werner *et al.*, 1997; Rempel *et al.*, 1998; Rempel *et al.*, 2008), 5 studies had a semi-pronated forearm posture (45° pronation) (Rempel *et al.*, 1994; Keir *et al.*, 1998a; Keir *et al.*, 1998b; Keir *et al.*, 1999; Keir *et al.*, 2007), and 5 had a supinated posture (Gelberman *et al.*, 1981; Okutsu *et al.*, 1989; Rojviroj *et al.*, 1990; Hamanaka *et al.*, 1995; Luchetti *et al.*, 1998). From this, the effect of forearm posture on CTP was found across a series of studies. This effect is illustrated in Figure 3.6 where two curves represent the mean CTP at each posture, one of which is weighted by sample size, and the second is simply a mean of pressures. The data set using the weighted means from each study was selected since it had the largest sample size.

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Figure 3.6

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3.3.6 Fingertip Loading

Fingertip loading has been shown to affect CTP in control subjects in 3 studies (Keir *et al.*, 1997; Keir *et al.*, 1998b; Rempel *et al.*, 1997). Of these three studies, one study (Keir *et al.*, 1997) measured CTP in cadaveric controls (n=4), and therefore did not measure fingertip force directly. Instead the authors loaded the tendons with 1-kg loads and measured the resulting CTP.

The lower two curves in Figure 3.7 represent the results of Keir *et al (*1998b) (CTP *versus* fingertip load and hand posture) while the upper curve represents the results of Rempel *et al.* (1997) (CTP and fingertip press). While the mean CTP presented by Rempel et al (1997) were greater than those of Keir *et al.* (1998a), and thus a more "conservative" estimate of risk, the testing posture in this study was a pronated forearm and extended fingers. Since extending the fingers has been shown to increase CTP (approximately 20 mmHg in a neutral according to Keir *et al. 1998b*), Keir *et al.* (1998a) was selected due to its starting posture of relaxed fingers. The data set published by Keir *et al.* (1998a) was selected for fingertip loading as a result of their larger study sample and their research on the effect of grip type (fingertip pinch) on CTP.

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Figure 3.7

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3.3.7 Postures based on CTP Thresholds

Keir *et al.* (2007) presented the concept of a threshold above which 75% of the sample is at or above a 30 mmHg, thus at greater risk of CTS. These postural thresholds were limited to two planes of motion (FE and RUD) and there is insufficient data available to determine similar thresholds for the remaining three variables (pronation/supination, finger posture, and fingertip loading). While predicting mean CTP is useful, it ignores the 50% of the target population above the mean. As well, ergonomic guidelines typically accommodate 75% of the target population. It was determined that adding two standard error of the means predicted similar thresholds to Keir *et al.*'s (2007) threshold postures in flexion-extension and radioulnar deviation. In order to provide a "best guess" of the 30 mmHg thresholds in the remaining tool inputs (forearm rotation, finger posture, and fingertip loading) at which 75% of the sample is at, or below the 30 mmHg threshold, two standard error of the means were added to each data set, and used to develop regression equations. A polynomial regression analysis was performed on each of the data sets resulting in quadratic (second order polynomial) equations for all motions (SPSS, PASW 18, 2009). R^2 values for each of the quadratic equations were 0.98 (wrist flexion-extension), 0.99 (radioulnar deviation), 0.98 (forearm rotation), 0.89-0.99 (finger posture), and 0.96-0.98 (fingertip loading).

3.3.8 Combined Postures

There is limited data available that describes the effect of combined postures (such as wrist flexion and radioulnar deviation), which is unfortunate considering wrist motion is rarely in a single plane. Two options to overcome this particular hurdle were available. The first was to use the limited data available to predict the effect of combined postures, while the second was to only use the axis of movement that resulted in the highest CTP and disregard CTP associated with the other 2 planes. To date, only one study has investigated the effect of combined wrist and forearm postural deviations from neutral (Werner *et al.*, 1997). In their small sample (n=7), they found a minimal response in CTP due to changes in posture which could result from having a sample of nonresponders. As well, only 3 means were provided in each plane of motion (i.e. flexed, neutral, and an extended wrist), which decreased use of this data for the purpose of prediction (performing a regression analysis on three data points would result in an R^2 value of 1). Basing risk estimates on the one factor, out of the three, the single plane of movement that provided the highest CTP was determined to be the best approach. Once the effects of posture were determined, the independent effects of loading were added to the posture effects which resulted in an overall predicted CTP.

3.3.9 Tool Overview

A graphical user interface was developed to provide a user-friendly ergonomic tool (MATLAB, "graphical user-interface design environment" (GUIDE, Mathworks, 2009). Input variables manipulated by the user are wrist FE, RUD, pronation/supination, finger posture, as well as fingertip load and type (fingertip pinch or press). Table 3.1 contains the regression equations used to predict CTP.

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Table 3.1

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A screen capture of the graphical user-interface is shown in Figure 3.8. In addition to predicting CTP in given posture, visual estimations of the posture in each plane are displayed to provide a visual representation of the posture to the user.

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Figure 3.8

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3.4. Methods:

3.4.1 Data collection:

Injury statistics from August 2009 to August 2010 were obtained from a large automotive assembly plant in Ontario, Canada. The dataset of 273 injury records, that indicated lost time or restricted duties in two main departments, was filtered by location of injury (e.g. hand, wrist, arm, leg) and only injuries regarding the hand, wrist, and fingers were kept. Two CTS cases were found. Four additional cases, where CTS symptoms may have been present (i.e. worker reported tingling/paresthesia in the hand), were identified during the manual (case by case) search of the 56 hand/wrist injury records (including doctor, supervisor, and employee statements). Two workers for each of the six jobs identified in the injury review were observed (where possible). An additional twenty nine participants were recorded completing jobs with no incidence of CTS or symptoms. In total, 39 subjects were observed completing 35 unique tasks. Each job was first observed for 2-3 cycles, and the subject's forearm, wrist, and hand were videotaped for two full cycles (2-5 minutes of recording time). Each subject was also asked to rate their fingertip exertion during the task using a modified Borg Scale (Borg, 1982) to provide a force estimate for input to the tool.

3.4.2 Data analysis

Each of the 39 video clips were edited down to a single cycle (approximately one minute), and down sampled to 5 Hz using video-analysis software (Kinovea 0.7.10.). The resultant video clips were approximately 300 frames per job. Wrist, hand, and forearm posture were estimated and recorded. To simplify the video analysis for the pilot evaluation (six input variables from each of the approximately 12 000 frames of video were required) and to acknowledge the errors associated with obtaining angles from field video, wrist and forearm angles were categorized into low, moderate, or high risk postures instead of inputting discrete angles (the regression equations were used to identify posture thresholds at 20 and 30 mmHg). For each frame of video, wrist and forearm postures were categorized into one of the three bins, using the lower bin threshold to represent the posture. For wrist and forearm postures in the "low risk" category (between -17° and 36° of wrist extension-flexion, -9° and 6° of radioulnar deviation, or any forearm posture except full supination), a neutral value (0° in wrist flexion-extension or radioulnar deviation, and 45° in forearm rotation) was used as the input. (Note the tool predicted that the 30 mmHg threshold was not attainable in forearm supination alone, and the 20 mmHg threshold was not attainable in forearm pronation alone.) If the wrist or forearm posture was in the "moderate risk" category (between -33° to -17° or 35° to 51° in wrist flexion-extension, -22° to -9.4 or 18.7° to 6.4° in wrist radioulnar deviation, or in full supination), the lower posture threshold was input into the tool. If the wrist or forearm posture was in the "high risk" category (beyond -33° or 51° in wrist flexion-extension, or -22° or 18.7° in wrist radioulnar deviation), the lower posture threshold was input into the tool. For example, if the subject's wrist appeared to be between the 20 and 30 mmHg thresholds in wrist flexion (as shown in the reference threshold angles in Figure 3.9), the wrist angle associated with a predicted CTP of 20 mmHg (35°) was input as the flexion-extension angle. Posture estimation for each job ranged from 10-25 minutes depending on the complexity of the task. Tasks varied widely in terms of duration of hand movement. For example one cycle may require 15 seconds of high-frequency hand work, while another task may require 40 seconds of low-frequency hand work.

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Figure 3.9

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Any finger exertion rated at or over *5* on the Borg Scale was assigned a fingertip load of 7 N for a fingertip press or 2 N for a pulp pinch. Finger exertions rated less than a "5" were assigned a 2 N fingertip press or a 0 N fingertip pinch. Each frame of digitized video resulted in a 1 x 6 array consisting of forearm and wrist angles, hand posture, finger force type, and load. Each subject was represented by a 300 x 6 array, which was processed using the tool. Once CTP was predicted, a time-weighted average (TWA) for each job was determined, and sorted into risk categories: High risk (more than 30 mmHg), moderate risk (between 20 and 30 mmHg), or low risk (less than 20 mmHg).

The predicted CTS risk values of each group were then compared using a Mann-Whitney U test. The Mann-Whitney U test was used to compare group means since the data was not normally distributed. (Note that the data was also not normally distributed after the application of other transforms.)

3.5 Results

Figure 3.10 represents the predicted TWA CTP for each worker observed. The predicted CTP and CTS-risk were not significantly different between the two groups (Mann-Whitney U test, $p < 0.062$). The mean CTP of the jobs with an incidence of CTS or potential CTS symptoms was 22.8 ± 2.4 (standard deviation) mmHg while the predicted pressures for jobs with no incidence of CTS was 20.8 ± 2.4 mmHg. The mean across both groups was 21.3 ± 0.4 mmHg (18.5-27.8 mmHg range).

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Figure 3.10

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It was predicted that twenty three of the thirty nine workers had a mean TWA CTP in the "moderate risk" category (20 mmHg < CTP > 30 mmHg), while no workers were found to have a mean CTP above the "high risk" (30 mmHg) threshold. Of the 10 subjects working in a job with a reported CTS claim, 9 were in the "moderate risk" category. Figure 3.11 represents CTP vs. Time trace for one of the 31 jobs identified that did not have any reported injury data.

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Figure 3.11

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3.6 Discussion and Conclusions

This study describes a preliminary version of an ergonomic tool that predicts CTP using upper-extremity postures and fingertip loading as input variables, and a pilot study that evaluated the tool against the incidence of CTS injury claims was performed. The ultimate goal of the current tool is to provide ergonomists with a means to quantitatively assess CTS-risk in the design or redesign stages, similar to tools currently available to assess manual material handling. A standalone graphical-user-interface that predicted CTP was developed. Subjects from two groups (consisting of subjects completing a job with or without a previous incidence of CTS or potential CTS symptoms) were recorded and mean CTP for each subject was predicted. While the predicted CTP were higher than those found in the literature, this is likely due to the tasks completed in the current study. Sommerich *et al.* (1998) reported a mean pressure of 11 mmHg in subjects performing a typing task while the current tool predicted a mean pressure of 21 mmHg for workers completing automotive assembly tasks. As well, the regression equations derived from the literature fit the data well (all regression equations had an R^2 greater than 0.9).

CTS risk was determined by ranking each predicted TWA CTP into one of three categories: low risk (less than 20 mmHg), moderate risk (between 20 and 30 mmHg), or high-risk (more than 30 mmHg). Although there was no statistically significant difference between the two test groups, the current tool marks an important step in providing ergonomists with a user-friendly, quantified estimate of CTS risk based on the available literature.

The current tool predicts CTP based on the postures required to complete a task, and a time weighted average was used to determine overall pressure. Predicting an overall CTP has been found to be important when considering cyclic loading of peripheral nerves in animal models (Szabo and Sharkey, 1993). In a rat tibial nerve, constant compression of the nerve had similar effects to cyclic loading of the nerve. As a result, it was suggested that mean pressure has a greater impact on nerve function in comparison to isolated peaks. In a study that experimentally increased CTP *in-vivo* (Lundborg *et al.* 1982), the authors found that even at pressures three times that of the "high risk" pressure threshold (30 mmHg) used in this study, the first evidence of disruption in sensory or motor function of the median nerve took 10 minutes to appear. The same degradation in nerve function took up to 60 minutes in individuals with CTP of 30 mmHg. There is also a possibility that CTP thresholds may vary based on exposure time such as with vibration exposure. For example, there are limits on horizontal or vertical vibration that change based on exposure time (ISO 2631, 1974). Since there is a lag in nerve function degradation, even at high pressures, it is likely that an individual may be able to withstand higher peaks in CTP for a short period of time, while prolonged exposure to the same pressure may negatively affect nerve function. It would be beneficial to expand on the research pioneered by Lundborg *et al.* (1982) to develop a better understanding of the effect of exposure duration on pressure thresholds that affect median nerve function.

The output of the tool was compared to an external, quantitative outcome (injury claim incidence). There was no significant difference in predicted mean CTP between workers in jobs with a reported incidence of CTS or potential CTS symptoms and workers in jobs without an incidence of CTS or potential CTS symptoms. As well, the predicted TWA CTP for all of the observed jobs was below the “high risk” threshold of 30 mmHg. It is possible that the jobs observed were not “high-risk” (at least one of the CTS cases identified in the injury review may have arisen from an acute wrist injury, and not from a sustained increase in CTP). Also, the incidence of CTS may not have been the most appropriate measure to compare the tool output to. The injury data showed only 6 out of 274 medical records that had documented or possible cases of CTS (2 jobs where a worker had a documented case of CTS, and 4 jobs where a worker presented potential CTS symptoms). While it is one of the few variables readily available to compare the tool output to, injury incidence in a single automotive assembly plant over the course of one year may not have been the most appropriate variable. A true validation study (comparing predicted CTP to *in-vivo* CTP) would be beneficial.

Further research is needed to investigate the effect of wrist, hand, and forearm posture, and fingertip loading both in isolation (e.g. pure wrist flexion), and in combined postures (e.g. wrist flexion and ulnar deviation) in the same study (large) sample.

Accounting for combined wrist postures would provide a more accurate prediction of CTP and CTS risk. In addition to CTP, mechanical compression of the median nerve has been shown to be useful in describing trauma to the nerve in flexion. Since the current tool is based on CTP, it is most sensitive to variables that have the greatest impact on CTP, such as wrist extension, which increases CTP to a greater extent than wrist flexion. However, wrist flexion impacts mechanical compression to a greater extent than wrist extension as illustrated using the belt-pulley model, or clinically using the Phalen's manoeuvre (an exclusion test that uses sustained wrist flexion to elicit CTS symptoms in patients) (Phalen, 1972). Unfortunately, there is currently no mechanical compression equivalent to the CTP thresholds proposed by Keir et al. (2007). As well, a recent lab simulation employed a novel method of predicting fluid pressure in the carpal tunnel and mechanical compression of the median nerve (Ko and Brown, 2007). They developed two models using finite-element models of the carpal tunnel based on a reconstruction from MRI images and estimated mechanical compression of the median and fluid pressure within the carpal tunnel. While their models accounted for compression of the median (due to mechanical and fluid stress), it was a lab simulation and not meant for use as an assessment tool. Although predicting mechanical compression of the median nerve has been modelled in the past, and could be easily included in the ergonomic tool, it is impossible to provide a risk-estimate based on *in-vivo* studies.

There were a several limitations to this study. In an attempt to predict the posture threshold beyond which 75% of the sample would be at or above a given threshold, a floor effect may have been introduced. The variance of the tool's radioulnar deviation data set (Keir *et al.,* 2007) was higher with respect to the other data sets. This resulted in a “neutral” pressure of 18 mmHg compared to 13 mmHg for the flexion-extension data set. As well, the tool did not account for the effect of combined postures on CTP, owing to the dearth of research on the topic. In addition to CTP, mechanical compression of the median nerve has also been suggested as a parallel mechanism for the development or aggravation of CTS but was not incorporated into the current tool. The tool estimates CTS risk based pressure alone. Other CTS risk factors (pregnancy, diabetes, previous wrist trauma, etc.), or the CTP dynamics in wrists with CTS were not addressed.

In the field study, there was no significant difference in CTS risk between the two study groups (subjects completing jobs with or without a previous incidence of possible incidence of CTS). However, a promising result of the tool evaluation was that one of the highest predicted pressures, and therefore closest to the “high risk” CTP threshold, was a job with an incidence of CTS (Job # 2 in figure 3.10). The current tool represents the first attempt to provide ergonomists with a user-friendly tool to quantify CTS-risk. To create a more powerful tool, further research is needed to account for mechanical compression of the median nerve, as well as interactions between movement in different planes of movement and CTP.

3.7 List of key points

- A tool to predict CTP from posture of hand and wrist and force was developed
- CTP was used to estimate CTS risk and incorporated into a software program
- Tool was tested on the floor of a manufacturing plant using 39 individuals performing 35 jobs

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3.9 Manuscript Tables and Figures

Table 3.1 Regression equations used in the ergonomic tool.

Wrist and Forearm Posture:

CTP associated with relaxed fingers or in a flexed wrist (regardless of finger posture)

$$CTP_{FE} = 0.010*\theta_{FE}^2 - 0.19\theta_{FE} + 13.93 \quad (1)$$

CTP in a neutral or extended wrist

Flexed fingers

$$CTP_{FE} = 0.010*\theta_{FE}^2 - 0.38\theta_{FE} + 17.89 \quad (2)$$

Extended fingers

$$CTP_{FE} = 0.010*\theta_{FE}^2 - 0.56\theta_{FE} + 39.23 \quad (3)$$

$$CTP_{RUD} = 0.029*\theta_{RUD}^2 + 0.087\theta_{RUD} + 18.3 \quad (4)$$

$$CTP_{PS} = 0.0007*\theta_{PS}^2 - 0.041*\theta_{PS} + 10.2 \quad (5)$$

$$CTP_{posture} = \text{Maximum } |CTP_{FE}, CTP_{RUD}, CTP_{PS}| \quad (6)$$

Fingertip loading:

$$CTP_{pinch} = -0.12*load^2 + 4.89*load + 18.5 \quad (7)$$

$$CTP_{press} = 0.084*load^2 + 1.09*load + 11.7 \quad (8)$$

Overall CTP equation:

$$CTP_{Total} = CTP_{posture} + CTP_{pinch/press} \quad (9)$$

(FE = Flexion-Extension, RUD = Radioulnar Deviation, PS = Pronation/Supination, MCP_F = Flexed fingers, MCP_N = Neutral fingers, MCP_E = Extended fingers.)

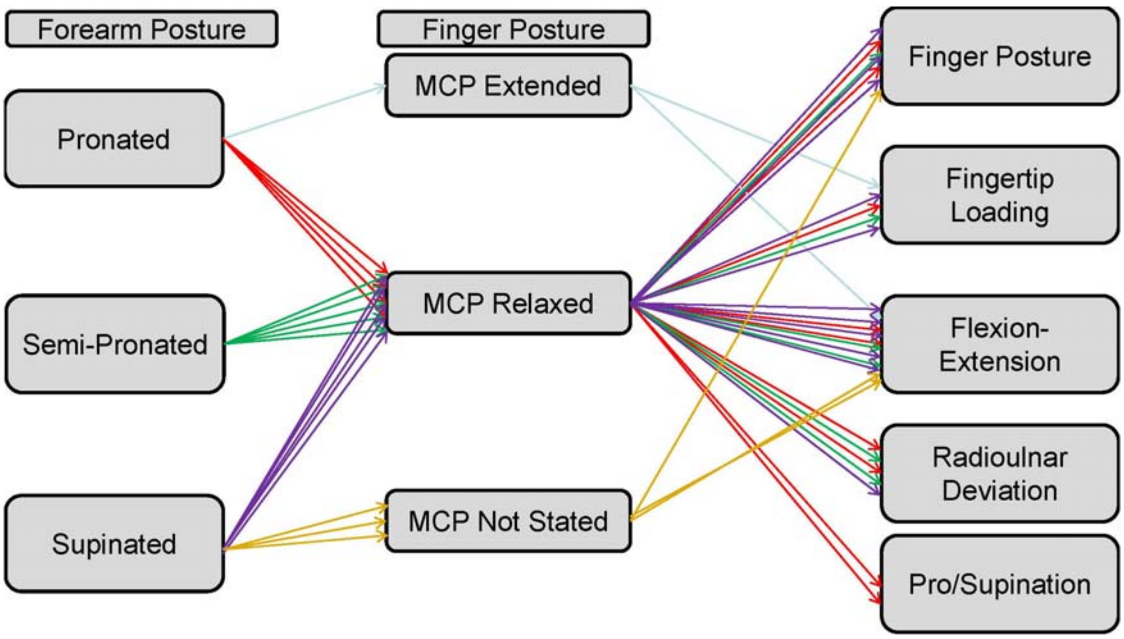

Figure 3.1. Distribution of studies by independent variables. Each arrow represents a study that investigated that particular variable. Left to right: Forearm posture refers to the forearm posture the protocol was completed in; finger posture refers to the initial or baseline finger posture (extended, relaxed, or not stated), and the last column indicates the different variables and their effect on CTP.

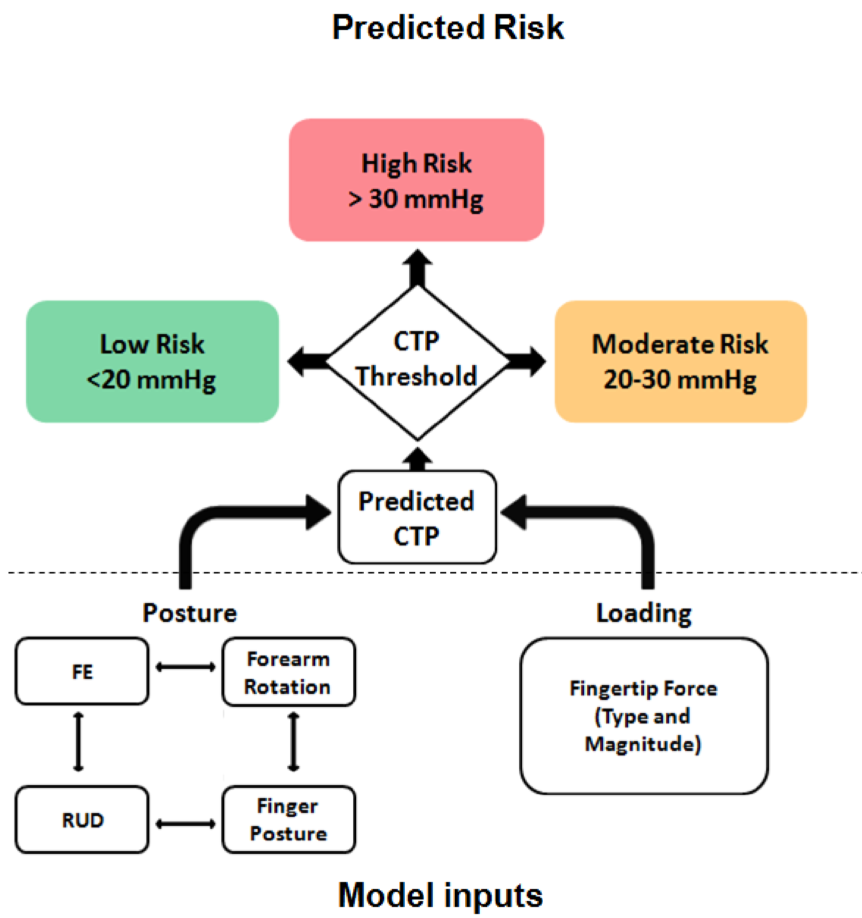

Figure 3.2 Construct of algorithm to predict CTP and CTS risk. Items below the dashed line represent inputs, while the objects above the line represent calculated variables and outputs. (FE = flexion-extension; RUD = radioulnar deviation)

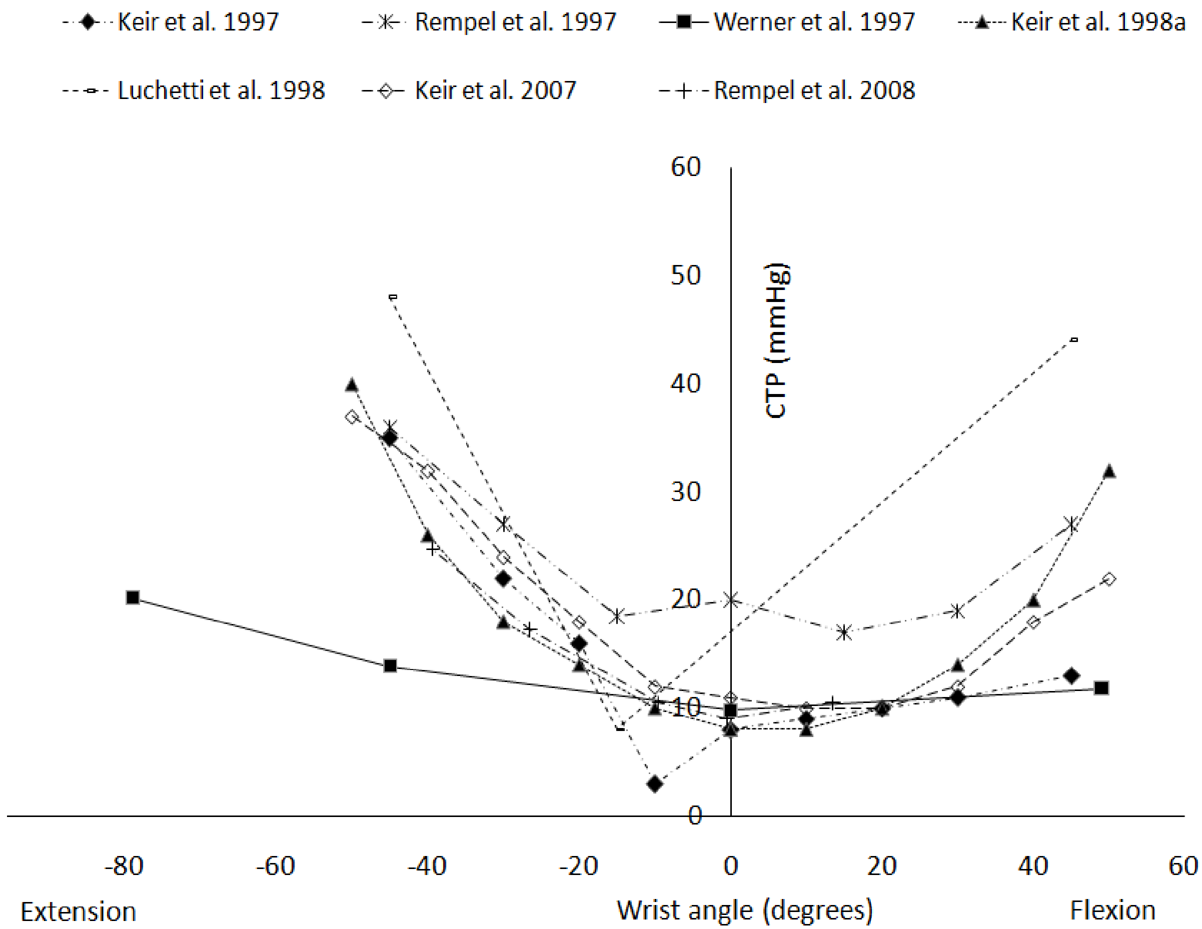

Figure 3.3 Wrist Flexion-Extension vs. CTP. Studies using passive ranges of motion were not included (Gelberman *et al.*, 1981; Szabo and Chidgey, 1989; Rojviroj *et al.*, 1990).

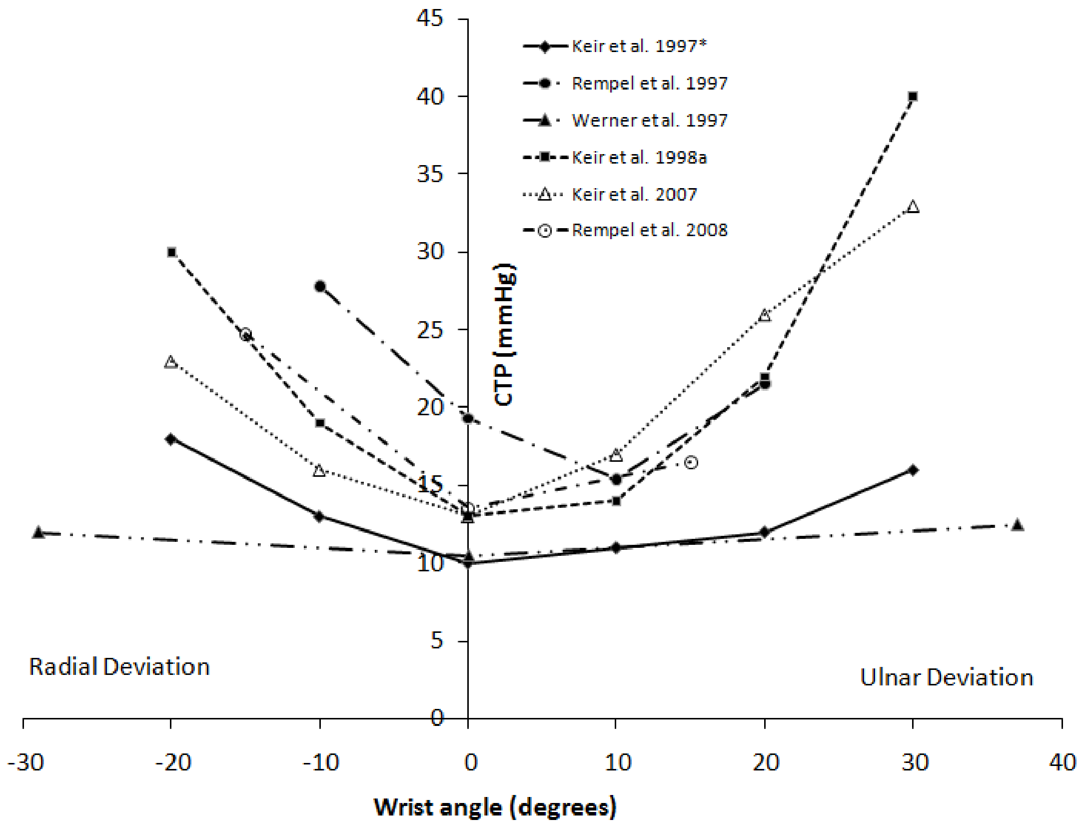

Figure 3.4 Radioulnar deviation vs. CTP. Note all but one study (Rempel *et al.* 1997) found a higher CTP in ulnar deviation.

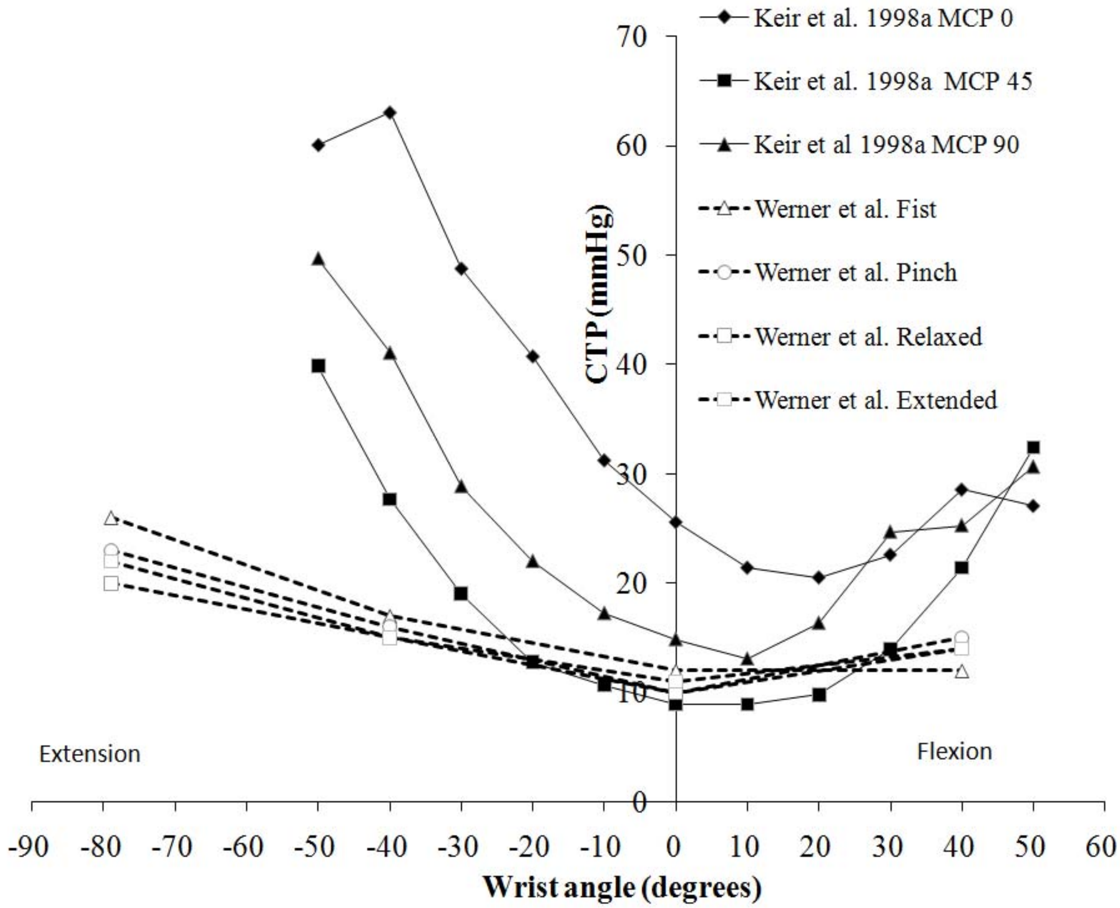

Figure 3.5 The effect of MCP posture on CTP changes as a result of wrist posture in flexion and extension. Altering MCP posture from 50° of wrist extension to 10 degrees of wrist flexion results in a significant change in CTP.

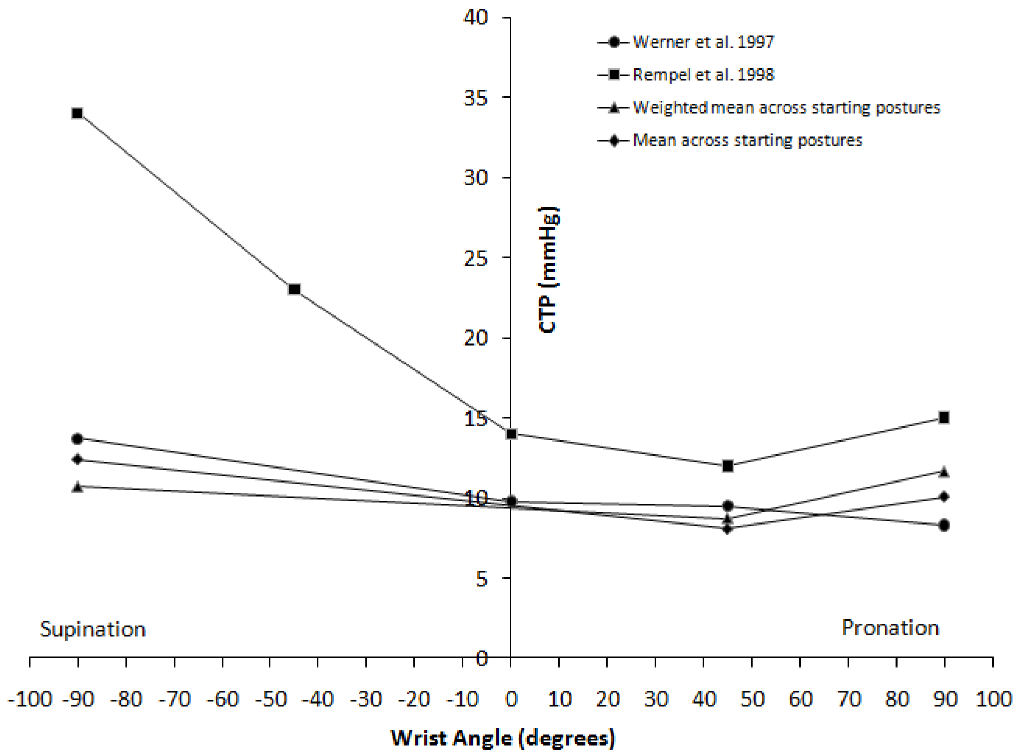

Figure 3.6 Pronation/Supination and its effect on CTP. Weighted mean is determined by sample size and mean CTP.

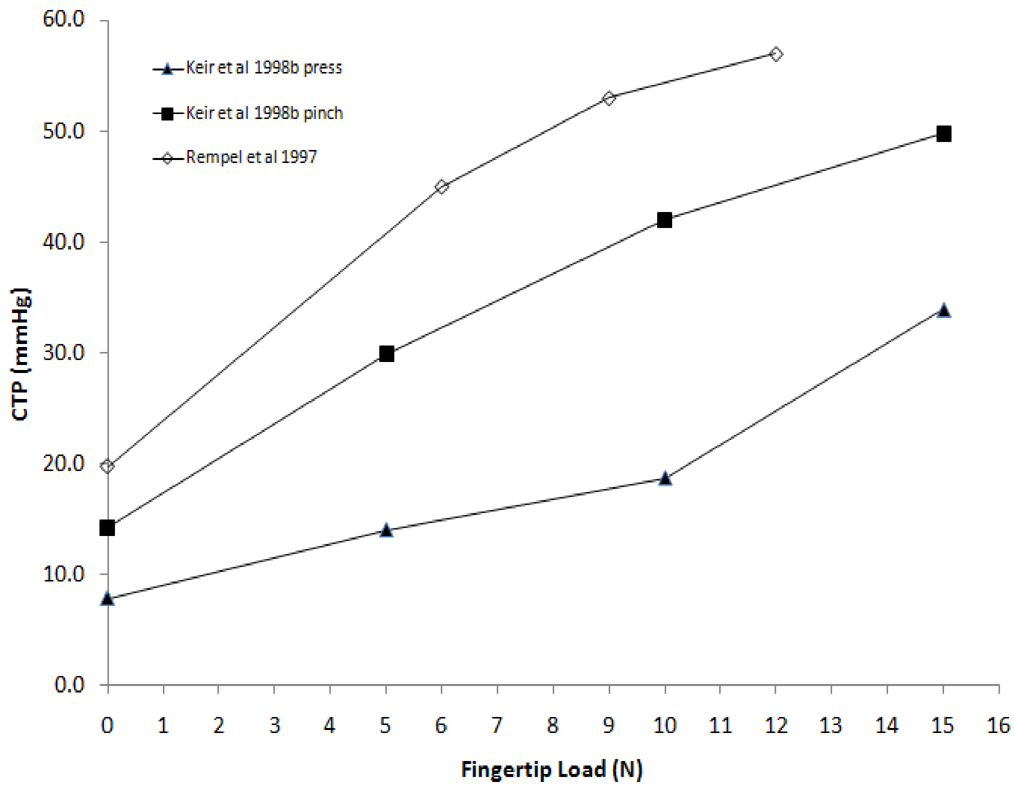

Figure 3.7 Effect of Fingertip Loading on CTP. Note the difference in CTP between a pulp pinch and press (Keir *et al* 1998b).

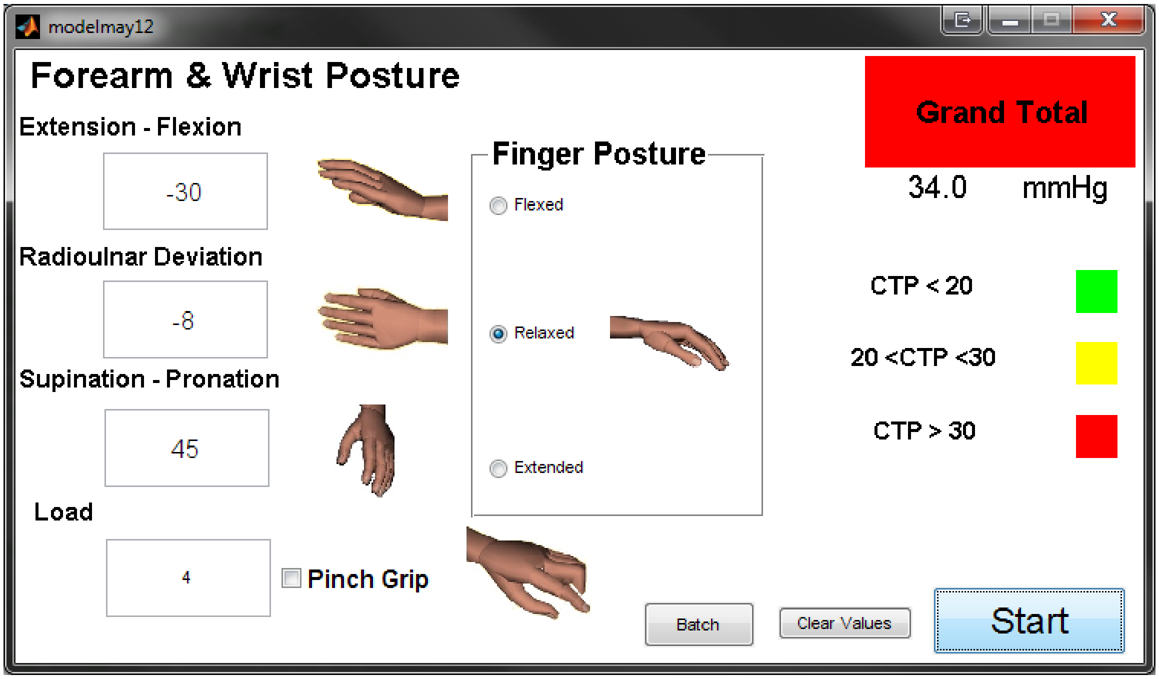

Figure 3.8 Screen capture of graphical user interface (The larger number [left] indicates wrist or forearm angle in degrees, while the subscripts indicate the CTP associated with that posture).

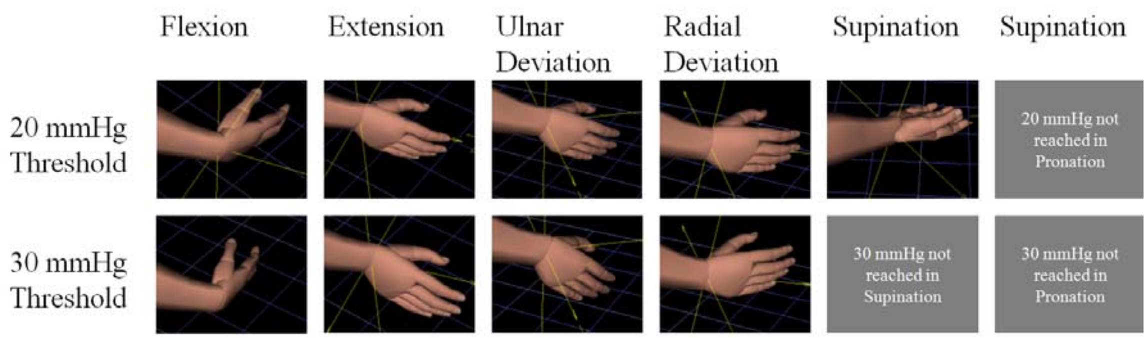

Figure 3.9. Posture thresholds for 20 and 30 mmHg in each plane of movement. (Note that CTP of 30 mmHg was not attainable in pronation or supination, and 20 mmHg was not attainable in pronation.)

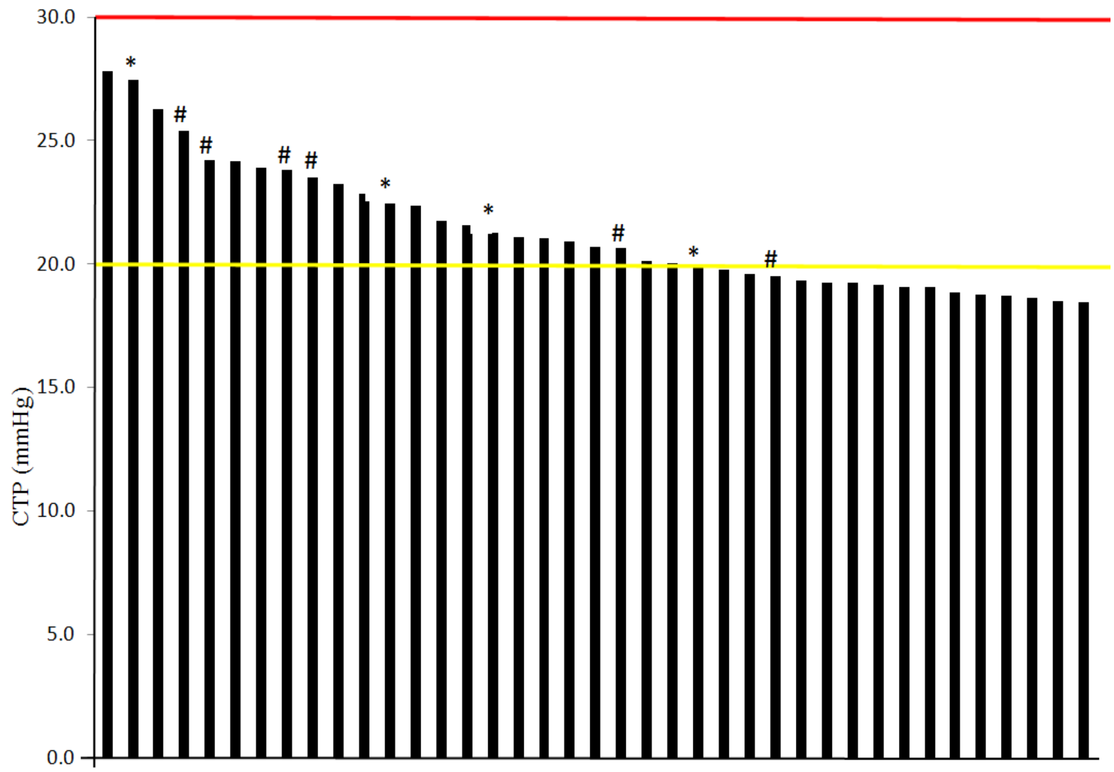

Figure 3.10 A breakdown of mean CTP (mmHg). Mean pressures marked by an asterisk (*) indicate the job had an incident of CTS, while any pressures marked by a number sign (#) indicates the job had a record of injury with signs or symptoms of CTS.

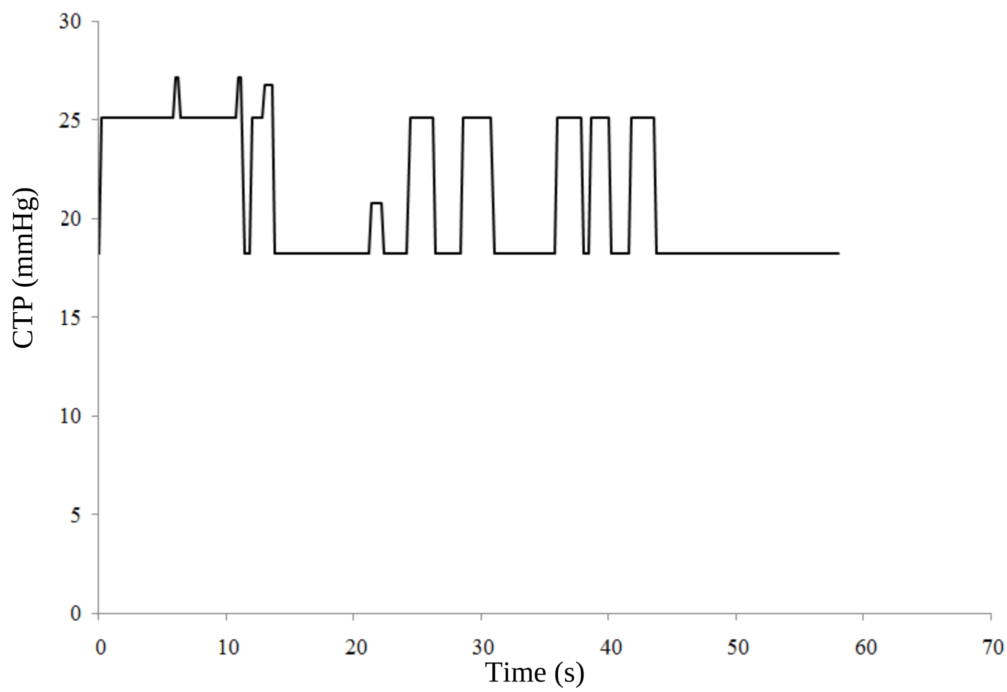

Figure 3.11. Pressure vs. Time graph for a job (# 19) that did not have an incidence of CTS (mean CTP was 22 mmHg**).**

CHAPTER 4 – THESIS SUMMARY AND FUTURE DIRECTIONS

Carpal Tunnel Syndrome continues to contribute to lost-time injuries in Ontario despite efforts to lower the risk. Research has suggested that elevated CTP is a mechanism that leads to the development and aggravation of CTS. More specifically, when CTP is sustained at or above 30 mmHg, median nerve function degrades. While there is a wide range of research investigating the effect of wrist, hand, and forearm posture on CTP, this study represents the first attempt to provide a comprehensive review of the pertinent literature, and to develop a functional tool to predict CTS risk for use by ergonomists. The tool was developed, and evaluated in a field-study. While further research to provide more accurate predictions, this project marks the first step towards a much needed tool to provide applied ergonomists with a user-friendly program that predicts CTS risk based on over 60 years of accumulated research.

In this study, a tool based on a series of regression equations that predicts CTP based on forearm, wrist, and hand posture, as well as fingertip loading was developed. The predicted CTP was then compared to 20 mmHg (moderate risk) and 30 mmHg (high risk) thresholds to provide an estimate of CTS risk. A graphical-user-interface was programmed using a high-level programming language. Although the tool was easy to use, manually entering all postures and fingertip loads required to complete a task with a relatively short cycle time (approximately one minute) proved to be labour intensive.

Additional research to determine the effect of combined wrist postures is needed to improve the fidelity of the tool. While completing the above field study in an automotive assembly plant, it was evident that few work tasks require wrist or forearm postures in a single plane of movement. Based on the current available literature (one study with seven subjects), it was not feasible to predict the relationship between combined postures and CTP. In the current tool, the plane of movement with the highest predicted pressure was used as the "posture" component for the tool, while ignoring the other posture components. Accounting for combined wrist postures would provide a more accurate prediction of CTP, and subsequently CTS risk.

It is also possible that the duration of exposure to increased CTP may impact the threshold at which median nerve function degrades. For example, vibration thresholds for the human body have been established that change based on the duration of exposure. *In-vivo* research has shown the even at high pressures (90 mmHg), median nerve function degrades after 10 minutes of increased CTP. Coupled with the fact that postures exceeding the "high risk" threshold in extension are common in the workplace, it is possible that the median nerve is able to safely withstand pressures above the "high risk" threshold (30 mmHg) for a short duration. It should also be noted that constant compression of the nerve had similar effects to cyclic loading of the nerve. As a result, mean pressure may have a greater impact on nerve function in comparison to isolated peaks. Research expanding on the findings of Lundborg (1982) and Sharkey *et al.* (1983) would illuminate the response of median nerve function to higher CTP values for a short period of time, and what effect exposure time has on the "moderate" and "high risk" thresholds.

The role of mechanical compression of the median nerve in the development and aggravation of CTS also needs to be considered. Research and clinical evidence point to the importance wrist flexion (compounded by tendon load) on mechanical compression of the median nerve (illustrated by the use of the modified Phalen's test, and modelled by likening the finger flexor tendons and the transverse carpal ligament to a belt wrapped around a pulley). Accounting for both CTP and mechanical compression of the median nerve would provide a more encompassing picture of median nerve trauma, and provide ergonomists with a better indication of CTS risk. While it is currently possible to predict median nerve trauma using the belt-pulley model, there is a dearth of research regarding *in-vivo* mechanical compression thresholds, so any prediction of compression would not have a reference point to quantify CTS risk. As well, a true validation study (comparing predicted CTP to *in-vivo* CTP) would provide a better evaluation of tool accuracy. The current study predicted one aspect of CTS risk (CTP) to an outcome (injury risk) that could be affected by confounding variables (i.e. previous wrist trauma, pregnancy, diabetes mellitus, etc.); since the development of CTS may not be solely dependent on elevated CTP.

A subsequent large-scale research study would also provide a more accurate estimation of "at risk" postures for the 75th percentile. Keir *et al.* (2007) calculated posture thresholds in flexion-extension and radioulnar deviation below which 75% of their study sample had CTP below 30 mmHg in the flexion-extension and radioulnar deviation planes. The current tool expanded on these planes of motion to include forearm rotation, finger posture, and fingertip loading. While the current tool estimates threshold postures for additional planes of movements and loading conditions, a large-scale research study would provide a more accurate estimation of the thresholds not addressed in the paper by Keir *et al.* (2007).

This thesis was based on the development of an ergonomic tool that predicts CTS risk based on wrist, forearm, and hand posture, as well as fingertip loading. The tool was developed to provide ergonomists with a means to quantitatively assess CTS risk based on CTP in a user-friendly, non-invasive manner. Tool application ranges from the design phases (using part, tool, or workstation prototypes) to workstation redesign (identifying areas of concern regarding CTS risk). Although further research is needed to provide a more accurate prediction of CTP and CTS risk, this thesis marks the first step in providing ergonomists with a much needed tool to further prevent workplace CTS.

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APPENDIX A: CTP DATA FROM THE LITERATURE

Appendix A1: Flexion-Extension Data

Author	Date	*n*	FE Angle (degrees)	CTP (mmHg)
Gelberman et al.	1981	*12*	-90.0	30.0
			0.0	2.5
			90.0	31.0
Okutsu et al	1989	*16*	-90.0	158.0
			0.0	14.0
			90.0	143.0
Szabo and Chidgey	1988	*6*	-90.0	27.0
			0.0	5.0
			90.0	16.0
Rojviroj et al.	1990	*16*	-90.0	12.7
			0.0	3.5
			90.0	9.3
Serradge et al	1995	*21*	-90.0	101.0
			0.0	21.0
			90.0	80.0
Keir et al.	1997	*8*	-45.0	35.0
y=0.0085x^2-0.2015x+7.6749			-30.0	22.0
R^2=0.8813			-20.0	16.0
			-10.0	3.0
			0.0	8.0
			10.0	9.0
			20.0	10.0
			30.0	11.0
			45.0	13.0
Rempel et al.	1997	*15*	-45.0	36.0
y=0.0068x^2-1.06x+17.381			-30.0	27.0
R^2=0.9529			-15.0	18.5
			0.0	20.0
			15.0	17.0
			30.0	19.0
			45.0	27.0
Werner et al.	1997	*7*	-79.0	20.2
y=0.0013x^2-0.266x+9.9023			-45.0	13.9
R^2=0.9995			0.0	9.8
			49.0	11.8

Author	Date	*n*	FE Angle	CTP
Keir et al.	1998a	*14*	-50.0	40.0
y=0.0109x^2-0.0782+7.2494			-40.0	26.0
R^2=0.9865			-30.0	18.0
			-20.0	14.0
			-10.0	10.0
			0.0	8.0
			10.0	8.0
			20.0	10.0
			30.0	14.0
			40.0	20.0
			50.0	32.0
Luchetti et al	1998	*12*	-45.0	48.0
y=0.0215x^2-0.444x+2.5			-15.0	8.0
R=1 (3 data points)			45.0	44.0
Keir et al.	2007	*37*	-50.0	37.0
y=0.0078x^2-0.1682x+10.883			-40.0	32.0
R^2=0.9846			-30.0	24.0
			-20.0	18.0
			-10.0	12.0
			0.0	11.0
			10.0	10.0
			20.0	10.0
			30.0	12.0
			40.0	18.0
			50.0	22.0
Rempel et al 2008	2008	*20*	13.5	10.5
y=0.009x^2-0.0458x+9.31			-0.5	9.0
R^2=0.9979			-9.5	10.5
			-26.5	17.3
			-39.3	24.8

Appendix A2: Wrist Radioulnar Data

Author	Date	*n*	RUD Angle (degrees)	CTP
Keir et al.	1997	*8*	-20.0	18.0
y=0.0109x^2-0.1432x+10.6			-10.0	13.0
r^2=0.9793			0.0	10.0
			10.0	11.0
			20.0	12.0
			30.0	16.0
Rempel et al.	1997	*17*	20.0	21.5
y=0.0365x^2-0.593x+18.49			10.0	15.4
r^2=0.9819			0.0	19.3
			-10.0	27.8
Werner et al.	1997	*7*	-29.0	12.0
y=0.0016x^2-0.0052x+10.5			0.0	10.5
R^2=1 (3 points)			37.0	12.5
Keir et al.	1998a	*14*	-20.0	30.0
y=0.0359x^2-0.1875+12.75			-10.0	19.0
R^2=0.9933			0.0	13.0
			10.0	14.0
			20.0	22.0
			30.0	40.0
Keir et al.	2007	*37*	-20.0	23.0
y=0.0211x^2+0.293x+14.514			-10.0	16.0
R^2=0.9612			0.0	13.0
			10.0	17.0
			20.0	26.0
			30.0	33.0
Rempel et al.	2008	*20*	-15.0	24.8
y=0.0317x^2-0.275+13.5			0.0	13.5
R^2=1 (3 points)			15.0	16.5

Appendix A3: Forearm Rotation Data

Author	Date	*n*	Wrist Angle (degrees)	CTP
Werner et al.	1997	*7*	-90	13.7
y=0.0001x^2-0.0288+10.27			0.0	9.8
R^2=0.9951			45.0	9.5
			90.0	8.3
Rempel et al.	1998	*17*	-90.0	34.0
y=0.0012x^2-0.1089x+14.6			-45.0	23.0
R^2=0.9801			0.0	14.0
			45.0	12.0
			90.0	15.0

Appendix A4: Finger Posture Data

Author	Date	*n*	MCP Angle	CTP (mmHg)
Werner et al. 1997	1997	*7*	0	11.2
			45	9.8
			90	12
Keir et al. 1998a	1998a	*14*	0	25.6
			45	8.9
			90	14.9
Rempel et al. 1998	1998	*17*	0	27
			45	14
			90	27

Appendix A5: Fingertip Loading Data

Study information			CTP (mmHg)			
Keir et al 1998	Fingertip Load (N)		0.0	5.0	10.0	15.0
n=20	Hand Posture	Press	7.8	14.0	18.7	33.9
		Pinch	14.2	29.9	42.0	49.8
Rempel et al 1997	Fingertip Load (N)		0.0	6.0	9.0	12.0
n=15	Wrist Posture (degrees)	-45	36.0	64.0	71.0	74.0
		-30	27.7	54.0	62.0	62.0
		-15	18.5	41.0	51.0	53.0
		0	19.7	45.0	53.0	57.0
		15	16.9	42.0	51.0	55.0
		30	18.8	33.0	41.0	44.0
		45	26.6	42.0	44.0	46.0

APPENDIX C: MATLAB CODE

(The following code executes on checking the hand posture check-box)

```
% --- Executes checkbox in pinch. %Purpose of this section is to
% account for any changes in the check box
function pinch_Callback(hObject, eventdata, handles)
% hObject    handle to pinch (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
   if get(handles.pinch,'Value')==get(handles.pinch,'Max'); %gets the value of the checkbox (i.e. determines
if the hand is pinched or not)
   a=1; %pinched
   else
   a=0; %not pinched
   end

%This is the where part you can input code
if a==0 %if the fingers are not pinched
   axes(handles.pinchpic)
        picture=imread('fingerpress.jpg');
        imshow(picture)
   %Put whole string of code in here
   fewristangle=str2num(get(handles.feangle,'String'));
    if fewristangle>0.1 && 14.99>fewristangle %Sets the picture to change based on wrist FE posture
        axes(handles.fepic)
        imshow('flex15.jpg');
     elseif fewristangle > 15
        axes(handles.fepic)
        picture=imread('flex30.tif');
        imshow(picture)
     elseif fewristangle<-0.1&&fewristangle>-14.99
        axes(handles.fepic)
        picture=imread('ext15.jpg');
        imshow(picture)
     elseif fewristangle<-15;
        axes(handles.fepic)
        picture=imread('ext30.tif');
        imshow(picture)
     elseif fewristangle==0;
        axes(handles.fepic)
        picture=imread('neutral.tif');
        imshow(picture)
     end
   fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
   %turns the text from above to a number that matlab can use
   stringfectp=num2str(fectp);
   %Display the value associated with fectp in the FE box next to the input
   set(handles.fectp,'String',stringfectp);


   %Same thing but with RUD picture
```

```
    rudwristangle=str2num(get(handles.rudangle,'String')); %#ok<*ST2NM>
        if rudwristangle>0
          axes(handles.rupic)
          imshow('ulnar.jpg');
       elseif rudwristangle <0
          axes(handles.rupic)
          picture=imread('radial.jpg');
          imshow(picture)
       elseif rudwristangle==0;
          axes(handles.rupic)
          picture=imread('neutralru.jpg');
          imshow(picture)
       end
    rudctp=0.0291*(rudwristangle)^2 + 0.087*(rudwristangle) + 18.255;
    stringrudctp=num2str(rudctp);
    set(handles.rudctp,'String',stringrudctp);

    %same thing with the PS
    pswristangle=str2num(get(handles.prosupangle,'String'));
        if pswristangle<-45
          axes(handles.pspic)
          imshow('sup.jpg');
       elseif pswristangle <0
          axes(handles.pspic)
          picture=imread('semisup.jpg');
          imshow(picture)
       elseif pswristangle==0;
          axes(handles.pspic)
          picture=imread('psneutral.jpg');
          imshow(picture)
       elseif pswristangle <=45
          axes(handles.pspic)
          picture=imread('semipro.jpg');
          imshow(picture)
       elseif pswristangle>45;
          axes(handles.pspic)
          picture=imread('pro.jpg');
          imshow(picture)
       end
    psctp=0.0007*(pswristangle)^2-0.041*(pswristangle)+10.162;
    stringpsctp=num2str(psctp); %#ok<*NASGU>
    set(handles.psctp,'String',psctp);

%Switch/Case code to gain CTP based on finger posture

    h=get(handles.fingerposture,'SelectedObject');
    buttoncase=get(h,'Tag');
    switch buttoncase
       case 'flexedfingers';
     fewristangle=str2num(get(handles.feangle,'String'));
     axes(handles.fingerpic)
          picture=imread('flexed.jpg');
```

```
        imshow(picture)
    if fewristangle<=0
    fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
    stringfectp=num2str(fectp);
    set(handles.fectp,'String',stringfectp)
    fingerctp=fectp-0.184*fewristangle+3.9526;
    stringfingerctp=num2str(fingerctp);
    set(handles.fingerctp,'String',stringfingerctp);
    else
       fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
        stringfectp=num2str(fectp);
    set(handles.fectp,'String',stringfectp)
    fingerctp=fectp;
    stringfingerctp=num2str(fingerctp);
    set(handles.fingerctp,'String',stringfingerctp);
    end

      case'relaxedfingers'
        axes(handles.fingerpic)
        picture=imread('relaxed.jpg');
        imshow(picture)
    fewristangle=str2num(get(handles.feangle,'String'));
    fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
    stringfectp=num2str(fectp);
    set(handles.fectp,'String',stringfectp)
    fingerctp=stringfectp;
    stringfingerctp=num2str(fingerctp);
    set(handles.fingerctp,'String',stringfingerctp);

      case 'extendedfingers'
        axes(handles.fingerpic)
        picture=imread('extended.jpg');
        imshow(picture)
    fewristangle=str2num(get(handles.feangle,'String'));
    if fewristangle<=0
    fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
    stringfectp=num2str(fectp);
    set(handles.fectp,'String',stringfectp)
    fingerctp=fectp-0.3729*(fewristangle)+25.3;
    stringfingerctp=num2str(fingerctp);
    set(handles.fingerctp,'String',stringfingerctp);
    else
    fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
    stringfectp=num2str(fectp);
    set(handles.fectp,'String',stringfectp)
    fingerctp=fectp;
    stringfingerctp=num2str(fingerctp);
    set(handles.fingerctp,'String',stringfingerctp);
    end
  end
% %Loading Code:
```

```
        if get(handles.pinch,'Value')==get(handles.pinch,'Max');
            a=1; %pinched
        else
            a=0; %not pinched
        end
    if a==0    %If the fingers are not pinched, do this
            axes(handles.pinchpic)
            picture=imread('fingerpress.jpg');
            imshow(picture)
        loadmagnitude=(str2num(get(handles.loadinput,'String')));
        if loadmagnitude>15
        set(handles.loaderror,'String','Data only available to 15N')
        loadctp=0.0839*(loadmagnitude)^2+1.0852*(loadmagnitude);
        fingerctp=str2num((get(handles.fingerctp,'String')));
            maxarray=[fingerctp,rudctp,psctp];     maximum=max(maxarray(:));     totalctp=maximum+loadctp;
            if totalctp<=20
            set(handles.grandtotal,'BackgroundColor','green')    ;
            elseif totalctp<=30
            set (handles.grandtotal,'BackgroundColor','yellow')
            else
            set (handles.grandtotal,'BackgroundColor','red');
            end
        stringtotalctp=num2str(totalctp,'%10.1f'); % the 10.1f indicates going to 1 decimal place in the
num2string function --> check help if you forget how to use this function
        set(handles.totalctp,'String',stringtotalctp);
        else
        set(handles.loaderror,'String','')
        loadctp=0.0839*(loadmagnitude)^2+1.0852*(loadmagnitude);
        fingerctp=str2num((get(handles.fingerctp,'String')));
            maxarray=[fingerctp,rudctp,psctp];     maximum=max(maxarray(:));     totalctp=maximum+loadctp;
             if totalctp<=20
            set(handles.grandtotal,'BackgroundColor','green')    ;
            elseif totalctp<=30
            set (handles.grandtotal,'BackgroundColor','yellow')
            else
            set (handles.grandtotal,'BackgroundColor','red');
            end
        stringtotalctp=num2str(totalctp,'%10.1f'); % the 10.1f indicates going to 1 decimal place in the
num2string function --> check help if you forget how to use this function
        set(handles.totalctp,'String',stringtotalctp);
        end
    else%that means they are pinched
            axes(handles.pinchpic)
            picture=imread('fingerpinch.jpg');
            imshow(picture)
    if loadmagnitude>15
 set(handles.loaderror,'String','Data only available to 15N')
     loadmagnitude=(str2num(get(handles.loadinput,'String')));
    loadctp=-0.1161*(loadmagnitude)^2+4.8645*(loadmagnitude)+6.847;
    fingerctp=str2num((get(handles.fingerctp,'String')));
    maxarray=[fingerctp,rudctp,psctp];     maximum=max(maxarray(:));     totalctp=maximum+loadctp;
        if totalctp<=20
```

```
        set(handles.grandtotal,'BackgroundColor','green')    ;
        elseif totalctp<=30
        set (handles.grandtotal,'BackgroundColor','yellow')
        else
        set (handles.grandtotal,'BackgroundColor','red');
        end
    stringtotalctp=num2str(totalctp,'%10.1f');
    set(handles.totalctp,'String',stringtotalctp);
    else
    set(handles.loaderror,'String','')
    loadmagnitude=(str2num(get(handles.loadinput,'String')));
    loadctp=-0.1161*(loadmagnitude)^2+4.8645*(loadmagnitude)+6.847;
    fingerctp=str2num((get(handles.fingerctp,'String')));
    maxarray=[fingerctp,rudctp,psctp];     maximum=max(maxarray(:));     totalctp=maximum+loadctp;
        if totalctp<=20
        set(handles.grandtotal,'BackgroundColor','green')    ;
        elseif totalctp<=30
        set (handles.grandtotal,'BackgroundColor','yellow')
        else
        set (handles.grandtotal,'BackgroundColor','red');
        end
    stringtotalctp=num2str(totalctp,'%10.1f');
    set(handles.totalctp,'String',stringtotalctp);
    end
    end
else
        axes(handles.pinchpic)
            picture=imread('fingerpinch.jpg');
            imshow(picture)
    fewristangle=str2num(get(handles.feangle,'String'));
     if fewristangle>0.1 && 14.99>fewristangle %Sets the picture to change based on wrist FE posture
            axes(handles.fepic)
            imshow('flex15.jpg');
        elseif fewristangle > 15
            axes(handles.fepic)
            picture=imread('flex30.tif');
            imshow(picture)
        elseif fewristangle<-0.1&&fewristangle>-14.99
            axes(handles.fepic)
            picture=imread('ext15.jpg');
            imshow(picture)
        elseif fewristangle<-15;
            axes(handles.fepic)
            picture=imread('ext30.tif');
            imshow(picture)
        elseif fewristangle==0;
            axes(handles.fepic)
            picture=imread('neutral.tif');
            imshow(picture)
        end
    fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
    stringfectp=num2str(fectp);
    %Display the value associated with fectp in the FE box next to the input
```

```
set(handles.fectp,'String',stringfectp);

%Same thing but with RUD
rudwristangle=str2num(get(handles.rudangle,'String'));
   %Same thing but with RUD
rudwristangle=str2num(get(handles.rudangle,'String'));
    if rudwristangle>0
       axes(handles.rupic)
       imshow('ulnar.jpg');
   elseif rudwristangle <0
       axes(handles.rupic)
       picture=imread('radial.jpg');
       imshow(picture)
   elseif rudwristangle==0;
       axes(handles.rupic)
       picture=imread('neutralru.jpg');
       imshow(picture)
   end
rudctp=0.0291*(rudwristangle)^2 + 0.087*(rudwristangle) + 18.255;
stringrudctp=num2str(rudctp);
set(handles.rudctp,'String',stringrudctp);

%Same thing but with PS But this is only with the average of the means, so
%i'd have to add the 2SEM to it in order to get a better idea
pswristangle=str2num(get(handles.prosupangle,'String'));
   if pswristangle<-45
       axes(handles.pspic)
       imshow('sup.jpg');
   elseif pswristangle <0
       axes(handles.pspic)
       picture=imread('semisup.jpg');
       imshow(picture)
   elseif pswristangle==0;
       axes(handles.pspic)
       picture=imread('psneutral.jpg');
       imshow(picture)
   elseif pswristangle <=45
       axes(handles.pspic)
       picture=imread('semipro.jpg');
       imshow(picture)
   elseif pswristangle>45;
       axes(handles.pspic)
       picture=imread('pro.jpg');
       imshow(picture)
   end
psctp=0.0007*(pswristangle)^2-0.041*(pswristangle)+10.162;
stringpsctp=num2str(psctp);
set(handles.psctp,'String',psctp);

%code to get the value of the radio button and return the respective CTP
h=get(handles.fingerposture,'SelectedObject');
buttoncase=get(h,'Tag');
```

```
switch buttoncase
    case 'flexedfingers';
            axes(handles.fingerpic)
        picture=imread('flexed.jpg');
        imshow(picture)
      fewristangle=str2num(get(handles.feangle,'String'));
      if fewristangle<=0
      fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
      stringfectp=num2str(fectp);
      set(handles.fectp,'String',stringfectp)
      fingerctp=fectp-0.184*fewristangle+3.9526;
      stringfingerctp=num2str(fingerctp);
      set(handles.fingerctp,'String',stringfingerctp);
      else
      fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
       stringfectp=num2str(fectp);
      set(handles.fectp,'String',stringfectp)
      fingerctp=fectp;
      stringfingerctp=num2str(fingerctp);
      set(handles.fingerctp,'String',stringfingerctp);
      end
    case'relaxedfingers'
                axes(handles.fingerpic)
        picture=imread('relaxed.jpg');
        imshow(picture)
  fewristangle=str2num(get(handles.feangle,'String'));
  fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
  stringfectp=num2str(fectp);
  set(handles.fectp,'String',stringfectp)
  fingerctp=stringfectp;
  stringfingerctp=num2str(fingerctp);
  set(handles.fingerctp,'String',stringfingerctp);
    case 'extendedfingers'
                axes(handles.fingerpic)
        picture=imread('extended.jpg');
        imshow(picture)
  fewristangle=str2num(get(handles.feangle,'String'));
  if fewristangle<=0
      fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
      stringfectp=num2str(fectp);
      set(handles.fectp,'String',stringfectp)
      fingerctp=fectp-0.3729*(fewristangle)+25.3;
      stringfingerctp=num2str(fingerctp);
      set(handles.fingerctp,'String',stringfingerctp);
  else
      fectp=0.0098*(fewristangle)^2 - 0.186*(fewristangle) + 13.929;
      stringfectp=num2str(fectp);
      set(handles.fectp,'String',stringfectp)
      fingerctp=fectp;
      stringfingerctp=num2str(fingerctp);
      set(handles.fingerctp,'String',stringfingerctp);
  end
end
```

```
% Loading--> Finger Press

    if get(handles.pinch,'Value')==get(handles.pinch,'Max');
        a=1; %pinched
    else
        a=0; %not pinched
    end
if a==0
loadmagnitude=(str2num(get(handles.loadinput,'String')));
    axes(handles.pinchpic)
            picture=imread('fingerpress.jpg');
            imshow(picture)
        if loadmagnitude>15
 set(handles.loaderror,'String','Data only available to 15N')
 loadctp=0.0839*(loadmagnitude)^2+1.0852*(loadmagnitude);
        fingerctp=str2num((get(handles.fingerctp,'String')));
    maxarray=[fingerctp,rudctp,psctp];     maximum=max(maxarray(:));     totalctp=maximum+loadctp;
            if totalctp<=20
            set(handles.grandtotal,'BackgroundColor','green')    ;
            elseif totalctp<=30
            set (handles.grandtotal,'BackgroundColor','yellow')
            else
            set (handles.grandtotal,'BackgroundColor','red');
            end
        stringtotalctp=num2str(totalctp,'%10.1f');
        set(handles.totalctp,'String',stringtotalctp);
        else
            set(handles.loaderror,'String','')
        loadctp=0.0839*(loadmagnitude)^2+1.0852*(loadmagnitude);
        fingerctp=str2num((get(handles.fingerctp,'String')));
    maxarray=[fingerctp,rudctp,psctp];     maximum=max(maxarray(:));     totalctp=maximum+loadctp;
            if totalctp<=20
            set(handles.grandtotal,'BackgroundColor','green')    ;
            elseif totalctp<=30
            set (handles.grandtotal,'BackgroundColor','yellow')
            else
            set (handles.grandtotal,'BackgroundColor','red');
            end
        stringtotalctp=num2str(totalctp,'%10.1f');
        set(handles.totalctp,'String',stringtotalctp);
        end
else
                axes(handles.pinchpic)
            picture=imread('fingerpinch.jpg');
            imshow(picture)
        loadmagnitude=(str2num(get(handles.loadinput,'String')));
        if loadmagnitude>15
 set(handles.loaderror,'String','Data only available to 15N')
 loadctp=-0.1161*(loadmagnitude)^2+4.8645*(loadmagnitude)+6.847;
        fingerctp=str2num((get(handles.fingerctp,'String')));
    maxarray=[fingerctp,rudctp,psctp];     maximum=max(maxarray(:));     totalctp=maximum+loadctp;
            if totalctp<=20
            set(handles.grandtotal,'BackgroundColor','green')    ;
```

```
            elseif totalctp<=30
            set (handles.grandtotal,'BackgroundColor','yellow')
            else
            set (handles.grandtotal,'BackgroundColor','red');
            end
        stringtotalctp=num2str(totalctp,'%10.1f');
        set(handles.totalctp,'String',stringtotalctp);
        else
        set(handles.loaderror,'String','')
        loadctp=-0.1161*(loadmagnitude)^2+4.8645*(loadmagnitude)+6.847;
        fingerctp=str2num((get(handles.fingerctp,'String')));
    maxarray=[fingerctp,rudctp,psctp];     maximum=max(maxarray(:));     totalctp=maximum+loadctp;
            if totalctp<=20
            set(handles.grandtotal,'BackgroundColor','green')    ;
            elseif totalctp<=30
            set (handles.grandtotal,'BackgroundColor','yellow')
            else
            set (handles.grandtotal,'BackgroundColor','red');
            end
        stringtotalctp=num2str(totalctp,'%10.1f');
        set(handles.totalctp,'String',stringtotalctp);
        end
end
end% Hint: get(hObject,'Value') returns toggle state of pinc
```

APPENDIX C: ETHICS

Appendix C1: Ethics Application

McMaster University Research Ethics Board (MREB)
FACULTY/GRADUATE/STAFF
Application to Involve Human Participants in Research
[Behavioural / Non- Medical]

Please refer to the McMaster University < Research Ethics Guidelines and Researcher's Handbook >, found prior to completion and submission of this application. If you have questions about or require assistance respecting completion of this form, please contact the Ethics Secretariat at ext. 23142, or ethicsoffice@mcmaster.ca

Send in this form and all accompanying material in duplicate if being submitted in hard-copy. If submitting by e-mail, send the application plus attachments, and forward the original signed signature page to the Ethics Secretariat, Office of Research Services, Room 305/H Gilmour Hall, ext. 23142, ethicsoffice@mcmaster.ca. If you want to change a previously approved protocol, please complete the "< Change Request >" form.

Date: June 28	**Application Status: New [X] Change [ ] Renewal [ ]**	**Protocol#:**

<Helpful Hints> Check all Bold Blue hypertext links for help on completing this form

SECTION A – GENERAL INFORMATION

1. **TITLE:** A Model to Predict Carpal Tunnel Syndrome Risk

2. **Investigator Information (This form not to be completed by < Faculty of Health Science researchers >)**

	Name	Dept./Address	Phone No.	E-Mail address you regularly use
Principal Investigator	Dr. Peter Keir	Kinesiology (IWC 216)	Ext 23543	pjkeir@mcmaster.ca
Co-Investigator(s)				
Student Investigator(s)	Justin Weresch	Kinesiology	Ext 26825	werescj@mcmaster.ca

		(IWC AB108)		
Student Faculty Supervisor				

3. **When will you begin recruiting participants or reviewing private papers?: July 2010 (Contact ethics office for urgent requests)**

Estimated Completion Date: August 2010

4. **Indicate the < location >**(s) where the research will be conducted:

McMaster University **[ ]**
Hospital **[ ]** Specify Site
Community **[ ]** Specify Site
Other **[X]** Specify Site:

5. **Other Research Ethics Board Approval**

(a) Is this a multi-centred study? **[ ] Yes [X] No**
(b) Has any other institutional Ethics Board approved this project? **[ ] Yes [X] No**
(c) If Yes, there is no need to provide further details about the protocol **at this time,** provided that **all** of the following information is provided:
Title of the project approved elsewhere:
Name of the Other Institution:
Name of the Other Board: Date of the Decision:
A contact name and phone number for the other Board:
A copy of the application to the other institution together with **all** accompanying materials
A copy of the clearance certificate / approval

If all of the above information cannot be provided, please complete the balance of this application.

(d) Will any other Research Ethics Board be asked for approval? **[ ] Yes [X] No**
If yes, please specify

6. **Level of the Project**

[ ] Faculty Research **[ ]** Post-Doctoral **[ ]** PhD.
[ ] Staff/Administration **[X]** Masters **[ ]** Undergraduate
[ ] Other (specify)

7. **Funding of the Project**

(a) Is this project currently being funded **[X] Yes [ ] No**
(b) If **No**, is funding being sought **[ ] Yes [ ] No**
(c) Period of Funding: From To:
(d) Agency or Sponsor (funded or applied for)

[ ] CIHR **[ ]** NSERC **[ ]** SSHRC **[ ]** ARB

[ ] Health Canada **[X]**Other (specify): Auto21

8. **Conflict of Interest**

(a) Will the researcher(s), members of the research team, and/or their partners or immediate family members:

(i) receive any personal benefits (for example a financial benefit such as remuneration, intellectual property rights, rights of employment, consultancies, board membership, share ownership, stock options etc.) as a result of or being connected to this study?**[ ] Yes [X] No**

(ii) if **Yes**, please describe the benefits below. (Do not include conference and travel expense coverage, possible academic promotion, or other benefits which are integral to the conduct of research generally).

(b) Describe any restrictions regarding access to or disclosure of information (during or at the end of the study) that the sponsor has placed on the investigator(s).

SECTION B – SUMMARY OF THE PROPOSED RESEARCH – ***Please be as Clear and Concise as Possible***

9. **Rationale**
Describe the purpose and background rationale for the proposed project, as well as the hypotheses(is)/research questions to be examined.

Carpal tunnel syndrome (CTS) continues to be a burden to the healthcare system and the workplace. In Ontario, the cost (treatment and lost-time benefits) to the WSIB associated with CTS was approximately $13,000,000 in 1996 (Manktelow *et al.*, 2004) while the incidence of occupational CTS almost doubled from 1981 to 2005 in the state of Minnesota (Gelfman *et al.*, 2009). Increased hydrostatic pressure within the carpal tunnel, also known as carpal tunnel pressure (CTP) is a proposed mechanism for the development of CTS. Measuring CTP is invasive, however predicting CTP based on wrist, forearm, and hand posture is not. The increased cost associated with CTS, and the lack of current research predicting CTS risk based on mechanical vs. epidemiological evidence indicate the need for proactive solutions to reduce the incidence of CTS and the associated costs to both employers and employees. An ergonomic tool has been developed that predicts CTP and CTS risk based on forearm, wrist, and hand posture, as well as fingertip loading. The goal of this project is to investigate if there is a correlation between the output of this model (CTS risk) and the incidence of CTS and related injuries in a large automotive manufacturing environment.

10. **Methodology**

Describe sequentially, and in detail, all procedures in which the research participants will be involved (e.g. paper and pencil tasks, interviews, surveys, questionnaires, physical assessments, physiological tests, time requirements etc.)

***N.B. Attach a copy of all questionnaire(s), interview guides or other test instruments*.**

Approximately 45 jobs will be selected based on the incidence of CTS (or potential CTS precursors) using existing injury data. Once selected, a video camera will be used to collect forearm, wrist, and hand posture (field of view will a side view of the forearm below the elbow, wrist, and hand). Video will be collected for a short period of time (<5 minutes per job, or up to 3 cycles of the participant's task) since the work is cyclical. When available, force data will be obtained from an existing database of force requirements for each task to minimize decreased participant productivity. When this data is unavailable, the operator will be asked to rate their exertion on a scale from 0-10 (no effort to maximum effort). The operator's identity will remain confidential and no videos or images with any identifying marks or characteristics will be used to present the data.

11. **Experience**

What is your experience with this kind of research?

We have previously successfully examined long term care nurses and personal care workers in Ontario.

12. **Participants**

Describe the number of participants and any salient characteristics (such as age, gender, location, affiliation, etc.)

Participant selection is dependent on their assigned job. 45 participants (1 per job analyzed) will be recruited with no selection criteria for age, gender, or affiliation.

13. **Recruitment**

Describe how and from what sources the participants will be recruited, including any relationship between the investigator(s) and participant(s) (e.g. instructor-student; manager-employee).

<u>N.B. Attach a copy of any poster(s), advertisement(s) or letter(s) to be used for recruitment.</u>

Once the appropriate jobs to be studied have been identified, the supervisor for that particular line will be approached to explain the purpose of the study. If the supervisor is able (due to time or work constraints) to have their workers participate, informed consent will be then obtained by willing workers by approaching potential participants. There is no relationship between the investigators and the participants.

14. **Compensation** **Yes** **No**

(a) Will participants receive compensation for participation?	**[X]**	**[ ]**	
Financial	**[ ]**	**[ ]**	
In-Kind		**[ ]**	**[ ]**

Other (specify): Gift Card

(b) If yes, please provide details.

A $2 Tim Horton's gift card will be given to participants.

(c) If participants choose to withdraw, how will you deal with compensation?

After signing the consent form, participants will receive compensation regardless of them withdrawing or completing the protocol.

SECTION C – < DESCRIPTION OF THE RISKS AND BENEFITS OF THE PROPOSED RESEARCH >

15. **Possible Risks**

1. Indicate if the participants might experience any of the following risks:

a) Physical risk (including any bodily contact or administration of any substance)? **[ ] Yes [X] No**

b) Psychological risks (including feeling demeaned, embarrassed worried or upset)? **[ ] Yes [X] No**

c) Social risks (including possible loss of status, privacy and / or reputation)? **[ ] Yes [X] No**

d) Is there any deception involved? **[ ] Yes [X] No**

e) Are any possible risks to participants greater than those the participants might encounter in their everyday life? **[ ] Yes [X] No**

2. If you answered **Yes** to any of a – e above, please explain the risk.

3. Describe how the risks will be managed (including an explanation as to why alternative approaches could not be used).

16. **Possible Benefits**

Discuss any potential direct benefits to the participants from their involvement in the project. Comment on the (potential) benefits to (the scientific community) / society that would justify involvement of participants in this study.

We hope to understand the loads experienced within the body and relate them to injuries and disorders that develop in the workplace. Ultimately we hope to prevent workplace disorders. The research will not immediately benefit the study participants, however will provide a better description of potential risk associated with CTS and help assess jobs in the future such that their injury risk is reduced.

SECTION D – < THE INFORMED CONSENT PROCESS >

17. **The Consent Process (< link to sample consent form >:**

Describe the process that the investigator(s) will be using to obtain informed consent, including a description of who will be obtaining informed consent and a script of what they will say, if anything.

Informed consent will be obtained during off-time (i.e. prior to the start of a shift) where possible or in between job cycles to minimize the reduced productivity of the potential participants. With the aid of an on-site ergonomist, line supervisor (where necessary) and the primary and student investigator, potential participants will be informed that a research study is being performed within the plant, participation is completely voluntary, and will minimally impact their productivity. If they express interest the following script will be read:

"Good Morning/Afternoon:

We are from McMaster University and are performing a study looking at wrist, hand, and forearm posture and hand forces. Our research involves videotaping your hands and forearms while you perform your normal duties (up to 3 cycles) and may also ask you rate your exerted hand force. Your identity will not be recorded and participating in this study does not pose any additional risks to you. We will not be assessing, or providing feedback on particular jobs. Your participation in this study is completely voluntary and you will be compensated with a $2 Tim Horton's gift certificate. You are free to withdraw at any time without consequence."

Indicate how consent will be documented. Attach a copy of the Letter of Information if applicable and the consent form if applicable. If there will be no written consent, explain why not and describe the alternative means that will be used to document consent. Attach the content of any telephone script that will be used in the consent process (if applicable)

For information about the required elements in the letter of information and the consent form, please refer to "**< Instructions for the Preparation of an Information Letter/Consent Form >**":

See attached Letter of information and Consent. This letter has been approved by both unions and administration at the Plant.

18. **Consent by an authorized party**

If the participants are minors or for other reasons are not competent to consent, describe the proposed alternate source of consent, including any permission / information letter to be provided to the person(s) providing the alternate consent.

N/A

19. **Alternatives to prior individual consent**

If obtaining written documentation of participant consent prior to commencement of the research project is not appropriate for this research, please explain and provide details for a proposed alternative consent process.

N/A

20. **Debriefing (Participant feedback**)

Explain what feedback/ information will be provided to the participants after participation in the project. (For example, a more complete description of the purpose of the research, access to the results of the research.)

N.B. Please provide a copy of the written debriefing form, if applicable.

The participants will be thanked for their participation, and if they would like to receive information regarding the results of the study, they may contact the principle investigator directly (see "Information

About the Study results section in attached Letter of information and consent). Information will be passed to the workers from the union and administration.

21. **Participant withdrawal**

a) Describe how the participants will be informed of their right to withdraw from the project. Outline the procedures which will be followed to allow the participants to exercise this right.

Participants will be informed of their right to withdraw both in the verbal introduction to the study (See Section 17) as well as in the writing (See attached Letter of information and consent).

b) Indicate what will be done with the participant's data and any consequences which withdrawal might have on the participant, including any effect that withdrawal may have respecting participant compensation.

There will be no negative consequence to the participants following withdrawal. They will still receive compensation, and the data (if already collected) will be utilized for the purposes of this study where possible.

c) If the participants will not have the right to withdraw from the project, please explain.

n/a

SECTION E – CONFIDENTIALITY

22. a) Will the data be treated as confidential? **[X] Yes [ ] No**

b) Describe the procedures to be used to ensure anonymity of participants or confidentiality of data both during the conduct of the research and in the release of its findings.

All video data will be focused at the upper-extremity (below the elbow). The only personal information that will be collected from the participants will be in the Letter of Information and Consent, and there will be no attempt to associate any personal information to collected data. For the purposes of presenting data or teaching, no videos or images with indentifying marks will be used. As well, information on particular jobs pertaining to injury risk will not be assessed. The purpose of this study is to validate an ergonomic tool, not to assess particular jobs.

c) Explain how written records, video/audio tapes and questionnaires will be secured, and provide details of their final disposal or storage.

All hard-copies will be stored in a locked cabinet, and all digital copies will be password-protected. Upon final disposal (15 years), all hard-copies will be physically destroyed, and all digital copies will be deleted.

d) If participant anonymity/confidentiality is not appropriate to this research project, explain, including providing details of how all participants will be advised of the fact that data will not be anonymous or confidential.

N/A

SECTION F -- MONITORING ONGOING RESEARCH

23. **Annual Review and Adverse Events**

a) Minimum review requires the completion of a “Renewal/Project Completed” form at least annually. Indicate whether any additional monitoring or review would be appropriate for this project.

It is the investigator’s responsibility to reply to the Annual Completed Status Report Email which is sent one year from date of ethics approval.

b) **Adverse events** (unanticipated negative consequences or results affecting participants) must be reported to the REB Secretariat and the MREB Chair, as soon as possible and in any event, no more than 3 days subsequent to their occurrence.

24. **ADDITIONAL INFORMATION**

(Use an additional page if more space is required to complete any sections of the form, or if there is any other information relevant to the project which you wish to provide to the Research Ethics Board.)

This project has been approved by both the CAW and management at the Plant. We have attached the confirming email.

25. **< POSTING OF APPROVED PROTOCOLS ON THE RESEARCH ETHICS WEBSITE >**

a) Effective January 1, 2006, it is the policy of MREB to post a list of approved protocols on the Research Ethics website. Posted information usually includes: title, names of principal investigators, principal investigator department, type of project (i.e. PhD; Faculty; Masters etc)
b) You may request that the title be deleted from the posted information.
c) Do you request that the title be eliminated from the posted information? **[ ] Yes [ ] No**
d) The ethics board will honour your request if you answer **Yes** to the above question 25 c) but we ask you to provide a reason for making this request for the information of the Board. You may also use this box for any other special requests.

< SECTION G – SIGNATURES > **Campus Mail Address = GH-305/H** **< HOW TO SUBMIT >**

Faculty Investigator Assurance:

"I confirm that I have read the < McMaster University Research Ethics Guidelines and Faculty Handbook > and I agree to comply with the conditions outlined in the Guidelines".

Signature of Faculty Investigator **PLEASE PRINT HERE** **Date**

Faculty Supervisor Assurance: For undergraduate students and graduate students where the supervisor is the primary supervisor for a thesis:

"I confirm that I have read the < McMaster University Research Ethics Guidelines and Faculty Handbook >, and I agree to comply with the conditions outlined in the Guidelines. I have read the application and proposal and deem the project to be valid and worthwhile, and I agree to provide the necessary supervision of the student(s) and to make myself available should problems arise during the course of the research."

Signature of Faculty Supervisor PLEASE PRINT HERE Date

Signature of Graduate Student PLEASE PRINT HERE Date

Faculty Supervisor Assurance: For graduate students where the supervisor is not the primary supervisor, and where the research is not for a graduate thesis:

"I confirm that I have the < McMaster University Research Ethics Guidelines and Faculty Handbook >, and I agree to comply with the conditions outlined in the Guidelines. I have read the application and proposal and deem the project to be valid and worthwhile, and I agree to make myself available for consultation should problems arise during the course of the research."

Signature of Faculty Supervisor PLEASE PRINT HERE Date

Signature of Graduate Student PLEASE PRINT HERE Date

Appendix C2: Letter of Information and Consent

July 12, 2010

Letter of Information and Consent

Collection of Wrist & Forearm Posture on Production Tasks

Principal Investigator: Dr. Peter Keir
Department of Kinesiology, McMaster University
(905) 525-9140 ext. 23543 (pjkeir@mcmaster.ca)

Student / Co-Investigator Justin Weresch, MSc Candidate **(905) 525-9140 ext. 21075**

Research Sponsor: AUTO21 Network of Centres of Excellence

Purpose of the Study
Carpal tunnel syndrome and other disorders are common in repetitive jobs that use forceful efforts in awkward wrist postures. We are currently developing a new assessment tool to identify the features of tasks which increase the risk these disorders. The purpose of this study is to collect inputs to the model (posture and force) and compare its outputs to the injuries reported for various types of tasks.

Procedures involved in the Research
Your arms, from below your shoulder and hands, will be videotaped while you perform your normal duties for up to 3 cycles (see image at right). In some cases the videographer may ask you to rate your exertion level on a scale from 0-10 (no effort to maximum effort). No other information will be collected and your identity will not be recorded. The video recorder may move around you to acquire different angles of your arms but will not record anything else.

Potential Harms, Risks or Discomforts: The data collection poses no additional risk to you.

Potential Benefits: We hope to understand the loads experienced within the body and relate them to injuries and disorders that develop in the workplace. Ultimately we hope to prevent workplace disorders. The research will not benefit you directly but should help assess jobs in the future so that their injury risk is reduced.

Confidentiality: Your identity will be kept confidential and the data collected will be used for teaching and research purposes only. No videos or video images with any identifying marks will be used to present the data. The information directly pertaining to you will be secured in a locked cabinet or on a secure computer for a maximum of 15 years. Information will be kept confidential to the full extent of the law and all information provided will be subject to researcher-participant privilege.

Participation: Your participation in this study is voluntary. If you agree to participate, you can decide to stop at any time, even after signing the consent form or part-way through the study, with no consequences to you.
Payment or Reimbursement: You will be compensated with a $2 Tim Horton's gift certificate.
Information About the Study Results: You may obtain information about the results of the study by contacting Dr. Keir directly.
Information about Participating as a Study Subject:
If you have questions or require more information about the study itself, please contact Dr. Keir.
This study has been reviewed and approved by the McMaster Research Ethics Board. If you have concerns or questions about your rights as a participant or about the way the study is conducted, you may contact:

McMaster Research Ethics Board Secretariat
c/o Office of Research Services
Telephone: (905) 525-9140 ext. 23142
E-mail: ethicsoffice@mcmaster.ca

CONSENT

I have read the information presented in the information letter about a study being conducted by Dr. Peter Keir and Justin Weresch of McMaster University. I have had the opportunity to ask questions about my involvement in this study, and to receive any additional details I wanted to know about the study. I understand that I may withdraw from the study at any time, if I choose to do so, and I agree to participate in this study. I have been given a copy of this form.

____

Name and Signature of Participant

In my opinion, the person who has signed above is agreeing to participate in this study voluntarily, and understands the nature of the study and the consequences of participation in it.

____

Signature of Researcher or Witness